Review: In-Delta Storage Program CALFED Science Review Public Workshop

Introduction

The In-Delta Storage Review Panel convened by the CALFED Science Program has reviewed documents and met with In-Delta Storage (IDS) Program Staff for the purpose of evaluating the scientific quality and technical soundness of the draft feasibility reports. The template for the project evaluated is the Delta Wetlands Project as modified and refined by DWR project staff and their consultants.

The Review Panel recognizes the importance of water supply and drinking water quality to the California Bay-Delta Authority (CBDA) and the future of California. It is not the Review Panel's role to recommend whether or not to move forward with in-delta storage options. Rather, this Panel provides this report to decision-makers within CBDA and local, state and federal agencies to inform them regarding the science used in the studies, and the level of uncertainty surrounding the scientific and technical aspects of the proposed project.

The Review Panel's general charge from the Science Program:

The panel was instructed as follows: "The key policy question for DWR and CALFED is whether the Delta Wetlands Project and other in-Delta storage options considered in the reports are technically feasible based on the reports' assessments. We do not expect the science review to address this question directly, but your input should help policy makers understand the scientific underpinning available to address this question. It is important to articulate both the strengths and limits of that underpinning. With regard to the studies that were conducted to determine feasibility, please help policy makers understand: Have those studies used approaches at the state of the science? Are the experiments, field studies and analyses credible? Are there alternative approaches that might provide more credible results? Are there scientific issues that are potentially important to evaluating feasibility that remain unaddressed? Have the studies articulated uncertainties and assumptions in a balanced manner? Are there studies in the literature in similar circumstances that could be brought to bear to address the issue of feasibility? In short, would the scientific community view these studies as valid, at the state of the science, and useful to helping managers address the complex questions surrounding operations, water quality and environmental issues of the in-delta storage question? If not, what else can be done in the short-term and the long-term?"

Previous Major Recommendations from Science Panel's Summary Review of 2002 Reports, August 2002 (see attached review)

- **Quantify and assess uncertainties:** For almost all aspects of the work reviewed, the Panel recommended a quantitative assessment of uncertainties in experimentally determined or model parameters. The general lack of error estimation prevents a complete and reasonable assessment of the possible effects of the project thereby elevating the risk of any decision based on these assessments.

- **Develop a process-oriented conceptual model of the system:** Another theme touched on by all reviewers was the need to develop a comprehensive, process-oriented conceptual model of the reservoir system, showing the processes and their linkages, both driving project operation and affected by project operation. Because of the complexity of the system within which the project is set, a series of nested conceptual models is recommended. The conceptual models should include quantitative information (including uncertainty) about fluxes and linkages and provide the framework for future data collection and modeling to further reduce uncertainty. The primary advantage of using a conceptual model that is frequently reexamined is a continuing directed focus on what is important to effectively evaluate project effects and yields. This type of integrative tool would underpin the more holistic, ecosystem based approach recommended by the panel.
- **Consider and assess potential mercury issues:** The Panel noted the lack of any detailed attention to the potential mercury and methyl mercury problems in the proposed project. The proposed project will produce environmental conditions conducive to methyl mercury formation. The Panel recommended that the mercury issue be critically addressed.
- **Develop climate change and variability scenarios:** The Panel recognized the limited incorporation of these important influences into their assessment. The Panel recommended the development of future scenarios of climate change and variability (e.g., precipitation and temperature regimes) that would provide a range of water availability conditions within which in-delta storage dynamics can be assessed.
- **Diffusion of dissolved organic carbon (DOC) from peat soils:** Measurement of diffusive fluxes of DOC from reservoir soils using either intact soil cores or *in situ* mesocosms was recommended to obtain valuable information regarding contributions of DOC from the peat soils.
- **Modeling of DOC:** As an alternative to the empirical, logistics/regression-equation approach to modeling DOC in the reservoir, development of a process-oriented model that takes into account pertinent processes affecting DOC, such as sediment-water flux, water column vertical diffusion and mixing, water column production and biogeochemical transformations of DOC, horizontal exchanges or flushing, etc., is suggested.
- **Modeling Seepage returns:** The reviewers' recommended using a 3-D model for estimating seepage returns for the complex peat soil-reservoir system and emphasized the importance of understanding and incorporating the interactions between the reservoir surface water and the local and regional groundwater system into the model to better reflect the hydrologic complexities of the system. At least, seepage return flows and loads and their uncertainties need to be better quantified.
- **Vertical stratification and horizontal variability:** Due to concern over the possibility of vertical temperature stratification (and horizontal variability)

within the proposed reservoirs and possibly in adjacent channels, the Panel recommended that a three-dimensional hydrodynamic model be applied to the proposed reservoirs and adjacent channel environments and include components for heat flux and transport, wind-induced turbulent mixing and residual circulation, wetting and drying of computational cells, spatially variable bathymetry, and transport capabilities for embedded reactive constituents.

- **Modeling of dissolved oxygen (DO) and water temperature (T):** The Panel recognized the importance of considering biological and biogeochemical processes, as well as taking into account vertical stratification and horizontal variability, in the modeling of DO and T. Thus, the recommendation for assessing and modeling these biological and physical processes and incorporating them into a three-dimensional model.

In addition to the above recommendations, the Panel recommended a series of ten tasks over a five-year timeline designed to reduce uncertainty about whether the project is likely to meet water quality criteria controlling operation, and provide a sound scientific basis for making a decision regarding project implementation (please see the attached review).

To expedite this process and meet the proposed timeline it was recommended that DWR make use of the best available expertise in the various fields of science and call upon in-house personnel, consultants, and both in- and out-of-state experts to move these Tasks to fruition on the proposed timeline. To accomplish this, it also was recommended that a Steering Committee of independent advisors (i.e., experts not directly involved in accomplishing any of the Tasks) be convened to advise DWR in the selection of study participants, to review draft reports, and recommend modifications of these Tasks and/or the timeline as appropriate.

Progress

The Review Panel recognizes the complexities of the system that the In-Delta Storage Program Staff is dealing with and recognizes the challenge and difficulties they faced in assessing the feasibility of this project, especially considering the time constraints imposed on them. The IDS Staff is commended for putting forth a tremendous effort in producing the feasibility reports.

The panel acknowledges the progress of the DWR IDS staff in responding to some of the panel's initial recommendations. First, the mismatch between modeled timescales and real-world operational and regulatory timescales has begun to be addressed with the modification of CALSIM and DSM2 to allow CALSIM to generate and pass to DSM2 daily operational information (previously, this was done on a monthly timestep). Second, a large step toward addressing the panel's concern over the reservoirs' stratification potential was taken in contracting with Flow Science, Inc. to apply the DYRESM model to the proposed reservoirs.

Remaining Major Issues

Quantifying uncertainty

Many simulations and calculations were performed to estimate the answers to specific questions like "What will the change in DOC at the Rock Slough Intake be under conditions similar to Water Year 1976-1991 if the reservoirs are built?" and "What is the expected change in SWP/CVP delivery with the reservoirs operating and several operational constraints in place?" Many well-established tools (DSM2, CALSIM) and field measurements have been invoked to generate answers to these questions, and the simulations run thus far have been instructive in learning about critical interactions between operations, hydrology, and water quality.

The Panel is concerned, however, that there is not just one possible answer to a particular question. Instead, there is a *range* of possible answers for any particular question. The reason for this range of answers is the ***error or uncertainty*** associated with every step in the calculation process. These errors include inherent inaccuracies and simplifying assumptions associated with individual numerical models, errors associated with field or laboratory measurements used as input to the models, uncertainty associated with empirical relationships between water quality parameters, and cumulative propagation of errors when models are used iteratively or in series. Uncertainty due to such errors is unavoidable, and it can be very small or very large compared to the magnitude of the answer. The error size relative to the size of the answer is really an answer to the question: "***How wrong can our answer be?"*** Without knowing this, we are unable to say whether the feasibility study or state of scientific knowledge is adequate for decision makers to reach a conclusion on whether the project is feasible.

The Panel sees quantitative estimation of uncertainty as one of the most critical and pervasive, though as yet inadequately addressed, issues related to this feasibility study. The DWR IDS team has conducted and presented a large amount of valuable work, but we still do not know how wrong the answers could be. For example, we are told that the change in SWP/CVP delivery with reservoirs operated with circulation and DOC constraints is 66 thousand acre feet (TAF) (if DOC growth rate is 0.24 g/m^2-d). But is that 66 TAF +/- 1 TAF or +/- 10 TAF or +/- 100 TAF? Such an uncertainty estimation would need to incorporate error associated with all steps in making that estimate. Information exists for quantifying the uncertainty associated with some calculation steps. For example, extensive validation of the DSM2 model was performed previously, including comparisons between model calculations and measurements of electrical conductivity (EC) and other variables. Errors could be quantified from such validation studies as one of the sources of error. Lack of error analysis and uncertainty estimation was a pervasive problem in the feasibility studies---it applies to DOC, disinfection byproduct precursors (DBPs), DO, temperature, mercury, EC, and storage/delivery estimates. We reiterate here that conceptual models---developed to identify and estimate the relative magnitudes of critical processes and rates---can be valuable tools in the estimation of uncertainty.

Modeling and Predicting DOC

We suggested that the IDS staff develop and apply a process-based conceptual model of carbon dynamics for the reservoir in our first review and reiterated our suggestions several times during the March 2003 meeting between selected Panel members and the IDS Staff. The Panel believes that the appropriate scientific approach to understanding and modeling the carbon dynamics in such a complex system is to use a conceptual model to help focus the key questions, hypotheses, and data gaps. This process should help prioritize their efforts, which, in turn, should help develop the pertinent information and knowledge to better assess the feasibility of the project, as well as improving the conceptual model of the system. We envision that the conceptual model could initially include quantitative information about fluxes and linkages between model compartments and their respective uncertainties. The model should be updated and refined as more data are collected.

In addition, development and application of mathematical models that quantitatively capture pertinent DOC processes (as suggested in the initial summary review) needs to replace the empirical "logistics/regression" modeling approach that does not account for the biogeochemical processes affecting carbon dynamics.

The consensus of the Panel is that the current mesocosm experiments do not effectively represent Delta organic carbon dynamics, and that the important biogeochemical processes are not distinguishable through this approach. The Panel sees the need for a new experimental approach that allows quantification of significant biogeochemical and physical processes separately, so that the relative magnitude of each process is determined. The Panel suggested that other approaches such as *in-situ* benthic flux chambers in existing Delta environments and process-specific microcosms in analogous environments and habitats be used to bound conditions. These types of approaches are essential to quantifying uncertainties.

Assessment of DOC dynamics needs to recognize that the quality of DOC can be as important as the quantity of DOC. In other words, DOC derived from different sources (e.g., peat soils, algae) and subjected to a variety of biogeochemical processes (e.g., microbial decomposition, photolysis) can have vastly different potentials to form DBPs in general and trihalomethanes (THMs) in particular. For example, the quantity of DOC diffusing from peat may be 5 times greater than algal contributions during late summer, but the type of DOC that decomposing algae produce may be 5 times more reactive with respect to the formation of THMs; thus contributions from both peat and algae would be significant and need to be considered. This example further emphasizes the need to distinguish processes, timing of reservoir release, and hydrodynamics within the reservoir and in the channel.

Further considerations that should be addressed in future assessments include:

1. Accounting for DOC production and dynamics under low reservoir water levels (< 4 ft.). Reoxidation of surface soils will undoubtedly occur under these conditions, especially in areas where soils are exposed to the atmosphere due to

topographic irregularities. Wetting and drying of peat soils has been shown to cause enhanced production of available carbon that is mobilized upon rewetting.

2. The Panel has concerns regarding the current assessment of the contribution of DOC from seepage that is captured and reintroduced to the reservoir. Both seepage flows and associated DOC concentrations need to be critically reassessed, using possible ranges of expected flows and DOC concentrations to capture potential uncertainties of these estimates.

   Three key uncertainty and conceptual issues plague the seepage estimates. First, what seepage return values were used in the reservoir water quality modeling? The July 2003 In-Delta Storage Program State Feasibility Study Draft Report on Water Quality stated that seepage losses and returns are 9.8 and 1.96 cubic feet per second (cfs) for Bacon and Webb, respectively. However, the URS modeling estimate for Webb is 8.3 cfs. Was 1.96 cfs was used in subsequent reservoir modeling? If so, why? Second, seepage modeling appears deficient in that there is a lack of uncertainty quantification in seepage return estimates and reservoir water quality modeling. The most recent 2002 URS modeling did not vary hydraulic conductivity values during sensitivity analysis and provided no range for seepage return volumes. However, using a similar modeling approach but including sensitivity analysis using a range of reasonable sand hydraulic conductivity values, the 2000 URS evaluation identified a potential 5 fold increase in seepage return volumes .
   Also, we find the two-dimensional model for estimating seepage to have over constrained boundary conditions and to not fully account for system variability and well to well interactions. There is a key need to quantify flow paths and travel times of high DOC pore water that certainly resides in shallow peat layers to seepage return pumps. This will enable estimation of DOC concentration changes over time in seepage pumps.

   Lastly, uncertainty in predicted seepage rates and potential variability in DOC concentrations should be used to estimate the possible range of DOC loads to the reservoir due to seepage return pumping.

3. A "circulation" or "recirculation" operational model was proposed to lower the potential DOC content of waters stored in the reservoir islands. In this model, equal quantities of water were diverted from the channel to the reservoir and released from the reservoir to the channel. This model was not part of the initial proposal, but was developed to compensate for continuously increasing reservoir DOC concentrations that occurred if the water remained in the reservoirs for long periods of time.

   The Panel had several concerns regarding the proposed circulation operational model. Among these concerns are the assumption that the reservoir are acting as a Continuously Stirred Tank Reactor, within which concentrations are uniform.

The Panel’s concern with this assumption is discussed below in the Horizontal Variability subsection of the Remaining Major Issues section.

Other concerns include the potential for recirculating discharged reservoir water high in DOC and whether this operational scheme is economic feasibility due to the potentially high cost of pumping. In addition, this proposed operational scheme has the potential for increasing loads (concentration x volume) of DOC, DBP precursors, and methyl mercury to Delta channel waters.

The Panel thought that these concerns were not adequately addressed and will require further assessment in the future.

Water Temperature

The Flow Science, Inc. report on stratification formation in reservoirs and relationships with adjacent channels was a positive step toward addressing stratification potential. This work also highlighted the criticality of meteorological forcing and data (especially windspeed), as well as the potentially large amount of spatial variability in meteorological forcing within the Delta. The panel recommends that meteorological stations be installed at the proposed reservoir sites to gather site specific data and reduce the level of uncertainty in DYRESM’s projected stratification scenarios. This effort could be amplified by incorporating long-term estimates of changes in meteorological forcing (e.g. air temperature) due to climate change. We further recommend, depending on the results of amended DYRESM simulations, that stratification-sensitive water quality variables (e.g. organic carbon, dissolved oxygen, conductivity, etc.) and reservoir release constraints be investigated in a stratified or stratifiable context.

Dissolved Oxygen

Dissolved oxygen could be an important constraint on reservoir release; however, there are critical shortcomings in how DO has been treated thus far. First, DO was assumed to be 5 mg/l (or 6 mg/l, depending on where one looks in the reports) and artificially maintained at this level throughout the simulations. Given the constraints on release of reservoir water (cannot release if DO of stored water < 6 mg/l or if depresses channel water to <5 mg/l), it is not surprising that DO violations are not predicted. The panel does not understand this methodology and regards this as *specifying* DO as opposed to modeling DO. DO should be modeled freely as an unconstrained function of the sources and sinks outlined in the Draft Report on Water Quality, Fig. 4.1. Otherwise, the “modeling” of DO in this study is not deemed useful or reliable.

Second, the Flow Science report on stratification indicated that, under some conditions, the reservoirs could become persistently temperature stratified. Such a situation could lead to low dissolved oxygen levels below the thermocline. Thus, reservoir DO dynamics should be studied in a thermally stratified context. Furthermore, Susan Paulson (Flow Science, Inc.) indicated that thermal stratification need not be present for DO to be stratified. Therefore, this possibility (of vertically variable DO in the absence of thermal stratification) should be looked into.

Third, the Panel recommends that biological oxygen demand (BOD) be considered in the assessment of oxygen dynamics in the reservoir system and channel water. BOD may be a better predictor of changes in oxygen concentrations when reservoir water is released into Delta channel waters.

Mercury

The Panel again emphasized the need to include a comprehensive assessment of potential methyl mercury production in the reservoirs, and noted the need for specialized expertise in mercury cycling, as well as for sampling and analyses of total and methyl mercury. Anticipated reservoir conditions of warm temperatures, elevated concentrations of DOC, and probable anoxic sediments are conducive to methylation of mercury. The Panel also noted the existing evidence of high rates of mercury methylation in wetlands in the Delta, as well at other wetland locations.

Climate Change

The panel understands that positive progress is being made in using CALSIM to investigate scenarios of drought and changes in the hydrograph (earlier peak flows) due to long-term climate change. It is unclear, however, what other projected changes are or will be accounted for. We recommend that sea level rise and changes in precipitation and air temperature should also be addressed on some level.

Horizontal Variability

The modeling work performed thus far has assumed that water quality variables and related processes will not vary in the horizontal dimension within reservoirs. In reality, variations in bathymetry, fetch, proximity to inflows/outflows and other factors could result in marked variability in three-dimensional transport and mixing, submergence/emergence of the sediment boundary, water clarity, temperature, generation and processing of organic carbon (e.g. phytoplankton, submerged and emergent aquatic vegetation, DOC, etc.), contaminants, and mediation of key processes by primary and secondary consumers. The assumption of horizontal homogeneity was a logical place to start in modeling the key processes and quantities. However, the panel believes horizontal variability is likely. Other nearby flooded island habitats subject to tidal mixing can exhibit substantial horizontal variability in quantities such as water temperature, chlorophyll *a*, EC, and dissolved oxygen; chlorophyll *a* in Mildred Island, for example, has been shown to vary ten-fold from the northern end to the southern end. The predicted success of “recirculation” of water through the reservoirs relies on reservoirs acting as a Continuously Stirred Tank Reactor, within which concentrations are uniform. If horizontal mixing is incomplete, then the effectiveness of recirculation may be limited. The panel therefore recommends that a multidimensional numerical model of hydrodynamics and transport be implemented to study potential horizontal variability in water quality and key processes. A very important step in this effort could involve simulation of transport of passive, conservative tracers (e.g. numerical “dye”) to visualize and quantify spatial differences in water residence time, vertical mixing rates, horizontal dispersion, etc.

CALSIM

The CALSIM model is an impressive tool that simultaneously accounts for numerous operational constraints in deciding how, when, where, and how much water can be moved from one location to another. This tool appears to incorporate variability in hydrology and, to some degree, climate, but it is unclear whether or how evaporation and precipitation are accounted for, whether for past and present scenarios or for future scenarios. How much could accounting for these processes, as well as sea level rise and long-term change in air temperature (see above) change the answers?

With respect to use of CALSIM for this particular study, the Panel understands that CALSIM is not currently equipped to simultaneously account for constraints on DOC, DO, T, and EC. We realize that making such changes to the code would be quite complex and time-consuming. On the other hand, we cannot currently evaluate interactions between different types of reservoir operation constraints. Such interactions are important because a sequence of constraints on water release could potentially result in long periods (>1 yr) without the possibility of release. For example, once a DO constraint is lifted, a temperature constraint could become applicable, followed by other constraints. We do not currently know how likely such scenarios are, and therefore recommend further work to simultaneously investigate sequential reservoir release constraints due to the full range of applicable water quality, flow, and environmental restrictions.

Finally, as a major step in estimating uncertainty, we encourage the CALSIM modelers to think creatively to find ways to estimate the size of uncertainty associated with CALSIM predictions of water yield. Without some estimate of how big the CALSIM error typically is, we cannot draw any conclusions on "how wrong we could be" or on the adequacy of the science employed in this feasibility study.

DSM2

The DSM2 model is a powerful tool that has been used extensively and shown to work well in calculating transport of water and conservative tracers. There are, however, several issues which could limit the reliability or usefulness of the DSM2 results in this study. First, DSM2 appears to have difficulty handling complete or near-drying of reservoirs. Shallow reservoir depths will be potentially critical periods for natural organic matter and mercury transformations; therefore, this problem needs to be addressed. Second, it is not clear whether evaporation and precipitation are accounted for. Third, there is disagreement over the appropriate seepage flow rates to use in the simulations. Fourth, there are questions as to the correctness of the particle tracking results; predicted particle trajectories should be compared (at least qualitatively) to any other relevant data available (e.g., USGS drogue and dye release studies). Finally, we would like to reiterate the importance of quantifying uncertainties associated with this model.

Panel Conclusions

The Review Panel has identified important short-comings of the current scientific studies supporting In-Delta Storage. Key uncertainties still exist and the generation of new understanding (information) is essential before the pros and cons of the project can be fully evaluated. Few decisions about implementation require complete scientific knowledge. However, some of the current uncertainties are severe enough that substantial risks exist if decisions proceed without further elucidation of these issues.

The review has identified substantial uncertainties regarding the water quality of the discharges from the project. The review has documented inadequate consideration of the processes controlling DOC concentrations and DO levels, both of which are important to the viability of the project. Implementing the project before these issues are more fully addressed poses great risk for the quality of water in the lower Delta and for the operators of the project who may fail to realize the expected benefits of the project because of water quality criteria. Several additional issues, such as the potential for mercury methylation, need to be addressed in order that the full implications of the project for the Delta can be assessed.

During the review process, the Panel has provided recommendations on research required to move towards an informed decision on in-delta storage implementation. To expedite development of crucial information for decision-makers, the Review Panel urges the use of the best available expertise in the various fields of science including state agency personnel, consultants, and both in- and out-of-state experts.