CALFED Science Program

A Two-Part Workshop on Conveyance Modeling in support of the Delta Vision Blue Ribbon Task Force

Summary Findings of Workshop 2: Linking Physical and Biological Models for Ecosystem Prediction, Planning, and Performance

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Executive Summary

This was the second of two workshops of the CALFED Science Program related to conveyance modeling. The purpose of this workshop was an assessment of the state-of-the-science of models that integrate hydrodynamics and water quality with ecosystem response specifically related to decisions facing the Delta Vision Blue Ribbon Task Force (Task Force). There is a great sense of urgency to make decisions regarding the Delta catalyzed by the Task Force. One of the primary findings of the workshop is that there needs to be a similar sense of urgency to ensure the science, specifically ecological analysis and modeling, is available to support these decisions.

> The purpose of Science in the Delta is to reduce risk, uncertainty and cost in making wise decisions for the long term future of the Delta System.
>
> *Paraphrased from comments by Duncan Patten and Jason Peltier May 20, 2008*

Scientists and engineers studying the Delta represent one of the most talented, mature, interdisciplinary and largest applied environmental research communities in the world, comprising multiple state and federal agencies, the private sector, the University of California, Stanford University, San Francisco State University and other internationally recognized organizations from across the US. This was well illustrated throughout the workshop by the quality of presentations and frank discussion. There appeared to be consensus of the panel, presenters and participants that currently:

- There is no predictive comprehensive model of ecosystem dynamics for the Bay Delta System. The previous workshop found that the physical process modeling is advanced and although additional work is required the limitations, challenges and capabilities of the hydrodynamic modeling are well understood.
- A visionary and holistic model aimed at building an understanding of how key components of the Bay-Delta ecosystem might respond to possible future scenarios of change is being developed – Computational Assessments of Scenarios of Change in the Delta Ecosystem (CASCaDE) – and there are several sophisticated models for the response of individual species. The DRERIP conceptual models provide a very useful start for unraveling the complexities of ecosystem function for selected species and indicators. These conceptual models identify the current state of understanding, are rigorously peer-reviewed and documented where possible with peer-reviewed literature.
- The SacEFT model represents a promising blend of hydrodynamic modeling and simplified output information for decision support analysis that can be of near-term use for management purposes for the Sacramento River, and perhaps guide development of similar models for the Delta in the future.

Although these models are improving our understanding of Delta ecological processes it is important to recognize that they have been developed to address specific scientific questions about specific species or elements of ecosystem function. The CASCaDE project, for example, has a strong emphasis on climate change and global warming.

To manage the Bay-Delta Estuary in an ecologically sustainable manner will require consideration of the estuary as an ecosystem. In the Delta, significant interplay exists between the physical and biological processes that control the health of the estuary. Ecosystem models must be based on sub-models of the estuarine physics (hydrodynamics, salinity, and sediment) attached to sub-models of the chemistry and biology. Because especially the biology of an ecosystem is so complex, it is necessary to simplify the components of an estuarine ecosystem model. The development of a model requires balancing the complexity needed for model

thoroughness and the simplification needed for practicality. Only once the processes controlling ecosystem health are understood can the resilience of the estuary, defined as its ability to cope with human stresses, be in any way quantified. Knowledge of the resilience of the Delta ecosystem is needed to develop the management plan for ecologically sustainable development of water supplies and for remediation measures on the already degraded condition.

The Task Force is developing a Strategic Plan that will recommend the broad outlines for a modified Delta conveyance system and steps to restore the Delta ecosystem. The fundamental conflict these decisions address is that the Delta must convey high quality water to meet water demands while functioning as a healthy and resilient ecosystem that fosters native species and accommodates sea-level rise and future seismic events. The models described at the workshop may be most properly classified as ecological models[1] rather than true ecosystem models that combine physics, chemistry, and biology sub-models. As noted above, the existing models are being developed to address specific scientific questions and to focus on certain ecosystem processes or components. A key workshop finding is that although the models being constructed represent major advances over previous modeling tools, they are still not fully suited (or designed) to meet the challenging requirements for Delta Vision decision support. The Task Force seeks decision support on how Delta restoration and conveyance facilities can achieve co-equal water supply and ecosystem resilience goals.

For example, the individual based delta smelt model (presented by Wim Kimmerer) is concerned with the processes of spawning, growth, mortality, food, and movement. Each component challenges limited available data for reducing process uncertainty. The question that motivates the work is “what are the environmental controls on delta smelt abundance?” The phytoplankton model presented by Lisa Lucas is concerned with the details of how light, consumption, and transport control phytoplankton abundance in time and space. The CASCaDE model presented by Jim Cloern uses a series of linked models that consider multiple scales of the water system from climate to watershed and Delta chemical/biological processes. It is motivated by the conceptual model that the Bay-Delta is driven by large scale processes scaling down, and small scale processes scaling up.

While the ecosystem process understanding captured by these models is fundamental, they cannot directly address the questions the Task Force is asking to discern an ecosystem restoration and reliable water conveyance solution for California. Nevertheless, the Task Force will make decisions. Given the quandary, the Panel proposes short, interim, and long-term approaches for assuring that policy decision support is an enduring output from ecosystem models.

<u>Short-term decision support:</u> the Task Force Strategic Plan will broadly define the relationship between water supply and ecosystem quality in time and space, with the financial and governance structures to support it. The Panel believes that short-term decisions are well supported by existing Task Force initiatives, especially the Ecosystem Work Group. This group is relying on the ecosystem conceptual models prepared for the DRERIP process. Although still in progress, the DRERIP conceptual models represent an outstanding synthesis of physical, chemical, and biological processes of the estuary. Additional short-term decision support is provided through the "*Initial Assessment of Dual Delta Water Conveyance*" (DWR, April 2008) requested by the Task Force.

[1] The entire suite of linked sub-models that compose the CASCADE project is closest to a true ecosystem model, but still lacks certain key components of the estuarine food web, for example zooplankton.

Interim decision support: after the Task Force Strategic Plan is submitted in October 2008, agencies will address the details of conveyance and ecosystem restoration implementation. The panel does not expect ecosystem models to offer direct decision support for the reasons already discussed. Nevertheless, the scientists/authors of these models have essential knowledge and insights that would improve the development of restoration site acquisition criteria, restoration designs and dual conveyance alternatives. The panel recommends that the best ecosystem scientists should be engaged in interim implementation planning through the following venues:

1. Conveyance/Ecosystem Charette's
   One of the presenters asserted that scientists work effectively in multi-disciplinary groups when the decisions that will be made and the questions that flow from them are well defined. The Panel recommends using the "charette" process to synthesize the best scientific and engineering understanding for well-defined Delta alternatives. Scientists naturally resort to conceptual model-based thinking where system drivers, linkages, outcomes, and feedbacks are integrated. We believe this would be an efficient way to use scientist's time in the absence of decisions supporting ecosystem models. The knowledge gained from the existing process-based ecosystem models would be implicitly incorporated in recommended actions.

2. Focused modeling teams
   The Public Policy Institute of California has successfully advanced the debate about water and ecosystem alternatives for the Delta. Their approach employs a small interdisciplinary team that examines deeply just a few ecosystem/conveyance alternative futures. The panel believes this approach could be used to explore the emerging Delta vision alternatives. Keeping groups small and interdisciplinary allows integrated analysis of economics, governance, and ecosystem function under dual conveyance management options.

Long-term decision support: while the panel strongly believes that decisions on Delta conveyance facilities need to be made in the short term, once those decisions are made, a large number of additional decisions will be required to define the optimum operation of facilities. If the existing numerical ecological models are not adequate to guide decision-making in the short term, there is a strong need for these models to guide decisions in the longer term (the next three to fifteen years) while new through-delta options are implemented and tested, and a new isolated facility is planned and possibly constructed. The research and development of Delta models must be an ongoing process that is supported with adequate funding. In recent years we have observed a significant return from the investment made in science for understanding the causes of the Delta Pelagic Organism Decline (POD).

An example of a quantum leap in understanding through the scientific method – Delta Smelt

The individual-based modeling system described at the workshop is an example of a model system that could not have been built as recently as 2005 for the elusive Delta Smelt. The science underlying the conceptual models upon which the system is built was simply not available when the POD studies first began. The recent rapid increase in our understanding of the issues affecting the decline in delta smelt abundance in the estuary is an example that investments in science pay off, whether or not we see an immediate improvement in the numbers of the species. Today, competing scientific hypotheses can be tested by fish scientists allowing more detailed insight and understanding of the limiting factors and management alternatives.

The panel recommends that the development of quantitative ecological models of the Delta be continued and at an increased pace over what has occurred to date and in concert with the

hydrodynamic modeling initiatives. Much can be learned from the individual models of ecosystem components being developed and these models are needed as sub-models for full ecosystem models. A variety of modeling approaches need to be applied, including those that attempt to model the behavior of a complex system by simplifying it. In addition, we recommend that a project similar to CASCaDE, but focused specifically on the ecosystem implications of changing Delta conveyance, should be pursued. The project would build from the significant progress already made by the CASCaDE project and the work by the team developing the delta smelt population model. We also believe that developing a decision analysis tool for the Delta, similar to SacEFT, should be considered. The tool could be used for weighing the relative merits to the ecosystem of alternative conveyance operations and to assist in clarifying scientific uncertainties that hinder decision-making processes.

Secondly, it is recommended that consideration is given to the establishment of a Science Center. The goal of this Center will be to provide a forum for data management (in the form of distributed data management systems or a common data warehouse), model development, management of models to ensure consistency among stake-holders and training in the use of models. It could also establish career tracks in science for young professionals that will ultimately transition to leadership roles in modeling. This will increase the efficiency of stake-holders who wish to use their own staff or consultants to model future scenarios and reduce the risk of achieving conflicting results due to different versions of models or different data sets. The creation of such a Center faces many challenges but could build from existing strengths in academia, federal and state agencies. Further comment is beyond the charge to this Panel.

List of Contents

	Page number
Executive Summary	2
List of Contents	6
I. Introduction	7
II. Modeling Ecosystem Dynamics and Ecological Response	8
III. Examples of the State of the Science for Ecosystem Modeling in the Delta Ecosystem	
III.1 CASCaDE	10
III.2 Phytoplankton Model	11
III.3 Bivalve Model	11
III.4 Individual-Based Model of Delta Smelt	11
III.5 SacEFT	12
III.6 Key Questions arising during workshop discussion	13
IV. A Vision for the Future	16
Acknowledgements	20
References	20
Appendix I: Workshop Objectives and Agenda	22

I. Introduction

On May 20, 2008, the CALFED Science Program convened the second of two workshops on Delta conveyance modeling in support of the Governor's Delta Vision Blue Ribbon Task Force (Task Force). The Task Force has developed a vision for the Delta (Delta Vision Blue Ribbon Task Force, 2007) that recommends that "*new facilities for conveyance and storage, and better linkage between the two, are needed to better manage California's water resources for both the estuary and exports*." The vision calls for immediate improvements to the existing through-Delta export system and for studies to be done to assess a dual conveyance system as the preferred direction. Dual conveyance is defined as an optimized combination of through-Delta conveyance and conveyance around the Delta using some form of an isolated facility. The Task Force is charged with developing a strategic plan to implement their vision for the Delta by fall 2008. The first workshop was aimed primarily at providing a forum to exchange information on the available hydrodynamic models being used in Delta conveyance studies and both the Panel report and Summary Letter to the Task Force from the Lead Scientist is available at http://calwater.ca.gov/science/. The first panel report highlighted the need for models to forecast ecosystem response to changes in conveyance. In response, the Task Force requested that the focus of the second workshop be modified to highlight current efforts to develop reliable computer models linking physical models to ecosystem response. There are many different efforts currently underway to further our understanding of individual species response to altered hydrological conditions in the Delta and the presentations selected for this workshop represented a range of scales, biota and objectives to illustrate the current state of the ecological modeling and to explore the future for ecosystem modeling.

The presentations began with CASCaDE, which is a suite of models designed to assess how the ecosystem might respond to possible future scenarios of change from the global to local scales within the Delta system. CASCaDE models couple climate change effects with hydrodynamics, specific contaminants, and the phytoplankton and invasive species models presented during the workshop. The next presentation by Dr. Lucas described recent developments in modeling elements of the food web within the Delta, specifically phytoplankton populations. This model calculates phytoplankton biomass as a function of growth rates, light regime, consumption by grazers, and transport; its outputs are maps of changes in phytoplankton over time and space. The influence of invasive species on the food web was illustrated by Dr. Thompson who

described a model that integrated an understanding of hydrodynamics with the dynamics of *Corbula* and *Corbicula*, two invasive clams. The current knowledge of particle tracking models and the extension of these models to individual-based modeling of Delta Smelt was described by Dr. Kimmerer. This model is concerned with the processes of spawning, growth, mortality, food, and movement. Each model component is strongly reliant upon data to reduce the uncertainty. To this point, the management question that motivates the work is "*why does smelt abundance change with outflow*?" The formal presentations concluded with Dr. Marmorek who described the application of hydroecological models to design resilient management strategies and policies through the specific example of the Sacramento River Ecological Flows Tool (SacEFT). These presentations are available for viewing at http://calwater.ca.gov/science/

The formal presentations were followed by a discussion facilitated by Dr. Ott, with the presenters, panelists and audience participants. The models presented in the workshop were considered as examples of the current capabilities, the barriers currently facing scientists and engineers engaged in these simulations and what might be required to develop ecosystem response models that are at the same level of maturity as hydrodynamic and mass transport models.

II. Modeling Ecosystem Dynamics and Ecological Response

The National Research Council of the National Academies (NRC) has conducted several recent reviews of national priorities for resolving water problems (NRC 2000, 2001a, 2002, 2004) many of which are epitomized by the immense challenges facing the Delta and the people of California. One of the key areas identified in these reports is the prediction of ecological response to change. The NRC (2001b) identified the most important environmental challenges of the next generation that included:

- biological diversity and ecosystem functioning
- hydrologic forecasting
- infectious disease and the environment
- land-use dynamics
- climate variability

and acknowledged the close inter-relation between these priorities, which basically reflects a general ecosystem approach. The recognition of the critical nature of these topics and the lack of adequate scientific knowledge led to the mobilization of the national scientific community to create research entities such as the National Ecological Observatory Network (NEON) through the National Science Foundation (www.neoninc.org). One of the NEON 'Grand Challenge' Initiatives is:

> *To understand land-change dynamics as coupled human-environment systems and to forecast the land change outcomes at regional and continental scales that are relevant to management and policy.*

This illustrates the high profile of the importance of understanding and predicting ecological response nationally and how the research presented at the workshop is compatible with the national trend. However, it should be recognized that the challenges facing scientists in the Delta are more severe than many other systems due to:

- the extensive spatial scale from the upper watershed to the estuary
- the extreme complexity of the Delta landscape and interconnected channels; the physical processes, and number of government agencies and stakeholders involved
- the non-stationarity of the physical system
- the shifting priorities of society
- the long time required to understand many ecological processes, which usually exceeds the time available prior to executing essential management actions.

III. Current State of the Science of Ecosystem Modeling in the San Francisco Bay Delta Ecosystem

The complete presentations are available at http://calwater.ca.gov/science/.
This sequence of presentations illustrates a suite of modeling approaches ranging from the downscaling of global processes (such as global climate change models) to local effects within the Delta (CASCaDE). Also included are models being developed to simulate parts of the food web, the effects of invasive species, detailed prediction of population responses of threatened species such as Delta Smelt and an example of how ecological response can be linked directly to policy decisions.

III.1 Computational Assessments of Scenarios of Change in the Delta Ecosystem (CASCaDE)

James Cloern (USGS) described a visionary modeling approach that links a series of models across multiple scales of the water system from global climate changes models to watershed and Delta chemical- biological processes. It is motivated by the conceptual model that the Bay-Delta system is driven by large-scale processes scaling down, and small-scale processes scaling up. The primary objective is to build an understanding of how ecosystems targeted for restoration by CALFED might respond under plausible scenarios of change. This is a challenging initiative since there are multiple drivers of change.

The approach is to integrate existing models and analyses to understand the magnitude of the change expected from the external drivers. Global Climate Models have been downscaled to the region of the Central Valley (M. Dettinger and D. Cayan) and predictions of climate change scenarios are then used to drive a watershed model (N. Knowles). The outputs from these models include inflows to the Delta, water temperature, weather and sea-level rise which in turn are used to drive the TRIM model of the hydrodynamics in the Delta (N. Monsen). Changes in sea-level rise and hydrology of the Delta tributaries will in turn generate changes in the geomorphology (or landforms) of the Bay and Delta. These changes are then used to project expected variations to intertidal habitat in Suisun Bay (N. Ganju and D. Schoellhamer) and overall changes in sediment budgets and San Francisco Bay morphology (B. Jaffe, M. Vanderwegan and D. Roelvink). Projections of ecological change include temperature (W. Wagner and M. Stacey), fish (L. Brown, W. Bennett and C. Woodley), mercury/selenium (R. Stewart and S. Luoma), phytoplankton (L. Lucas) and invasive species (J. Thompson).

This project is an excellent illustration of both the complexity of the problem and the cascade of models and analyses necessary to understand change within the Delta. A talented interdisciplinary team of researchers has been assembled but the Panel is concerned about the sustainability of this effort after the current 3-year project finishes. This type of initiative requires a long-term view where models can be updated, the experienced team retained, assumptions quantified and trends verified as more data become available in the future.

Further details are available at http://sfbay.wr.usgs.gov/cascade/

III.2 Phytoplankton Model

Lisa Lucas (USGS) presented a phytoplankton model she has been developing with other colleagues for some time. She presented a conceptual model of phytoplankton productivity and biomass that considers consumption, transport, and light. Of these, transport processes are the dominant linkage between phytoplankton productivity and ecosystem scale food web support. Locally, consumption can also be a dominant process. She emphasized that no "finished" phytoplankton model yet exists because data is often inadequate for chemical/biological empirical relationships and process rates. Especially difficult is that "different species do/like different things at different times and different places." Her model represents large scale spatial patterns of chlorophyll concentration in the Delta rather well, but does less well across time. The model is expected to be one of the linked models in the CASCaDE model.

III.3 Bivalve Model

Jan Thompson of USGS presented a bivalve model she is developing with other colleagues. She emphasized that bivalve lifecycle conceptual model has been developed for the DRERIP process that contains all of the elements needed for a numerical model. They tell us what we know, how we know it, and what critical data are lacking. While the bivalve conceptual model is rather complete, its numerical adjunct is still in development because available data does not support several process rates like magnitudes of grazing in space and time. Similar to the phytoplankton model physical processes dominate much of bivalve life history. Dr. Thompson is working on a numerical model in a network flow framework that will be linked to the CASCaDE model. She expects the model to elucidate thresholds, processes, and limits, and provide linkages to changeable variables. She acknowledged that a particular value of numerical models is their ability to surprise us!

III.4 Individual-Based Model of Delta Smelt

Wim Kimmerer described three studies involving modeling of delta smelt and other fishes in the estuary. His most recent study is aimed at building and applying an Individual-Based Model (IBM) of delta smelt. The model is referred to as "individual-based" because it simulates the

life-history characteristics of individual fish. The overall population response of the species is determined from the summation of the individuals. A novel feature of the IBM model design is that it incorporates the DSM2 hydrodynamic and particle tracking models to simulate the movement and entrainment of young life stages of delta smelt. The IBM model is intended mostly for use in gaining new understanding of the population ecology of delta smelt and for providing insights into the decline of the species. It is possible that the study may also identify strategies that could lead to the eventual recovery of the species.

The panel feels the IBM study is a useful step forward in understanding a key species of concern in the estuary and for revealing insights into the important linkage between population levels of the species and water operations (especially export losses) and water-year type (wet or dry). As was pointed out during the workshop, the model and study were not designed to directly assess the effects of any future modifications to Delta conveyance on delta smelt population levels. The model has so far been used in predictions of delta smelt population dynamics for an historical period (1995-2005) and for periods defined by hypothetical sequences of repeated conditions for a "good" (1999) and "bad" (2002) water year for delta smelt. The model cannot be used in predictions of future or hypothetical events when data (such as for salinity and food) or hydrodynamic simulations are not available. It is likely that the study will reveal useful information for assessing the potential advantages to delta smelt populations of a dual-conveyance system if it succeeds at better quantifying the population-level effects from entrainment at the south Delta export facilities. Because the IBM model simulates only one component of the ecosystem (delta smelt) it cannot be expected to contribute to understanding mechanisms behind the observed behavior of the entire ecosystem.

III.5 Sacramento River Flow Tools (SacEFT)

David Marmorek stressed the importance of selecting models that directly relate to the decisions to be made. These models should then be used to explore the range of possible futures that account for uncertainties in both our understanding and the natural variability of the forcing functions. The presentation also demonstrated how models should be sufficiently complex to address the question – but no more so. The primary model that was described is SacEFT which assesses the effects of management actions on the hydrological characteristics of the Sacramento River and associated habitats of native species. The tool has been designed to have a strong science base but can be used for water operations gaming. Results are displayed with very visual

'traffic light' graphics (red, yellow and green) so that managers from different disciplines can quickly grasp the consequences of different outcomes so that target and avoidance flow regimes can be established. The model also allows an understanding to be developed of how habitat is affected in different flow years. Key elements of the model success includes the degree of user-friendliness, the utility of the model to decision-makers, the peer review of the underlying science and model projections, and an overall solid scientific base.

Further details of this decision support tool are available at:
www.delta.dfg.ca.gov/erp/sacriverecoflows.asp

III.6 Key Questions Arising During Workshop Discussions

Several key questions were raised during the afternoon discussion that had particular relevance to the request of the Task Force. These questions and comments/responses by the panel are given below.

1. *Why are there no quantitative models of ecosystem dynamics for the Delta that are able to predict ecological response to changed physical conditions in a manner comparable to the hydrodynamic models DSM2, RMA2, UnTRIM?*

The approach has been to model particular components of the ecosystem (e.g. phytoplankton, Delta smelt) and to build models from scratch that are unique to the Delta. There were no presentations or suggestions of any attempt to model complete ecosystem dynamics. Population models that are linked to hydrodynamic models were presented but nothing about any ecosystem models. An ecosystem model is one that incorporates physical, chemical and biological components of the system. We therefore classify the models being developed as "ecological models" rather than true "ecosystem models."

There are more unknowns – linkages, pathways, and rates – in the biological and biogeochemical components of the ecosystem than in the physical. It is difficult for a biologist who understands the complexities of the system to greatly simplify that complexity in a model. Yet that simplification is necessary, at least initially. The particle tracking models begin to do that in that they treat organisms as particles and then add some behavior on top of that. The presentations showed no attempt to try to lump biological components into meaningful

functional groups, develop models based on that functional grouping, and link those models to hydrodynamics.

2. *To what extent will the current research and development of ecological models for the Delta (e.g., CASCaDE, Individual Based Population Models, DRERIP, others) address this limitation?*

It is interesting that this question refers to ecological models and not ecosystem models. As noted above, the models presented at the workshop are largely population models, so they can be called ecological models, but not ecosystem models. Clearly the modelers are making progress through these population models and the DRERIP Conceptual Models, but a greater variety of approaches could be implemented. For example, the potential benefits of a more lumped ecosystem model could be explored as well some different modeling approaches, such as artificial neural networks. The models presented at the workshop are rich in biological detail and specific to the species and processes of the Delta, but no one appears to have asked the question – to what extent can these be simplified? Can ecological models be built with fewer components (e.g., where species are combined into functional groups) that still allow one to evaluate some scenarios of future change? To what extent is spatial and biological detail required for the policy questions that need to be answered? One wonders if the spatial and temporal detail that has been made possible by the detailed hydrodynamic models has not led the ecologists into a morass of detail that will not provide the kinds of answers that managers and policy analysts need at this point in time. Clearly that level of detail will eventually enhance understanding of the system, but it will not be available to answer the current policy questions.

At this point we have two components of potential future ecosystem modeling in place. First, there are sufficient conceptual models developed by DRERIP to help guide future development of numerical models that might be integrated into a semblance of ecosystem level model(s). Second, there are also in place some, but not many, habitat and population numerical models that are based on ongoing research. However, there appears to be little effort except perhaps by groups like ESSA, to try to create more comprehensive models that represents some or all of a particular system.

3. *What is the prognosis for developing a fully linked hydrodynamic/ecosystem model for the Delta within the next decade*?

It depends on what is meant by an ecosystem model and the level of detail that is desired. It is likely that models focused on the linkage between hydrodynamics and individual species will continue to be developed as shown by the presentations, for example, the likelihood of linking hydrodynamics and phytoplankton models seems most likely to be developed in the near term. Extending those to the entire food web or ecosystem in the next decade seems less likely, although new modeling approaches that attempt to model a more simplified biological system might provide insights; however, those models can also lead one astray. The approach is extremely difficult and unlikely in the near future.

Often, in management settings, empirically based statistical models have been used (e.g., to predict lake eutrophication with changing P loading); is anyone taking that approach? Similarly, to understand environmental flow requirements in rivers, a much coarser scale approach has been used with some success and management application. Simplification of integrated models, as demonstrated by SacEFT may prove to be a fruitful approach.

It is important to note that we are attempting to leap from hydrodynamics to ecosystems (although the models shown are models of the biological components of the system, that is ecological not ecosystem models) with limited attention to biogeochemistry of the ecosystem. The status of modeling developments to integrate hydrodynamics, water quality and nutrient dynamics was unclear to the Panel, although these elements would be required as a bridge to more complete ecosystem models.

There is a need to have algorithms that capture the essence of the DRERIP conceptual models so that cross walking among the numerical models is possible. This will require standardized model interfaces, overlapping drivers and forcing functions and consistent habitat characteristics and descriptions). At this point, there appear to be only numerical ecological (biological) models that have potential for some cross walking through overlapping drivers (e.g., flow inputs, salinity, temperature, turbidity, etc.)

4. *In the absence of quantitative ecosystem models what is the most effective and efficient means to assess the ecological impact of changed hydrology?*

The hydrodynamic models provide insight into physical changes resulting from changed climate and hydrology. The downscaling approach of CASCaDE seems very promising and likely to result in future scenarios that could incorporate both management decisions and climate change. Given the hydrodynamic scenarios that arise from those physical models, qualitative assessments of ecological impacts are possible using conceptual models such as those in DRERIP. More effort devoted to qualitative modeling could prove useful. The SacEFT model offers an interim approach that captures current knowledge in a way that is useful to managers. What Jan Thompson is doing with *Corbicula* and *Corbula* offers another potentially useful path, i.e., use a fairly simple modeling framework (STELLA) and model the 'fat red arrows' in DRERIP.

It may be useful to attempt to adapt a model that has been used successfully in another estuary for the Delta.

IV. A Vision for the Future and Recommended Actions

It is unlikely that a comprehensive ecosystem model for the Delta as a whole will ever be developed given the complexity of the ecosystem (in terms of number of species, ecological interactions, and the heterogeneity of the estuarine habitat in both space and time). A true ecosystem model must incorporate all the physical, chemical, and biological components of the system and their interactions. Building a highly detailed ecosystem model for the Delta is severely limited by a lack of understanding and information regarding the linkages, pathways, and rates required to define the mathematical relationships in the model.

However, there was a consensus among the panel and speakers at the workshops that it is feasible to move toward a vision of a useful ecosystem model for specifically exploring responses to particular changes (such as to the conveyance system). Simplifications would be required such as limiting the number of ecosystem components included in the model and building significant simplifications into the functional relationships. A simplified, purpose-specific model would require thoughtful analyses of exactly what ecosystem attributes and components are required to sustain the key species populations. This effort is so important that there may be no choice but to attempt this ambitious vision due to the multiple concerns and multitude of stakeholders.

As the presentations at the workshop demonstrated, significant recent progress has been made in developing models of somewhat reduced complexity that include one or a few ecosystem components (e.g. phytoplankton, clams, or delta smelt). These models are still complex in comparison with what has been attempted in the past, and they represent a significant overall advance in Delta ecological modeling (to be distinguished from true ecosystem modeling). The models being developed incorporate strong linkage between hydrodynamics and the individual species being modeled. Given the important role of hydrodynamics, water diversions, and entrainment in affecting so many of the biological processes in the Delta, the panel believes this linkage is critical to the success of ecological modeling.

It was made clear at the workshop that the modeling studies presently being done are not addressing specifically the Task Force needs for information regarding how a new dual conveyance system, or a substantially modified through-Delta conveyance system, will affect either the estuarine ecosystem as a whole or the selected individual species being investigated. While a goal of the CASCaDE project is to determine how the Delta ecosystem might respond to plausible scenarios of change, dual conveyance is not a change that has been investigated by the study team (at least so far). As little as two years ago, the choice of constructing an isolated facility around the delta did not seem to be a serious option being considered by CALFED and the management agencies. The growing support that has emerged since late 2006 or early 2007 for considering an isolated facility as one component of a possible solution to the Delta's problems is a valuable lesson on how quickly and unexpectedly projections for change can occur, and how unforeseen they can be.

The development and application of the population models for delta smelt being done by Wim Kimmerer and his team was initiated in response to the pelagic organism decline in the Delta and because of the special management attention being paid to delta smelt as a threatened species. The models are being used mostly as diagnostic tools to understand the cause of the fish decline. As noted above (in Section III), the design of these models is not such that they can be applied to evaluate population responses to future scenarios involving major conveyance changes.

The panel recognizes that the Task Force is faced this year with making decisions on what changes to recommend for Delta conveyance facilities. From what the panel heard regarding the current status of ecological modeling activities, it seems clear that any short-term decisions of

the Task Force regarding conveyance must be made in the absence of specific ecological modeling studies designed to address this information gap. It seems these decisions will have to be made from evaluations, such as done for the Bay Delta Conservation Plan (BDCP) Conservation Strategies Options Evaluation Report (Science Applications International Corporation, 2007), that are largely qualitative, but based on the best professional judgment of individuals who are knowledgeable about the overall ecology of the Delta and the particular fish species of concern. The conceptual DRERIP models provide additional tools for these qualitative assessments. Additional helpful ecological evaluations of conveyance options in the Delta are anticipated by late summer from the scientists writing the PPIC II report.

We expect that the Task Force understands that once the selection of a new conveyance option is confirmed, a host of new, more-detailed decisions will eventually need to be made leading ultimately to how the new conveyance facilities will be operated. There is a strong need for ecosystem models to guide decisions in the intermediate and longer term while new through-delta options are designed, implemented and tested, and a new isolated facility is planned and possibly constructed. The research and development of Delta models must be an ongoing process that is supported with adequate funding.

The work on a Delta Vision strategic plan has generated an especially strong sense of urgency for making decisions and taking actions regarding new conveyance facilities for the Delta. The panel believes it is essential that a similar sense of urgency be developed for initiating a dedicated project to build a simplified ecosystem model that is tailored to assess responses to changes in conveyance facilities. This project could build upon existing modeling capabilities (such as the climate-change modeling capabilities of the CASCaDE project and the delta smelt modeling capabilities of the Kimmerer team), but it will require that a full-time multidisciplinary team be devoted to the project for at least several years. Although tailored to conveyance facilities and operations, the model development must consider all other scenarios of change within the Delta that are foreseeable (such as restoration projects and potential levee failures) and the large-scale changes (such as from the climate system and sea-level rise) that propagate down to the scale of the Delta. Admittedly, a model-building investigation of this kind will be expensive, but the cost will be tiny in comparison with the cost of the construction for the new conveyance facilities themselves. We hope that the Task Force will consider using its influence to promote the development of an ecosystem-response model for conveyance changes so that the model will be

available in the near future for the decisions (some unforeseen) that will undoubtedly need to be made.

For further improvements in ecosystem modeling, we suggest that CALFED might work with groups such as ESSA who have thought through integration and simplification of models. CalFed has made a step in the right direction by commissioning the DRERIP process that has developed a suite of useful ecosystem and species conceptual models for the Delta that incorporate the most recent scientific information on the Delta. Although qualitative rather than quantitative, the DRERIP models can lead to identifying overlapping drivers of ecosystem functions and provide the framework for building quantitative models. CALFED might put a staff member working with DRERIP on the task of identifying overlapping drivers and cross walking potentials among the DRERIP models. In this way, development of more comprehensive (i.e. ecosystem structure) conceptual models could get underway and allow integration of existing and developing numerical models.

Additional recommendations and comments from the panel include:

- There needs to be capacity-building. This is a 10-20 year effort – most of the existing intellectual capacity will retire in this period. Consideration should be given about how to create career tracks in agencies, water boards and academia that will attract and retain talented young scientists willing to make careers out of this challenging problem.
- Similar workshops or special sessions at the upcoming CALFED Science Conference could be considered to explore different modeling approaches in the Delta and in other estuaries. Phytoplankton modeling would be one obvious topic area.
- The ecological modeling approaches that are being used are all bottom-up and unique to the Delta. They are based on a relatively detailed understanding of the biology of particular species or groups of species. In part that may be because the investigators are very familiar with the ecological and biological details of the system. Is there an aversion to using off-the-shelf models, or have off-the-shelf models been investigated and identified as inadequate? An aversion to using off-the-shelf models is understandable when one is trying to do research to understand the mechanisms behind the observed behavior of the system and to use that mechanistic understanding to develop scenarios of response to future conditions. Clearly continued investment in the existing approaches is needed. But there are other approaches that may be valuable to explore. We suspect

there are estuarine models that are more generic that have been applied in other estuaries. It might be useful to adapt one of these for the Delta, its hydrodynamics and groups of species.

- We recommend that further thought be given to the extent to which spatial and biological detail are needed for the policy questions that must be answered? Is species level information needed? The extent to which species level predictions are possible seems limited at present. At this stage in ecological modeling, a variety of approaches might be tried. One approach that could be applied to see whether it provides any insights is more of a simpler, whole system model where species are lumped into functional groups.
- If the propagation of uncertainty is great in the hydrodynamic models, it will be orders of magnitude greater in the ecological models.

Acknowledgements

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References

Delta Vision Blue Ribbon Task Force, 2007. Our Vision for the California Delta: Report prepared for the California Governor, December 2007, 70 p. (accessed May 27, 2008 at the URL *http://deltavision.ca.gov/*)

Department of Water Resources, 2008. An Initial Assessment of Dual Water Conveyance. Final Draft, April. 41p.

NRC, 2000. Engineering and Environmental Challenges. National Academy of Engineering Annual Meeting. Washington, DC. 117 p.

NRC. 2001a. Envisioning the Agenda for Water Resources Research in the Twenty-First Century. National Academy Press, Washington, DC. 61 p.

NRC. 2001b. Grand Challenges in Environmental Sciences. Oversight Commission for the Committee on Grand Challenges in Environmental Sciences. 106 p.

NRC, 2002. Predictability and Limits-to-Prediction in Hydrologic Systems. National Academy Press, Washington, DC. 118 p.

NRC, 2004. Confronting the Nation's Water Problems: the Role of Research. Committee on Assessment of Water Resources Research. National Academy Press, Washington, DC. 310p.

Science Applications International Corporation, 2007, Conservation Strategy Options Evaluation Report: Prepared for the Steering Committee of the Bay-Delta Conservation Plan, September 17, 2007 (accessed May 27, 2008 at the URL *http://www.resources.ca.gov/bdcp/options.evaluations.html*).

Appendix I: Workshop Objectives and Agenda

WORKSHOP 2: LINKING PHYSICAL AND BIOLOGICAL MODELS FOR ECOSYSTEM PREDICTION, PLANNING, AND PERFORMANCE

May 20, 2008
9:00 a.m. - 5:00 p.m.
Bay-Delta Room, 650 Capitol Mall, 5th Floor
Sacramento, CA 95814

This workshop will be webcast:
http://www.visualwebcaster.com/event.asp?regd=y&id=48473

Download Meeting Notice

Workshop Purpose

This workshop will explore approaches to linking hydrodynamic and biological (ecological) models and assess the potential outcomes in an effort to advise the Task Force regarding what approaches might best be used to achieve planning objectives now and in the future.

Ron Ott, Science Advisor for the CALFED Science Program will facilitate the workshop.

Workshop Product

The science advisors will provide a technical report to the CALFED Lead Scientist Michael Healey. The Lead Scientist will summarize workshop proceedings for the Delta Vision Blue Ribbon Task Force at its May meeting.

Agenda

Order of agenda and listed times are approximate and subject to change.

- **9:00 a.m. Welcome and Introduction: Ron Ott**
  Presentations (proposed):
  - Using Models to Develop a Long View for the Delta - James Cloern, U.S.G.S.
  - Hydrodynamic Environment and Phytoplankton Growth - Lisa Lucas, U.S.G.S.
  - Water Management Scenarios and Clams - Jan Thompson, U.S.G.S.
  - Individual-Based and Particle-Tracking Models for Estuarine Biota - Wim Kimmerer, S.F.S.U.
  - How to use hydro-ecological models to design resilient policies: principles and examples, including the Sacramento River Ecological Flows Tool (SacEFT) - David Marmorek, and Clint Alexander, ESSA Technologies, Ltd
- **12:00 p.m. Lunch**
- **1:00 p.m. Question and Answer Session with Presenters and Science Advisors: Ron Ott**
- Science Advisors:
  - Peter Goodwin, University of Idaho, Boise
  - Pete Smith, U.S.G.S. (emeritus)
  - Chris Enright, Department of Water Resources
  - Duncan Patten, Montana State University
  - Judy Meyer, University of Georgia (emerita)
- **4:30 p.m. Public Comment**
- **5:00 p.m. Adjourn**