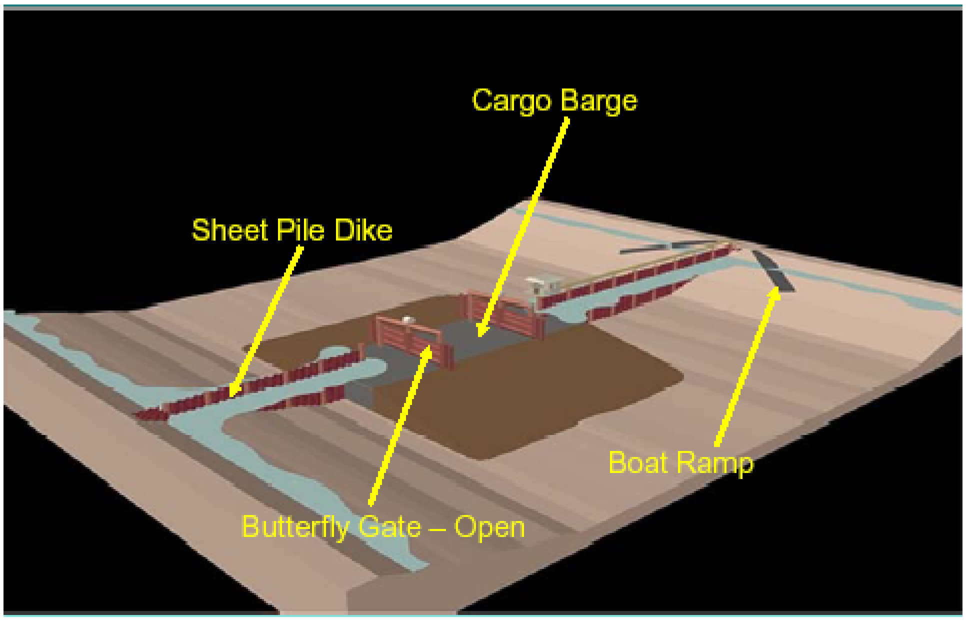
CALFED BAY-DELTA PROGRAM

CALFED Science Program

Science Review of the Two Gates Project

September 29, 2009



Report Prepared for:

Clifford N. Dahm, Ph.D.
CALFED Lead Scientist

Lauren Hastings, Ph.D.
Deputy Director for Science

Review Panel

James Anderson, University of Washington
Alan Blumberg, Stevens Institute of Technology
Peter Goodwin, University of Idaho (co-chair)
Stephen Monismith, Stanford University (co-chair)
Charles 'Si' Simenstad, University of Washington

List of Contents

Page Number

1. Introduction

Developed by the Metropolitan Water District of Southern California (hereafter referred to as "Met"), the Two Gates Project is designed to manipulate water flows, transport patterns and the turbidity field in the Sacramento-San Joaquin Delta so as to lessen entrainment of federally (ESA threatened) and state (California CESA endangered) protected juvenile and adult delta smelt (*Hypomesus transpacificus*) by state and federal pumps in the south Delta. The central idea is that gates located in Old River and in Connection Slough (see Figure 2 of "2-Gates Fish Protection Demonstration Project Summary Document") can be operated on a tidal basis so as to rectify flows in the central Delta. That is, closing the gates on flood tides and leaving them open on ebb tides will eliminate the southward tidal flow, producing a mostly northward flow in Old River and in the Franks Tract complex west of Connection Slough.

The evidence used to justify this strategy is based to varying degrees of quantitative certainty on four premises:

1. Entrainment is identified as key stressor and factor in the survival of delta smelt;
2. There is a significant statistical correlation between turbidity and delta smelt distribution;
3. There is a significant statistical correlation between turbidity and salvage of delta smelt at the pumps; and,
4. 15 NTU is an empirically established threshold (trigger) to qualify a low turbidity zone.

The direct goals of these flow manipulations are two-fold:

1. create a low turbidity "bridge" across the central Delta that will serve to keep adult delta smelt from swimming towards higher turbidity water near the pumps, where they can be entrained;
2. enhance tidal dispersion in the central Delta so as to reduce entrainment of juvenile delta smelt.

An explicit contingency of these manipulations is that they have no adverse effects on other ecosystem functions of the central Delta, and specifically that no other at-risk resources or water quality would be deleteriously impacted.

If successful, the project proponents believe that operation of Two Gates will *"...provide equal or improved protection to delta smelt (reduced entrainment at the export pumps) with higher than the minimum allowed water exports described in the Operations Criteria and Plan (OCAP) Biological Opinions (BOs) Reasonable and Prudent Alternatives (RPAs) of the U.S. Fish and Wildlife Service and National Marine Fisheries Service, while operating within the other water management requirement (D-1641)."*[1]

In short, the Two Gates Project aims to increase export levels above current levels set by recent legal opinions (e.g. Wanger) and currently extant BOs.

In large part, the project was developed using modeling combining hydrodynamics and fish behavior. i.e., physical (albeit computer-based) models were used to investigate how gate operations would affect flows and turbidity in the Delta. The behavior of delta smelt was developed combining a hydrodynamic circulation and particle tracking model. In this case, the particles responded according to rules that encapsulated the assumed behavior of delta smelt. As the smelt moved around in this simulated Delta, the primary response rule was to the turbidity field encountered where the governing rules were designed to keep them in water that had turbidities in excess of 12 NTUs. Finally, the operational rules for the gates and the overall performance of the Two Gates concept were determined by keeping track of virtual "fish" entrained at the pumps.

Most importantly, as proposed, the Two Gates Project poses the opportunity for an exemplary experiment in adaptive management because it has the potential to include detailed hydrodynamic and fish behavior modeling to generate predictions and test alternatives; extensive monitoring of physical and water quality variables, most notably turbidity and fluxes of chlorophyll *a* and salt; quantification of uncertainty and error; and additional monitoring of delta smelt. This information would be used to assess the effectiveness of the project, and (presumably) project operations adjusted accordingly. Indeed, the project integrates both construction and operation of facilities with new monitoring and research.

On August 6th, 2009, having been provided with a report detailing the project and the methodology used to develop the project, this panel met to review the Two Gates Project, hearing a series of presentations from the project proponents along with a brief

[1] Summary report p. 1

discussion of the regulatory issues given by representatives of the fisheries agencies charged with formulating BOs concerning the project. In keeping with the panel's charge, this report focuses on the scientific issues the project entails, in particular evaluating the methods and models used to develop the project and to make predictions of its possible benefits as well as how the project would actually would be implemented in terms of the proposed enhanced monitoring and how that monitoring would be used to determine project success at reducing delta smelt entrainment. The panel charge did not include assessing other impacts of the projects, e.g. the effects of gate operations on boat traffic and public safety issues, nor did we consider policy issues such as funding mechanisms for the project and/or associated monitoring or the expedited timetable of the project. Finally, the panel recommendations do not extend to recommending for or against the project.

In the sections below we present our evaluation of the project as proposed, listing aspects of the project that we viewed as being positive, then aspects of the project that we viewed as having major shortcomings, finishing with a set of recommendations aimed at improving the project and its associated monitoring and modeling.

2. Positives

This project represents a major initiative to try and resolve some of the conflicts surrounding the management of the Bay-Delta region through an innovative approach that has an objective of providing significant control over the circulation patterns in the south Delta. As we discuss below, the panel felt that the project had some significant positive merit.

2.1 Overall strategy

The panel was impressed (in a general sense) with the overall strategy used to develop the project. The project started with hypotheses and the best, albeit meager, available empirical data about how physical factors, turbidity and mean flows might affect entrainment of delta smelt. The project proponents then used advanced engineering tools to design and evaluate the project. The physical manipulations Two Gates would make possible represent (a) an excellent opportunity for large scale adaptive management experimentation and (b) potential for increased operational flexibility by effecting changes in mean circulation comparable to large changes in exports. Finally, the project appears to have been designed to minimize impacts on other listed species. Each of these aspects is elaborated below:

2.1a The findings of the study are based primarily on the use of hydrodynamic, sediment transport (turbidity) and fish transport/behavior models. The sediment and fish models are run after the water movement dynamics have been completed. The models employed are all consistent and reliable techniques and have been extensively evaluated during the past decade. This means the capabilities and limitations of the models are known and have been described in other recent reviews (for example: http://www.iep.ca.gov/suisun/modeling/ and http://cwemf.org/). While each of the models could be used in more rigorous fashion, their use suggests that the study has been designed well. Monitoring is a key here. The model findings to date are not intuitively obvious and suggest that observations must be available to substantiate the modeling and to serve as a first line of defense in case the modeling is not completely correct and ensure corrective capability exists in the management plan to adjust as more becomes known about the behavior of smelt. From the presentations in the workshop and subsequent discussion in the afternoon session, the monitoring plan appears strong but the details need to be fleshed out and the deployment of instrumentation guaranteed throughout the lifetime of the gates.

2.1b The project location, participants, coordination of science and modeling proposed for the Two Gates Project provide a rare opportunity to actually conduct a large scale adaptive management experiment, especially given the potential five-year time frame. Since the early origins of adaptive management (e.g. Hollings 1978), environmental managers have been struggling with the challenges of practically implementing experiments to test uncertainties in a decision-making structure that actually allows iterative experimentation and adjustment of management alternatives and refinement of decisions (NRC 2004; Lee 1999; Nybert 1999). Environmental decisions are typically under tight time restrictions and demands for results to allow the iterative learning process ("learning wheel" Nybert 1999) of: (1) *assessing* the shared understanding of key social-economic-ecological interrelationships and associated problems and opportunities, where characterizing the management problem and developing a range of hypotheses that predict how indicators might be affected by alternative actions is most effectively developed using conceptual (or preferably, dynamic) models; (2) *designing* management actions as experiments that address biophysical, social and institutional criteria and uncertainties; (3) *implementing* explicit tests of hypotheses and assumptions; (4) *monitoring* feedback from performance measures and indicators that were defined in the assessment phase; (5) *evaluating* options for future actions and changes based on monitoring results; and, (6) adaptively *modifying* experiments (as well as hypotheses and assumptions) based on what was learned (Nybert 1999; Williams *et al*. 2007). That all of these elements, and particularly the rigorous hydrodynamic and fish behavior modeling required to frame alternative hypotheses and management actions, are present or possible in the context of the Two Gates Project speaks to the possibility of an implementable adaptive management approach to assessing and perfecting the project objectives.

2.1c The Two Gates Project would give the water project operators (DWR/USBR) increased operational flexibility, i.e., as demonstrated in the modeling appendices to the summary project report, operation of the gates can effect large-scale changes in Delta circulation and transport patterns. We note that operation of similar existing facilities, notably the Delta Cross Channel and Montezuma Slough gates currently play a major role in management of the Delta pursuant to environmental regulations and goals for protection of habitats and species. In particular, the changes induced by Two Gates would most obviously be felt in Old River, since southward flows that occur now when exports are substantial could nearly be eliminated. On the other hand, conservation of mass requires that the overall southward flow from the Sacramento to the San Joaquin side of the Delta requires that southward flows in Middle River and in the main stem of the San Joaquin must increase to compensate for reductions in such flows in Old River. This produces a substantial residual counterclockwise circulation in the central Delta. Thus, the effects of the gate operations on tidally averaged Delta circulation could be comparable to relatively large changes in exports.

2.1 d The potential impacts on other species of ecological concern or interest would appear to be comparatively low. Although this question has not been addressed with much scientific diligence and requires further investigation (see below), the proposed structure and operation of the gates does not appear to present an obvious or significant impediment to other fish and wildlife. It might even be argued that the vulnerability of other fish and nekton associated with delta smelt to be entrained by the pumps will be reduced similarly.

2.2 Commitment to Project

As shown by the substantial investment made to date in designing the project, the project proponents have demonstrated a commitment to make the project work as a whole, i.e. not only to build the facility, but to support the modeling, monitoring, and research into delta smelt behavior that are integral to understanding how gate operations are affecting flows, turbidity and entrainment of delta smelt, and to incorporate this into an adaptive management framework. The panel is strongly supportive of incorporating science directly in the project. Indeed several of the current panel members participated in reviews of the Environmental Water Account (EWA) and recall unsuccessfully recommending that science to evaluate the hypothesized effects of EWA be included as part of the EWA directly.

2.3 Integration of Modeling with Project Design

This project has been conceived based on the current scientific knowledge regarding the dynamics of the Delta and builds upon the extensive experience of the modelers and scientists who developed the plan. The hydrodynamic models used have been calibrated, tested and evaluated extensively during the past decade and the capabilities and limitations are well known not just to the modelers but also the agencies and scientific community working on Delta issues. The Panel was impressed by the frankness of the modelers and scientists in the Q&A sessions of the workshop regarding the limitations surrounding the use of 2-d models and the simplifications involved in the preliminary turbidity algorithms. This bodes well for the future as one of the benefits of the proposed monitoring will be to quantify the uncertainties in the modeling as articulated by members of the Panel and experts such as Dr. Pete Smith (verbal contribution at workshop and subsequent personal communication to Panel). This monitoring will also facilitate the refinement of the turbidity algorithm to an appropriate level to give confidence in the management of the gates.

2.4 Recognition of the Importance of Integrated Modeling and Monitoring

The project intention of integration of monitoring and modeling will provide valuable information that will help evaluate the major project hypothesis that turbidity is a trigger that initiates migration of delta smelt from Suisun Bay into the western Delta. The monitoring project is strongest in characterizing the tidal distribution and fluxes of salt and turbidity through the Delta. The project plans two levels of monitoring: wide-area and site-specific monitoring programs. The wide program will use fixed sites to track the hydrodynamic and water property distribution associated with the gate operations. The site specific program is intended to study the movement of fish during the first winter flush of turbidity. The combination of the two component programs is a strong aspect of the project. In particular, the site specific monitoring will provide valuable information to test and improve the smelt behavior model. This link between model development and monitoring is particularly innovative, which the panel strongly encourages.

2.5 The project builds on existing "scientific infrastructure" of the Delta.

By this we mean that the project:

(a) draws substantially on scientific knowledge about the physics of the Delta and about delta smelt behavior and population distributions. Although, as we discuss below, some of the statements made in the summary report and appendices about delta smelt and turbidity are likely stronger than what is in the original source material. In many respects, the project makes best use of understanding of Delta hydrodynamics gained by the USGS over the past years (albeit the paucity of peer-reviewed documentation of this understanding).

(b) utilizes substantial investments made in developing, calibrating, verifying the RMA circulation models, work that has been carried out as part of the Delta Risk Management Strategy (DRMS) effort as well as other smaller projects. This development effort has included an effective set of post-processing tools that include versatile particle tracking (especially useful in the present context), and graphical representation of model output.

(c) is designed to largely use existing USGS-operated monitoring networks for flows, temperatures, and salinities, along with existing California Department of Fish and Game fish surveys.

By using what is known about the Delta and about delta smelt, the chances that the project will succeed are enhanced. From a practical standpoint, the use of existing tools and monitoring networks is efficient in terms of both resources and time.

2.6 The use of Bay-Delta-live website to distribute information and communicate is laudable.

A key to the success of the Two Gates Project will be independent confirmation of the impacts and benefits. This independent confirmation will be from academic scientists and environmental engineers. The project is taking advantage of the Bay-Delta-live website to disseminate the observational data collected by the monitoring program in a timely fashion and to provide information on impacts in almost real-time. An interested party should be able to evaluate the effectiveness of the Two Gates operation on their own.

2.7 Potential Rapid Reversibility

The chance of catastrophic outcomes arising from unanticipated consequences of the Two Gates Project is likely low, but the Panel feels is still uncertain without a formal adaptive management structure that would anticipate (hypothesize) and evaluate such alternative outcomes. If the additional monitoring and attention being given to this project by state and federal agencies and NGOs were to be formalized in an adaptive management framework, such trends and changes to the aquatic environment will be assessed and detected well before reaching a significant level. The resolution to most adverse trends would be to leave the gates open and the hydrodynamic model result indicates relatively small impacts on the overall circulation in the south Delta, but these alternative actions have yet to be evaluated. The Panel is also concerned that it is unclear who would be responsible for making the ultimate decision (e.g., how and who would organize and manage the adaptive management plan) if the gate operation was dramatically altered or even left fully open during certain periods, seasons or permanently.

3. Negatives

The project proposal also has some significant shortcomings and problems. These issues were partly due to lack of specific details and partly with the scientific approach. Some of these problems have to do with the way the modeling was done to develop the project, notably the panel found that the current version of the delta smelt behavior model is a valuable first step but represents an oversimplification of what is known about delta smelt. Specific problem areas are discussed below:

3.1 Project goals are not adequately defined

While the project proponents made clear that the Two Gates Project is about reducing entrainment losses of delta smelt, they did not make clear the extent to which the project is designed to aid delta smelt recovery versus enabling higher levels of export than are currently permitted. The goal of substituting protection of delta smelt by manipulating tidal flows in place of restrictions on Old and Middle River flows (OMR flows) that essentially restrict export seems obvious, and has been stated publicly by elected officials, yet this was not made clear in presentations given during the review. Interestingly, it is stated more clearly in the project documentation, where the text,

> *"..To provide equal or improved protection of delta smelt with higher than the minimum allowed water exports..."*

appears on page 2 of the project summary. Making this goal clear is important because it bears on all aspects of the design of the monitoring and operation of the project. For example, with the above goal, the question naturally arises as to under what circumstances or after what period of time changes in export rules might be considered. This means showing conclusively not only that the project reduces entrainment, but by how much.

3.2 Poorly Formulated Smelt Behavior Model

A critical element of project design, the smelt behavior model, is incomplete and not connected to existing literature on fish behavior models. The behavioral model takes a top-down approach using specific rules to produce a pattern similar to that observed between fish and turbidity in salvage. It implicitly assumes that producing an observed pattern implies that the movement rules sufficiently capture fish behavior throughout the Delta and, more importantly, that the rules will capture fish behavior when the patterns between flow, salinity and turbidity are disrupted by the operations of the Two Gates. The signals that cue fish behavior in the model are rather complex and many are based on km-scale horizontal gradients. However, organisms respond to events and forces they can detect in their immediate environment, and have no capability to respond to distant conditions (Kimmerer 2004). In short, the behaviors are biologically tenuous. Since the behavioral rules are biologically questionable, the assumptions that they will capture the response of fish to the Two Gates operations is a central defining aspect of the project that needs substantiation and comparison with alternative assumptions. Some of the issues involving the behavior model are detailed Appendix II, which compares the model with an alternative that takes a bottom-up approach beginning with the fish's response to its immediate environment.

3.3 The turbidity/behavior linkage is weakly statistical, not mechanistic.

Again this is a central, defining aspect of the project that needs substantiation. The link between the distribution of turbidity and behavior is largely made through concurrence of the fish and turbidity in salvage (Grimaldo et al. 2009). The relationship, while statistically significant, is weak. Furthermore, a major hypothesis is that the first winter flush of turbidity draws fish out of Suisun Bay and into the Delta. However, Suisun Bay is 70 km from the pumps so inferences on fish response to the first winter flush from the salvage pattern is tenuous. The studies to date do not provide direct clear evidence for the detailed response inferred in the behavioral model. The Grimaldo et al. (2009) study also demonstrated that salvage loss depends on the seasonal occurrence of fish near the pumps and the direction of the net flow at the time. This may suggest that a relationship between fish and turbidity is more correlation than causation. The project does partially recognize this possibility and addresses the issue with the proposed tidal monitoring study. However, this study is not sufficiently developed and connected with biologically realistic hypotheses for how delta smelt sense and respond to their environment.

3.4 The hydrodynamic model needs better substantiation and quantification of uncertainty/reliability.

The hydrodynamic/turbidity modeling component of the Two Gates impact analysis will be a key factor in getting the right answer for the right reasons. The modeling done to date is based on a 2D vertically integrated hydrodynamic model, RMA-11, and a recently developed sub-module that calculates turbidity using a simple first-order decay. The RMA models have a long and successful history and are well known to professionals in the field; thus, they are suitable for use here. As with any model, the proof of its validity is how well the model and its attendant data inputs can reproduce past conditions and project current and future responses. There is never enough data to completely resolve the predictive and replicative capability of the model and careful thinking is required to substantiate the results.

The use of RMA-11 for the Two Gates impact analysis has been extensive. The many comparisons with hydrodynamic observations (water level, temperature salinity, currents) are impressive. The calibration is reasonable based on visual comparisons. The tidal time scale results are good but the longer time scale dynamics like the net flow are less convincing. Quantitative metrics of model quality were not given in the reports and it is very difficult to critically assess the ability of RMA to simulate the Delta system for this application. The use of quantitative metrics should be factored into all subsequent analysis.

The turbidity component of the model is rudimentary. The turbidity modeling is based on simplified sediment transport dynamics. The model consists of transporting a passive scalar representing sediment. The role of sediment deposition and erosion is handled through the use of an exponential decay function. The Frank's Tract depositional area in particular may not be modeled well. The use of this simplified approach, while not necessarily bad, must be validated by careful comparisons with observational data.

The turbidity model calibration is not rigorous and the model results should be considered preliminary at best. The calibration is based on only one water year 2008. That year was an extremely dry period with very low flows and not representative of conditions under which the Two Gates operation is likely to occur in most years. Moreover, there was little data for comparisons in key areas like the Mokelumne River. It is strongly suggested here that results from other years should be included in the analysis. Modeling years without extensive turbidity data will be useful as well to provide a sense of how sensitive the results are to natural variability.

Although it appears that there is reasonable correlation between turbidity and the suspended sediment algorithm used in the current study, there are several processes that should be quantified as insignificant or included into the refined turbidity algorithm explored in the discussion sessions of the workshop. Specifically, the role of organic material (particularly the variation on a seasonal basis) and the effects of flocculation and resuspension should be explored. This is important if the project will affect salinity and bed shear in some areas so that the historic turbidity correlations may no longer be valid under some conditions.

3.5 Fish-turbidity studies are not clearly designed

- The design for sampling is not sufficiently detailed and should be NSF quality and detail. The fish turbidity studies need to focus on defining the local environment experienced by the fish. Vertically averaged measures of turbidity, salinity and velocity are not sufficient to evaluate the hypothesis in which fish move by surfing the tides. The studies need to characterize how the environment asymmetrically changes with the tides and how the fish respond. Some of the issues are discussed in Appendix II.

- Performance metrics are needed in the experimental design. In particular, characterizing the surfing response of fish over a tidal cycle presents observation and analysis challenges. The system is dynamic and separating directed "surfing" movement of fish from the movement of neutrally buoyant particles will require considerable thought involving scientists with the right expertise, i.e. fish biology, estuarine hydrodynamics, fish behavior, modeling and field sampling.
- Connections between fish and turbidity are only qualitative and anecdotal, especially for places other than salvage. The tidal monitoring study needs greater emphasis. The information from the study will be essential for testing and further developing the behavioral model.

3.6 Despite the potential "power" of an effective adaptive management framework to evaluate and refine the Two Gates Project toward its intended objectives, at present any actual plan is vague and undefined.

The team does not appear to have developed a *process* to develop an adaptive management plan. As a result, it is impossible for the Panel to evaluate whether:

- the specifications for monitoring, assessment, and modeling of project performance and evaluation are clearly identified;
- implementation of the proposed monitoring, assessment and modeling plan lead to adequate assessment of project performance;
- metrics are likely to be sensitive enough to detect effects of gate operations; or
- there are adequate resources provided for project monitoring, assessment and evaluation.

If it continues to be ignored or left to the later stages of project development, the lack of a practical decision analysis system will threaten the project's ultimate performance, or at least resolution of major uncertainties. Even fundamental components of a basic adaptive management plan have yet to be identified, not to mention the necessary analytical management structure, which includes:

(a) alternative hypotheses under different biophysical model conditions or assumptions;
(b) predictions of outcomes - what if the project is a success (assuming this is defined….What will happen then?);
(c) quantitative performance measures associated with the alternative hypotheses;
(d) management decision tree (e.g. as was developed for EWA – something that took several years)
(e) indicators, thresholds and triggers that are required for the assessment process, which should be derived from an expanded conceptual model to develop hypotheses/predictions;
(f) identification of the project management, team components or institutions/agencies responsible for the adaptive management plan.

Development of the framework, operational structure and process of adaptive management should not be put off any longer. The project involves very complex players and relationships, with different authorities and responsibilities. Given this complexity and short planning horizon, the Panel suggests that the team consider bringing in a respected advisor or consultant who specializes in organizing adaptive management systems and provide them with the independence and authority to draft an appropriate adaptive management plan.

4. Recommendations

4.1 The project goals should be clarified and stated explicitly and prominently.

The proponents should make explicit the extent to which the project is focused on helping delta smelt recover versus understanding links of turbidity and entrainment of delta smelt versus increasing exports while doing no additional harm. We recognize that all these issues are interlinked, but making clear what the project is designed to do will facilitate formulation of a definitive adaptive management plan, and make clear the extent to which the project functions as designed. It will also help clarify any future misunderstandings or criticisms from other interested parties.

4.2 Adaptive Management Plan

A rigorous adaptive management plan needs to be formulated that includes the decision process and specification of who is responsible to make decisions (refer to Section 3.6 above).

4.3 Commitment for monitoring, analysis and synthesis of results

Currently there are extensive efforts at the national (NOAA NMFS, NSF) and state level to develop distributed data management systems that allow managers and researchers to access information in a form that can be used and understood easily. These approaches do not rely on developing 'super-databases' that require extensive maintenance and management, but rather leaves the management of individual monitoring programs with the responsible agencies and developing the cyberinfrastructure framework for assimilation of data from multiple sources and the data mining, synthesis and display tools to make this data contribute to the knowledge of the system (for example, Atkins et al., 2003 and the CUAHSI Hydrological Information System).

The Panel concurs with the project team that the monitoring and adaptive management are absolutely essential and should be funded adequately. Data management and transparency have been a priority for the CALFED Science Program for the past three years, refer for example to summary report by Mike Healey (former CALFED Lead Scientist) to the Delta Vision Blue Ribbon Task Force and the recommendations by Dr. S. Luoma (former CALFED Lead Scientist, currently USGS and UC Davis). Depending on the availability of funding, consideration should be given by the Science Program and project proponents for a joint initiative to use the Two Gates monitoring program as a 'test-bed' to demonstrate these tools for future data management in the Bay-Delta.

The proposed monitoring for the Two Gates Project will supplement existing monitoring programs. A contingency plan should be developed and contingency funding allocated in the event of the elimination or suspension of any external data-streams that the Two Gates adaptive management relies upon.

4.4 Testing of mechanistic linkage is key and must be strengthened

4.4a Need a more detailed plan for mechanistic sampling especially for fish – these should be at the level of sophistication/detail of an NSF proposal. A targeted workshop should be held to help project scientists design experiments [the panel could help with this]. Appendix II illustrates a more biologically based hypothesis of the type that the panel believes is required for planning a sampling program. In particular, the tidal study needs to be developed with a 3D model that integrates hydrodynamics and water properties with specific hypotheses on fish behavior. The 3D model can then be used to evaluate the ability of sampling schemes to provide useful information on the behavioral hypotheses. In effect, by modeling the collection properties of the fish sampling gear within the 3D model, it is possible to evaluate in "silico" the ability of a sampling program to distinguish fish behavioral responses to the physical environment.

4.4b Construct several different behavior models and test them using an open/closed operations strategy on a week time scale – getting the physics accurate is relatively easy, but fish sampling (as described above) needs some thought. Design needs to be based on a set of hypotheses such is outlined in Appendix II.

4.4c Use a 3D model to confirm 2D hydrodynamic and particle tracking results. Today's state of the art in hydrodynamic/turbidity modeling is quite advanced. The approach taken here is based on simplified model physics (2D not 3D) and the effects of this simplification need to be quantified. Comparisons with results from other Delta models, e.g. 3D models like UNTRIM as well as 1D models like DSM2, to check flow changes predicted by RMA would increase the level of reliance that can be placed on model predictions. These comparisons would help confirm that RMA model-predicted changes in flows associated with project operations would be realized In addition, the particle tracking methodology upon which the fish behavior model is based has not been validated. Although this methodology is difficult to validate using field data, at a minimum the project modelers should compare particle tracking and scalar transport results for the release of virtual dye clouds at key points throughout the Delta (see Simons et al. 2007 for an example of this comparison). The rationale for this comparison is that the model's ability to predict salinity distributions reflects its ability to accurately compute scalar transport.

4.5 Consequences to Other Species

The Panel feels that considerable uncertainty remains around potential unanticipated consequences of the Two Gates Project operation, as designed to maximize benefits to delta smelt, for other species of concern or interest. We acknowledge that the team has made efforts to: identify beneficial and adverse effects to listed species; consider effects to critical habitat and its primary constituent elements; identify effects to essential fish habitat; and, evaluate construction and operational effects on sensitive species. But we find little rigor in any assessment of potential impacts on juvenile salmon (e.g., Central Valley fall Chinook, *Oncorhynchus tshawytscha*) or other species of concern or sensitivity, such as Sacramento splittail (*Pogonichthys macrolepidotus*) or Sacramento tule perch (*Hysterocarpus traski traski*). Although the potential for predator aggregations around the gates has been mentioned, we found no assessment of the likelihood or scale of such a response and nothing mentioned about potential piscivorous bird responses.

We understand the difficulty in making such an assessment. The team has depended on the IEP sampling network for the primary data, which is not really designed to address such questions or hypotheses. However, the response of juvenile salmon, splittail and tule perch and their habitats to Two Gates construction and operation should be quantified even if the finding is unlikely to be significant. The Panel recommends two elements be incorporated into the project: (1) continued, more in-depth investigation of datasets, modeling and other information sources that could at least lead to development of conceptual models of different response scenarios by such species of concern; and, (2) incorporation of monitoring for these other species into the Two-Gates project assessment.

For instance, other Delta species have different salvage patterns that reasonably reflect differences in their distributions and behaviors in response to the local environment. Expanding the modeling study to represent the distributions and salvage patterns of other species (e.g. Kimmerer, 2002, 2004) should provide valuable information on viability of the modeling system and would provide a valuable tool for a more comprehensive management of fish assemblages in the Delta.

The proposed monitoring of delta smelt around the gates should be augmented or complemented with further fish and habitat sampling to at least consider monitoring local fish composition, distribution and abundance. Unlike delta smelt, many of these other fish species offer the opportunity to employ PIT or hydroacoustic tags that could be detected with receiver arrays at and around the gates. While it is unlikely that a proxy can be found for delta smelt, a better understanding of how other species respond to tidal cycles will provide valuable information for understanding how fish, including delta smelt, use tidal cycles to move about the Delta.

4.6 Involve the CALFED Science Program in the project.

This program could serve as a strong example of coupling science, engineering, and policy for the Delta. The CALFED Science Program should be involved immediately in working with the USBR if the project goes forward. For example, why not use a focused Proposal Solicitation Process (PSP) process to aid with the science aspects of the project? i.e. the USBR (as the lead agency) could engage the CALFED Science Program to solicit and review proposals for work designed to test the hypotheses advanced by the project proponents, or to advance and test alternative hypotheses. We also recommend that there be continued participation of the Science Program in annually reviewing the progress of the monitoring and research activities associated with the project, more or less to objectively assess the extent to which the project's goals are being met, and to make sure that the data collected by the project is analyzed and written up in a timely manner. This is similar to what was done during the life of the EWA. Most importantly, since any likely review would be a public process, it would serve to make public the successes and failures of a highly visible and potentially contentious project, thus helping to ensure acceptance, especially in the Delta science community, of any conclusions drawn about its efficacy.

5. Summary/conclusions

The Two Gates proposal is a carefully prepared initiative that represents large-scale innovative thinking to provide greater flexibility in managing the Delta. The benefits of understanding the response of a controlled perturbation could provide insights of the dynamic functions of the Delta that extend beyond just the Two Gates Project. The project will provide considerable flexibility in operations. It is also founded on an adaptive management framework with a solid scientific basis that can evolve over time as the monitoring program generates a better knowledge of the current conditions and induced changes by the gates. The Two-Gates Project is not, and the project proponents do not claim, that this is the long-term panacea for balancing ecosystem recovery with flow diversions. The concept shows great potential for introducing some control over circulation patterns in the Delta, which would provide managers with greater flexibility. However, the Panel recommends several precautionary steps if the decision is made to proceed with the project.

- Clarify the goal of the project. Is the goal (a) species recovery, (b) maintaining the ecological status quo and increasing the duration and rates of pumping, or (c) some intermediate balance. If the goal is both ecological recovery and increased exports, how will the exact balance be made on a season-to-season basis? Who will make the ultimate decision and what will be the criteria for making these decisions?
- Despite considerable debate during the past decade, this project is probably the first detailed attempt to implement scientifically-based adaptive management on a large-scale in the Delta. The design team should be recognized for taking the concepts and ideas from these extended debates and developing a workable framework. However, some of the exact criteria and thresholds for intervention need to be clarified.
- Modeling the Delta hydrodynamics is extremely challenging, despite the depth of experience on the study team. There appears to be disparities between model predictions and observations, specifically related to net flows and particle tracking. Further analysis of model results for particles (delta smelt) through Old River and Middle River should be explored. During the proposed monitoring, these possible disparities should be quantified and the cause of uncertainties quantified. For example, how much is likely to be caused by the 2D simplification of a 3D flow field and in which areas are these uncertainties most significant.
- The proposed improvements to the turbidity algorithm as described in general by Dr. DeGeorge should be developed and included within the model when more field data become available to define the essential components of the revised algorithm.

- The hypothesis regarding the response of delta smelt to high turbidities should be tested in the field under a broader range of conditions and this could be a good potential topic for the CALFED Science Program PSP.
- The monitoring data collected to supplement existing IEP and other ongoing efforts could provide a demonstration of how distributed data management systems could work throughout the Bay-Delta system. This could provide a transparent, near real-time, depiction of conditions around the two gates that could be accessed by any interested party.
- The request by the project proponents for independent scientific review demonstrates commitment to science-based management and policy. It is recommended that the project retains a level of independent scientific review, through the CALFED Science Program.
- As part of the detailed design and adaptive management process, the Design Team may wish to consider alternative locations of gates that could be less expensive and achieve the same diversion objectives. In particular, the suggestion to construct a smaller gate on Georgiana Slough seems to merit investigation.

References

Arzberger, P., J. Bonner, D. Fries, and A. Sanderson. 2005. Sensors for Environmental Observatories. Report of the NSF Sponsored Workshop, Seattle. Dec. 2004. 64p. www.wtec.org/seo/

Atkins, D. (Chair). 2003. Revolutionizing Science and Engineering Through Cyberinfrastructure: Report of the National Science Foundation Blue-Ribbon Advisory Panel on Cyberinfrastructure. National Science Foundation. 84p.

CALFED Science Program. 2008. Linking Physical and Biological Models for Ecosystem Prediction, Planning, and Performance. Workshops 1 and 2, May 2008.

Holling, C.S.. 1978. *Adaptive environmental assessment and management*. London, JohnWiley & Sons.

Lee, K. N. 1999. Appraising adaptive management. Conservation Ecology **3**(2): 3. [online] URL: http://www.consecol.org/vol3/iss2/art3/

National Research Council. 2001. Grand Challenges in Environmental Sciences. Oversight Commission for the Committee on Grand Challenges in Environmental Sciences. 106 p.

National Research Council. 2004. *Adaptive Management for Water Resources Planning*. Washington, D.C.: The National Academies Press.

Nyberg, B. 1999. Implementing adaptive management of British Columbia's forests – Where have we gone wrong and right? In: McDonald, Fraser and Gray (eds). *Adaptive Management Forum: Linking Management and Science to Achieve Ecological Sustainability*. Ontario Ministry of Natural Resources, Peterborough , Ontario, Canada, pp. 17-20.

Simons, R., S. Monismith, F. Saucier, L. Johnson, and G. Winkler. 2007. Zooplankton Retention in the Estuarine Transition Zone of the St. Lawrence Estuary, *Limnology and Oceanography* 51(6), 2621-2631.

Williams, B.K., R.C. Szaro, and C.D. Shapiro. 2007. *Adaptive Management: The U.S. Department of the Interior Technical Guide*. Adaptive Management Working Group, U.S. Department of the Interior, Washington, D.C.

Appendix I: Meeting Agenda: August 6, 2009

CALFED Science Panel Review

Independent Review of the 2 Gates Fish Protection Demonstration Project

Thursday, August 6, 2009

8:00 a.m. – 5:00 p.m.

650 Capitol Mall, 5th Floor, Delta Room

Sacramento, CA 95814

Purpose and Product

The 2 Gates Project has been proposed as an adaptive management experiment using infrastructural modifications (operable gates) for protection of sensitive species and management of water supply. Two temporary, removable gates would be placed in the central Delta to manipulate flows in an effort to reduce entrainment of delta smelt at the water export facilities.

This independent scientific review will focus on:

a) the adequacy of the assembled information as justification for such an experiment;

b) an assessment of the proposed data collection, synthesis protocols, and performance measures for determining the success of such an experiment, and;

c) the likelihood for achieving the stated objectives of the adaptive management experiment.

The meeting will facilitate communication between an independent Review Panel and project proponents during the review of the 2 Gates Fish Protection Demonstration Project.

AGENDA

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

8:00 a.m. 1. Introduction and Review Process
2. Presentation of the 2 Gates Project
3. Regulatory Context – US Fish and Wildlife Service and National Marine Fisheries Service
4. Question and Answer session with Review Panel
5. Public Comment

12:00 p.m. Lunch
6. Panel deliberates in private

3:30 p.m. 7. Presentation of key points in Review Panel report
8. Additional discussion with Review Panel
9. Public Comment

5:00 p.m. Adjourn

Appendix II: Comparison of the smelt behavior model with an alternative biologically-based model

Here the smelt behavior model (SBM) presented in the Resource Management Associates DRAFT REPORT: June 16, 2009 is compared with a more biologically based alternative behavioral model (ABM) presented at the American Fisheries Society 2007 annual meeting in San Francisco (Anderson 2007).

<u>Smelt Behavior Model Description</u>

The SBM is implemented on top of the RMATRK particle-tracking model. At each step, the transport velocity is computed for a neutrally buoyant passive particle moving with the streamline velocity computed by the RMA Bay□Delta Model and subject to a random velocity component representing turbulent dispersion. Then the behavior model adjusts to the transport velocity utilizing the local concentration and gradient of electrical conductivity (EC, simulated as a surrogate for salinity) and turbidity computed by the RMA Bay-Delta model.

SBM algorithm contains five rules:

If the local EC is greater than the required maximum limit

❶ Surf toward lower EC.

Else if the local turbidity is lower than the required minimum limit

If the local turbidity gradient is greater than the minimum detectible gradient

❷ Surf toward higher turbidity

Else if the local turbidity gradient is lower than the minimum detectible gradient

❸ Hide.

Else if the local EC is lower than the desired minimum limit

❹ Surf toward higher EC.

If the local EC and local turbidity are within required limits

❺ Randomly move (explore desirable habitat).

The surfing behavior, in which fish move in a rectified movement with the tidal flow, is implemented by applying a scalar velocity factor to the transport velocity vector computed for neutrally buoyant particles. To resist the tidal flow the velocity factor is set to zero and to move with the tidal flow the factor is set to 1.2. Hiding is also implemented with a user defined scalar velocity factor, which causes the particles to move slowly or stop.

SBM characteristics

The horizontal movement from behavior is controlled by rules ❶ through ❺, which are triggered by salinity (EC) and turbidity levels and gradients. The possible interactions are not easily understood from the information available in the reports. However, the general character of the model can be illustrated in an idealized scenario (Figure 1).

Panel A represents the state of adult delta smelt located in the western Delta prior to the first winter flush when turbidity is lower than the minimum T_{min}. For fish that had previously been transported by tides or net outflow into the high salinity region, ❶, the SBM moves them east back into intermediate salinity where they hide ❸, presumably at the bottom. Fish in position ❹ experience low salinity and turbidity above T_{min}. The SBM moves these fish west back into intermediate salinity water. In a boundary region ❷, the salinity and turbidity are low but the turbidity gradient is detectable and the SBM moves the fish up the turbidity gradient. Under the scenario of panel A, the fish either hide in the X2 region or oscillate about X_{Tmin} as they switch between moving into the turbidity and salinity gradients.

Panel B represents the first winter flush where the turbidity gradient becomes detectable and signals the fish hiding in the X2 region to move up the turbidity gradient which consequently displaces them to the east ❷. Again, once the turbidity exceeds T_{min} the eastward movement is terminated by low salinity which induces downstream movement of fish ❹.

Panel C represents high winter turbidity in the central and eastern Delta. Fish in the west are directed upstream by behavior ❷ and turbidity and salinity are sufficiently high that fish move randomly in the central Delta ❺.

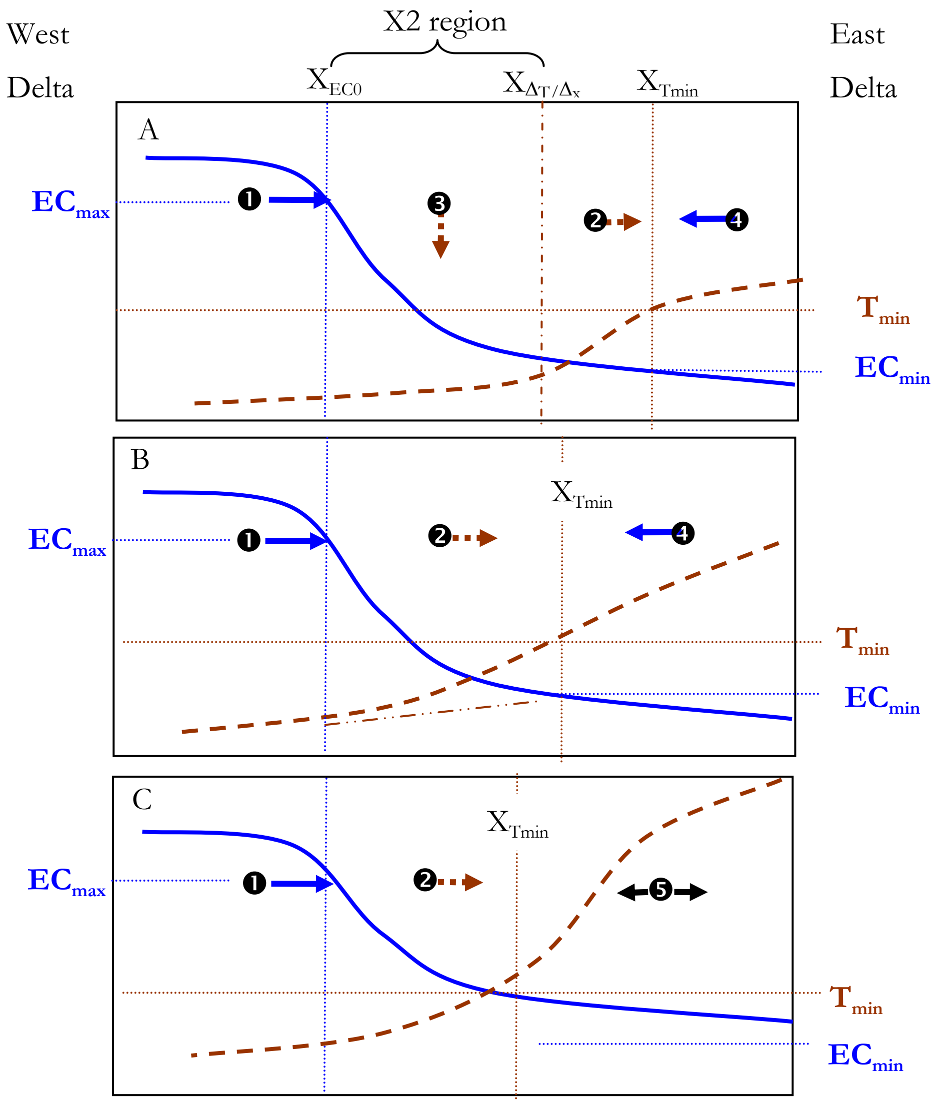


Figure 1. Fish movement in response to salinity (EC —) and turbidity (— —) . A: Movement of fish prior to the first flush, B: movement during first flush, C: movement after first flush.

<u>Alternative Behavior Model (ABM)</u>

The alternative model assumes that tidal surfing behavior of delta smelt results because fish coordinate their vertical movements with tides using small spatial-temporal scale changes in turbulence and turbidity. At the scale of the fish, the vertical gradients dominate horizontal gradients. In the ABM, fish produce rectified movements with tides using the asymmetry in flow over the tidal cycle (Figure 2). Importantly, with asymmetries in flow, fish have information on the tidal stage: with the flow asymmetry, vertical turbulence and buoyancy increase on the flood tide and decrease on the ebb tide (Rippeth et al. 2001). Furthermore, because of changes in shear stress and vertical mixing, turbidity resuspension is expected to follow a similar pattern. The time scale of sediment settling is on the order of 1 hour. In general, variations over the tides are significant. For example, in the Carquinez Strait, west of Suisun Bay, a turbidity maximum of suspended sediment appears on the flood tide and is controlled by local stratification, turbulent mixing and settling – not horizontal advection (Schoellhamer 2001). Thus, physical studies show that vertical structure of small-scale turbulence and turbidity are asymmetrical with the tidal cycle and depend on freshwater outflow and channel shape.

For fish to utilize these changes, they need to detect small-scale local variations. Here again the biological literature indicates that fish sensory systems are sufficient: the lateral line can detect direction and speed of vortices across a fish's body (e.g. Chagnaud et al. 2008) and the eye can detect variations in turbidity of a few NTU (e.g. Gregory 1993). Beyond being able to detect asymmetrical changes over the tidal cycle, fish must also evolve behaviors that move them from their adult feeding habitats to their spawning habitat. Studies in other species, such as salmon, indicate that behaviors facilitating a life cycle migration are strongly heritable and so it is inevitable that delta smelt have evolved behaviors that produce their Delta migration. Qualitatively, in an ABM the movement behaviors are vertical and, functions of the intensity of the local environment, i.e. small-scale temporal variations in the vertical structure of turbulence and/or turbidity. Fish should move up in the water column when turbulence and turbidity increase and down when the vertical gradients diminish. Thus, fish would exhibit strong surfing behavior under conditions with strong vertical gradients and when the gradients diminish, the fish should loose their ability to detect the tidal asymmetries and so move randomly over the tidal cycle. The signal for vertical movement should be strongest in the winter freshwater flush when strong vertical gradients in stratification and turbidity occur. In the inner Delta, the vertical salinity gradient is weak and the pattern between turbidity and the tidal pattern is expected to be more variable because of the multiple sources of turbidity and the complexity of the Delta connections. Thus, in the inner Delta, the coherence between vertical patterns and the tidal transport is expected to diminish and so the ability of fish to exhibit rectified movement with the tidal cycle should also diminish and fish should move randomly in the inner Delta.

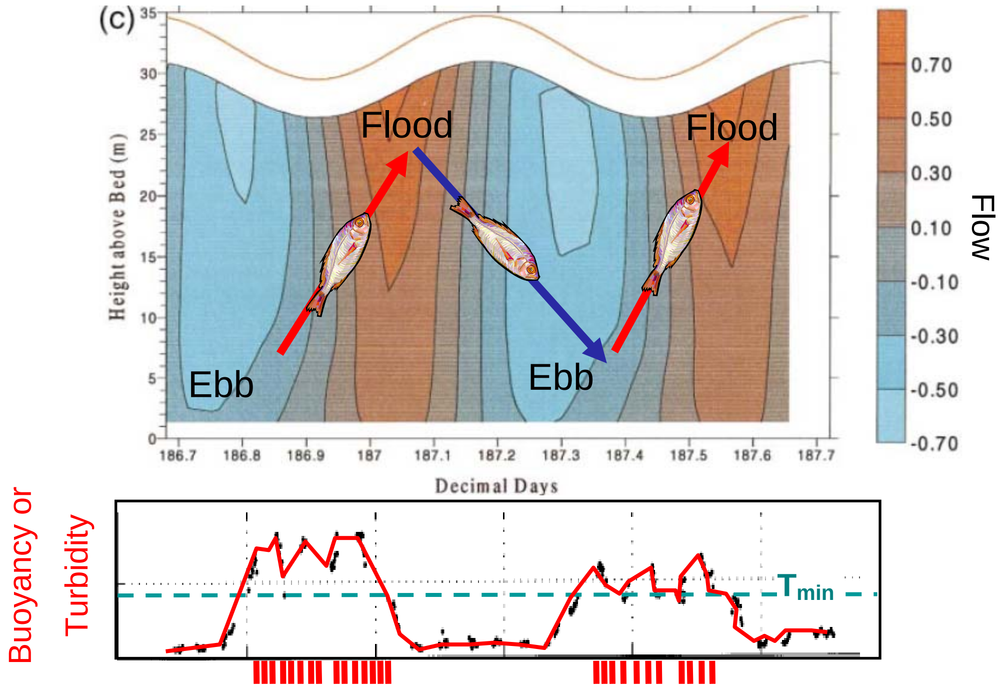


Figure 2. Alternative hypothesis, fish detects change in vertical buoyancy, (i.e. vortices) or turbidity over smalls scale. If fish migrate up when buoyancy and turbidity exceed thresholds, T_{min}, and down or move randomly below the thresholds then their net movement will be with the flood tide. Illustration from Rippeth et *al. (2001).*

<u>Comparison of models</u>

We now compare the SBM and the ABM to evaluate the similarities, attributes and issues in the two approaches.

Mechanism for surfing behavior

- The SBM assumes the fish move, or surf, on the tidal cycle by adjusting their vertical position over the cycle in response to specific thresholds or gradients of salinity or turbidity. In response to salinity, with behavior ❶ fish move on the flood tide and are transported into lower salinity water. With behavior ❹ they move on the ebb tide and are transported to higher salinity water. In response to turbidity, behavior ❷, fish move on the flood tide when the turbidity is low and the horizontal gradient exceeds a threshold. This flood tide behavior should move them upstream when turbidity is produced by resuspension or when it is transported with freshwater flow. However, in Old River when the Sacramento River is the major source of turbidity and the net flow is towards the pumps, then the net flow and turbidity source are from opposite directions. It is unclear how the fish might respond in this condition. The SBM switches fish surfing behavior with tides in complex ways. It is unclear what behavioral processes might induce such reversal of response to gradients or the effect of these changes on the fish migratory pattern.

- The ABM assumes fish respond to local short-term increases in turbidity/turbulence or loose the asymmetric signal associated with the tides and thus drift randomly with the net flow, whether it results from freshwater outflow or reversals due to pumping. In either case, the behavioral response is the same and the model requires simple and consistent response to the local environment.

Signal detection

- The SBM assumes fish detect turbidity and salinity gradients and thresholds averaged over tidal cycles. Fish visually detect minute variations in turbidity but they do not have organs to detect small-scale variations in salinity.

- The ABM assumes fish detect turbidity and small-scale turbulence that occur within the tidal cycle. Fish detect turbulence with their lateral line senses.

Gradient detection

- The SBM requires that the fish detect tidally averaged mean horizontal gradients in both salinity and turbidity. The horizontal gradients are many orders of magnitude smaller than the vertical and temporal gradients of these properties. In particular, in the SBM fish detect a gradient of 0.0001 NTU/m. Daily variations exceed 10 NTU over the tidal cycle and so it is unlikely that delta smelt can detect the tidally averaged horizontal gradients in turbidity. The model also assumes the fish reverse behaviors with respect to the gradients when the tidally averaged turbidity and salinity exceed thresholds. Fish are unlikely to have these capabilities.

- The ABM requires that fish only experience and respond to local variations in turbidity and turbulence on the scale of their body length over a tidal cycle. Fish are readily capable of sensing these levels of variations.

Effects of secondary factors

- The SBM requires that fish respond to tidally averaged salinity (EC_{max}, EC_{min}), a turbidity threshold (T_{min}) and salinity and turbidity gradients. The values are averages over the tide and the water column. Vertical stratification, gravitational flow, effects of topography and variations in neap and spring tides are not explicitly expressed through the thresholds. It is not clear if these secondary effects on fish movement are captured by the thresholds.

- Although the ABM is a conceptual model it is driven by vertical local gradients and so in theory the resulting behavior should be affected by second order physical factors such as the effects of topography, monthly variations in tidal intensity and interactions with pumping and river flow. These properties require a hydrodynamic model that deals with vertical structure or some manner of inferring how vertical structure changes using information contained in more aggregated horizontal structures such as flow and turbidity loading. Expressing approximate vertical dynamics relevant to fish will require evaluation of the suitability of a vertically integrated hydrodynamic model by a comparison with a 3-D model.

Need for behavior in the juvenile model

- The larval/juvenile model is separate from the SBM. It models the early life stage of delta smelt movement as passive particles without behavior. This appears adequate for the early stages but is inadequate for the later juvenile stage. The model predicts that the later juvenile stage drifts further west than is observed. A plausible reason for the model error is that juveniles actually exhibit vertical tidally-rectified flow as they enter Suisun Bay. This behavior could be model by including the adult behavior algorithms in the juvenile model, but this approach would incur the issues involved with the SBM discussed above.

- Including juvenile stages in an ABM may be a more tractable approach to developing a life history model that tracks the spatial movement of a population from egg to spawner. One approach for this linkage might be to express vertical swimming behavior as a function of fish age or length. A complete spawner-recruit model for delta smelt would not be a trivial undertaking but would provide valuable insights concerning the ranges of processes and model parameters required to sustain the population within the Delta.

Conclusions on model comparison

In both the SBM and the conceptual ABM, salinity and turbidity are variables that drive adult delta smelt movement, but they do so with significantly different approaches. The SBM is a top-down model using specific rules to approximate the observed pattern between fish and turbidity. It implicitly assumes that fitting observations implies that the model's rules capture fish behavior and will reproduce fish distributions when flow, salinity and turbidity are further altered by Two Gates operations. However, the signals that cue fish behavior in the SBM, and the rather complex nature of the behaviors, are biologically tenuous. The ABM uses a bottom-up approach in which vertical movement rules are cued from local asymmetrical properties of tidal flows. While having a more plausible biological foundation is valuable, the ABM is qualitative and it has not been demonstrated that the behavioral rules will produce realistic movement patterns in the Delta or when altered by the Two Gates Project. Therefore, more development of behavioral rules is needed and the resulting model must be tested with field experiments.

References

Anderson L. J. 2007. The boiling frog syndrome: navigating by weak and oscillatory cues. American Fisheries Society Annual meeting San Francisco.

Chagnaud et al. 2008. Measuring flow velocity and direction by analysis of flow fluctuations. Neuroscience 28:4479-4487

Gregory R.S. 1993. Effect of turbidity on the predator avoidance behaviour of juvenile Chinook salmon (*Oncorhynchus tshawytscha*).Canadian Journal of Fisheries and Aquatic Sciences 50(2): 241–246.

Kimmerer, W.J. 2002. Effects of freshwater flow on abundance of estuarine organisms: Physical effects or trophic linkages? Marine Ecology Progress Series 243: 39–55. doi:10.3354/meps243039.

Kimmerer, W.J. 2004. Open water processes of the San Francisco Estuary: from physical forcing to biological responses. San Francisco Estuary and Watershed Science (Online Serial) 2: Issue 1, Article 1. http://repositories.cdlib.org/jmie/sfews/vol2/ iss1/art1.

Rippeth et al. .2001. The cycle of turbulent dissipation in the presence of tidal straining. Journal of Physical Oceanography 31:2458-2479.

Schoellhamer, D. 2001. Influence of salinity, bottom topography, and tides on locations of estuarine turbidity maxima in northern San Francisco Bay. Interagency Ecological Program for the San Francisco Estuary 14- 4 , Fall 2001 p 54-62.