DELTA RISK MANAGEMENT STRATEGY

INITIAL TECHNICAL FRAMEWORK PAPER

HYDRODYNAMICS/WATER QUALITY

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Prepared for:
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Hydrodynamics/Water Quality

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Foreword

The purpose of the Delta Risk Management Strategy (DRMS) Initial Technical Framework (ITF) is to guide the analysis of specific technical topics as they relate to assessing potential risks to Delta levees and assets resulting from various potential impacts (e.g., floods, earthquakes, subsidence, and climate change). These ITFs are considered “starting points” for the work that is to proceed on each topic. As the work is developed, improvements or modifications to the methodology presented in this ITF may occur.

This document describes the Hydrodynamic and Water Quality Analysis component of the Water Analysis Module of the Delta Risk Management Strategy Risk Analysis Framework.

The Water Analysis Module of the Delta Risk Analysis Framework estimates the consequences of levee breach events on upstream reservoir operations, hydrodynamics and water quality transport, and Delta exports. This ITF paper describes the context within which the Water Analysis Module will be used and the hydrodynamic and water quality components of this module. The following aspects are discussed:

- Physical system/problem statement,
- Analysis approach,
- Engineering models utilized,
- Probabilistic approach,
- Assumptions, constrains and limitations,
- Information requirements and output products,
- Resource requirements, and
- Project tasks.

There are two general objectives for the Water Analysis Module corresponding to the risk analysis phase and the risk reduction phase of the study. During the risk analysis phase (first phase) the Water Analysis Module will be used to produce conditional probability distributions of water export disruptions and environmental conditions based on a wide range of explicit levee breach sequences for the current Delta configuration and generally accepted range of operating procedures. During the risk reduction phase (second phase) the Water Analysis Module will be used to evaluate proposed physical and operational alternatives designed to reduce consequences associated with levee breach events. Specific objectives of the Water Analysis Module during the risk analysis phase include the following:

- To provide base case and selected scenario results as requested by technical teams that aid in development of their risk assessment modules (for example, providing water surface elevations from hydrodynamic simulation of specific storm events in the Delta to the flood hazard team.)
- To simulate the water management decisions related to levee breach incidents – in particular upstream reservoir releases, in-Delta uses, and exports.
- To simulate the hydrodynamic and water quality responses to levee breach incidents – in particular salinity, but also including information on other relevant variables (possibly temperature and dissolved or total organic carbon), as needed for input to the economic and environmental consequence modules.
- To establish simulation tools that will be useful in the second phase of the DRMS project to assess risk reduction options (such as installation and operation of barriers).
- To estimate uncertainty associated with each simulation output.

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1.0 INTRODUCTION

This document describes the Hydrodynamic and Water Quality Analysis component of the Water Analysis Module of the Delta Risk Management Strategy Risk Analysis Framework. The Delta Risk Management Strategy (DRMS) project consists of two distinct phases. Phase 1, Risk Analysis, involves construction of a Risk Analysis Framework to evaluate the probability distribution of economic and environmental consequences associated with levee breach events in the Sacramento-San Joaquin Delta and Suisun Marsh. The Risk Analysis and its component Modules are described in individual technical papers, which will be available on the DRMS web site.

Phase 2 of the DRMS project involves detailed evaluation of risk reductions strategies. This and other DRMS technical papers focus on Phase 1 of the DRMS project. Phase-2 work will be documented separately.

The Water Analysis Module encompasses both water management decision making and Delta hydrodynamic/water quality response related to levee breach events and subsequent repair and recovery period. The water management component of the Water Analysis Module is presented in a separate technical paper.

The Water Analysis Module of the Delta Risk Analysis Framework estimates the consequences of levee breach events on upstream reservoir operations, hydrodynamics and water quality transport, and Delta exports. This ITF paper describes the context within which the Water Analysis Module will be used and the hydrodynamic and water quality components of this module. The following aspects are discussed:

- Physical system/problem statement,
- Analysis approach,
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The Water Analysis Module fits in the center of the risk analysis framework receiving the description of breach events from the seismic, flood hazard, levee fragility, and emergency response/repair modules and providing water supply, hydrodynamic, and water quality consequences to the economic and environmental modules (Figure 1). The water quality consequences of levee failure in the Delta and Suisun Marsh are dependent not only on the initial state of the Delta at the time of failure, but also on the time series of tides, inflows, and exports following the levee failure. Therefore, the Water Analysis Module is proposed as a simulation model that tracks the response from the initial breach event through the repair and recovery period.

The water management, hydrodynamic, water quality, and water export components of the risk analysis framework are combined in a single module because there is a tight

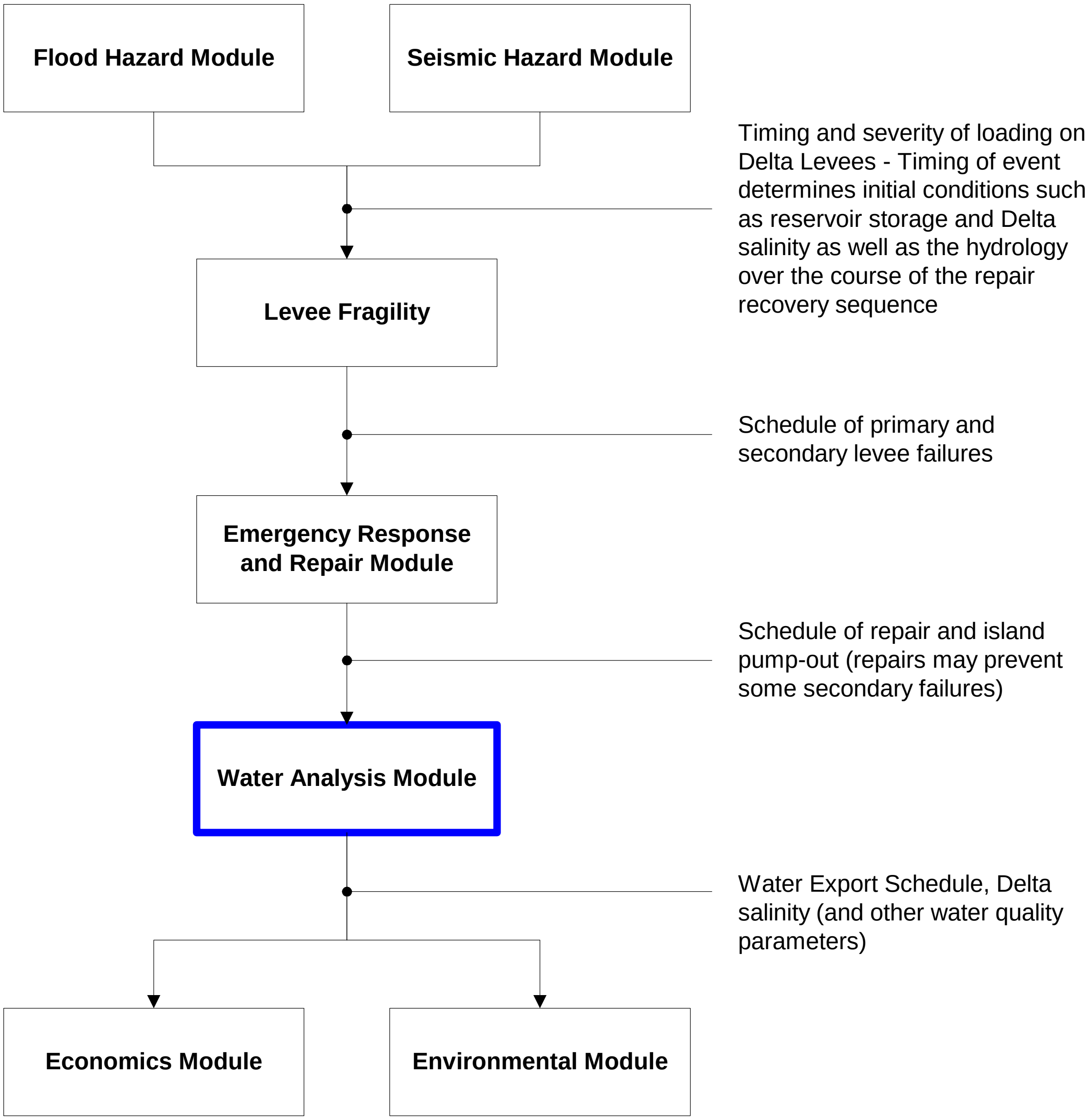

Figure 1: Position of the Water Analysis Module in the Risk Analysis Framework.

coupling between reservoir operations upstream of the Delta, hydrodynamics and water quality within the Delta and Suisun Bay, and the ability to export water from the Delta. When an emergency occurs, decisions will be made to manage ongoing reservoir releases and Delta exports based on the water quality of the Delta, so it is not possible to determine release or export strategies without simultaneously evaluating the evolution of Delta water quality (primarily salinity).

The decision model incorporated into Water Analysis Module will be responsible for determining reservoir releases and exports immediately following a breach event and throughout the repair/recovery period. The decision model may be based on operating rules included in existing models of the California water system such as CALSIM.

However, because it is likely that new and significantly different operating rules will be required to manage the emergency response to multiple levee failures, considerable input will be required from the operators and policy makers responsible for managing the State's water system in developing the decision model.

The water quality transport model incorporated into the Water Analysis Module will be responsible for determining salinity distribution in the Delta. Because the full risk analysis will require evaluation of hundreds if not thousands or tens of thousands of discrete levee breach sequences, the Water Analysis Module must provide very rapid calculation of consequences related to any given breach sequence. Dynamic simulation of the hydrodynamic and water quality impacts of levee breaches using the best currently available models is very time consuming, requiring hours to days or weeks of computation time to fully evaluate a multi-breach event where the repair/recovery period will span several years. A critical aspect of this work will be development of a reasonable and defensible simplified representation of water quality transport within the Delta to be used within the Water Analysis Module. The proposed approach will characterize the response of the Delta to a range of levee breach sequences using existing Delta models and then use that characterization to construct a simplified model. Once the simplified model has been exercised within the Water Analysis Module for many possible levee breach sequences, several of the most important sequences will be re-evaluated using the full Delta models to verify the performance of the simplified model. If necessary, the simplified model will be adjusted so that it correctly represents the magnitude of consequences produced by the full Bay-Delta models.

The Water Analysis Module will receive an explicit description of a levee breach sequence and produce the conditional probability distribution of consequences based on that sequence. As determined by the risk analysis framework, the probability distribution will be described by the mean and variance of each output. The variance of the consequences will be estimated based on uncertainty in both the decision model and hydrodynamics/water quality model. Sources of uncertainty include configuration data, initial conditions, and model parameters. Further information regarding uncertainty in the salinity response will be gathered by highly detailed three-dimensional simulation of select conditions. Because at least some of the outputs from the Water Analysis Module will be time series (water exports for example), an appropriate means of determining uncertainty of time series output (or each value of a time series) will have to be established.

2.0 OBJECTIVE

There are two general objectives for the Water Analysis Module corresponding to the risk analysis phase and the risk reduction phase of the study. During the risk analysis phase (first phase) the Water Analysis Module will be used to produce conditional probability distributions of water export disruptions and environmental conditions based on a wide range of explicit levee breach sequences for the current Delta configuration and generally accepted range of operating procedures. During the risk reduction phase (second phase) the Water Analysis Module will be used to evaluate proposed physical and operational alternatives designed to reduce consequences associated with levee breach events.

Specific objectives of the Water Analysis Module during the risk analysis phase include the following:

- To provide base case and selected scenario results as requested by technical teams that aid in development of their risk assessment modules (for example, providing water surface elevations from hydrodynamic simulation of specific storm events in the Delta to the flood hazard team.)
- To simulate the water management decisions related to levee breach incidents – in particular upstream reservoir releases, in-Delta uses, and exports.
- To simulate the hydrodynamic and water quality responses to levee breach incidents – in particular salinity, but also including information on other relevant variables (possibly temperature and dissolved or total organic carbon), as needed for input to the economic and environmental consequence modules.
- To establish simulation tools that will be useful in the second phase of the DRMS project to assess risk reduction options (such as installation and operation of barriers).
- To estimate uncertainty associated with each simulation output.

3.0 PHYSICAL SYSTEM/PROBLEM

3.1 Physical and Operational Issues Related to Delta Levee Breach Events

The Sacramento-San Joaquin Delta is a complex estuary that is carefully managed for fresh water conveyance, agricultural water use, and environmental quality. Management of the Delta involves balancing upstream reservoir releases with in-Delta water use and water exports, as well as operation of a variety of control structures such as the Delta Cross Channel. Levee breach events can have a dramatic and immediate impact on Delta water quality as high salinity water is drawn in from the seaward boundary to fill breached islands. Breach events can also have very important long term water quality impacts during the protracted repair and recovery process associated with multiple breach scenarios. Thus the time scale of the problem is on the order of months or years. The significance of economic and environmental consequences associated with a levee breach event depends upon the ability to compensate for the physical changes in the system by modifying management of the system. In some cases, there is sufficient management flexibility that economic and environmental consequences will be minimal. However, with multiple levee breaches it is probable that significant economic or environmental consequences will occur. The following is a listing of operational issues and physical processes related to Delta levee breach events.

- **Initial Flooding:** Breached islands fill with water from the neighboring channels, river inflows and high salinity water drawn from Suisun Bay and potentially San Pablo Bay. The salinity impact on the Delta of the initial flooding depends on the location and volume of the breached islands, the initial geometry and evolution of the breach, river inflow rate, and the salinity distribution in Suisun and San Pablo Bays. The breached islands initially fill with the neighboring channel water, and the channels are replenished with higher salinity water drawn from Suisun Bay and potentially San Pablo Bay. Therefore, salinity tends to be higher in Delta channels than flooded islands during the initial flooding phase.

- **Suspension of Exports:** At the time of the event, exports will be typically be suspended to inspect the facilities and to evaluate the salinity distribution in the Delta.
- **Flushing Releases:** If the initial flooding brings high salinity water into the western Delta, it may be important to flush the channels with additional reservoir releases before the high salinity water mixes into Franks Tract or the breached islands.
- **Gate Operations:** The operation of Delta Cross Channel and south Delta barriers will be considered and possibly changed to enhance effectiveness of flushing releases. Temporary south Delta Barriers may need to be removed.
- **Emergency Procedures:** If the initial flooding is severe, emergency procedures may be required such as modified operation of permanent operable gates (including the Delta Cross Channel and planned south Delta facilities) or placing additional temporary channel barriers.
- **Initial Tidal Mixing:** Following the initial flooding, the salinity distribution in the Delta will be far from equilibrium. The strong salinity gradients present following the initial flooding will gradually weaken over a period of weeks as a result of tidal mixing. The salinity distribution from the western Delta through Suisun Bay will move toward a new equilibrium determined by the Net Delta Outflow and tidal exchange that is now modified by the breached islands. During this period of initial tidal mixing, high salinity water in the channels mixes in and out of flooded islands, increasing the salinity in the islands. Due to strong horizontal salinity gradients during this period, Delta channels and flooded islands may become stratified.
- **Levee Repair:** As soon as possible following the event, levee breaches are capped to prevent widening. Then, based on the availability of materials, equipment, and personnel, breaches are repaired over a period of months to years depending on the number of breaches. Ideally, the breach closures should be prioritized to most effectively facilitate restoration of Delta exports, although other issues may override export water quality concerns. As levees are repaired, the active tidal prism in the Delta returns toward that of the original Delta configuration.
- **Secondary Failures:** Secondary levee failures may occur due to damage from the flood or seismic event, or due to wind induced wave action resulting from the large wind fetch over the surface of newly flooded islands. Secondary failures may flood additional islands drawing additional high salinity water into the Delta.
- **Reservoir Management:** Throughout the repair and recovery period reservoir release decisions will be based on managing the salinity in the Delta, providing for Delta exports if possible, meeting flood control requirements and providing for water users upstream of the Delta. Managing salinity in the Delta involves balancing Net Delta Outflow with tidal mixing to meet water quality standards in conjunction with operation of in Delta barriers. Tidal mixing will be strongly affected by the un-repaired breaches because they will allow exchange between flooded island and channels and alter the tidal currents in Delta channels.
- **Export Decision Making:** The ability to export water from the Delta for agricultural or municipal use is dependent on the quality of water. Salinity is a primary constituent of concern, although other constituents such as dissolved organic carbon,

trihalomethane precursors, or other toxic chemicals releases from newly flooded islands may limit the ability to export. With careful management it may be possible to export water before the breaches are completely repaired, perhaps at a limited rate. And if the repair period spans at least one high runoff period, there may be opportunities to intermittently export water.

- **DICU Management:** Diversions and returns associated with in-Delta agriculture (Delta Island Consumptive Use) are a very import component of the summer time water balance and strongly influence the Delta salinity distribution due to the high salinity of return flows. Depending on the severity of a levee breach scenario, DICU may be eliminated or curtailed during the repair and recovery period.
- **Channel Scour:** The increased tidal prism associated with breached islands may increase channel flows sufficiently to cause deepening due to scour. This may affect tidal mixing and thereby change the Net Delta Outflow required to maintain a given salinity distribution.
- **Island Pump Out:** Once levee repairs are complete on an island, water from the island is pumped back into the adjacent Delta channels. The pump flow will have a small effect on the overall water balance, but may have a significant impact on Delta water quality.
- **Salt Transport:** Salt transport in the system is a function of tidal flows through the complex network of interconnected Delta channels and flooded islands as well as the net flows determined by tributary inflows, in-Delta consumptive use, and Delta exports. Newly breached islands add tidal prism to the Delta, increasing tidal flow between the flooded islands and the seaward boundary. This increased tidal flow leads to increased dissipation of tidal energy and damping of tidal range through out the system, reducing tidal flow landward of the flooded islands. These changes in tidal flow affect the salt flux from Suisun Bay into the western Delta and mixing within the Delta. In addition, levee breaches will alter the path of tributary flows take through the Delta. Changes in tidal flows and residual flows in the Delta channels will alter the Net Delta Outflow required to maintain water quality standards in the Delta.
- **Other Water Quality Issues:** In addition to changes in salinity, island flooding may impact other water quality parameters important to economic and environmental consequence analysis such as temperature, dissolved or total organic carbon, dissolved oxygen, and toxic contaminants. Heating of shallow breached islands and exchange between these islands and adjacent channels act to generally increase the temperature of the Delta, although it is not clear that this will be a significant issue. Newly flooded islands may act as sources of carbon and trihalomethane precursors. If there were spills of toxic contaminants on the islands prior to or associated with the breach event, these materials may be introduced into the Delta channels. Flows patterns in the Delta during and subsequent to flooding events may adversely impact important fish species.

3.2 Evaluating Hydrodynamic and Water Quality Consequences

Simulating tidal hydrodynamics and salinity in the Delta is challenging due to the complex branching channel structure of the Delta, strong tidal flows and exchange with Suisun Bay, variable tributary flows and complex operations. Accurate representation of the geometry and bathymetry of Delta channels, junctions, flooded islands, marsh areas, and structures is one essential step in achieving accurate predictions. Models also require a large number of boundary condition data describing salinity and tidal conditions at the seaward boundary, freshwater inflows, diversions, wind velocities, precipitation, and evaporation. Hydrodynamic processes in the Delta are complex with large spatial variability in salinity, current speeds, tidal amplitude and phase, and residual flow direction and magnitude. Furthermore, these quantities vary in time over the spring-neap cycle and with tributary flows. In addition to the spatial variability along and between channels, Suisun Bay and the western Delta are often stratified during conditions with significant salinity in the Delta, which are the conditions of interest in the DRMS study.

During and following any levee failure sequence, hydrodynamic conditions in the Delta will change, primarily as a result of tidal exchange between the channels and flooded islands. Flooded islands with multiple breach locations will also introduce new flow paths for tidally-averaged flows. Changes in tidal and tidally-averaged flow magnitude in any one channel will affect neighboring channels.

The changes in Delta hydrodynamics may greatly influence salinity in the Delta. Due to initial filling of flooded island and increased tidal exchange between islands and channels, the salinity of the Delta will increase, probably leading to stratified conditions in some channels and flooded islands. Changes in tidally-averaged flows in each channel will also affect salinity. In some channels the seaward flow magnitudes will decrease leading to decreased ability to flush salt from these channels. Increased tidal prism will affect the tidal excursion leading to potentially significant impacts on dispersion.

The hydrodynamics and transport mechanisms in the Delta are further complicated by the evolution of bathymetry resulting from increased tidal prism near (seaward of) levee breaches. As channels deepen and, possibly, widen to reach equilibrium with the increased tidal prism, the tendency for salt to mix into the Delta will increase because tidally-averaged velocities will decrease in inverse proportion to the increase in channel area, leading to decreased flushing of salt from the Delta by tributary flows. Deeper channels are also much more likely to become stratified because bottom friction is less effective in mixing deeper water columns leading to increased gravitational circulation. For the same reasons sea level rise is likely to increase salinity and stratification in the Delta. Monismith et al. (2002) indicate that moderate increases in water depth may lead to quite large increases in salinity and stratification.

In addition to salinity, other water quality parameters important to environmental quality and the ability to export may be impacted by levee breach events. These include water temperature, dissolved or total organic carbon, dissolved oxygen, trihalomethane precursors, and other toxic chemicals.

Water temperature in the Delta is a function of tributary inflow temperature, San Francisco Bay temperature, and heat exchange throughout the system. Tributary inflow temperatures tend to be at or near equilibrium with atmospheric temperature while Bay temperatures are much cooler, creating a temperature gradient across the Delta. Some areas of the Delta, such as the Stockton Ship Channel and Mildred Island (which is flooded), experience intermittent temperature stratification. Islands flooded by breach events may collect solar energy and provide additional sources of warm water to Delta channels through tidal exchange. Since much of the Delta is already near equilibrium temperature, it is not clear that this will be a significant effect. The temperature regime within the flooded islands will, however, have an important impact on biological activity which affects the production of organic carbon.

Changes in the availability of organic carbon in the Delta may have both environmental and water supply consequences. Organic carbon is important to maintenance of the Delta food chain, however, excessive concentrations may lead to low dissolved oxygen conditions and restrict water exports. Production of organic carbon in newly flooded islands may result from biological activity in the water column and in the bed, and tidal exchange will carry the material into the Delta channels.

Dissolved oxygen in the water column is influenced by water temperature, reaeration at the water surface, transport processes and chemical and biological activity in the water column and bed. Modeling dissolved oxygen concentrations requires adequate representation of the complex processes of primary productivity and decay of organic matter. Salinity or temperature stratification also plays an important role by restricting vertical mixing and thereby limiting reaeration, which can lead to very low dissolved oxygen concentrations in the lower portion of the water column. Stratification can also decrease turbidity near the surface and reduce benthic grazing of phytoplankton, potentially leading to phytoplankton blooms.

Newly flooded islands may also act as a source for trihalomethane precursors and other toxic contaminants. Toxic contaminants such as solvents or fuels may be present in Delta soils from previous spills or dumping, or may be introduced during the flood event if storage tanks are damaged.

3.3 Challenges in Performing the Risk Assessment

Evaluation of hydrodynamic and water quality consequences within the risk analysis framework presents significant challenges including

- Linking the water management decision model with water quality simulation
- Developing an appropriate and defensible approach to evaluating hydrodynamic, salinity, and other water quality impacts of the full range of levee breach sequences
- Evaluating uncertainty
- Developing a good estimate of Delta Island topography

Many physical and operational issues associated with levee breach events are reasonably well represented with existing simulation modeling tools. However, a model that includes coupling between water quality and emergency management (reservoir releases, exports, and gate/barrier operations) has not yet been developed. Further, the tools available for fully dynamic simulation of flow and salt transport during multiple levee breach events are complex and numerically intensive models so it is not possible to use them directly to evaluate hundreds, let alone thousands of breach sequences.

To meet the needs of the Risk Analysis (Phase 1) component of the DRMS study, a tool must be developed that couples water management decision making with a reasonable and defensible simplified model of hydrodynamics and salt transport in the Delta that allows rapid estimates of water quality consequences. This new tool, the Water Management Module of the Risk Analysis Framework, is envisioned to be similar in function to CALSIM and the DWR Artificial Neural Network (ANN) but with specialized logic for managing levee breach emergencies. The simplified model discussed in the following sections of this paper provides a function within the Water Analysis Module that is equivalent to the ANN. The ANN itself cannot be used within the Water Management Module because it is trained on model results for the existing Delta configuration. Retraining the ANN for emergency response/repair/recovery simulation, if possible, would require retraining with fully dynamic flow and salinity simulations of many if not all possible breach scenarios. It is important to note that Phase 2 of the DRMS project, which addresses issues of risk reduction, will rely on detailed simulations with fully dynamic models of the Bay-Delta System and not the simplified model to performed detailed analysis of specific emergency management procedures.

It is not feasible to develop a simplified numerical tool for water quality constituents other than salinity within the time constraints of the DRMS project. It will therefore be necessary to estimate the consequences of specific breach events from a small set of representative simulations. Further, “production quality” numerical models do not yet exist for all of the water quality constituents of interest. Numerical models suitable for simulation of temperature in the full Delta exist and can be used in the DRMS project, although consideration of temperature stratification could only be considered in select regions with numerically intensive 3D models. Detailed simulation of organic carbon, primary productivity for dissolved oxygen analysis, or complex constituent relations related to the fate and transport of toxic chemicals represent areas of active research in the system and are subject to significant uncertainty. For these constituents the DRMS project may rely on simulation of surrogate consequence measures such as residence time and/or transport of simple conservative or non-conservative constituents added to the system via source rates in flooded islands.

As discussed above, the water management and hydrodynamic/water quality response to levee breach sequences evolves over time, necessitating a simulation approach as opposed to a static evaluation of impacts. While the final outputs of the entire risk analysis may be distilled down to probability distributions for single values such as dollar damages or an environmental habitat index, the Water Analysis Module will need to receive time series input and generate conditional probability distributions of time series output. The primary inputs to the Water Analysis Module are the levee breach, repair, and pump-out schedules. Also critical to the Water Analysis Module is the hydrology during the repair/recovery period, which describes the time history of inflows to reservoirs upstream of the Delta and tributary flows directly entering the Delta.

There are multiple, and in some cases, time dependent outputs that should be passed to the economic and environmental consequence modules. In particular, it is very likely that many breach sequences will reduce the ability to export water at intermittent periods during the repair and recovery period rather than completely preventing exports. In this situation reporting a single value probability distribution for time of export disruption is a very poor estimate of the water supply consequences of the event. Therefore, it will be necessary to compute and pass on to the economic module a time series of exports during the repair/recovery period.

Perhaps the most important physical data influencing the impact of initial flooding is the Delta Island topography, which determines the flood volume. The data currently available is not believed to adequately represent current conditions, with errors potentially on the order of five to ten feet vertically.

4.0 APPROACH

This section describes the approach to simulating hydrodynamic and water quality consequences within the Water Analysis Module of the Risk Analysis Framework for the Phase 1-Risk Analysis of the DRMS project. This document describes only those tasks associated with the hydrodynamic and water quality analysis of the Water Analysis Module. A more complete description of the module logic is presented in the overall Water Analysis Module technical paper. The Risk Analysis Framework and other modules of the DRMS Risk Analysis are also described in separate technical papers.

There are several existing mechanistic numerical models of the Bay-Delta system capable of simulating the dynamics related to levee breach events (RMA Bay-Delta Model, TRIM and UnTRIM models, DSM2 and others). However, because many thousands of potential levee breach events must be considered, it is not practicable to use the existing models of the Bay-Delta system directly within the full risk analysis due to their computational expense. There are also parametric models developed to represent the behavior of the existing Delta system that compute very rapidly, but these models are limited in there applicability to the existing Delta configuration for which they were calibrated (Delta Artificial Neural Network, G-Model). It is therefore proposed:

1. To utilize existing physically based numerical models of the system to explicitly evaluate hydrodynamic, salinity, and other water quality impacts of a limited number of specific breach events as well as to characterize the dynamics of the system, and
2. To create a new numerical tool to rapidly evaluate salinity impacts of levee breach events and interact with the water management decision-making component of the Water Analysis Module.

4.1 Multi-Dimensional Simulations of Select Levee Breach Events

The RMA Bay-Delta model has previously been used to simulate the Jones Tract levee failure in 2004 and, through the Preliminary Delta Levee Seismic Risk Assessment Project, 1-, 3-, 10-, 30-, and 50-breach cases. These flow, stage, and salinity results will act as a resource for early estimation of consequences and will be made available to other Risk Analysis Teams as needed.

New simulations of specific events may be performed as required for the Flood Hazard Team to evaluate water surface elevations and shear velocities in the Delta during high flow and/or high tide events. Flood event simulations are likely to span several days to a few weeks.

The Environmental Consequences Team has expressed a need for simulating the impact of levee breach events on residence time, water temperature, and possibly other water quality constituents in addition to salinity. Only salinity will be simulated in the Water Analysis Module; impacts on other constituents will be addressed by a limited number of simulations with the full RMA Bay-Delta Model.

- A methodology for evaluation of residence time in flooded islands from RMA hydrodynamic simulations was developed as part of the CBDA Flooded Islands Study. This methodology can be conveniently applied to islands flooded through levee breaches.
- The RMA Bay-Delta Model is currently being configured for simulation of water temperature and a simple representation of organic carbon with funding from DWR as part of on going evaluation of Franks Tract, Through Delta Facility, and Delta Cross Channel studies.
- The RMA modeling suite has been used successfully for simulation of water temperature in other estuaries (Upper Newport Bay for example), and no difficulties are anticipated in configuring the temperature simulation capability for the Delta. It is expected that the temperature simulation capability will be functional in September.
- The approach that will be used for organic carbon simulations is not yet defined. For the purposes of the DRMS Environmental Consequences Team, simulations of organic carbon may be limited to considering island sources as conservative or first order constituents.

The details of specific modeling tasks will be developed with the Environmental Consequences Team. The preliminary breach case hydrodynamic results provide convenient data sets with which new temperature, residence time, or tracer simulations may be performed. If necessary, new hydrodynamic simulations can be performed for additional breach cases.

4.2 Development of a Simplified Hydrodynamic/Water Quality Consequence Model

The primary challenge in developing a simplified hydrodynamic/water quality model is representing enough of the physics to provide sufficient accuracy while maintaining the computational speed needed to simulate many thousands of levee breach events. The primary outputs of the Water Analysis Module will be monthly average quantities including export volumes and salinity, and in-Delta salinity at selected locations. As such, it is not necessary for the simplified model to explicitly represent the tidal flow and transport. It is proposed to create a tidally-averaged transport model that utilizes net flow and tidal mixing (tidal dispersion and turbulent diffusion) relations derived from full dynamic models of the system. The simplified model must also be able to interact with the water management component of the Water Analysis Module during the course of simulation, both providing input to the water management decision making component and receiving calculated for inflows and exports.

Water Analysis Module Design

The Water Analysis Module receives the breach and repair schedule as input, and predicts monthly average export volumes, monthly averaged salinity at key Delta locations, end of period reservoir storages, and other summary information. The module will operate on a weekly to monthly time step, with shorter period sub-steps for periods of island flooding and short-term flushing releases.

The overall logic flow for the Water Analysis Module is show in Figure 2.

- At initiation, information is gathered from base data sets to fully describe the initial state of the Delta and all upstream reservoirs and the hydrology for the simulation period.
- At initiation and at the beginning of every simulation time interval the model will update the levee breach state as defined in the levee breach event specification.
- If new islands are flooded, the model simulates immediate emergency operations and the evolution of the salinity distribution for the number of days it takes to fill the islands.
- When islands have filled the model will determine if flushing releases are needed based on Delta salinity criteria. If flushing releases are needed, the water management component estimates releases based on water availability. The model then simulates the evolution of the Delta salinity distribution for the number of days that flushing releases occur.
- Delta Island Consumptive Use (DICU), which includes both diversions and returns, are estimated based on the Delta salinity distribution and island breach state. If an island is flooded, consumptive use is set to an estimate of evaporation from the island. If an island is not flooded, but salinity in the neighboring channels is to high to allow agricultural use, then channel withdrawals and returns are stopped.
- The ability to pump based on salinity criteria and pump damage is evaluated and the required relationship between net Delta outflow, inflows, and exports is determined (see below for more description).
- The water management component of the Water Analysis Module makes reservoir release and export decisions for the remainder of the time step and updates the reservoir storage accounting. These decisions take into account the required relationship between net Delta outflow, Delta inflows, and exports determined in the previous step. This is similar to the way the CALSIM model utilizes information generated by the DWR Artificial Neural Network model.
- The hydrodynamic/water quality component simulates salt transport over the remainder of the time step and updates the salinity distribution. Exports may be constrained if salinity criteria are not met.
- If system is recovered the simulation is complete, otherwise the module begins the next time step. The definition of system recovery is not yet fully determined, although it will most likely be when the upstream reservoirs have returned to normal operation and the Delta has returned to a state where normal export pumping can occur. Additional consideration may need to be given to recovery of South-of-Delta surface and groundwater storage and farmland salt balances.

Because the salinity state following the initial flooding event may have an impact on island repair priority, the initial flooding analysis of the Water Analysis Module may be run before the Levee Emergency Response and Repair Module. In this case it will be the

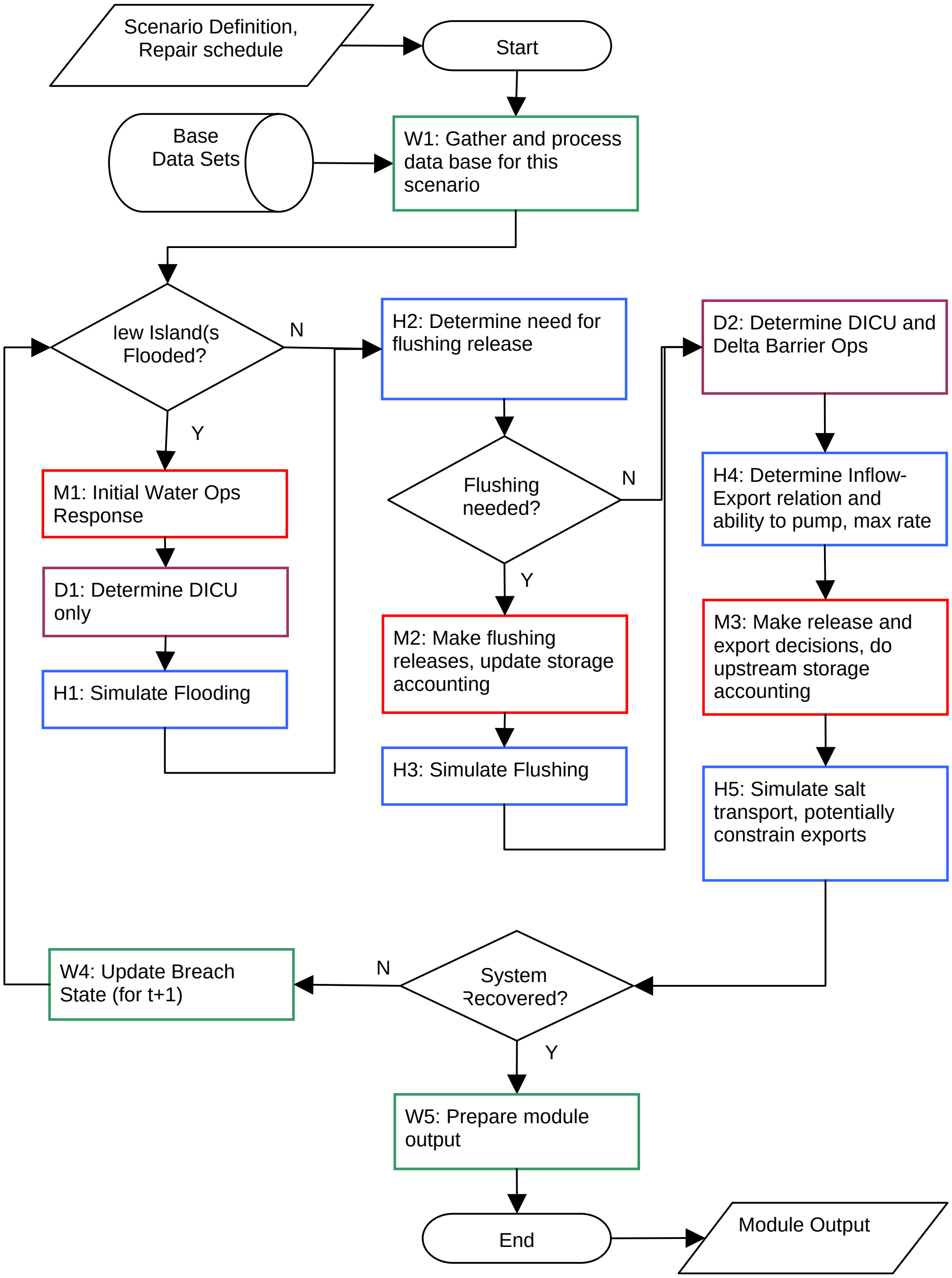

Figure 2: Water Analysis Module Basic Logic Flow Chart. Simplified Hydrodynamic/Water Quality Model Is Responsible for Steps H1, H2, H3, H4, and H5.

responsibility of the Water Analysis Module to recommend the repair priority based on salinity concerns. The Levee Emergency Response and Repair Module will consider the recommendation along with other criteria in determining the final response and repair schedule.

Hydrodynamic/Water Quality Simulation Tasks Within the Water Analysis Module
In the Water Analysis Module flow chart the simplified hydrodynamic/water quality model contributes to five of the tasks. Input and output data for each of these tasks are summarized in Table 1.

H1: Simulate island flooding – the model must simulate the impact of island flooding on the salinity distribution in the Delta. This impact is primarily a function of the island volume filled. While the time required to fill the islands is an important consideration, it is probably sufficient to derive an estimated time based on the 1-, 3-, 10-, 30-, and 50-breach events. Given the time to fill estimate, net flow rates can be determined for each island that is flooding. Using the estimated flows to fill the islands along with the initial salinity distribution, Delta inflow, Cross Channel gate status, and pumping status, the simplified model will be used to determine the salinity distribution when the islands have filled.

H2: Estimate volume required to flush high salinity water from the Sacramento and San Joaquin Rivers in the central Delta – If island flooding leads to a salinity distribution in the central Delta that precludes exports, then a flushing volume in addition to expected Delta inflows will be estimated to push the salt gradient seaward. An estimate of the flushing volume may be developed based on the volume of water in the main channels that must be displaced to move the salinity gradient seaward the required distance plus the flow over the flushing period required to compensate for the tidally-averaged dispersive flux tending to transport salt landward. The release rate for flushing will be determined by the reservoir operation component of the Water Analysis Module. When flushing of the Delta is required, the Delta Cross Channel should be open unless it must be kept closed due to regulatory constraints.

H3: Simulate salt transport during flushing period – Simulation of salt transport will consider Delta inflow, exports (if any), and DICU flows as well as net salt flux in/out of breached islands.

H4: Estimate relationship between net Delta Outflow, inflows and exports required to salinity standards and determine the ability to pump – The ability to pump will be controlled by Delta salinity and pump damage. Conditions that will constrain pumping include the following:

- A pump has suffered damage due to seismic activity or flooding,
- Salinity standards in the central Delta are exceeded such that export pumping will draw salt into the south Delta where it is difficult to flush,
- The net salt flux out of flooded islands along the conveyance corridors is sufficient to drive the salinity of exported water above standards, or
- The salinity in channels south of the San Joaquin River is too high for south of Delta water users to accept.

Table 1
Water Analysis Module (WAM) Computational Processes (Simple Hydrodynamics/Water Quality Model Component)

Process	Description	Input	Output
H1	Simulate impact of island flooding on salinity distribution. The simulation period will be determined by the time required to fill the breached islands.	Levee breach state DICU, Inflow, Exports Control Structure Operation (DCC) Salinity Distribution	Salinity distribution at time when all breached islands have filled. Requested changes in Water Operations (pumps, gates, releases)
H2	Determine need for adjusted flushing releases (after flooding) with the intention of reducing salinity in central Delta to make pumping possible. It is expected that the volume required to flush the Delta will be a function of the release flow rate	Levee breach state DICU Salinity Distribution	Request for flushing release as a Flow-Volume function
H3	Simulate salinity response to flushing releases. The period of simulation will be determined by the reservoir management flushing release decision	Levee breach state DICU, Inflow, Exports Control Structure Operation (DCC) Salinity Distribution	Salinity distribution at end of flushing period
H4	Determine Inflow-Export relation and ability to pump based on the predicted salinity distribution and damage to pumps	Levee breach state Salinity Distribution WQ Standards Pump damage state	Inflow-Export function (determines required net Delta outflow) Ability to pump at each export location
H5	Simulate salinity and potentially constrain exports if WQ standards are not met	Levee breach state DICU, Inflow, Exports Control Structure Operation (DCC) Salinity Distribution	Salinity distribution at end of time period Actual export volume from each location

If the salinity in south Delta channels is above standards, but pumping is allowable by the other criteria, it may be permissible to begin exports in an effort to flush the south Delta. This is only allowable if the salt load in the south Delta channels can be accepted by south of Delta water users.

The model must also estimate the relationship between net Delta Outflow, inflows and exports required to keep salinity low enough in the central Delta so that exports are possible, which will vary depending on the number and location of breached islands. In general, tidal mixing (dispersion) will increase with the number (area) of islands that are actively filling and draining. Therefore, each additional levee breach will likely result in a greater need for net Delta outflow to counteract tidal mixing of salt into the Delta.

H5: Simulate salt transport - Simulation of salt transport will consider Delta inflow, net Delta outflow, exports (if any), and DICU flows as well as net salt flux in/out of breached islands and pump out of flooded islands that have been repaired. If salinity standards at the pumps are exceeded, exports may be curtailed.

“Straw Man” Simplified Model Configuration

The simplified model is conceived as a tidally-averaged advection–diffusion model with net flow and tidal dispersion properties derived from the multi-dimensional models. The simplified model configuration should contain enough spatial resolution to reasonably represent salinity variability in the system. It must also represent key control structures (including the Delta Cross Channel), aggregate DICU locations, and all Delta islands with breaches.

To compute salinity at the export locations in the south Delta, the simplified model must represent the transport of fresh water from north to south through the Delta, across the San Joaquin River. The most basic model configuration to accomplish this would include the primary flow axis from the Golden Gate/Central Bay up through the north Bay and Suisun Bay up through the San Joaquin River to Vernalis. The model would also include the Delta flow corridors from the north that bring fresh water to the San Joaquin River and flow corridors to the south that bring water to the pumps.

A conceptual schematic for the simplified model is show in Figure 3. The primary flow axis runs from the Golden Gate up the San Joaquin River to Vernalis. It is not certain at this time whether stratification will need to be explicitly considered within the simple model. If possible, it is preferable to parameterize the effects of stratification on salt transport based on information derived from the TRIM or UnTRIM multi-dimensional models. If necessary, the simple model might utilize a layered formulation like the Uncles-Peterson model.

Flow corridors from the north include the Sacramento and Mokelumne Rivers. The Delta Cross Channel moves flow from the Sacramento to the Mokelumne. Three Mile Slough splits some of the Sacramento flow and Potato Slough/Little Connection Slough splits some of the Mokelumne flow. Conveyance of all other channels north of the San Joaquin are included as part of the principal channels. For example, flow in Georgiana Slough is effectively included in Mokelumne flow.

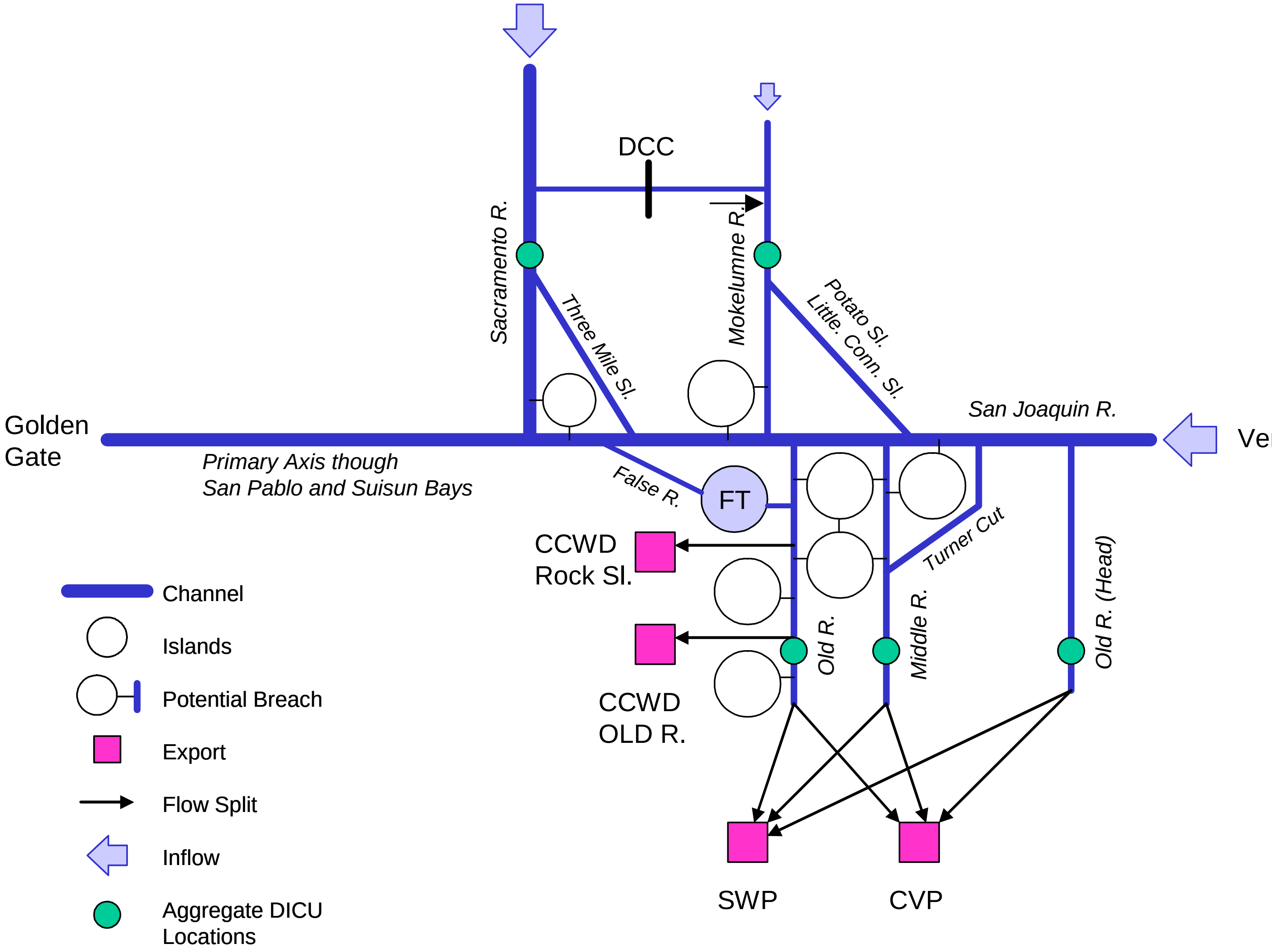

Figure 3: Simplified Model Concept Schematic (only example islands shown)

Flow corridors south of the San Joaquin include Old River, Middle River, and Old River at Head. Turner Cut brings additional flow to Middle River from a point farther upstream on the San Joaquin. The complex channel connections in the south Delta and south Delta barriers are not included explicitly. To determine salinity at the pumps, flow splits will be evaluated from the multi-dimensional models and the quality of exports will be derived from the quality of the three primary flow corridors – Old River (northern section adjacent to Franks Tract), Middle River, and Old River at Head. If this approach proves to be unsatisfactory, then the configuration can be extended to connect the Old River, Middle River, and Old River at Heat and add at least Grant Line Canal.

Five aggregate DICU locations will be considered, one on each of the principal flow corridors north and south of the San Joaquin River.

All of the islands considered in the risk analysis will be included (only examples are shown in Figure 3). Because the model will be operated with tidally-averaged flows, exchange with islands and channels through breaches will have to be analyzed with the multi-dimensional models and exchange estimates given to the simplified model so that salt flux can be determined. Because islands might breach on more than one levee creating short circuits among existing delta channels, the net flow through islands will also be estimated from the multi-dimensional models. In the simplified model, Franks Tract is treated in the same manner as other islands except that it is always flooded.

To test the simplified model concept, an approximate one dimensional representation of Suisun Bay and the Delta was constructed as shown in Figure 4. The model grid and associated bathymetry (cross-sectional geometry) were used to develop a 1-dimensional RMA finite element model (the RMA finite element modeling framework is a generalized tool for simulation of surface water systems, the RMA Bay-Delta model is a specific application of the RMA finite element modeling system for the San Francisco Bay /Sacramento-San Joaquin Delta). The conceptual test model uses 1 km elements with very approximate cross-sectional geometry for each cross section. Salinity was simulated for calendar year 2003 using approximate Net flows taken from the 2003 Delta simulation by the full RMA Delta model. Dispersion coefficients were coarsely tuned by trial and error to match salinity gradient predicted by the full model from Martinez to Vernalis along the San Joaquin River. Dispersion coefficients for the test simulation varied in space but not in time. Figures 5 and 6 show the tidally-averaged salinity distributions calculated by the simple and full models for September 18, 2003. As a concept test the results are very encouraging. The simplified model took approximately 6 seconds to simulate one year. Although, the simulation time will likely increase as island components are added, the execution time is certainly appropriate for use within the Water Analysis Module.

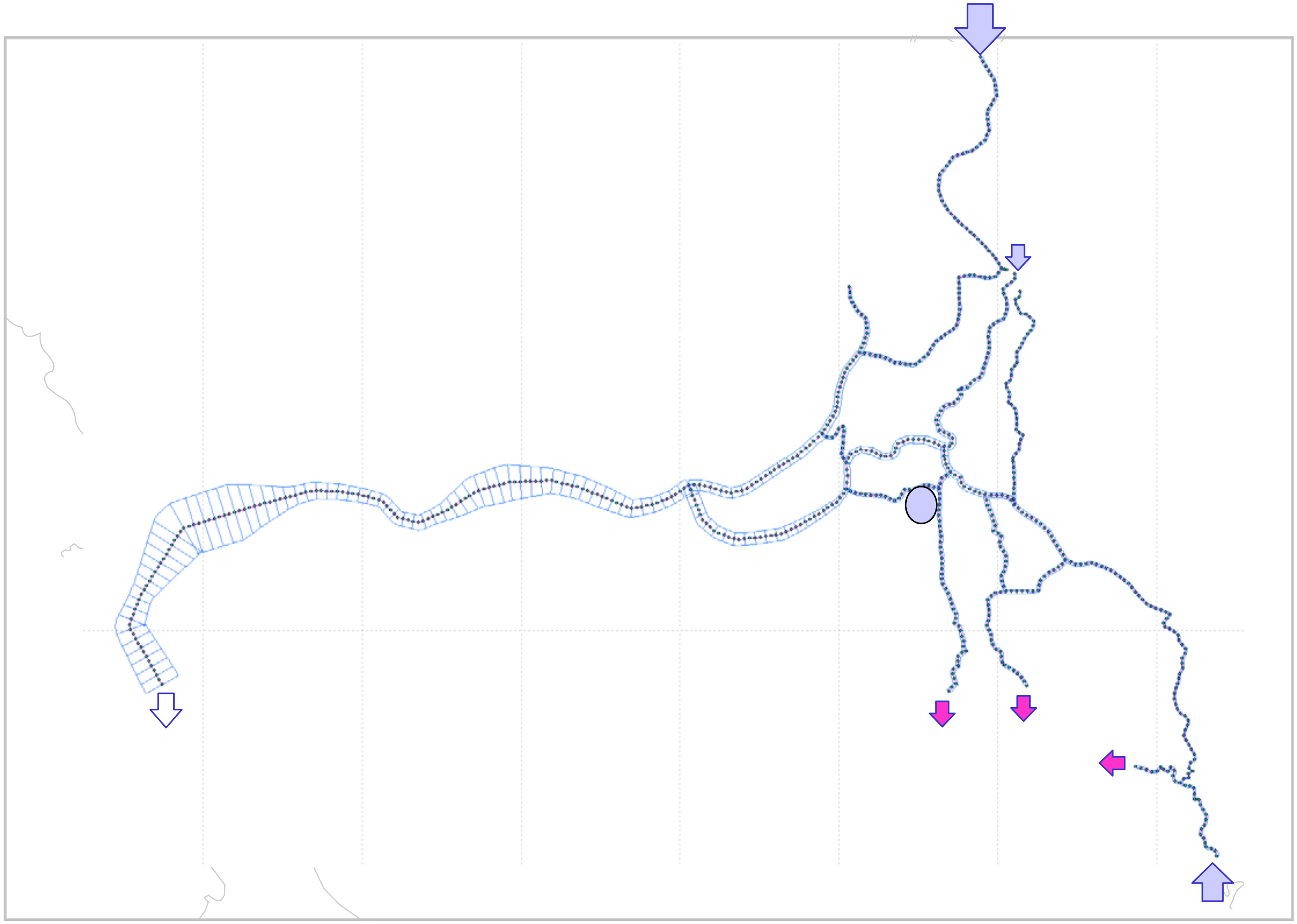

Figure 4: Simplified Model "Concept Test" Configuration: 1-Dimensional RMA Finite Element Model.

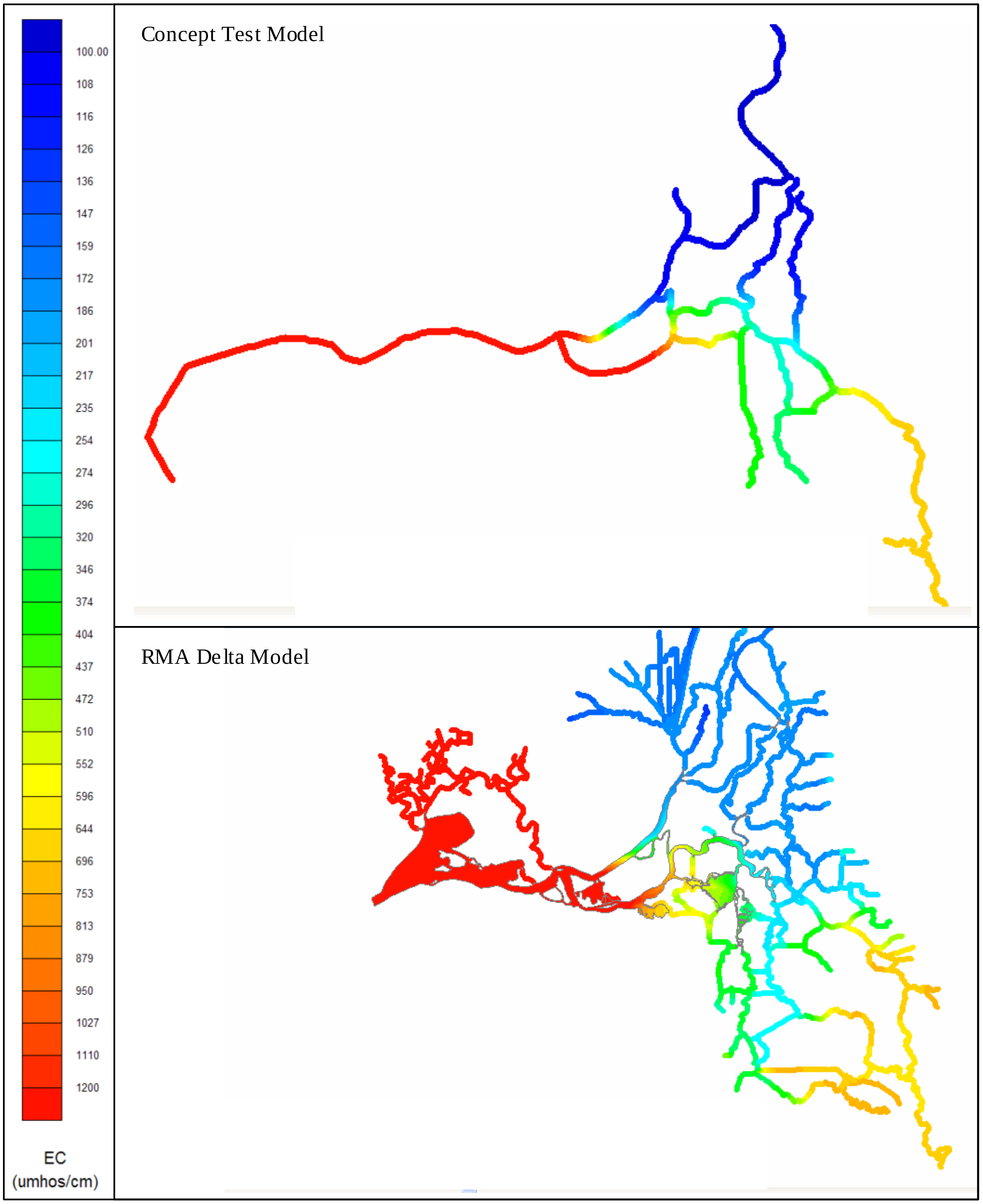

Figure 5: Comparison of Concept Test Model and RMA Delta Model: EC contours, Simulation Date: 9/18/2003

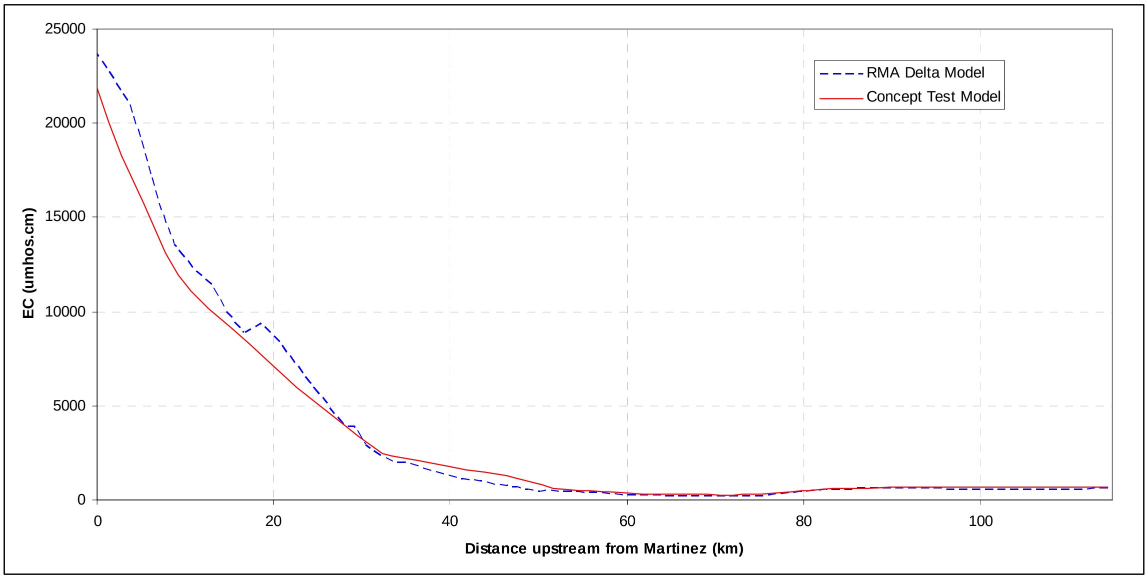

Figure 6: Comparison of Concept Test Model and RMA Delta Model: EC Profile Along San Joaquin River Upstream from Martinez Toward Vernalis, Simulation Date: 9/18/2003.

4.3 Representation of Transport Processes

Key aspects of the simplified model include the following.

- The geometry must have the appropriate volume and conveyance area.
- Net flows must be distributed appropriately across the channel network.
- Tidally-averaged mixing coefficients must be representative of the dynamic tidal flows and may need to be sensitive to salinity gradients.
- Net salt flux between Delta channels and flooded islands must account for daily tidal exchange and horizontal variability in salinity within the islands. The horizontal salinity gradient may or may not be explicitly represented in the simplified model. The flooded island representation must also allow net flow through the flooded islands when multiple breaches are present.
- Net flow distribution and mixing coefficients will be functions of the number and location of levee breaches.

Configuration and calibration of the simplified model will be based on existing multi-dimensional models of the system, specifically the RMA Bay-Delta and UnTRIM models.

The primary geometry will be derived from the RMA Bay-Delta model. The simplified model will not explicitly represent all Delta channels, so some channels will represent aggregate cross sections designed to represent the total volume and conveyance area of multiple channels.

Distribution of net flows, including flow splits to export locations, and tidally-averaged mixing coefficients will be derived from short-term hydrodynamic simulations with the RMA Bay-Delta model.

Direct simulation of net flows in the Delta without simulating tidal flows will not yield the correct flow distribution because the geometry of the system and resulting propagation of the tides favors some channels on flood flows and others on ebb flows. The most direct means of determining the net flows is by tidally averaging the tidal flows. The net flow distribution will be a function of boundary flows, control structure operation, and breach event. While it will not be possible to simulate every possible combination of breaches with the full Bay-Delta model, the net flow distribution should vary smoothly as boundary flows change for a given configuration so that it is possible to interpolate between net flow distributions for representative conditions.

Tidal mixing in the Delta is largely a function of tidal excursion and the splitting and rejoining of flows in the channel network. Particle tracking provides an appropriate methodology for estimating mixing in the system. At representative channel cross sections throughout the system sets of particles can be released at a regular interval during the tidal day. Particles will move with the mean velocity predicted by the hydrodynamic model plus a random variation based on the dispersion coefficients utilized by the RMA Bay-Delta salt transport model. After each set of particles has traveled for one tidal day, positions of the particles will be evaluated to determine the spread of the particle plume. The spread for all sets of particles released at a cross section will be used to determine the longitudinal (along-axis) net dispersion coefficient for the associated reach in the simplified model. The particle distribution derived from the full model will be mapped onto the 1-D geometry of the simplified model and the along-axis dispersion coefficients will be derived from the mapped particle distribution. This methodology will be tested by simulating salinity with dispersion coefficients derived for historic (or existing) Delta geometry. The salinity predictions will be compared with salinity observations for a period spanning a large range of Delta outflow.

A database of net flow and net tidal dispersion estimates will be developed using short term RMA Bay-Delta hydrodynamic simulations for a range of conditions. The database of simulations will include all individual island breach conditions and representative groupings for multiple breach conditions. Each breach condition will be run for several inflow and export flow states. A lookup/interpolation strategy will be developed to determine net flow and tidal mixing estimates for each specific condition required during the risk analysis. For this purpose, a repeating 19-year mean tide will be used (spring-neap variations will not be directly simulated). Each condition will be held constant in the model for five to seven days and the final simulation day for each condition will be used to derive the net flow distribution and dispersion parameters. Unlike the long-term evolution of salinity gradients, the hydrodynamic response in the Delta to changes in tide, boundary flows, and geometric configuration equilibrates relatively rapidly. “Spin-up” of the hydrodynamic model from a flat water surface typically requires less than seven days of simulated time, whereas the “spin-up” of the salinity distribution from a state far from equilibrium can take many months to a year or more. While this approach will require significant computational effort, limiting the hydrodynamic simulations to five to seven days per condition makes the effort feasible in the time frame of the DRMS study. Because the distribution of flows averaged over a mean tide may be different than flows averaged over a spring-neap cycle or longer periods, the sensitivity of estimated net flows to averaging period may be explored. In addition, particle tracking may be performed at different points in a spring-neap cycle to examine sensitivity of estimated dispersion coefficients to tidal conditions.

To support this effort the RMA Bay-Delta model used for the 50-breach event will be modified to include all islands and breach sites to be considered in the risk analysis.

The dispersion coefficients used by the simplified model should parameterize all processes that result in landward transport of salt. Several of these processes can be resolved by a depth-averaged model, while others are inherently three-dimensional. While the simplified model uses dispersion coefficients to represent all dispersive transport processes, the dispersion coefficients used by RMA, which we will refer to as “3D dispersion coefficients,” should parameterize unresolved processes including “three-dimensional processes”, sub-grid scale processes and turbulent mixing. These unresolved transport processes are relatively unimportant in some regions but quite important in other regions depending on local geometry/bathymetry, salinity gradients and other factors. One three-dimensional salt transport process is gravitational circulation, which is believed to be substantial in Carquinez Strait, Suisun Bay and may occasionally be substantial in the western Delta when strong salinity gradients are present. In order to estimate dispersion coefficients that also account for gravitational circulation, different approaches may be taken.

In order to estimate these “3D dispersion coefficients” multiple approaches will be explored including idealized three-dimensional simulations, analysis of existing (three-dimensional simulation results, analysis of field observations and analytical expressions which relate dispersion coefficients to salinity gradients and water depth. The goal of this analysis is to define a function or “lookup table” that can be used to estimate 3D dispersion coefficients as a function of salinity gradient and water column depth. The UnTRIM model will be used to perform select three-dimensional simulations of the systems to estimate the effect of gravitational circulation on salinity predictions.

An alternative approach that we may follow is to parameterize the landward salt transport caused by gravitational circulation using “3D dispersion coefficients” in the particle tracking method (“random walk” coefficients). Therefore, the dispersion coefficients calculated in the particle tracking would be aggregate dispersion coefficients that should roughly account for all dispersion mechanisms including gravitational circulation. However, these dispersion coefficients might not apply to unusual salinity conditions because they would not vary as the predicted salinity gradients vary in the simplified model.

4.4 Calibration/Verification of the Simplified Model

Because the purpose of the simplified model is to simulate a wide range of levee breach events for which there are no observed data, the primary source of calibration/verification information will be the RMA Bay-Delta Model. The 1-, 3-, 10-, 30, and 50-breach simulated events and Jones Tract levee failure in 2004 will be used for initial comparisons. For the base (no-breach) event, however, the simplified model will be compared directly to historic data for the period of 1991 thorough 2005.

It is expected that initial runs of the Risk Analysis Framework will identify important breach events that were not explicitly simulated using the RMA Bay-Delta Model. These events may be important either due to particularly high probability of occurrence, or due to potentially high damages. To validate the results of the simplified hydrodynamic/water quality model, important “bookend” cases will be simulated with the RMA Bay-Delta Model. In this way the simplified model embedded in the Water Analysis Module acts as a screening tool to assist in identifying the levee breach events that warrant fully dynamic simulation.

5.0 ENGINEERING/SCIENTIFIC MODELS

The primary existing models of the San Francisco Bay-Delta System that will be used in the DRMS project are the RMA Bay-Delta Model and the Trim and UnTrim 3D models. Other existing models that may be used for supporting data or conceptual references include DWR DSM2, DWR ANN, the Uncles-Peterson model, and the G-Model.

5.1 Detailed Simulation Models with Full Tidal Dynamics

RMA Bay-Delta Model

Resource Management Associates (RMA) has developed and maintains a comprehensive numerical model representing the Bay-Delta system from its tidal boundary seaward of the Golden Gate to the limits of tidal influence on the Sacramento and San Joaquin rivers. The model includes all of the major features of the system including tributary streams, rivers, channels and facilities of the north and south Delta, as well as the entire San Francisco Bay, including areas such as the Coyote Creek, Alviso Slough, Lower Guadalupe River, Guadalupe Slough, San Clemente Creek, Petaluma River, Napa River, Napa-Sonoma channel system, Montezuma Slough, and Suisun Marsh channels.

The RMA Bay-Delta model is based on the RMA suite of finite element models for simulation of hydrodynamics, water quality, and sediment transport. The majority of the system is represented using a two-dimensional depth-averaged approximation. Tributary streams and minor Delta channels are represented using a one-dimensional approximation. Because the model uses a finite element numerical scheme, it is readily adaptable to the needs of specific studies ranging from analysis of localized outfalls or marina sedimentation to the analysis of large-scale effects associated with Delta Island restoration. Results from the RMA Bay-Delta model have been widely presented among stakeholders and members of the Bay Area modeling community such as the Regional Water Quality Control Board, California Department of Water Resources, California Bay-Delta Authority/CALFED, Bay Area Dischargers Association, IEP Hydrodynamics Committee, and the California Water and Environmental Modeling Forum.

RMA has applied the Bay-Delta model in recent years to numerous projects related to marsh restoration, wastewater discharge, sediment transport, water quality and hydrodynamics and salinity in the San Francisco Bay. RMA has also been active in a number of large scale modeling projects sponsored by The California Bay-Delta Authority/CALFED and the California Department of Water Resources (DWR) focused on water quality in the Sacramento-San Joaquin Delta.

Documentation for the RMA model including calibration results and representative project reports are available at the following web links:

http://baydeltaoffice.water.ca.gov/ndelta/floodedislands/FloodedIslandsCalibrationFinalReport-2005-06-30.pdf

http://baydeltaoffice.water.ca.gov/ndelta/floodedislands/FranksTractAlternativesFinalReport-2005-06-30.pdf

http://calwater.ca.gov/Programs/LeveeSystemIntegrity/Seismic_Risk_Report_2005/Appendix_A.pdf

TRIM and UnTRIM Three-Dimensional Models

The UnTRIM model is an ideal three-dimensional model for Delta simulations due to the flexible grid structure allowed by the model, similar to the grid structure of finite element models (e.g., RMA2), and the highly efficient and stable finite difference numerical method and matrix solver of UnTRIM. This combination of flexibility and efficiency allows the model to use high resolution where it is needed to accurately describe the geometry (bathymetry) of Delta channels junctions and other features. Every aspect of the method has been published in peer reviewed journals and the method is well established, and widely duplicated, in the scientific community. The TRIM and UnTRIM models also been applied extensively in the San Francisco Estuary and are accepted both in scientific and regulatory applications. The model has been used in dozens of widely varied applications and settings without any “tuning” of model parameters to maintain model stability. The only model parameter that is typically chosen on a site specific basis is a bottom friction parameter, which represents the roughness of the bed. Because only one site specific parameter of the model must be tuned in an application, the model is readily applied and calibrated in any setting.

The application of a three-dimensional hydrodynamic model in the DRMS project will improve understanding and quantification of model uncertainties in the RMA2 model and the simplified model used in the risk calculator. The proposed tool for these applications are the Cartesian grid TRIM model (Casulli and Cattani 1994) or the unstructured grid UnTRIM model (Casulli and Walters 2000). These models have been applied extensively to the San Francisco Estuary (e.g., Cheng et al. 1993; Gross et al. 1999; Cheng and Casulli 2001) in both consulting and research applications. The TRIM model covers San Francisco Bay, San Pablo Bay, Suisun Bay and the western Delta. The model is calibrated to accurately simulate tidal hydrodynamics and salinity and ready for applications in the DRMS study. The UnTRIM model covers roughly the same model domain and is calibrated to reproduce tidal hydrodynamics.

In addition to quantifying some model uncertainties and increasing the defensibility of the simplified and two-dimensional salinity modeling tools used in the DRMS, the three-dimensional model could be extended throughout the Delta in future studies and used to evaluate risk reduction alternatives.

DWR Delta Simulation Model II (DSM2)

DSM2 consists of several modules for simulation of one-dimensional river and estuarine hydrodynamics and water quality transport as well as computation of land-based processes such as consumptive use and agricultural runoff. DSM2-Hydro, the hydrodynamics module, is based on the U.S. Geological Survey’s FourPt implicit model and has been extended by DWR staff and other to support a variety of issues specific to simulation of the Delta and Central Valley River System. DSM2-Qual, the water quality module, is based on the U.S. Geological Survey’s Branched Lagrangian Transport Model and has been extensively modified by DWR to simulate multiple non-linearly coupled water quality constituents. Supporting modules include a Particle Tracking module and Delta Island Consumptive Use module, both developed by DWR. DSM2 is used extensively by the DWR Delta Modeling Section as well as by other public and private groups for analysis of Delta and Central Valley hydrodynamic and water quality issues.

Documentation for DWR DSM2 can be found at the following web link:

http://modeling.water.ca.gov/delta/models/dsm2/documentation.shtml

5.2 Simplified Simulation Models: Uncles-Peterson Model

The Uncles-Peterson (U-P) estuarine model is an advective-diffusive intertidal box model of the San Francisco estuary with a daily time step. This model has been applied in several studies of the San Francisco Bay and has been shown to accurately reproduce salinities at weekly to interannual time scales over a wide range of flow regimes [e.g., Knowles et al., 2002; Peterson et al., 1995].

The Uncles-Peterson model is a box-model comprised of 51 boxes/segments extending from the coastal ocean to the western Delta (Uncles and Peterson 1995). Two vertical layers are present in each box with the bottom layer representing the lower portion of deep channels and the top layer representing shoal regions and the top 5 meters of the surface layer in the channel region.

This model can be readily applied in the estuary up to the Western Delta. However, it has not yet been applied in other regions of the Delta. Applying the Uncles-Peterson model to the DRMS project would require extending the model into the Delta by adding many additional boxes to represent segments of Delta channels and calibrating the model using salinity observations in the Delta.

Applying the Uncles Peterson model to estimate the effects of Delta levee breaches on Delta salinity would require additional of boxes do represent flooded islands and estimation of the dispersion coefficients and vertical mixing coefficients for conditions with flooded islands.

5.3 Parametric Models

DWR Neural Net Model

The following text is taken from the DWR web site: http://modeling.water.ca.gov/delta/models/ann/index.html.

“In 1995 the Modeling Support Branch started using ANNs to quickly simulate the flow-salinity relationships in the Delta as an alternative to using DSM2. The ANNs are typically trained on the input and output of DSM2 simulations.

Improving the ANNs is an ongoing process. As improvements are made within DSM2 or the estimation of its boundary conditions, new ANNs are trained. Currently the DSM2 ANN is used to estimate salinity within CALSIM. Other networks have been trained to represent other water quality relationships in the Delta (such as the THM simulator), but the most common use of ANNs by the branch is to estimate salinity compliance based on flow conditions within CALSIM.”

G Model

The G-model (Denton 1993) predicts daily-averaged salinity at a number of locations in the Delta as a function of antecedent Delta outflow. The equations of the G-model are based upon a one-dimensional advection-dispersion equation but are applied at fixed locations where salinity observations are available. The G-model has been applied primarily to locations in the western Delta and does not predict spatial distributions of salinity. Spring-neap filling and draining of the Delta can be accounted for in the G-model by adjusting DAYFLOW appropriately.

In order to develop an empirical relationship between salinity and antecedent Delta outflow at a specific location the G-model coefficients are calibrated to optimize its ability to predict observations of salinity over a range of Delta outflow. Because the model is entirely empirical, as opposed to mechanistic, it applies to conditions and locations for which the salinity observations were collected. The only independent variable used in the G-model is Delta outflow. The model does not account for Delta management actions such as placement of temporary barriers. Therefore, if major changes to the geometry of the Delta result from levee failures, restoration, or other Delta modifications, the empirical coefficients may no longer be valid.

The primary limitation of the G-model is that it is an empirical relationship and, therefore, can not independently predict salinity for levee failure sequences. In order to generate a database to calibrate the G-model for a new Delta geometry (with flooded islands), a mechanistic model would be required to simulate a range of Delta outflow conditions. The existing G-model may be useful to predict salinity as a function of Delta outflow after repairs are complete and the Delta has returned to its initial geometry.

The G-model approach may be a useful guide in developing a parametric model that predicts salinity for levee breach sequences. It is likely that additional model parameters and independent variables would be required to account for variability in Delta geometry.

6.0 PROBABILISTIC APPROACH

The following discussion focuses on the uncertainties present in the existing hydrodynamic and salt transport models of the Delta as well as the likely uncertainties that will be present in the simplified hydrodynamic and water quality model developed for the DRMS project. The complete probabilistic approach has not yet been developed and will be one of the work products of the Water Analysis Module Team.

6.1 Uncertainties in Model Formulation and Parameters

The one-dimensional approach being considered appears promising, but the details of specifying the necessary dispersion parameters are not yet settled. It is expected that the "data set" used to derive and/or calibration the simplified model will include a substantial set of simulation results from detailed tidal time scale models, including the two-dimensional RMA2 model, and the three-dimensional UnTRIM model. Therefore, to the extent that the simplified model is able to reproduce the behavior of the tidal time scale models, any uncertainties in those models will also affect the simplified model results.

The simplified model will have additional sources of uncertainty to those present in the tidal time scale models. However, because the formulation of the simplified model has not been decided, these additional uncertainties cannot be discussed at this time.

6.2 Uncertainties in Tidal Time-Scale Models

The following discussion outlines several key uncertainties typically present in tidal time scale hydrodynamic models. For completeness, one-dimensional hydrodynamic models are also discussed, though a one-dimensional tidal model is not likely to be used in the DRMS study. Most of the sources of uncertainty also apply to tidally-averaged models, which is one form of model under consideration as the simplified model for the DRMS project.

The equations governing fluid motion and salt transport represent conservation of water volume, momentum and salt mass. Because these equations cannot be solved analytically for complex geometry and boundary conditions, numerical models are used to give approximate solutions. Many decisions are made in constructing and applying numerical models. The governing equations are chosen to represent the physical processes in one, two or three-dimensions and at the appropriate time scale. Then these governing equations are discretized to apply over distinct volumes, surfaces, curves or points in space. The resulting discretized equations are solved, often requiring the use of an iterative matrix solver. The discretization and matrix solution must be developed carefully to yield a numerical approach that is consistent with the governing equations, stable and efficient. To apply the models, a bathymetric grid, boundary conditions, initial conditions and several model parameters must be chosen. The accuracy of the model application will depend on the accuracy of this input, including site-specific parameters. Numerical errors are controlled by choosing appropriate time step and grid size and orientation for the solution. The following discussion will discuss the largest sources of uncertainty common to different models.

6.3 Three-Dimensional Models

The most detailed description of fluid motion is provided by the three-dimensional turbulent time scale models. However, simulation of turbulent motions for a domain the size of the Delta is not computationally feasible because it would require prohibitively small grid cells and time steps. Therefore, large scale models typically average over the turbulent time scale to describe tidal motions. The resulting three-dimensional hydrodynamic models represent the effect of turbulent motions as small scale mixing of momentum and salt, parameterized by eddy viscosity and eddy diffusivity coefficients, respectively. These turbulent mixing coefficients are estimated from the tidal flow properties (velocity and density) by “turbulence closure” models embedded within the three-dimensional models. These three-dimensional models estimate the variability in velocity and salinity in all dimensions and through the tidal cycle, therefore provide a detailed description of hydrodynamics and salinity. However, there are several limitations and uncertainties inherent in the application of three-dimensional models:

- Spatial resolution/computational cost: the spatial resolution of the bathymetry, velocity, and salinity distributions is limited by the large computational expense associated with three-dimensional models to account for vertically variable processes.
- Site-specific parameters: at a minimum, three-dimensional models require bottom friction coefficients to parameterize the resistance to flow at solid boundaries. These parameters are specified in model calibration either from reference manuals (e.g., Chow 1959) or by tuning to improve calibration and may be specified globally or in map form.
- Turbulence closure: the effect of turbulent motions on tidal time scale motions is estimated by a turbulence closure. Turbulence modeling is an active area of research and, particularly in stratified settings, different turbulence closures may give significantly different results (e.g., Warner et al. 2005).
- Numerical errors: A numerical method approximates the governing equations to some level of accuracy. The predictions of the model can vary substantially among different numerical methods (e.g., Gross et al. 1999). Even numerical methods that are theoretically accurate often have unfavorable stability properties that require use of unrealistic diffusion/dispersion coefficients to maintain stability. Some models have additional limitations, for example, not allowing wetting and drying of computational cells.

6.4 Vertically Averaged Two-Dimensional Models

Vertically-averaged two-dimensional models average the three-dimensional equations of motion over the vertical dimension and discretize the resulting equations. Vertical averaging typically provides an order of magnitude reduction in the total number of grid cells and computational expense relative to three-dimensional models. However, the vertical distributions of velocity and salinity are not represented by these models and, therefore, they have a limited ability to represent density-driven flow, wind-driven flow and several salt transport mechanisms. The effect of the unresolved vertical distributions of velocity and salinity on salt transport are parameterized by dispersion coefficients. These dispersion coefficients represent mixing by "three-dimensional processes" and are typically several orders of magnitude larger than eddy diffusivity (the effect of turbulence). The limitations of vertically-averaged models are:

- All of the limitations associated with three-dimensional models, except reduced computational cost.
- The models do not describe the vertical variation of velocity and salinity.
- These models rely on dispersion coefficients. These site-specific parameters vary spatially and should theoretically be varied with flow conditions and tidal conditions (Monismith et al. 2002; Uncles and Peterson 1996). In practice a constant set of dispersion coefficients, often in map form, are usually applied for all flow and tidal conditions. For this reason, two-dimensional models are likely to be less accurate than three-dimensional models for unusual flow and/or tidal conditions. Furthermore, dispersion coefficients that are appropriate for existing conditions may be inappropriate for levee failure sequences because they will not account for altered tidal prism, salinity gradients and other changes.

6.5 One-Dimensional Models

One-dimensional models average the three-dimensional (turbulent averaged) equations of motion over the vertical and lateral directions and discretize the resulting equations. One-dimensional models have minimal computational expense relative to three-dimensional models. Due to minimal computational expense, and the ability to provide a precise representation of cross-sectional area as a function of water elevation (stage), one-dimensional models are appropriate for many studies, in particular studies of flood management issues. While one-dimensional models are often used for simulations of tidal prism and elevation they are less commonly applied to simulate salt transport in estuaries. In one-dimensional models, dispersion coefficients represent the effect of "two-dimensional processes" and "three-dimensional processes" on salt transport. The limitations of one-dimensional models include:

- All of the limitations of two-dimensional models except reduced computational expense.
- Do not describe the lateral variability of salinity.
- Rely more heavily than two-dimensional models on dispersion coefficients.

In summary, all numerical modeling approaches have substantial limitations. However, three-dimensional models provide more information about the spatial distribution of salinity than lower dimensional models and rely on fewer empirical parameters (dispersion coefficients) to accurately simulate salinity.

6.6 Expected Challenges with Numerical Model Applications

Some expected difficulties in numerical modeling of hydrodynamics and salinity for the DRMS project are emphasized below.

- Process resolution – All models choose to represent a limited number of processes and neglect other processes.
  - Small scale mixing – The flow near levee breaches will be complex with large variability in velocity and salinity at the "sub-grid" scale of large-scale models. This small scale mixing is difficult to simulate due to the complex geometry of Delta channels and the density differences between the flooded islands and the channel.
  - Dispersion coefficients – One-dimensional and two-dimensional models generally rely on dispersion coefficients. Even if appropriate dispersion coefficients can be determined for existing conditions, they may not be appropriate for project (levee breach) conditions. Given substantial changes expected in the tidal prism and salinity of Delta channels, it will be particularly difficult to specify dispersion coefficients that are appropriate for these regions.
- Grid resolution and bathymetry –The accuracy and spatial coverage of bathymetry and topographic data will limit accuracy.
  - Grid resolution - Due to substantial computational time/expense associated with two-dimensional and three-dimensional modeling, feasible grid resolution is likely to limit model accuracy. Substantial errors may be present in representation of channel geometry and representation of breach geometry.
  - Bathymetry and topography data – The spatial coverage and accuracy of bathymetry and topography data often limit model accuracy. The limited accuracy of existing island topography data is likely to be a large source of error in simulations.
- Boundary conditions – At the seaward boundary salinity and tidal boundary conditions must be specified. Any method of specifying this information will introduce model uncertainty. For example, if salinity observations are available at one or two locations near the seaward boundary, these observations will not describe the full vertical and lateral variability of salinity along the boundary.

6.7 Methodology for Estimating Uncertainty

Several sources of uncertainty will be present in the predictions of the simplified model used in the DRMS study. The uncertainty in model predictions for a scenario will increase with the severity of the levee breach scenario, in terms of number of breaches and/or area of islands flooded, and vary with location and time of salinity predictions. Therefore an estimated variance will be associated with each salinity value predicted.

The first step in estimating the uncertainty associated with the simplified model will be the application of this model to historic conditions, both for the existing Delta geometry and for a period following a historic levee breach, most likely the Jones Tract breach. The predictions of salinity by the simplified model will be compared with available salinity observations in order to estimate model uncertainty for this well-defined set of conditions. The computed variance will provide a lower bound of model uncertainty for the DRMS study that accounts for many of the uncertainties in model formulation and model parameters.

Because some levee failure sequences considered by the DRMS project will be more extreme than any historic conditions, comparisons to available observations may substantially underestimate the uncertainty associated with the more severe levee failure scenarios. In order to quantify the uncertainty in simplified model formulation and parameters for those conditions, simulations of severe levee failure scenarios will be performed with the detailed models to provide the best possible estimate of salinity. The simplified model predictions will be compared with the detailed model predictions and variances in predicted time series of salinity at different locations will be computed. Estimates of uncertainty related to the formulation and parameters of the detailed models, as described previously, will also be incorporated into this analysis.

In addition to the uncertainties related to model formulation and parameters, additional uncertainty will be present in prediction of future conditions due to model input data not provided as part of an the sequence. These additional uncertainties include uncertainties in initial conditions, water operations, geomorphic change in Delta channels, tidal and wind conditions, and other factors. For the 50, 100 and 200 year simulations the uncertainty of model predictions will be greatly increased due to uncertainty in changes in Delta geometry and operations. The effect of these uncertainties on predicted salinity will be estimated by simulations spanning the likely range of uncertain and important model inputs using the simplified model, the RMA2 model and the UnTRIM model. This analysis will be limited to model inputs that are believed to have a substantial effect on salinity predictions.

Gravitational circulation in the channels of Suisun Bay and the western Delta reduce the ability of increased reservoir releases to flush salt from the western Delta following a levee breach. Gravitational circulation results from horizontal salinity gradients and causes landward (up-estuary) transport of salt. Because the strength of gravitational circulation depends strongly on salinity gradients (Monismith et al. 2002), the effect of this process depends on Delta outflow and levee failures. Because levee failures and subsequent flushing releases will lead to spatial shifts in the salinity field, the location and strength of gravitational circulation will be different for conditions with additional flooded islands than for existing conditions. For this reason, the effect of gravitational circulation on salt transport for levee failure scenarios cannot be easily parameterized in depth-averaged models. It is likely that RMA2 will underestimate the flow required from reservoirs in order to flush salt from Delta channels following severe levee failure events. The UnTRIM model will be applied to estimate uncertainty related to errors in the representation (or neglect) of gravitational circulation in the simplified model and/or the RMA2 model. This uncertainty is particularly important because it may introduce a persistent bias to the water quality analysis in which water quality impacts are underestimated for most events.

The UnTRIM model will also be used to evaluate fluxes in and out of flooded islands. The exchange between a flooded island and a neighboring channel is complex and three-dimensional. Even in an unstratified setting, three-dimensional flow patterns near a levee breach are present due to vertical shear in the velocity profile. Stratification either in the flooded island or the channel makes the exchange processes much more complex. Particularly in the presence of stratification, a three-dimensional model should provide more accurate predictions of exchange between the island and the channels than a depth-averaged model.

Stratification in a flooded island will allow high salinity water to remain near the bed of a flooded island, reducing exchange between the island and channels and decreasing the flushing rate of the island. Stratification in a channel neighboring and levee breach will affect exchange between the island and the channel. The effect of stratification on exchange will depend on levee geometry, particularly the invert elevation of a levee breach. If a breach is relatively shallow, relative to the neighboring channel, stratification in the channel will be particularly important. This stratification would result in exchange of surface water in the channel, with salinity substantially lower than depth-averaged salinity, with island water.

The three-dimensional simulations of exchange between flooded islands and channels may be useful in improving the representation of exchange in the simplified model and will inform the uncertainty analysis in DRMS.

7.0 ASSUMPTIONS, CONSTRAINTS, LIMITATIONS

The proposed methodology will be limited in several ways. Many of these limitations follow from assumptions of the analysis and will not be reflected in the uncertainty analysis.

The bathymetry of San Francisco Bay, San Pablo Bay and Suisun Bay will not change in configuration during a breach event or over the future 50, 100, and 200 year scenarios. The water module will assume no changes in current Delta operations in the year 50, 100 and 200 scenarios. This includes no new barriers and gates and no major changes in operation of existing infrastructure. At this time it has not been determined if the planned permanent operable barriers in the south Delta are to be included in the “business as usual” case for the Risk Analysis. If the planned south Delta barriers are to be included, there standard proposed operation will be considered in the hydrodynamic simulations, however, any use of the barriers for emergency operation will be deferred to Phase 2 of the project when risk reduction strategies are explored.

A key limitation of the salinity analysis is that the Delta bathymetry and topography will be based upon best available data and will be assumed to be known accurately. Available data are actually limited and often inaccurate, particularly on the Delta Islands. Quantification of the effect of the uncertainties in island topography on the simulations will rely on error estimates in island volumes from DWR and DRMS project team GIS analysis. The fundamental Delta channel network geometry and bathymetry will also be assumed static. Geomorphic evolution of the channels due to levee failure or due to natural evolution of the channels in the year 50, 100 and 200 simulations will not be accounted for in the analysis. Subsidence in Delta islands over time will, however, be accounted for in island volume estimates. In reality, a very significant seismic event may breach large sections of levees in a way that fundamentally changes the flow paths in the Delta. While we will consider flow through islands breached on more than one side, wholesale changes to the major flow paths (in Delta channels) that might accompany significant scour will not be considered.

The water module will consider a limited set of water quality issues. Several important water quality issues will not be considered and others will be analyzed at a screening level. Contaminant mobilization and transport and dissolved oxygen will not be considered in the water quality analysis because these issues are complex and can not be addressed meaningfully within the schedule of the DRMS project. Simplified simulations of TOC/DOC may be performed for a limited number of scenarios. These simulations would consider TOC/DOC as a conservative tracer and treat islands as sources of TOC/DOC. These assumptions are not realistic because TOC/DOC is not conservative and the islands will not be constant sources. Furthermore, the source rates from the islands are uncertain. The purpose of these screening level simulations is to evaluate whether TOC/DOC is an issue that merits more detailed analysis. For example if predicted TOC/DOC exceeds standards while predicted salinity is low enough for export for a number of likely scenarios, this issue should be analyzed in more detail in future studies. Similarly, residence time simulations will be performed for a limited number of scenarios. These simulations may provide insight to locations of potential dissolved oxygen problems.

The levee failure sequence is an input to the water module and will not be affected by the results of the water module. In reality, both secondary levee failures and breach geometry are related to hydrodynamics. Secondary levee failure may occur due to sudden drawdown in water surface elevation when flooded islands fill or due to wind wave action over the long fetch of a flooded island acting on the inside of an island levee or for other reasons. In addition, breach geometry will evolve as breaches scour due to strong currents through the breaches. Because coupling the levee fragility and water modules would increase the complexity and computational expense of the overall DRMS analysis, these modules will not be coupled.

The output of the water module will also be limited and is discussed in the Anticipated Outputs section.

8.0 INFORMATION REQUIREMENTS

8.1 Basic Data

Basic data requirements for hydrodynamic and water quality analysis include the following:

- San Francisco Bay-Delta channel geometry
- Tide
- Ocean and tributary salinity
- Initial Delta salinity distribution for all potential events
- Hydrology (if not provided as part of event sequence)
- DICU patterns for all base case year types
- Gate and Barrier Operating procedures for base case year types
- Set of options for emergency physical and operational options
- Base Delta and Suisun Marsh island topography
- Meteorological data for base case temperature simulation (screening simulations only)
- Source rates for surrogate water quality parameters (screening simulations only)

The majority of the base data is already included in the existing models of the Bay-Delta system. Initial salinities will need to be established for each hydrologic condition and event start time considered in the risk analysis. Rough estimates of island topography are currently available, however, it is very important that new higher quality topographic data be acquired from DWR or other agencies. If the Environmental Consequences Team requests selected simulation of tracer constituents, then source rates for those constituents will need to be determined in conjunction with the Environmental Consequences Team.

8.2 Interface (Input) Requirements

Interface requirements for hydrodynamic and water quality analysis include the following.

- Hydrology (if not provided as base data)
- Breach timing and size (a table of primary and secondary breaches)
- Breach closure and pump out schedule
- Sea level rise (acts to shift tidal boundary condition and changes tidal dispersion estimates)
- Change in island topography due to subsidence (shifts base topography)

8.3 Anticipated Outputs/Products

Output products of the simplified hydrodynamics and water quality component of the Water Analysis Module will include the following monthly average time series data and corresponding conditional probability distributions.

- Net Delta Outflow and net flows in main channels including the Sacramento River, Mokelumne River, Old River, and Middle River.
- Export quantities including State Water Project, Central Valley Project, Contra Costa Water District at Rock Slough and Old River.
- Salinity Distribution along the San Joaquin River and primary conveyance channels including the Sacramento River, Mokelumne River, Old River, and Middle River.
- Salinity of Delta exports
- DICU estimated based on breach state and Delta salinity distribution
- Time of disruption (reduction in export)

Output products from selective hydrodynamic and water quality simulations using the RMA Bay-Delta Model as required by the Flood Hazard and Environmental Consequences Teams may include the following.

- Stage time series at selected locations.
- Peak stage distribution throughout the Delta.
- Velocity time series at selected locations.
- Average and/or peak channel velocity distributions.
- Temperature time series at selected locations.
- Daily maximum temperature distribution.
- Residence time as a surrogate indicator for locations where significant biological activity may occur and where dissolved oxygen issues may arise.
- Conservative or non-conservative tracer distributions resulting from island sources as a surrogate for release of organic carbon, trihalomethane precursors, and/or other toxic constituents from flooded islands.

Output products from the Water Analysis Module will be available for the full range of levee breach events considered in the DRMS study. Output products from runs of the full Bay-Delta models will only be available for a limited number of cases selected by the Flood Hazard and Environmental Consequences Teams in conjunction with the Water Analysis Team.

9.0 RESOURCE REQUIREMENTS

9.1 Experts invited for direct collaboration on formulation of a simplified model

These experts will directly collaborate with the hydrodynamics/water quality consultant team in the development of the simplified model approach. Their contributions will include

- Suggesting appropriate approaches for the simplified model
- Advising on the evaluation of existing models and approaches that may be useful as the basis of the simplified model
- The formulation of one or more approaches to develop and test the approach for evaluation of model uncertainty.

The level of effort is expected to be several days to a few weeks.

Dr. Mark Stacey, UC Berkeley
Dr. Steve Monismith, Stanford (possibly)

9.2 Hydrodynamic/Water Quality Modeling Review Team

The Team invited to review the ITF paper will consist of local experts with extensive knowledge of Bay-Delta issues and modeling approaches and outside experts with experience studying similar issues and applying similar tools in other systems. Several of these experts will also be invited to review and discuss progress in the DRMS project either early in the project or toward the midpoint of the project.

The review of all experts will cover several topics including:

- Comprehensiveness: Does the approach address the most important water quality issues? Is the proposed output of the hydrodynamic/water quality model adequate for assessment of economic and environmental consequences? Are the required inputs to the hydrodynamic/water quality model clearly identified?
- Conceptual Model: Is the approach based upon a clear understanding of relevant physical processes and operational issues? Is the conceptual understanding of these processes and issues clearly stated?
- Scientific Validity: Is the proposed simulation approach appropriate given the goals and schedule of the DRMS project? Would another approach be better suited to the goals and schedule of the DRMS project? Is the proposed approach adequately documented? How could the approach be improved?
- Uncertainty Analysis: Are important uncertainties clearly articulated? Is the approach to quantify model uncertainties clearly stated? Is the proposed approach to quantify uncertainties appropriate? How could the proposed approach be improved?

The review by San Francisco Estuary experts will ensure that relevant Bay-Delta knowledge is taken into consideration in the approach and that the model outputs are appropriate. The inclusion of outside experts in the review process will provide bring additional knowledge and perspectives to bear on the project and suggest additional references and approaches that may be useful to the DRMS project. The experts listed below are from the numerical modeling community, other experts from the DWR and USBR operations community will be invited to review the Water Analysis Module – Water Operations technical paper which deals more specifically with operational decision making.

San Francisco Estuary Experts

Chris Enright, DWR Suisun Marsh Section
Tara Smith, DWR Delta Modeling Section
Ralph Finch DWR Delta Modeling Section
Jamie Anderson, DWR Delta Modeling Section
KT Shum, EBMUD
Paul Hutton, MWD
Chu Ching Wang, MWD
Richard Denton, CCWD
Leah Orloff, CCWD
Pete Smith, USGS
Larry Smith, USGS
William Fleanor, UC Davis

Outside Experts

Robert McAdory, USACOE
Eric Deleersnijder, Universite' Catholique de Louvain
Rocky Geyer, Woods Hole Oceanographic Institution
Parker MacReady, University of Washington

9.3 Additional Data Required

Most of the physical and operational data required for the hydrodynamic and water quality analysis is currently available. The most important additional data that is required is an updated topography data set for all of the Suisun Marsh and Delta islands that are to be considered in the DRMS study. These data set may also be critical for other teams participating in the risk analysis, and, as such, a common topography data set should be established for all teams to work from. The first point of contact for collection of topography data is Joel Dudas of DWR.

10.0 PROJECT TASKS

The scope of work for the Hydrodynamic and Water Quality component of the Water Analysis Module is divided into four phases:

1. Multi-Dimensional Modeling and Testing of Simplified Model Concepts
2. Implementation of Simplified Hydrodynamic/Water Quality Model
3. Verification and Refinement of the Simplified Model
4. Evaluation of risk reduction alternatives

Phases 1, 2, and 3 are part of the Risk Analysis portion of the DRMS project. Phase 4 is part of the Risk Reduction portion of the DRMS project and is not discussed in detail in this scope.

Three project milestones are identified.

- Draft Water Analysis Module Complete – design of the simplified hydrodynamic/water quality model and water management models are complete and tested in draft form.
- Water Analysis Module incorporated into Risk Analysis Framework – Water Analysis Module is functional and ready for initial risk analysis.
- Revised Water Analysis Module Finalized – water analysis model performance has been validated and final implementation incorporated in the Risk Analysis Framework.

If Optional Task 3-2 is determined to be necessary and is funded, then the date for the final milestone will be pushed back approximately two months.

10.1 Phase 1: Multi-Dimensional Modeling and Testing of Simplified Model Concepts

Task 1-1: Two-Dimensional Modeling Using the RMA Bay-Delta Model

Task 1-1.1: Extend RMA Bay-Delta Model to Represent all Islands and Breach Locations

- **Task Objectives:** Extend the existing RMA Bay-Delta model configuration used for the 50-breach scenario to include representation of all Delta islands and levee breach locations to be considered in the DRMS hazard analysis.
- **Task Description:** During the Preliminary Delta Levee Risk Assessment, the RMA Bay-Delta Model finite element representation of Delta channels was extended to include the topography of 21 Delta Islands and 50 potential breach locations. For the DRMS analysis, the model will be extended further to explicitly represent all of the Delta and Suisun Marsh islands and will include representative breach locations along all levee segments considered by the Levee Fragility Team. In construction of the new finite element network, a naming convention for island breach locations will be established in coordination with the Levee Fragility Team and Emergency Response Team to facilitate explicit definition of levee breach scenarios within the Risk Analysis Framework.

  Best available topographic data will be gathered from DWR, USACE, and other sources to determine island elevations. Because DWR has experienced delays in acquiring new LIDAR data for the Delta, the topography incorporated into the RMA model will likely contain significant uncertainty. As new data becomes available, the RMA model will be updated, however, new data may not be available before the initial risk analysis is performed.

Task 1-1.2: Evaluate Flow and Mixing Characteristics for Wide Range of Levee Breach Cases

- **Task Objectives:** Develop tidally mixing and net flow parameterization based on short term hydrodynamic simulations for a wide range of levee breach cases and Export/Inflow ratios that will provide the primary data set for construction of the simplified hydrodynamic/water quality model.
- **Task Description:** The RMA Bay-Delta Model will be utilized to derive tidal mixing and net flow parameters that will provide the basis for configuring the simplified hydrodynamic/water quality model to be used within the Water Analysis Module. This will be achieved by running sequences of short term hydrodynamic simulations for a wide range of breach configurations, exports, and inflows and then post processing the results to

determine tidally averaged mixing and net flow splits through the primary channels. As currently conceived, the model will be run with a repeating 19-year mean tide for 5 to 7 tidal days for each breach/Export/Inflow combination. Experience with modeling the system suggests that the hydrodynamic response stabilizes after approximately 5 to 7 days. The flow result from the last day of simulation will be post processed to derive mixing parameters and net flow splits. Net flows are developed by tidally averaging the dynamic flows (applying a digital filter). Mixing coefficients will be related to excursion in the system, probably derived by particle releases at representative channel locations.

While it will not be possible to simulate all possible breach/Export/Inflow combinations, it will be possible to evaluate several hundred scenarios.

Task 1-1.3: Preliminary Hydrodynamic/Water Quality Simulations for Other DRMS Teams

- **Task Objectives:** Perform select hydrodynamic and water quality simulations as required by the Flood Hazard and environmental consequence DRMS project teams.
- **Task Description:** The Flood Hazard Team has expressed an interest in having flow and stage results for several representative storm events. The RMA Bay-Delta model will used to simulate up to 5 storm events (up to one week duration). Time series of and spatial plots of flow and stage (and possible mean velocity and/or shear velocity) will be provided to the Flood Hazard Team.

  The Environmental Consequence Team is concerned with spatial distribution of temperature, residence time, salinity, and possibly other parameters derived from the RMA model simulations. The hydrodynamic and salinity results from the 1-, 3-, 10-, and 50-breach cases performed under the Preliminary Delta Levee Risk Assessment will be made available to the Environmental Consequence Team. In addition, new simulations of temperature and residence time will be performed. To evaluate possible impacts of organic carbon production, mass loading of a conservative tracer can be applied to flooded islands. This task was budgeted assuming new simulations will be limited to three scenario simulations of 9 months duration for temperature, residence time, and mass loading of a conservative tracer.

Task 1-2: Three-Dimensional Modeling Using UnTRIM

Task 1-2.1: Setup Existing UnTRIM Model for Scenario Simulations

- **Task Objectives:** Extend existing UnTRIM model of San Francisco Bay to include Sherman Island and portions of the western Delta at least as far upstream as Rio Vista and Jersey Point. Confirm hydrodynamics calibration on extended grid and perform salinity calibration.
- **Task Description:** The proposed scope of the three-dimensional UnTRIM modeling is tailored to produce results rapidly in the DRMS project so that these results will inform the estimation of uncertainty related to the more simplified model(s). The project team, model, model input data, calibration dataset and validation dataset were all selected so that the project will proceed rapidly. The approach will use the best currently available data and numerical and computational methods but will not involve any significant model development or additional data collection. The model setup effort will allow the three-dimensional model to be applied with confidence to scenario simulations.

In general, the data requirements for the UnTRIM model are nearly identical to those for the RMA2 model, with the exception that the 3D model does not require the specification of dispersion coefficients. The UnTRIM model setup and application will utilize data and experience from previous RMA2 applications to minimize model setup time.

The application of the UnTRIM model for the DRMS study will require extending the model grid further into the Delta, at least to Rio Vista and Jersey Point. The unstructured grid will consist of a mixture of quadrilaterals and triangles configured to allow both model efficiency and accuracy.

The calibration effort will build upon previous UnTRIM calibration efforts in San Francisco Bay to minimize effort. The current UnTRIM model is calibrated to accurately simulate tidal hydrodynamics. When this model is extended further into the western Delta the calibration coefficients and the accuracy of the calibration is not expected to change. A Cartesian grid model (TRIM) with essentially the same formulation as UnTRIM (without the grid flexibility) has been calibrated and validated to predict salinity over the entire range of observed Delta outflow. There are no "tunable" parameters in UnTRIM salinity simulations. Therefore the calibration effort is expected to be modest.

While the model domain will include all of the San Francisco Estuary, the calibration and validation effort will focus on Suisun Bay and the Delta. The calibration period and dataset will be under "normal" conditions without any recent levee breach events. The UnTRIM model will be calibrated using the same dataset used to calibrate the RMA2 model and/or a dataset used previously with the TRIM model. If the project schedule and budget allow for model validation, a levee breach event will be considered for model validation. Data collected at the time of the Jones Tract levee failure has been used previously with the RMA2 model and may be used with UnTRIM. Some assumptions regarding Jones Tract topography and levee geometry may be required in this simulation.

Task 1-2.2: Simulation of Flushing of Salt from the Western Delta

- **Task Objectives:** Apply UnTRIM model to simulate two or three flooded island scenarios. The initial salinity fields will be specified using RMA2 simulation results immediately following island flooding. Simulate effect of increased reservoir releases on flushing salt from the western Delta and Suisun Bay. Quantify the extent to which three-dimensional processes influence salt flux and the reservoir releases required to limit salt intrusion into the central Delta.
- **Task Description:** The analysis of key "three-dimensional processes" will quantify key epistemic uncertainties associated with application of a depth-averaged model in the DRMS study. One key "three-dimensional process" is gravitational circulation. Gravitational circulation results from horizontal salinity gradients and causes landward (up-estuary) transport of salt. Previous simulations with the TRIM model (Gross et al. in press) strongly suggest that this model accurately simulates gravitational circulation in Carquinez Strait and Suisun Bay.

  Following levee breaches one or more flooded island will begin to fill with water from the Delta. As this occurs, water from Suisun Bay (and possibly San Pablo Bay) will be drawn into the western Delta. Depending on the salinity conditions at the time of the levee breaches, this may lead to dramatically increased salinity in the Delta. In order to limit the salt intrusion in the Delta and eventual mixing of salt into flooded islands, reservoir releases may be increased rapidly following a levee breach event. The likely response to the increased Delta outflow will be increased salinity gradients in the Delta as the freshwater releases flush salt from the Delta. Because the strength of gravitational circulation depends on salinity gradients, the effect of this process on salt transport increases with Delta outflow.

In other tasks of the DRMS project, the response of salinity to increased Delta outflow (reservoir releases) will be estimated by the RMA2 model for a limited number of scenarios and the simplified model for many additional scenarios. While the actual response of Delta salinity to increased flow will depend substantially on the degree of gravitational circulation present in the western Delta and Suisun Bay, RMA2 and the simplified model will not resolve this process. The purpose of the three-dimensional simulations is to predict the strength and location of gravitational circulation during levee failures and the effect of gravitational circulation on salinity predictions. This information will inform uncertainty analysis in DRMS and may allow improved estimation of dispersion coefficients in simulations using RMA2 and the DRMS simplified model. This uncertainty is particularly important because it may introduce a persistent bias to the water quality analysis in which water quality impacts are underestimated for most scenarios.

Each UnTRIM simulation will be initiated with a salinity field from RMA2 representing salinity after the flooded islands have filled with water for a levee breach scenario. From this point onward, all boundary conditions, including the reservoir releases used to flush salt from the Delta, will be identical to the boundary conditions used in the analogous RMA2 simulation.

The evaluation of uncertainties in the RMA2 model will be performed in multiple steps. First, the salinity predicted by UnTRIM will be compared with the RMA2 predictions (and, possibly, simplified model predictions) and the mean and variance between the predictions will be computed at several locations in the western Delta and Suisun Bay. This will identify locations and conditions (Delta outflow, etc.) where significant biases may be present in the RMA2 predictions. Both UnTRIM and RMA2 results may also be analyzed in terms of time to reach a certain salinity target at different locations. The times calculated may correspond to times of curtailed water exports. In addition, maps will be made showing the magnitude of stratification throughout Suisun Bay and the western Delta for different conditions. These maps will suggest where the depth-averaged approximation may lead to error and will aid in the interpretation of depth-averaged results.

Next, salt fluxes past different cross sections in the western Delta and Suisun Bay will be calculated. This salt flux quantifies the rate of flushing of salt from the Delta. The salt flux calculated from three-dimensional model results will be compared to the salt flux calculated from depth-averaged model results. Locations and conditions where salt flushing is overestimated by RMA2 will be identified and the magnitude of the error will be quantified.

Task 1-2.3: Salt Exchange Between a Flooded Island and a Channel

- **Task Objectives:** Simulate up to two flooded island events at Sherman Island, which will be included in the UnTRIM model domain. Evaluate the stratification within the island and the effects of stratification on exchange flow between the island and neighboring channel. Quantify the effect of stratification on residence time in a flooded island and evaluate a potential bias in RMA2 (and other depth-averaged models) salinity predictions in Delta levee failure simulations that causes an underestimate the time required to flush salt from flooded islands.

- **Task Description:** The exchange between a flooded island and a neighboring channel is complex and three-dimensional. Even in an unstratified setting, three-dimensional flow patterns near a levee breach are present due to vertical shear in the velocity profile. Stratification either in the flooded island or the channel makes the exchange processes much more complex. Particularly in the presence of stratification, a three-dimensional model should provide more accurate predictions of exchange between the island and the channels than a depth-averaged model.

  Stratification in a flooded island will allow high salinity water to remain near the bed of a flooded island, reducing exchange between the island and channels and decreasing the flushing rate of the island. Stratification in a channel neighboring and levee breach will affect exchange between the island and the channel. The effect of stratification on exchange will depend on levee geometry, particularly the invert elevation of a levee breach. If a breach is relatively shallow, relative to the neighboring channel, stratification in the channel will be particularly important. This stratification would result in exchange of surface water in the channel, with salinity substantially lower than depth-averaged salinity, with island water.

  While the representation of stratification is expected to be the largest advantage of a three-dimensional model in predicting exchange between a flooded island and a channel, several other three-dimensional effects are relevant. One additional three-dimensional process is wind driven circulation which leads to surface velocities moving in the direction of the wind and, eventually, return flows in the opposing direction at depth. Another three-dimensional effect is vertical shear in the velocity field near a levee breach. These additional three-dimensional effects that influence exchange between flooded islands and channels may also be considered if time and budget permit.

  The analysis of exchange between the flooded island and neighboring channel will be evaluated in several steps. First the salt mass transported into the island during a levee failure sequence will be evaluated. In this period stratification in the channel will affect the salinity of water that enters the flooded island. As reservoir releases increase, the Delta channel salinity will decrease and the flooded island will serve as a source of salinity to the channel. During this period, representation of stratification inside the flooded island will be the key difference between the three-dimensional model simulation and the RMA2 simulation. UnTRIM will predict the average salinity in the island, the stratification in the island, and the salt flux from the island to the channel during this period.

  The salt flux calculations will be analyzed to estimate flushing rates and/or residence times within the flooded island. Both the salinity and residence time estimates will be compared with predictions of RMA2 in order to evaluate the degree of bias associated with the depth-averaged approximation.

  This task is critically important because the epistemic model uncertainty related to stratification effects on exchange between a channel and an island is likely to result in a persistent bias in RMA2 (and other depth-averaged models) salinity predictions in Delta levee failure simulations. Specifically, depth-averaged models are likely to underestimate the time required to flush salt from flooded islands.

Task 1-3: Simplified Hydrodynamic/Water Quality Model

Task 1-3.1: Development of Simplified Model Concepts

- **Task Objectives:** Design and document one or more approaches to a simplified hydrodynamic/water quality model appropriate for use within the Water Analysis Module, identifying required inputs, outputs, and information exchange with the water management component of the Water Analysis Module.
- **Task Description:** The simplified hydrodynamic/water quality model will be limited to evaluating salinity impacts of levee failure scenarios. Evaluation of other water quality impacts such as changes in temperature will be estimated from a small number of simulations using the RMA Bay-Delta model as discussed under Task Item 1-1.3.

  Initial design of the Water Analysis Module has identified four specific tasks that the simplified hydrodynamic/water quality model must perform:

  - Estimate the salinity distribution following an island flooding event.
  - If salinity in the central Delta is above standards, estimate the volume of water to be released from upstream reservoirs to flush the central Delta. This will be presented as a flow-volume relation as it is expected that higher flows will be more effective in flushing salinity from the central Delta.
  - Required Export/Inflow ratio based on breach configuration and ongoing DICU.
  - Given Inflows, DICU, and Exports, estimate the salinity distribution at the end of a Water Analysis Module time step (weekly to monthly). This must consider salt fluxes in and out of flooded islands that are open to tidal filling and draining as well as salinity loads from island pump-out.

  Several concepts are under consideration for the simplified model approach. The most promising appears to be a simple advection-dispersion model based on tidally averaged dispersion and net flows derived from the multi-dimensional models. Other concepts that may be considered include a variation on the DWR Artificial Neural Network model and the G-Model.

  The model design will present the rational for the approach, governing equations, model input and output, and expected advantages and limitations.

Task 1-3.2: Develop Methodology for Evaluation of Uncertainty

- **Task Objectives:** Determine the methodology for evaluation of uncertainty in the simplified model considering uncertainty in base data, parameters and formulation of the simplified model, and the parameters and formulation of the multi-dimensional models used to calibrate the simplified model.
- **Task Description:** Output of the Water Analysis Module must include an estimation of the uncertainty in the time dependent salinity distribution, export volume, and quality. Both the water management and hydrodynamic/water quality components of the Water Analysis Module contribute to this uncertainty.

With regard to the simplified hydrodynamic/water quality model, it will be necessary to estimate the uncertainty in each data item passed to the water management component, which include the salinity impact of island flooding, the flow-volume relation defining the request for flushing releases, the Export/Inflow ratio, and the evolution of salinity distribution given DICU, Inflows, and Exports. These uncertainties must combine with uncertainties in the management decision analysis to generate the final uncertainty in the Water Analysis Module data products.

Sources of uncertainty in the simplified model include

- The geometry representation of Delta channels and islands (bathymetry/topography),
- The ability of the simplified model formulation to replicate the behavior of the multi-dimensional model(s),
- The accuracy of the multi-dimensional model(s) upon which calibration of the simplified model is based, and
- Estimation of DICU, Inflows, and Exports defined by the water management component.

A methodology will be developed to evaluate the resultant uncertainty in output products of the simplified hydrodynamic/water quality model based on these sources of uncertainty.

Task 1-3.3: Draft Water Analysis Module Development

- **Task Objectives:** Test the simplified hydrodynamic/water quality model concept by implementing draft algorithms in a spreadsheet or similar form, which will interact with the draft version of the water management component of the Water Analysis Module.
- **Task Description:** Before moving toward full implementation of the Water Analysis Module, draft version will be constructed as a proof-of-concept tool to illustrate the interaction of the water management and simplified hydrodynamic/water quality analysis components. This tool will most likely be in the form of a spreadsheet, although some aspects of the calculations may be implemented with a compiled language (FORTRAN).

  The draft Water Analysis Module will explicitly demonstrate the logic flow and information exchange between the water management and hydrodynamic/water quality analysis components as described under task 1-3.1. An iterative approach to the development will be used, focusing first on the logic flow and progressing to testing concepts for the simplified hydrodynamic/water quality model. Simultaneously the water management team will be testing concepts for DICU impacts, reservoir operation, and export decision making.

  On completion of this task, the design of the Water Analysis Module will be finalized marking completion of milestone 1.

10.2 Phase 2: Implementation of Simplified Hydrodynamic/Water Quality Model

Task 2-1: Implementation of Simplified Hydro-WQ Routines and Water Analysis Module

- **Task Objectives:** Implement the simplified hydrodynamic/water quality model and Water Analysis Module framework (the water management logic will be coded by the water management team) in a form that is compatible with the risk analysis framework.

- **Task Description:** The draft Water Analysis Module will re-implemented in form callable from the Risk Analysis Framework. Most likely it will be implemented as a FORTRAN standalone program or subroutine library. The Water Analysis Module will consist of both the executable code and the base data sets required for determination of hydrology, antecedent Delta salinity state, network connectivity, etc. Close coordination with the Risk Analysis Team will be required to ensure compatibility of input data structures and output data structures within the Risk Analysis Framework. The target run time for the Water Analysis Module to process any single breach scenario is less than 6 minutes.

Task 2-2: Calibration for Select Breach Scenarios

- **Task Objectives:** Calibrate the simplified hydrodynamic/water quality model to adequately represent flow and salinity distributions predicted for 1-, 3-, 10-, and 50-breach cases simulated with the RMA Bay-Delta model.
- **Task Description:** The compiled version of the Water Analysis Module will be tested and calibrated to match previously simulated levee breach scenarios. This will be done outside of the Risk Analysis framework with input sets configured explicitly to match the previous 1-, 3-, 10-, and 50-breach scenarios.

Task 2-3: Evaluate Uncertainties in Water Analysis Module

- **Task Objectives:** Utilizing the methodology developed in Task 1-3.2, determine the uncertainty to be assigned to simplified model inputs and parameters and the resultant uncertainty in Water Analysis Module output.
- **Task Description:** Utilizing the methodology developed in task 1-3.2, the completed simplified model and its base data set will be evaluated to determine the uncertainty contributions to the overall Water Analysis Module. The logic to produce uncertainty estimates in the Water Analysis Module output will be implemented and tested for the 1-, 3-, 10-, and 50-breach scenarios.

Task 2-4: Incorporation of Water Analysis Module into Risk Analysis Framework

- **Task Objectives:** Deliver the water analysis model implementation and ensure that it is functional within the Risk Analysis Framework.
- **Task Description:** The calibrated Water Analysis Module and associated base data sets will be delivered to the Risk Analysis Team for incorporation within the Risk Analysis Framework. Together with the Risk Analysis Team the Water Analysis Module will be tested for correct and efficient operation.

  Delivery and testing of the Water Analysis Module within the Risk Analysis Framework marks completion of milestone 2.

10.3 Phase 3: Verification and Refinement of the Simplified Model

Task 3-1: Verification of Simplified Model for Critical Scenarios

Task 3-1.1: Perform Runs of RMA Model for Critical Scenarios Based on Initial Output of Risk Analysis

- **Task Objectives:** Based on initial analysis with the full Risk Analysis Framework, determine the most important bounding (bookend) levee breach scenarios and perform full simulations with the RMA Bay-Delta model.
- **Task Description:** It is expected that initial runs of the Risk Analysis Framework will identify important breach scenarios that were not explicitly simulated using the RMA Bay-Delta Model. These scenarios may be important either due to particularly high probability of occurrence, or due to potentially high damages. To validate the results of the simplified hydrodynamic/water quality model, important "bookend" scenarios will be simulated with the RMA Bay-Delta Model. In this way the simplified model embedded in the water analysis model acts as a screening tool to assist in identifying the levee breach scenarios that warrant fully dynamic simulation.

  For these scenarios, the water management decisions for DICU, Inflow, and Exports predicted by the Water Analysis Module will be maintained. The RMA Bay-Delta Model will perform dynamic simulation of island flooding, tidal exchange, and island repair and pump-out.

  This task was budgeted assuming that four new levee breach scenarios will be simulated.

Task 3-1.2: Evaluate Performance and Update Simplified Model and/or Revise Uncertainty Estimates

- **Task Objectives:** Evaluate flow and salinity predictions of the simplified model relative to the RMA Bay-Delta model to validate its performance. Revise/update the simplified model if required.
- **Task Description:** The RMA Bay-Delta Model results produced in task 3-1 will be compared to those produced by the simplified hydrodynamic/water quality model. To perform the comparison the dynamic results from the RMA model will be time averaged to the equivalent time step used by the Water Analysis Module (weekly or monthly). If the results are significantly different, it may be necessary to either update the configuration/calibration of the simplified model or to increase the estimate of uncertainty associated with the simplified model output.

  This is an important validation test for the simplified model. While every effort will be made during the formulation of the simplified model to achieve a good time-averaged representation of transport in the Delta, because of the inherent complexity of the system it will not be known in advance how accurate the simplified model will be. It is possible that the validation test will identify shortcomings in the simplified model configuration or calibration that can be corrected. If so, the risk analysis should be re-run with the updated model. It is also possible that the validation test will show that simplified model is less accurate than expected, in which case the uncertainty estimate of the output will increase, leading to increased uncertainty in the final consequence assessment.

Task 3-2: Additional Refinement of Simplified Model and Uncertainty Estimate (Optional Task)

Task 3-2.1: 3-D Analysis of Dispersion Coefficients (Not Currently Budgeted)

This additional analysis would involve estimation of dispersion coefficients. The predicted salinity and salt fluxes from UnTRIM can be used to estimate dispersion coefficients that represent “three-dimensional processes.” Because the dispersion coefficients in RMA2 primarily represent the effect of “three-dimensional processes” on salt transport, the dispersion coefficients estimated using UnTRIM will be compared to those used with RMA2. These dispersion coefficients will be a function of tributary inflow due to the strong dependence of gravitational circulation on salinity gradients (Delta outflow). In addition to estimating dispersion coefficients related to “three-dimensional processes” UnTRIM will be used to estimate dispersion coefficients that represent ALL relevant transport processes. While three-dimensional processes are not represented by RMA2 and must be parameterized using dispersion coefficients, other transport processes are explicitly represented by RMA2. Therefore, the errors in transport predictions of RMA2 depend on both the importance of “three-dimensional processes,” relative to processes that are represented by a depth-averaged model, and the accuracy with which “three-dimensional processes” are parameterized in RMA2. The analysis will suggest substantial model uncertainty under conditions in which “three-dimensional processes” are important and are not parameterized accurately by RMA2. It is expected that these conditions will correspond to a range of moderate to high Delta outflow conditions.

The variability in estimated dispersion coefficients for different Delta outflows should be useful to improve the parameterization of “three-dimensional processes” in RMA2 and the parameterization of all transport processes in the simplified models.

This additional analysis will be performed pending additional funding.

Task 3-2.2: 3-D Analysis of Reservoir Releases Required to Flush the Western Delta (Not Currently Budgeted)

In the previously described analysis, the UnTRIM simulation uses the same tributary inflow (reservoir release) conditions as the RMA2 model. In the RMA2 model these inflow conditions are calculated in a water management module. The calculation of the required reservoir releases following levee failures will be made primarily based on salinity conditions in the Delta. Therefore the RMA2 hydrodynamic and water quality simulations will be coupled to the water management module while the proposed UnTRIM simulations will not be coupled to the water management module but, instead will use the same inflows as the RMA2 model.

In this optional task, the water management module would be coupled with UnTRIM. This would allow UnTRIM to calculate required reservoir releases independently of RMA2. Therefore, while the previous analysis would calculate the (different) salinity response for the same tributary inflows used in RMA2, this analysis would use UnTRIM to calculate the (different) reservoir releases required to achieve roughly the same salinity response in the western Delta.

This additional analysis will be performed pending additional funding.

<u>Task 3-2.3: Incorporate Revised Water Analysis Module into Risk Analysis Framework</u>

- **Task Objectives:** If the Water Analysis Module was updated or revised, deliver the new module and ensure that it is functional within the Risk Analysis Framework.
- **Task Description:** If the validation test leads to an update to the simplified hydrodynamic/water quality model, the updated Water Analysis Module will be provided back to the Risk Analysis Team and the risk analysis calculations should be re-run.

10.4 Phase 4: Evaluation of Risk Reduction Alternatives

- **Task Objectives:** Perform multi-dimensional modeling using the RMA Bay-Delta model and the UnTRIM model to evaluate the effectiveness of specific physical configuration and operational alternatives to minimize risks associated with levee breach scenarios.
- **Task Description:** Scope and schedule to be determined once the initial risk analysis is complete.

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