Summary of Scientific and Technical Review Panel Comments on Water Quality and Environmental Aspects of the In-Delta Storage Program's Reports

1.0 Introduction

The goal of the In-Delta Storage Program is to increase water supply reliability, improve operational flexibility, and allow water to be conserved during wet periods. The purpose of the current evaluation contained in the reports is to determine the technical feasibility of the Delta Wetlands Project or other in-Delta storage options. Additional reports examine the financial feasibility of the project, and a separate review panel has examined engineering aspects of the project. This panel has focused on the water quality and environmental implications of the projects and has considered engineering and operational aspects only as necessary to complete their assessment.

Our summary of the review panel's comments is structured as follows:

- Comprehensiveness - have the studies adequately considered the range of issues necessary to fully assess the water quality and environmental implications of this project, and if not what are the key factors that need to be addressed?
- Scientific Validity – do the studies use adequate approaches (experimental, empirical, and numerical) to address the issues they identify, are these approaches adequately documented, especially regarding their assumptions and uncertainties, and how could the studies be improved?
- Future Work – what further research and studies are needed to fill in critical gaps or reduce uncertainties, what monitoring or evaluation is needed if the project is implemented, and what immediate steps should be taken to move the project forward?

2.0 Comprehensiveness

2.1 Review

Overall, the scientific reviewers generally believed DWR did a commendable job of working with the tools, data, and time available. Reviewers expressed that many of the individual assessments and approaches have merit and provide a basis for further investigation. However, the studies are highly empirical and derived from incomplete information about the system, rendering forecasts of likely impacts of the DWP limited in their generality and validity. A proper evaluation of the proposal will require new and different data, additional and expanded, more mechanistic and integrated models, and more rigorous analysis of uncertainties.

The evaluation of water quality and environmental issues in these studies is seemingly driven by two needs:

1) operational criteria defined by the State Water Resources Control Board in their Decision 1643, and

2) assessments necessary to mitigate for impacts of water storage operations on state-listed threatened species, jurisdictional wetlands, and winter waterfowl habitat.

As such, the scope of the studies is limited to those issues, which are raised, in a regulatory context, rather than in the context of understanding the implications of the water storage operations in the broader hydrologic and ecological context. As a consequence water quality studies focus on dissolved organic carbon (DOC) (TOC needs to be considered), chloride, disinfection byproduct (DBP) precursors (only total trihalomethanes, TTHMs, were considered), dissolved oxygen (DO), electrical conductivity (EC), chloride, and temperature.

Reviewers called for a broadening of this approach in two ways:

- A more ecosystem-based assessment of the in-delta storage plans, and their relationship to ERP goals for the Delta.
- A more explicit programmatic assessment of how these storage projects interface with other aspects of SWP/CVP operations including EWA and CVPIA b(2) waters.

Reviewers recognized that the Delta is a critical element of the state's water transfer system and that the addition of water quality, biological and ecological considerations on top of conveyance systems greatly complicates the assessment of the water storage projects. However, consideration of ecosystem functions is considered essential to forecasting the changes that will be associated with in-delta storage. These include ecological and biogeochemical processes, such as elemental inputs, recycling and losses, primary production and decomposition, fate and transfer of pollutants, and food web interactions.

The existing list of chemical features misses important system linkages. For example, the biological productivity studies are lacking essential components such as quantitative treatment of chlorophyll a (phytoplankton biomass being an important dependent variable for assessing ecosystem response), suspended particulate matter (as primary production may be light limited this will be an important control on chlorophyll a as well as an influence on potential sedimentation on the reservoirs), and biological oxygen demand (which may be a more important factor to assess in operating for water quality criteria than the DO content of the discharged waters). Understanding these water storage projects as part of the Delta ecosystem is essential to understanding the implications for ecosystem restoration goals as well as water conveyance.

Related to this lack of a systemic approach to project assessment is the lack of detailed attention to the potential mercury and methyl mercury problems in the proposed project. Methyl mercury production is enhanced by an adequate supply of organically-bound mercury, very warm water temperatures, anaerobic conditions, high organic matter contents and dark water which can block UV demethylation – all conditions likely to occur within the proposed reservoirs. Although SWRCB Decision 1643 does not address mercury specifically, Delta Waterways are on the State's 303 (d) list as impaired for mercury and thus the implications of delta storage operations for mercury must be addressed.

In addition to the lack of detailed consideration of the implications of the project for the Delta ecosystem, reviewers also noted the very brief attention paid to long-term changes in hydrologic drivers of the ecosystem – most notably those associated with climate change. The state of California and the Delta are likely highly sensitive to subtle shifts in temperature and weather patterns associated with global climate change scenarios. Water storage and conveyance concerns will change as snow pack and snow melt patterns change in the Sierras. Explicit consideration of future changes in hydrologic drivers must be linked with the ecosystem evaluation of delta storage options.

Long-term management of the water in the Delta will likely include operational as well as engineering changes of the kind proposed here. A variety of operational changes are converging toward decision points in the near future, and this project must be considered in the future operational context. Definitions of environmental water and environmental management are rapidly changing, as perhaps they should in an adaptive management context. Among the programmatic/operational issues that may affect the role of in-delta storage are the renewal of long-term water contracts; modifications to cross channel management based on new science; questions regarding the status of CVPIA b(2) water; the role of EWA water vis a vis b(2) unmet needs; and proposals to increase pumping rates. While a decision on moving forward with in-delta storage plans may not be able to wait until all of these issues are resolved (and as new ones will likely arise) the project must be viewed in a more varied context for future water operation

2.2 Recommendations - Comprehensiveness

The reports and assessments are responsive to the statutory climate within which implementation needs to proceed. A more holistic approach is necessary for CALFED to evaluate the implications of in-delta water storage for its goal of restoring ecosystem health, as well as water quality and water supply reliability goals.

The first step in this broader approach to considering in-delta storage is the development of the conceptual model showing the processes, and their linkages, both driving project operation and affected by project operation. Specifically this conceptualization should embrace:

- the project in the context of the water conveyance system and its hydrologic and programmatic controls,
- the project in the context of the Delta ecosystem and the spatial and temporal patterns of ecosystem functions, and
- the detailed hydrologic and ecological dynamics of the reservoirs and surrounding channels, including the operation of intakes/discharges.

Because of the complexity of the system within which the project is set, a series of nested conceptual models is recommended: the water conveyance system (largely hydrologic, considering EC and operations), the delta (including ecosystem and water quality considerations), and the reservoirs/channels (including water quality and ecosystem processes).

The models will demonstrate the relative importance of the project for the various scales of the hydrologic and ecological system. It is not necessary to quantify the relationships among all model components. Rather, the models should be used to identify process linkages to which project operation is sensitive, and process linkages which are sensitive to project operation. In addition, the level of scientific certainty or uncertainty regarding the linkages also should be shown in the models, allowing prioritization of research and data collection needs.

Such conceptual models can also be used to evaluate the project in the light of current and proposed, or even hypothesized, water transfer operations to determine its potential role in the future of water supply and ecosystem restoration.

3.0 Scientific Validity

3.1 DOC and Other Drinking Water Concerns

One of the primary concerns related to the technical feasibility of the proposed in-delta storage project is how flooding peat islands will affect the quality of the water released to the Delta channels and potentially diverted for drinking water. Current and planned regulation of DOC are challenging the drinking water utilities and CALFED, DWR, and other state, local, and federal agencies to find innovative and robust means to comply with these regulatory and human health constraints. At times water diverted from the Delta can exceed the U.S. Environmental Protection Agency's current maximum contaminant level for disinfection byproducts (e.g., trihalomethanes, THMs) when chlorinated for drinking. Certain forms of DOC, as well as bromide, react with disinfectants, such as chlorine, to form carcinogenic and mutagenic byproducts (e.g., THMs). Therefore, it is extremely important that any changes to the Delta water-supply system (e.g., addition of reservoir island water storage and supply) not further degrade drinking water quality, especially with respect to increasing DOC and DBP precursor levels in the channel water. Because of the importance of the DOC water quality issue, this summary review section treats this topic separately.

The reviewers recognized and appreciated all of the effort put forth in developing estimates of DOC and THM precursors potentially contributed to the Delta by the proposed flooded island reservoir. However, the reviewers had several criticisms of the conceptual model, experimental approach and methods, and modeling of data. A general consensus of all reviewers was that the SMARTS experiments that estimated peat-derived DOC contributions did not use the state of the science to estimated DOC concentrations in reservoir water and failed to address the fundamental processes important to adequately understand, and therefore accurately model, release of DOC from flooded peat soils. This shortcoming calls into question the appropriateness of using these results to predict the concentrations of DOC and THM precursors that may result when the reservoir islands are flooded. In addition, the conceptual model for DOC release from peat soils is not complete, implying a lack of scientific understanding of the system and the underlying fundamental biogeochemical and hydrologic processes controlling the release DOC. Reviewers expressed concern over the high degree of uncertainty of almost all aspects of the DOC assessment, and the complete lack of error analysis further brings into question the credibility of the assessment. Thus, the validity and appropriateness of applying the results from the SMARTS studies to flooded islands is doubtful.

3.1.1 Conceptual Model

An appropriate conceptual model for release of DOC from flooded peat soils requires consideration of all significant biogeochemical and hydrologic processes affecting carbon cycling within the system. This process-level approach to understanding the system is important for identifying the key questions to answer or hypotheses to test, which in turn provides the guidance to design scientifically sound experiments that effectively address the questions or hypotheses. As voiced by several reviewers, the conceptual model for release of DOC from peat soils did not consider some of the most pertinent processes controlling the release of DOC from the soils.

The flux of DOC from the soil to the overlying water column depends on diffusive and convective transport of DOC across the soil-water interface. In the water column, mixing and hydrodynamic process will govern the distribution of DOC concentrations. Microbial activity in the peat soil is a potentially important DOC source term. However, microbial effects on DOC production may be relatively minor under flooded, reduced conditions. On the other hand, microbial decomposition of soil organic matter maybe very significant if the soils are exposed to oxygen through wetting and drying cycles, which may be unavoidable during drawdown of reservoir water levels to as low as 0.5 ft. The irregular topography of the island most likely means that some areas will be unsaturated and exposed to atmospheric oxygen. Studies on Twitchell Island have demonstrated the significant effect of wetting and drying cycles on the increased release of DOC from peat soils.

Another important consideration is the difference in the potential release of DOC from different soil layers. Upper, more oxidized peat soils tend to contribute much higher concentrations of DOC of different quality relative to deeper peat layers that have not been exposed to oxygen. This soil horizonation will be extremely important when considering the diffusive transport of DOC over time from the peat soil. The SMARTS tank experiments used only upper, oxidized peat soils that had potential to release much greater amounts of DOC when flooded compared to deeper peat soil zones, and omission of the lower, reduced peat layers may have affected the results obtained.

The importance of considering biological productivity was acknowledged but not included in the modeling of reservoir DOC concentrations. Algal and macrophyte growth and decay are well known sources of DOC and may be extremely important in determining DOC concentrations and quality in the water column. These biological processes may, in fact, dominate both DOC quantity and quality during critical times of the year. For instance, algal and macrophyte senescence and decomposition, and release of DOC may be greatest in late summer and early fall when river flows into the Delta are lowest and water releases from the reservoir islands may be critical. In addition, carbon quality data indicate that decomposition of some aquatic plants (e.g., algae and *lemna*) produces DOC with much higher propensities to form THMs, as much as 3 to 5 times more THMs form per mass of DOC compared to the peat-soil DOC. This example emphasized the necessity of quantitatively assessing DOC quality in the context of ecological, biological productivity, and carbon cycling processes in order to adequately evaluate and predict drinking water quality in the proposed reservoir islands. The current effort failed to take into account relevant processes such as these, making their assessment incomplete and inaccurate.

In general, many other processes (e.g., redox, hydrodynamic, nutrient cycling) and their effects on important ecosystem functions through controlling key ecosystem characteristics (e.g., DO and temperature dynamics) are not considered in their current conceptual model of the system. For example, consideration of nutrient supply and dynamics is essential because nutrient supply is directly related to plant growth, which, in turn, influences DOC levels and ecosystem function. Nutrient loading could strongly affect the phytoplankton communities and benthic microbial communities that are resident in a reservoir system. For example, certain nuisance algae may proliferate under high nutrient conditions. This will alter the population dynamics of important phytoplankton, such as diatoms, as well as lead to changes in ambient environmental conditions, such as dissolved oxygen concentrations. Also, benthic microbial communities and invertebrates that process DOC and POC also may be affected by eutrophic conditions, affecting their population dynamics. These examples emphasize the need to consider processes such as nutrient cycling and its effects on ecosystem functions.

3.1.2 Experimental Approach and Methods

The reviewers had many concerns about the validity of the methods and use of soils in the SMARTS experiments. A question raised by most reviewers was why soils from the proposed reservoir islands were not used. The use of Twitchell Island soil may have been convenient, but there are no assurances (at least no data were presented) of the transferability of results from one soil to another. At the very least, analyses and experiments should have been conducted comparing organic matter and other soil characteristics of the two different soils. In addition, it is impossible to tell from the level of detail provided how sensitive the DOC values were to water depth, the nature of the soil, and the depth of the soil used in the experiment. A greater acknowledgement of the factors the experiment fails to encompass also was lacking. These shortcomings of the experimental design and execution emphasize the need for a well-defined conceptual model that incorporates the processes controlling the ‘release’ of DOC from peat soils and better identifies which processes were examined and those that were not.
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Although the methods involved in the manipulation of peat soils to fill the experimental tanks were not described in detail, the procedure most likely caused significant disturbance of the soil structure and integrity. Destruction of soil structure and integrity causes significant changes in the hydraulic properties of the soil, which, in turn, alters the soil’s transport properties. This experimental artifact undoubtedly altered the movement and release of DOC from the soil to the overlying water. Disturbance of the soil and increased exposure to atmospheric oxygen most likely caused additional oxidation of the soil organic matter, further perturbing the carbon dynamics and release of DOC relative to *in-situ* soil conditions. Altering the soils structure also will increase the amount of water-soil contact, most likely increasing the amount of DOC in interstitial soil water. Thus, the soil manipulations involved in the tank experiments call into question the validity of the data obtained.

3.1.3 Modeling of DOC

Reviewers were in agreement that the use of the logistics equations to model the release of DOC from the soil was a poor choice because this modeling technique does not account for any of the processes governing the release of DOC. Because of the lack of representation of the biogeochemical and hydrologic processes, applicability of the results is limited to the system from which the data were collected, making it questionable, at best, to transfer these results to the proposed reservoir islands. To be valid, predictive models must be built on a mechanistic understanding of the processes involved. In addition, several of the reviewers had serious, well-documented concerns about the accuracy of the model and the assumptions, development, and application of the logistics-equation approach used to model DOC release. An alternative approach for modeling water-column DOC is clearly needed that takes into account the shortcomings cited above.

Another important concern voiced by the reviewers was the seepage return estimates to reservoir-water DOC. The model used contained overly constrained boundary conditions, was not adequately evaluated or validated, and may not have been appropriate for describing the system. A two-dimensional model is not adequate to simulate a peat system, suggesting the need for a 3-D model.

Modeling of DOC using DSM2 showed large disparities between observed and calculated concentrations, at both high and low concentrations, indicating that the dynamics of the system are not being captured by the model in many cases. Model predictions improved when monthly averaged data are used, but this tends to obscure the concentration extremes, missing the temporal dynamics that may be the most relevant periods for the water utilities to respond to in terms of TOC and TTHM formation potentials.

The calculations used to derive UVA and TTHM are based on DOC, for which large uncertainties are associated. Thus, these calculated values also have large uncertainties associated with them. The modeling of channel-water DOC and UVA used 5^{th} order, nonlinear, polynomial regression equations to provide channel-water DOC and UVA inputs to the model. Not only is the 5^{th} order model inappropriate (a 2^{nd} order model probably is more valid), discrepancies between modeled and measured values were very high for many of the months and, in addition, the large uncertainties apparent in the modeled data set were not addressed. These examples further emphasize the need to assess uncertainty through error propagation analysis, and to better quantify uncertainty throughout the reports.

The above examples demonstrate the need for further assessment and refinement of the models, and quantification and incorporation of error and uncertainty.

3.2 Use of Modeling in Planning In-Delta Storage

While it is essential to use numerical models to assess the hydrodynamics and ecosystem processes occurring within reservoirs and in adjacent channels, it is also important to recognize that the level of detail required for making planning decisions may be substantially greater than that used in operation of the system. Several reviewers note the limitations of CALSIM and DSM2 in assessing the proposed project. In large part this may be because these models were designed to inform operational aspects of the SWP/CVP, rather than to understand the dynamics of smaller-scale within-system features. Investments of the magnitude considered for in-delta storage require detailed analysis but the need for analysis in a timely manner usually means application of established modeling tools. However, the models, and all other investigative approaches, must work to reduce the current level of scientific uncertainty, and thus, the risks associated with such a project.

In addition, because of the need for public understanding of complex technical issues and the need to be clear concerning what the models can and cannot simulate, planning studies such as this can be more useful if they explicitly refer to, and perhaps summarize, critical parts of model documentation. Reviewers repeatedly indicated the need to understand how the models work in order to fully assess their output. For instance, it would have been helpful to understand the decision-making process for flow allocation at nodes within CALSIM, as well as the temperature approach used with DSM2, to assess their use in these studies.

Similarly, stating the level of accuracy and quantitative uncertainty of any models used, as estimated during verification and validation processes, also assists those interested in the planning process in determining how well the model does at simulating average conditions, extreme events, daily fluctuations and interannual trends. In this case, it would also provide an indication of the level of confidence in the model estimates of project water yield and water quality parameters relative to the operational criteria set forth on Decision 1643. Uncertainties (e.g. estimation errors) were generally not quantified in the studies. The magnitude of error for all predictions should be estimated so that, for example, predicted differences between base (no DWP) and DWP cases, which in many instances were very small, can be compared to the size of the error. For example, are the projected benefits of the DWP smaller or larger than the size of the estimation error? If error is larger than the magnitude of expected benefits, then those expected benefits might not be taken seriously. Quantification of uncertainties would also be necessary for evaluating predictions of DOC, temperature, and DO compliance.

Validation studies and quantification of estimation errors should be provided for the DSM2, CALSIM, DO, and temperature models. Further, since the output of a modeled scenario may be highly sensitive to uncertainties in the multiple model forcings (e.g. meteorological, geometric, operational), causing propagation of uncertainty and potentially extremely different outcomes, modeled outputs may best be expressed as a *range* of possible outcomes as opposed to one distinct outcome.

It is likely that some of this information is readily available for the models used and could be incorporated into future planning documents. However, it is necessary to also include this level of background detail for any additional existing models which are used or new models that are developed as planning proceeds.

3.2.1 Physical Modeling

CALSIM model

Use of the CALSIM II model as a driver to DSM2 is generally deemed to be a strength since together they appear to be those currently used to assess operations and water management within the Delta, allowing the project to be considered in the context of current delta operations. Some basic description of how the model works would have been helpful in further evaluating its reasonableness for this application. As discussed above, the lack of model documentation made it difficult for reviewers to assess the performance of this component of the modeling approach.

DSM2 model

For the multi-year simulations performed for this study, the computational efficiency and extensive previous application of the DSM2 model to the Delta make it a logical choice. Within the constraints and assumptions of the DSM2 one-dimensional framework, predictions of transport of water and conservative scalars (like EC) are expected to be generally valid; however, quantitative and graphical comparisons of measurements against DSM2 output for a wide range of operational and hydrologic scenarios is necessary to establish reviewers' confidence in the predictive ability of this model. For example, for a range of scenarios, how large is the DSM2 error in predicted water and EC quantities and fluxes? No such model validation information was provided with the review materials; therefore, although it is expected that the model performs well in those areas, reviewers were unable to vouch for the model's quantitative predictions.

One major limitation of the DSM2 model in the context of reservoir water quality prediction is its inability to resolve vertical or lateral variability within reservoirs or adjacent channels. DSM2 apparently treats reservoirs as continuously stirred (internally homogeneous) tank reactors, implicitly assuming that water is never stratified and that water quality constituents never vary spatially within them. In addition to the stratification issue, the irregular topography of the islands suggests horizontal variability in water depth and physical-biogeochemical processes will be present. Reviewers repeatedly called into question these assumptions.

Another limitation of the DSM2 model has to do with its apparent inability to simulate complete drying of reservoir beds and the requirement in some studies that modeled minimum water heights are 0.5 ft. Although operational schemes are unclear about the saturated/flooded condition of the soil post-discharge and pre-refill, implications of how the DSM2 model's limitations in accurately characterizing water depths could impact assessments of water quality, macrophyte growth, etc., should be addressed.

3.2.3 Ecosystem Modeling

Dissolved oxygen and water temperature modeling

The spreadsheet modeling approach taken in predicting DO and temperature (T) likely provide a reasonable start for the process of projecting DO and T compliance immediately in the vicinity of the reservoirs. However, as discussed elsewhere in this report, several simplifying assumptions (some of which the author discusses) may substantially limit the realism of the results. Such simplifications include the use of a daily timestep (instead of a timestep resolving diel dynamics), neglect of potential thermal stratification inside the reservoirs, and the probable assumption of full mixing of reservoir discharges across the adjacent channel cross-section. Further, important biological and biogeochemical processes are not considered in the DO model. Although there are good discussions of processes involving algal growth and submerged aquatic vegetation, of the limited data available to describe such productivity in this system, and of a sound conceptual model of fates of macrophyte detritus, the inability of the current quantitative assessments to embrace such issues is a major shortcoming.

The heat budget equations were openly described and were probably standard but were not referenced or shown to be validated quantitatively. The DO calculation approach was also for the most part unreferenced and presented without validation information. The mass balance approach was not described in detail (no equation was given) but was reasonable within a one-dimensional framework. Although the approaches are likely generally reasonable, the lack of supporting/validating information makes it impossible for the reviewers to really confirm the validity of the results. Little discussion was given of alternative models and their benefits.

Reviewers seriously questioned the use of the SMARTS experimental data in the DO sag term in the model. It was assumed that the SMARTS experiments captured most important DO losses, but no substantiation of this assumption was offered. Further, SMARTS data were used to estimate DO losses for cases of high and low organic carbon substrate. Unfortunately, the high organic carbon substrate also had deeper water, so it was difficult to separate out individual effects of water depth from carbon content of the substrate.

It appears that the so-called “verification” of the DO approach was actually “calibration” since algal growth rates were adjusted so that DO concentrations at Webb matched measurements. In the context of such a "model tuning" exercise, it should not be surprising that predicted Webb DO compares favorably to measurements. It appears a similar approach may have been taken at Bacon as well. If the model was tuned to match observations (a calibration exercise), then we cannot take the results of that calibration as reliable predictions of an independently tuned model. Rather, the model should be calibrated independently and then used (without further tuning) to provide actual *validation* output.

Although the T/DO approach provides a reasonable start to assessing bulk impacts of discharges immediately in the vicinity of the reservoirs, it is insufficiently sophisticated to assess the real impact of the discharged waters on water quality in the Delta. Reviewers suggest the use of three-dimensional models that can account for bathymetric complexities, local stratification, lateral variability, and variability in mixing that will affect the fate of reservoir outflows. In addition, both temperature and DO need to be modeled within the Delta-scale, one-dimensional context of DSM2.

3.3 Assumptions

The reports stated several assumptions with which reviewers had questions regarding validity and impacts on results. Examples are:

- The assumption that DOC is equal to raw-water TOC is clearly invalid and use of this relationship potentially can have tremendous repercussions on water utilities because regulations are based on TOC rather than DOC. Routine instrumental techniques to analyze TOC produce erroneous results and the need to separately measure DOC and POC to calculate TOC was emphasized by one of the reviewers.
- Another significant invalid assumption is treating DOC as a conservative constituent in the channel waters. The same biological productivity considerations discussed in detail above, also apply to channel-water DOC-carbon cycling and need to be explicitly addressed.
- Most studies assumed the water column was well mixed (i.e. not prone to vertical density stratification). Many reviewers questioned the validity of this assumption and remarked on the multitude of critical quantities and processes (such as dissolved oxygen, organic carbon, phytoplankton, macrophyte, and mercury dynamics) that could impact or be impacted by the very possible development of temperature stratification within the proposed reservoirs and possibly adjacent channels. In general, very little consideration was given in the reports to the implications of this assumption on the net water quality of reservoir discharges.
- Horizontal variability within reservoirs was not considered either. Reviewers expect that horizontal variability in physical and biogeochemical processes may---and probably will---develop due to variations in bathymetry, biases in wind direction, and development of secondary flows in corners and coves. Therefore, we cannot expect that the reservoirs would function as Continuously Stirred Tank Reactors; however, the predominant assumption in these studies was that they would.

- The DICU model, used to project consumptive uses in the Delta for 2020 level of development, does not incorporate any change in consumptive use associated with the project but rather redistributes without-project levels of use across the Delta.
- A 2020 level of demand and hydrology was assumed for the project instead of an extreme case (e.g. 2055) or a reasonable stepped progression through time. Extreme climate scenarios (e.g. El Nino, La Nina, extended droughts) should be considered.
- It was assumed that the SMARTS tanks incorporated (almost) all of the critical DO loss processes, so the DO "sag term" was based on SMARTS data. However, no specific discussion was offered of the universe of critical DO sinks and relevant processes (e.g. due to vascular plants, detritus, animals, etc.) potentially present in the reservoirs and specifically which of those the SMARTS tanks captured. Reviewers were skeptical of this simplifying assumption.

These examples (more are contained in the individual detailed reviews) emphasize the need to assess, test, and justify the validity and credibility of assumptions made throughout the reports.

3.4 Recommendations – Scientific Validity

Conceptual model of carbon

The reviewers strongly recommend development of a comprehensive, process-level, mechanistic-based conceptual model of the carbon dynamics in the reservoir system, specifically including release of DOC from peat soils, biological productivity, and the carbon dynamics and cycling processes associated with these carbon sources. The conceptual model needs to consider carbon sources, sinks, and biogeochemical processes affecting and controlling carbon quantity and quality in the system. Furthermore, the carbon cycling conceptual model needs to be integrated with the hydrologic and hydrodynamic frameworks driving carbon transport in the system.

Measure DOC flux from peat soils

Measurement and modeling of diffusive fluxes of DOC from reservoir soils using either intact soil cores or *in situ* mesocosms will provide valuable information regarding contributions of DOC from the peat soils. Replication and judicious selection of sites will aid the evaluation of both uncertainty estimates and spatial variability. Additionally, monitoring of gaseous carbon fluxes (CO_2 and CH_4) in the cores or mesocosms should provide information on the importance of microbial processes influencing DOC release.

Modeling reservoir water column DOC

An alternative to the logistics-equation approach for modeling water column DOC could take on the form:

$$DOC_{water\ column}\ \ or\ \ \frac{dDOC}{dt}_{water\ column} = \textit{sed-water flux contribution}$$

+ water column vertical diffusion and mixing contribution

+ water column production or transformation contribution (function of k)

+ horizontal exchanges or flushing contribution,

with the relevant biogeochemical, hydrologic, and hydrodynamic processes contained within each term.

Modeling seepage return

The reviewers recommend the use of a 3-D model for estimating seepage returns for the complex peat soil-reservoir system. In addition, the importance of understanding the interactions between the reservoir surface water and the local and regional groundwater systems, as well as using a more realistic groundwater DOC value, need to be incorporated into the model to better reflect the hydrologic complexities of the system.

Need to consider effects of photooxidation on DOC quality

An important process that needs consideration in evaluating DOC dynamics is the potential impacts of photooxidation on organic matter quality in Delta waters. Photooxidation of DOC is not a simple issue. It appears that photooxidation has the impact of making organic matter that is refactory to biological degradation (such as humic substances) more biodegradable, and making biologically labile constituents (such as algal exudates) less biodegradable.

Need for common scenarios and assumptions

A common observation of reviewers was the need for improved coordination between study components. A remarkable breadth of issues was covered in the studies, but in many cases the separate studies were based on different sets of operational, geometric, and hydrologic assumptions. For example, the Biological Productivity Study was based on the assumption of steadily filling reservoirs over a 3-month period; whereas DSM2 simulations were based on filling scenarios occurring over maximum 1-2 months. Other inter-study discrepancies occurred with respect to the depth of water in the reservoirs after release and the possibility of refilling within one year. Future studies should all be based on the same operational, geometric, and hydrologic scenarios.

Three-dimensional modeling

Due to concern over the possibility of vertical temperature stratification within the proposed reservoirs and possibly in adjacent channels, it is 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. Such a modeling approach would be implemented for
1) projecting and understanding the detailed physical interactions between wind, geometry, surface heating, inflows, and outflows in the proposed reservoirs;
2) ultimately studying the potential effects of those physical interactions on important physical, chemical and biological quantities such as EC, TOC, DOC, DO, TTHM, bromide, UVA, chlorophyll a, and temperature;
3) studying cross-sectional variability and mixing in channels adjacent to reservoir islands,
4) comparing with DSM2 results to identify regimes when a one-dimensional approach is appropriate, to generate error bars on the DSM2 estimates, and to refine the representation of key processes within DSM2,
5) refining the placement of reservoir intakes and discharges; and
6) potentially merging (if feasible) a three-dimensional representation of reservoirs and adjacent channels with the DSM2 one-dimensional representation of the greater Delta.
Also recommended is application to the proposed reservoirs and adjacent channel environments of a three-dimensional hydrodynamic model. Associated measurements resolving vertical and lateral profiles of hydrodynamic quantities as well as chemical and biological constituents are recommended for calibrating and validating the multidimensional, integrated model.

Other issues which a multi-dimensional hydrodynamic model could inform include: 1) effects of seepage pumps on internal circulation and residence time relative to SMARTS tanks and associated implications for water-peat contact and DOC flux; 2) effects of perimeter seepage pumps on adjacent channel hydrodynamics; and 3) forces of discharge on levees bordering islands adjacent to reservoir islands (i.e. for ultimate stability evaluation of adjacent island levees).

The hydrodynamic base of a 3D modeling effort would not have to be built from scratch. Examples of existing, verified, and potentially appropriate 3D hydrodynamic models include RMA-10 (Resource Management Associates, Inc.), ECOMSED (Hydroqual, Inc.), TRIM3D or UNTRIM (Prof. Vincenzo Casulli), and Delft3D (Delft Hydraulics).

Ecosystem Functions and Process integration

Because many of the modeled biological and chemical constituents have potentially large effects on other constituents (currently modeled separately), it is recommended that their dynamics be studied in tandem and in a mechanistic manner. For example, water temperature was studied separately from DOC, TTHM, and bromide. Because 1) DOC transformations are sensitive to temperature, 2) TTHM depend directly on DOC and bromide, and 3) other biochemical processes related to biological productivity and the carbon cycle such as algal growth and dissolved oxygen relate to most of the above constituents, it is suggested that these all be modeled and studied simultaneously within one model, with the same sets of hydrological, physical, and operational assumptions in place for all constituents and with mechanistic feedbacks between constituents explicitly incorporated and permitted. Similar process relationships exist and should be studied between vascular plant growth/decay, mercury dynamics, and the above processes. Admittedly, understanding and thus modeling ability may be limited for some key processes such as macrophyte growth and mercury transformations; however, the state of the knowledge should be used to at least *bound the range of possible outcomes* as functions of other more “modellable” processes.

Collaboration between multidimensional hydrodynamic modelers and fish biologists is recommended for projecting impacts of changes in flow and transport on sensitive populations.

Fingerprinting for partitioning of reservoir releases and organic matter sources

The use of the DSM2 model in the “fingerprinting” exercises for water source tracing is deemed a very worthwhile exercise. It was suggested that a similar approach be used for quantifying the partitioning of reservoir discharge flows and constituent fluxes between various destinations (e.g. pumps, Bay), as qualitative statements were made about such partitioning but no quantitative work shown.

Analytical techniques are currently being developed that show promise for identifying different sources of organic matter contributing to DOC. Some of these techniques rely on *in-situ* optical measurements that could be tested and suitably applied to the reservoir islands and surrounding channel waters.

Time scales, spatial scales, and time frames of study components

Water quality predictions were generally produced in the form of monthly averaged values, which smoothes out extremes and probably underestimates noncompliance events; whereas, compliance monitoring will presumably not be based on smoothed monthly averages. DO and temperature predictions were performed at a higher daily-averaged resolution, but those quantities may experience extreme diel variability. The time of day of sampling or reservoir release could thus easily determine whether water quality violations occur. Therefore, the day- or monthly-averaged model output so prevalent in most of the studies is generally not appropriate for predicting compliance (this limitation was acknowledged by several of the study authors). Water quality predictions need to be calculated at the time scales of expected monitoring and of the relevant controlling mechanisms (e.g. the daily heating cycle).

Further, the time frames of critical biogeochemical processes relative to expected periods of reservoir release must receive attention. For example, high growth rates of micro- and macroalgae will likely occur during the warm summer periods, potentially resulting in elevated DOC levels; such high-DOC periods could coincide with desired reservoir release times, potentially precluding releases on the basis of water quality violations.

In addition to resolving the time of monitoring and reservoir release, modeling studies should also resolve the location. For example, dissolved oxygen concentration, water temperature, and other water quality constituents such as algal concentration and consequently DOC may vary substantially over the depth of a water column. The vertical placement of samples or reservoir releases could easily determine whether water quality violations occur. Further, water quality may vary substantially in the horizontal, since reservoirs will not be subject to the homogenizing effects of tidal mixing. Residence time of reactive solutes and particles will likely vary spatially within reservoirs, thus affecting net transformation rates and, ultimately, concentrations. Therefore, compliance with water quality restrictions may depend on where *horizontally* monitoring and discharge are performed. The depth-averaged and laterally averaged DSM2 approach may not be appropriate for predicting compliance where and when vertical or horizontal variability is expected to be substantial. A three-dimensional model may help identify scenarios for which the DSM2 structure is appropriate and cases for which it is not.

Finally, it was not clear whether temporal or spatial variability were considered when measurements were used to drive models or compare with model results. For example, is point data from an incompletely mixed tank reactor (SMARTS experiments) or from the possibly stratified Stockton ship canal (for temperature) appropriate for use with the depth-averaged DSM2 model? Are new temperature and DO measurements needed at *actual* discharge locations? Are the environments at which DO measurements are available really representative of the environments to which they are applied?

4.0 Future Work and Next Steps

Successful implementation of the complex in-delta storage project requires addressing the shortcomings and making the enhancements to existing approaches recommended above, and in more detail in the reviews. Generation of new understanding (information) is essential before the project can be fully evaluated. Not all decisions about implementation need necessarily wait for complete scientific knowledge. But some of the shortcomings in knowledge are severe enough that substantial risks exist if decisions proceed without filling these gaps.

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 concentration, DO levels and water temperature, all of which are important to the viability of the project. It is paramount to know how likely it is that this project will meet the operational criteria laid out in State Water Resources Control Board Decision 1643. 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 be left with reservoirs full of water that cannot be released because of water quality criteria.

Reviewers also pointed to the great uncertainties regarding the effect on the migration and production of critical populations of fishes, the need for better understanding of project operations on mercury methylation, and the potential role of exotic species in altering system function in the future. These issues also need to be addressed in order that the full implications of the project for the Delta can be assessed, although their immediate implications are probably less severe than those for water quality.

Research should be targeted towards these and any other critical process linkages that the conceptual models show as being sensitive and of high uncertainty. Such research is called for under the adaptive management approach to ecosystem restoration adopted by CALFED. Research should be focused to reduce uncertainty and thus elucidate or improve the conceptual models of the system that assist in determining project benefits or impacts.

Screening of diversions to prevent fish mortality is a common practice. Reviewers expressed concerns regarding the design of the screens and these must be addressed as the development and evaluation of the project moves forward. However, before the standard current agency-approved designs are incorporated by default, a full evaluation of the potential effects, positive and negative, of screening these diversions should be undertaken. The size, number and placement of diversions should be examined relative to the efficacy of screening options, the operational criteria concerning Delta smelt outlined in Decision 1643, and likely variations in the magnitude and timing of diversion relative to changing river flow conditions in relation to anadromous fish use of the adjacent channels. Such information can then be used to optimize the design of the diversion configuration to minimize damaging effects on fish while allowing operation of the storage facilities to proceed.

Another crucial aspect of project implementation under adaptive management is monitoring, not simply to validate project expectations or meet regulatory constraints on system operation, but to improve understanding of the project in operation. Reviewers note that shallow aquatic ecosystems are increasingly reported as switching from one persistent condition to another. These transitions can be driven by alterations in nutrient supply, shifts in climatic conditions, or introductions of exotic species. Such state transitions can be associated with substantial changes in ecosystem function. Monitoring must be sensitive enough to identify these changes, and be used to modify conceptual models appropriately.

Currently, SWRCB Decision 1634 calls for the completion of a compliance and monitoring report to include:

> ‘A detailed and comprehensive monitoring program for the periods when the DW Project is discharging water that identifies parameters to be monitored including chloride, bromide, electrical conductivity, dissolved oxygen, modeled channel flow rate, discharge rate, total dissolved solids, turbidity, dissolved organic carbon, UVA, total organic carbon, and water temperature; sampling locations; sampling

> frequencies; analytical methods; and quality assurance/quality control procedures in accordance with the analytical methods defined in the SDWA regulations; (40 CFR § 141.135(b).)'.

This list should be expanded to include local meteorological data, vertical hydrographic profiling to assess stratification, detailed monitoring of seepage returns to assess their influence on water quality. These parameters must be assessed at sufficiently detailed temporal and spatial scales to drive the numerical models that govern operation, as well as to provide insights into system function. Further, since reservoirs will most likely not operate at steady state, rendering conditions during discharge periods a function of antecedent conditions, monitoring should be expanded temporally to include periods *between* discharge periods so that potential hindrances to discharge may be understood and effectively managed.

Considering all the issues above, and their relative risks, the following steps are recommended (Table 1) to reduce uncertainty about whether the project is likely to meet the water quality criteria controlling operation, and provide a sound scientific basis for making a decision regarding project implementation. The steps are presented as Tasks on a timeline to illustrate how they develop information to elucidate project dynamics and build towards a more complete assessment of how the project might operate under the Decision 1643 criteria and the variations in both conveyance operations and environmental drivers.

Table 1. Next Steps by Task and Timeline

Task	Year 1	Year 2	Year 3	Year 4	Year 5
1. Detailed Conceptualization to include detailed DOC conceptual model	xxxxxx				
2. Develop 3-D hydrodynamic model of reservoirs and adjacent channels inc. necessary data collection.	xxxxxx				
3. Empirical measurement of DOC fluxes from peat soils from reservoir islands inc. spatial variability	xxxxxx				
4. Technical forum to present current status of scientific understanding and consider next steps	xxx				xxx
5. Develop model of processes controlling biological prod. within reservoirs.		xxxxxxxxxxxxx			
6. Monitoring of biogeochemical processes in existing Delta habitats.	x x x x x x x x x x x x x x x x				
7. Develop model of processes controlling DOC within water column.			xxxxxxxxxxxxxx		
8. Develop climate change and variability scenarios to include extreme conditions.		xxxxxx			
9. Integration of physical modeling tools.		xxxxxx	xxxxxx		
10. Modeling of reservoir operation.				xxxxxxxxxxxxxxx	

Task 1. Detailed Conceptualization to include detailed DOC conceptual model: This Task would include the development of a conceptual model 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 water conveyance system (largely hydrologic, considering EC and operations), the delta (including ecosystem and water quality considerations), and the reservoirs/channels (including detailed consideration of DOC and ecosystem processes).

Task 2. Develop 3-D hydrodynamic numerical model of reservoirs and adjacent channels including necessary data collection: The need to address the potential for stratification within the reservoirs has been repeatedly noted by the reviewers. This effort would include vertical and horizontal variability within the reservoir islands and the adjacent channels. Data collection to establish local boundary conditions in the channels and to validate the model would be part of this Task.

Task 3. Empirical measurement of DOC fluxes from peat soils from reservoir islands inc. spatial variability: Reviewers repeatedly noted the need to assess DOC fluxes from peat soils from the reservoir islands in order to incorporate specific character of substrate (e.g., porosity, structure and organic content) and to evaluate in more detail the DOC dynamics of the islands, including these fluxes. Although empirical flux measurements using in-situ chambers cannot account for changes in flux associated with water movement across the substrate, chamber data can provide some estimate of the diffusive DOC fluxes from the substrate under the relatively quiescent conditions expected near the reservoir bed during maximum storage conditions, and an appropriate model of these processes can be developed as part of the water column model (Task 7). Measurement of gaseous carbon fluxes as part of this task also will provide insight regarding the role of soil microbial processes in DOC release.

Task 4. Technical forum to present current status of scientific understanding and consider next steps: Recognizing that these first three Tasks will address some of the most critical uncertainties regarding project operation under water quality criteria, that understanding of delta dynamics, water quality issues and ecosystem processes is developing rapidly, and that some ongoing studies may not have been considered in this review, this Task provides a mechanism for scientists, regulators, managers, operators and stakeholders to be informed of the current scientific understanding of the issues surrounding in-delta storage. The participants will review existing and newly developed information and suggest modifications to Tasks 5 through 10 as appropriate. A second technical forum is recommended when all the Tasks are completed.

Task 5. Develop numerical model of processes controlling biological productivity within reservoirs: The reviewers have indicated the importance of considering primary production (both algae and macrophytes) in assessing DOC production and DO levels within the reservoirs. Numerical models should be developed to allow these processes to be considered in the dynamic context of reservoir operations. The conceptual model (Task 1) will drive the processes incorporated in the model, and the importance of some factors (such as nutrient availability, turbidity and grazers as factors controlling algal primary production) should be assessed using sensitivity analysis prior to the development of detailed dynamic model components in the context of the 3D hydrodynamic model.

Task 6. Monitoring of biogeochemical processes in existing Delta habitats: Some analogs for the reservoir islands exist within the Delta, although they are mostly subject to tidal exchanges (which will not be the case for the reservoirs). In particular, Twitchell Island wetland restoration experiment areas (not subject to tidal exchange) provide examples of shallow flooded conditions (an analog for low water conditions within the reservoirs) and the southern part of Mildred Island is a relatively deep flooded area within limited tidal exchange. Monitoring of biogeochemical processes should be conducted in these areas to develop a context for the varying conditions reservoir islands might experience during flooding and discharge cycles. In addition, monitoring of biogeochemical processes in the channels adjacent to proposed reservoir islands will provide data to validate modeling of that area and the translation of information from Twitchell and Mildred to the proposed project location.

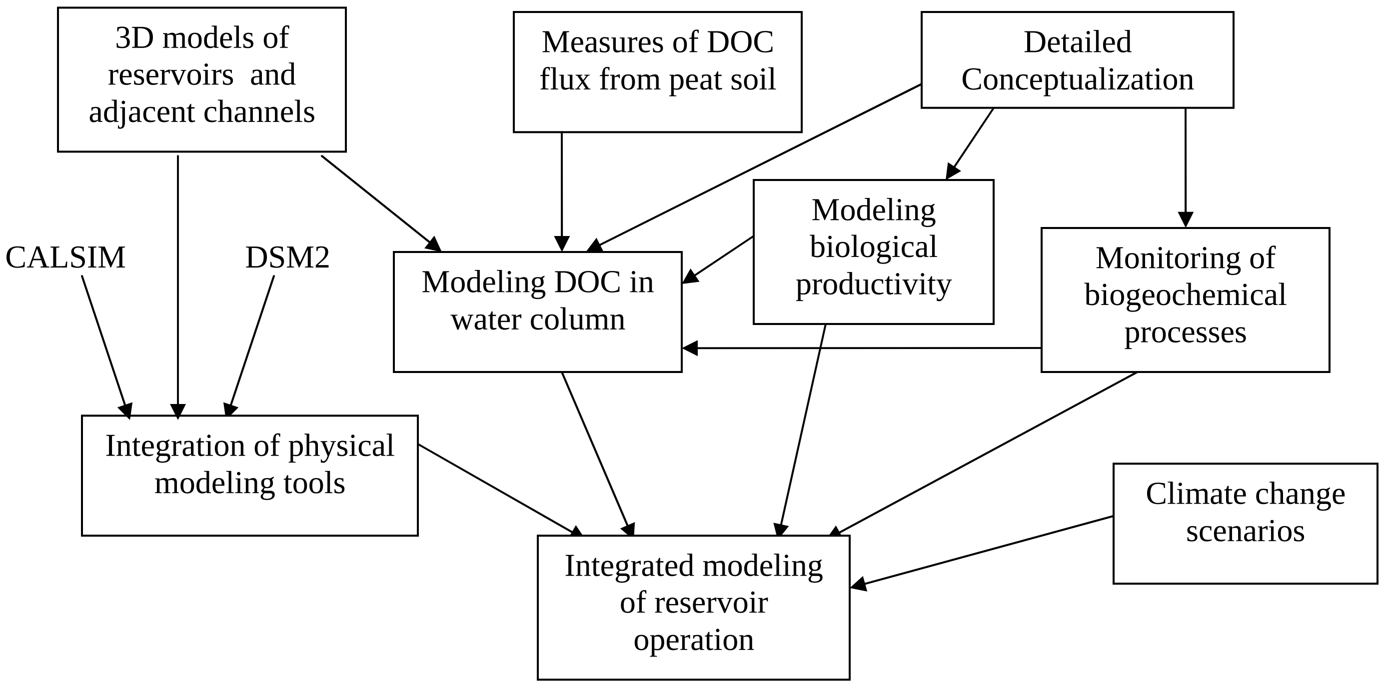
Task 7. Develop numerical model of processes controlling DOC within water column: This review has provided a conceptual basis for modeling DOC within reservoir waters, including the roles of flux from peat substrates (Task 3), and ultimate incorporation into a model of three-dimensional circulation within the reservoirs (Task 2). Data from monitoring in Task 6 and the empirical studies in Task 3 will be used to build and validate the model. Before incorporation of DOC processes into the full 3D model, initial development and verification within a one-dimensional vertically resolved framework (i.e. without net horizontal transport) may be helpful.

Task 8. Develop climate change and variability scenarios to include extreme conditions: Current and future variability in climate, including global warming trends and cyclic phenomena such as El Nino-La Nina, have a great influence on the availability of water within the Central Valley. Reviewers acknowledge the current limited incorporation of these factors into the evaluation on in-delta storage. This Task would develop 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, including extremes of water surplus and water deficit, as well the influence of increased air and inflow temperatures and modified hydrographs on reservoir circulation and biogeochemical dynamics.

Task 9. Integration of physical modeling tools: The review recognizes that most of the models currently used in the studies are designed at assist operational decisions rather than to be used in detailed planning assessments. However, it is also acknowledged that to the extent possible currently available and widely understood modeling tools should be used in the assessment. This Task develops mechanisms for integrating the newly developed, smaller scale, reservoir-specific three-dimension models (Task 2) with those that address system-scale water operations (CALSIM) and Delta dynamics (DSM2). The goal is to use output from the larger scale models to drive the smaller scale models, and provide for the necessary iterations and feedbacks to ensure that the physical dynamics of in-delta storage can be considered quantitatively in the context of the Delta and the whole conveyance system.

Task 10. Modeling of reservoir operation: Tasks 1 through 3, and 5 through 9 (as modified during the Task 4 technical forum), build information, technology and understanding towards the point where models can be used to fully evaluate in-delta storage operations in the context of the water quality discharge criteria required by Decision 1643 (Figure 1). This Task involves the development of an integrated modeling approach to incorporate the information derived from previous Tasks and our conceptual understanding of in-delta storage in a broader systems context. Extension of the DSM2 to include temperature, DO, and/or DOC dynamics in channels and the greater Delta may also be necessary. Using this model, agencies, stakeholders and operators will be able to evaluate project performance under a range of conditions (including climatic extremes) and make more informed decisions regarding the risks involved and potential benefits derived from proceeding with the Plan.

Figure 1. Linkages among Tasks outlined in Table 1 and described in the text.



The timeline in Table 1 has been derived based upon consideration of available approaches and expertise and the challenges involved in some of the Tasks. The goal of these recommendations is to move towards an informed decision on in-delta storage implementation. To expedite this process and meet the proposed timeline it is expected that DWR will make use of the best available expertise in the various fields of science and will call upon their in-house personnel, consultants, and both in- and out-of-state experts to move these Tasks to fruition on the proposed timeline. While this might be accomplished using a competitive RFP process, the need to move forward with these Tasks and to provide integration of models and information developed in different Tasks requires a more focused approach to the selection of those who can best accomplish what needs to be done. Thus, it is 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.