DELTA RISK MANAGEMENT STRATEGY

INITIAL TECHNICAL FRAMEWORK PAPER

UPSTREAM RESERVOIR MANAGEMENT / DELTA WATER OPERATIONS / DELTA ISLAND WATER USE

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Note

Details of Hydrodynamics & Water Quality are provided in a separate Initial Technical Framework Paper

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 paper presents an overview of the entire Water Analysis Module (WAM) and describes the detailed approach of and input needs for the submodels addressing upstream reservoir management, Delta water operations, and Delta island water use. A companion paper describes the detailed approach of and input needs for the hydrodynamics and water quality submodels. The separate papers occurred initially as a convenience of authorship. They have been maintained as separate papers (at the request of DWR) as a convenience for review. However, reviewers of each paper need to realize that the other paper exists and that both are essential to the unified design and functioning of the WAM.

Specifically, this ITF paper describes modeling of Delta water conditions within the context of levee breach incidents, as needed for risk analysis (phase 1) and risk reduction options evaluation (phase 2) for the DRMS. The ***Water Analysis Module*** (or ***WAM***) includes simulation of initial island flooding, upstream reservoir management, Delta water operations, water quality disruption of Delta irrigation, Delta consumptive water use, hydrodynamics, water quality, and water export.

The WAM calculates the direct, water-quality-related consequences of levee breach events. The module fits in the center of the risk analysis framework receiving the sequence description of a breach event from the seismic or flood hazard, levee fragility, and emergency response and repair modules. It provides water supply, hydrodynamic, and water quality consequences to the economic and environmental modules (Figure 1). Because the water quality consequences of levee failure in the Delta 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, exports, other uses, and on the water management decisions that influence these factors, the WAM is proposed as a simulation model that tracks water management and the Delta’s response from the initial breach event through the repair and recovery period.

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1.0 INTRODUCTION

This document describes modeling of Delta water conditions within the context of levee breach incidents, as needed for risk analysis (phase 1) and risk reduction options evaluation (phase 2) for the Delta Risk Management Strategy (DRMS). The ***Water Analysis Module*** (or ***WAM***) includes simulation of initial island flooding, upstream reservoir management, Delta water operations, water quality disruption of Delta irrigation, Delta consumptive water use, hydrodynamics, water quality, and water export. The following discussion describes the context within which this module will be used, information that will be available to it, outputs that it must generate, and the approach for its development. Note that modeling for initial flooding and flushing, hydrodynamics, and water quality is described in more detail in a separate Initial Technical Framework Paper (ITF).

The WAM calculates the direct, water-quality-related consequences of levee breach events. The module fits in the center of the risk analysis framework receiving the sequence description of a breach event from the seismic or flood hazard, levee fragility, and emergency response and repair modules. It provides water supply, hydrodynamic, and water quality consequences to the economic and environmental modules (Figure 1). Because the water quality consequences of levee failure in the Delta 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, exports, other uses, and on the water management decisions that influence these factors, the WAM is proposed as a simulation model that tracks water management and the Delta's response from the initial breach event through the repair and recovery period.

The water management, hydrodynamics/water quality, and water export aspects of the risk analysis framework are combined into a single module because there is a tight coupling between reservoir operations upstream of the Delta, hydrodynamics and water quality transport within the Delta, and the ability to use or 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 submodels incorporated into WAM will be responsible for calculating Delta water operations, upstream reservoir releases, and exports immediately following a breach event and throughout the repair/recovery period. The decision submodels may be based on operating rules included in existing models of the California water system (upstream of and including the Delta pumps). CalSim is an important example of such an existing model. 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 order to properly develop the decision submodels.

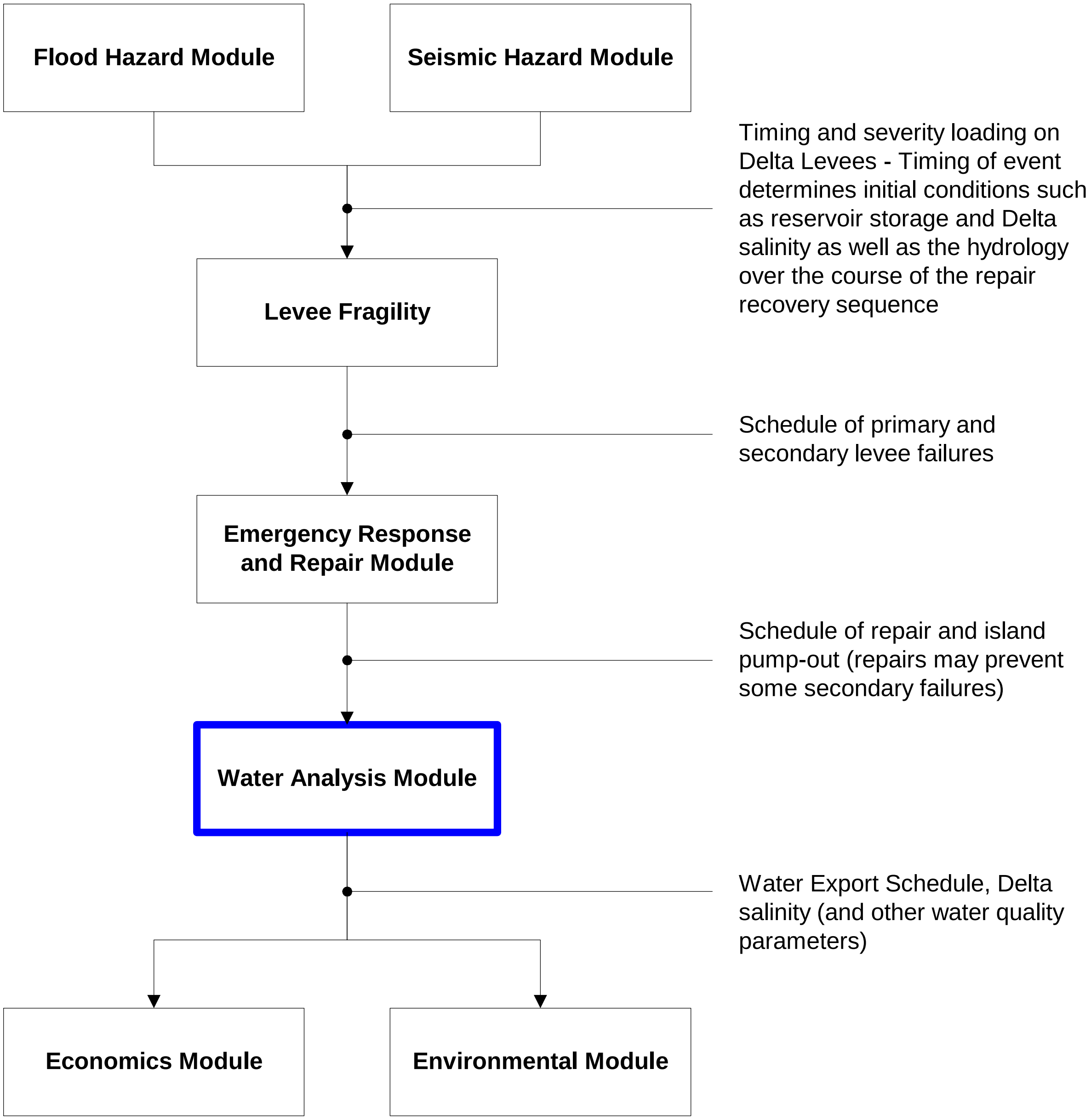


Figure 1: Position of the Water Analysis Module in the Risk Analysis Framework

The hydrodynamics/water quality submodel incorporated into the WAM will be responsible for calculating the water quality distribution in the Delta over time. Because the full risk analysis will require evaluation of hundreds if not thousands or tens of thousands of discrete levee breach sequences, the WAM 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 WAM. 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 WAM 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 more correctly represents the magnitude of consequences produced by the full Delta models. The approach for developing the simplified hydrodynamics / water quality model is detailed in another paper.

The WAM will receive an explicit description of a levee breach sequence and produce the conditional probability distribution of consequences based on that sequence. As required 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 water management decision models and hydrodynamics/water quality models. Sources of uncertainty include configuration data, initial conditions, parameters, and the ability of the model to reproduce observed data (normal operations and limited observations of historic breach events). Further information regarding uncertainty in the salinity response will be gathered by highly detailed three-dimensional simulation of select conditions.

Clearly, the water quality versus time that results from a given sequence will be random. Similarly, the time required so that various water quality dependent uses can recover will be random. We cannot precisely predict when water export can resume based on pumping criteria being satisfied or when other Delta water uses and ecosystem functions can return to normal. Nor will we have precise water quality estimates to characterize impacts. The randomness is due not only to the modeling uncertainties mentioned above, but also to the randomness of the inputs to the analysis (e.g., flooded islands, time of year, hydrologic inputs as the incident unfolds) and the randomness of the water system's and the Delta's response to the dynamic effects of levee failures. Because at least some of the outputs from the WAM will be time-series (water exports for example), an appropriate concept for variance for the time-series will have to be established.

2.0 OBJECTIVES

There are two general objectives for water analysis corresponding to the risk analysis phase (the base case) and risk management phase (options for risk reduction) of the study. During the risk analysis phase (first phase), the WAM is required to estimate the water-quality-related effects of levee breach incidents on water export, in-Delta water use, and environmental conditions. These effects are to be based on a wide range of explicit levee breach sequences for the present Delta configuration and the generally accepted current operating procedures. During the risk reduction phase (second phase), the WAM will assess water-quality-related effects of proposed physical and operational options for reducing the risks and consequences of levee breach events.

Concentrating on the risk analysis phase (the base case), the work products of water analysis will take at least five forms:

- A Water Analysis Module (WAM) – A computer code for calculating a specific set of water related outputs for a given set of levee breach incident inputs. This module will be suitable for use in the overall risk quantification model for calculating the required outputs in each of several thousand levee breach sequences.
- Required databases – The water data needed to drive and support the WAM will be developed by the WAM Team. This will include hydrologic data, water quality data, consumptive use data, and characteristics of the Delta and water management system. Supplemental water data will be developed and organized as needed in other modules, for example, south of Delta water storage data and hydrologic inflows.
- A limited number of more detailed analyses – So-called anchor sequences that will be calculated with more sophisticated and detailed computational tools in order to provide verification and a more complete representation of module results for a few examples.
- Carefully designed sidebar studies to answer specific questions, as necessary, in module development – For example, a three dimensional study of stratification may be needed to contribute to the above analyses or to estimating uncertainty. An additional example is an initial evaluation of the extra Delta outflow required to repulse salinity in response to various amounts of sea level rise.
- Supplemental information, as needed, for other module teams – For example, the Levee Vulnerability Team needs water surface levels and flow velocities during island flooding immediately following event initiation. The Environmental Consequences Team needs information regarding temperature and organic carbon. The Flood Hazard Team needs Delta water surface elevations from hydrodynamic simulation of specific storm events. Many teams will need Delta sea level and tide levels as impacted by climate change alterations to be seen at the Golden Gate.

Given the above, it is helpful to define objectives for water analysis on two levels – those for the overall water analysis work effort and more specific objectives for the WAM.

2.1 Objectives of the Water Analysis Work Effort

The objectives of the water analysis work effort are the following:

- To develop an accurate WAM, suitable for use in the risk calculation (see specific objectives below) and that will effectively represent necessary system processes and stand up to scrutiny under peer review.
- To establish simulation tools (including a WAM structure) that will be useful in the second phase of the DRMS project for assessing the water-quality-related effectiveness of risk management options – for example, installation and operation of barriers.
- To provide anchor sequences, supplemental water-related data, and results as needed for module verification and as requested by other technical teams to aid in developing their risk assessment modules (for example, for the Flood Hazard Team or the Environmental Consequences Team).

2.2 Objectives of the WAM

A specific requirement of this module is the capability to estimate – for each sequence that may be postulated in the risk analysis – the conditional probability distribution on monthly exports, ESM, (for station S and month M) for each of five Delta pumping stations for the duration of the incident (Figure 2). Each other module output (e.g., in-Delta water use or water quality at any specific location) can be characterized by an analogous illustration.

Thus, the objectives of the WAM can be summarized as follows:

- To simulate the water management decisions that must be made following a levee breach incident – in particular, the decisions that affect upstream reservoir releases, in-Delta uses, exports, and Delta outflow – and to translate those decisions into estimates of these effects.
- To simulate the hydrodynamic and water quality responses to a levee breach incident (sequence) and the resulting water management – characterizing Delta salinity (in space and time) as needed to estimate required module outputs.
- To calculate (and provide as output) a priority order for flooded island repair based on the initial salinity intrusion and hydrodynamic characteristics occurring in the sequence.
- To provide, for each simulation output, the probabilistic estimates necessary to characterize epistemic and aleatory uncertainty.

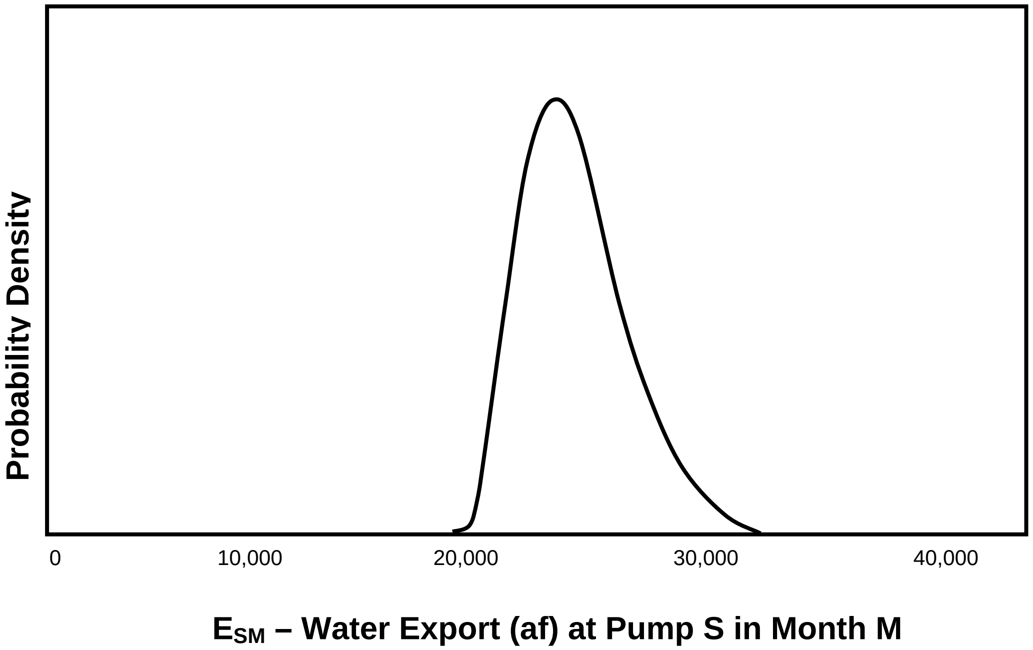


Figure 2: Illustration of a Probability Density Function on Water Export for a Pumping Station and a Particular Month

3.0 PHYSICAL AND OPERATION 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. 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 list of water oriented physical and operational issues and 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 water drawn from river inflow and higher salinity water drawn from the bays. Therefore, when salinity is drawn in, the concentrations tend to be higher in Delta channels than in flooded islands during the initial flooding phase. Similar flooding occurs when secondary breaches flood new islands later in the incident, but secondary breaches are less likely to be simultaneous. Thus, river inflows are more likely to provide a significant portion of the flooding flows.
- **Suspension of Exports** - At the time of the event, exports will typically be suspended or reduced in order to minimize salinity intrusion, inspect facilities, and evaluate the salinity distribution in the Delta.
- **Flushing Releases** - If the initial flooding brings high salinity water into the western Delta, it would 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, Clifton Court Forebay, and south Delta barriers would be considered and possibly changed to enhance effectiveness of flushing releases. Temporary south Delta Barriers might need to be breached or removed.
- **Emergency Procedures** - If the initial flooding is severe, emergency procedures might be implemented such as placing additional temporary channel barriers in strategic locations.
- **Initial Tidal Mixing** - Following the initial flooding (and flushing, if applicable), the salinity distribution in the Delta will be far from equilibrium. Over a period of weeks, strong salinity gradients generated by the flooding will diminish with 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 where tidal exchange is now modified by the

breached islands. During this period of initial tidal mixing, high salinity water in the channels will mix 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 damage will be stabilized and levee breach ends will be capped to prevent breach widening. Then, based on the availability of material, equipment, and personnel, breaches will be repaired over a period of months or years, depending on the number of breaches. The island stabilization and breach closures will be prioritized to most effectively facilitate restoration of Delta uses, which include local property use, infrastructure, Delta agriculture, environmental values (such as endangered fish species), recreation, and water exports. Delta island agriculture and water exports are particularly sensitive to restoration of water quality and this will be markedly impacted by the repair order selected. As levees are repaired, the active tidal prism in the Delta will return 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 and the unprotected interior levee slopes. Secondary failures may extend the repair schedule and could flood additional islands drawing additional high salinity water into the Delta.
- **Reservoir Management** - Throughout the repair and recovery period upstream reservoir release decisions will be based on managing the salinity in the Delta, providing essential environmental flows (e.g., for endangered fish), providing for Delta exports and in-Delta use if possible, meeting flood control requirements, and providing for water users upstream of the Delta. At the same time, the reservoirs must be managed to save enough water to meet needs in future years – years that could be wet or critically dry or anything in between. Managing Delta salinity involves balancing Net Delta Outflow with tidal mixing to meet water quality needs. Tidal mixing will be strongly affected by the un-repaired breaches because they will allow exchange between flooded islands and channels and alter the tidal currents in Delta channels. These factors will create extra demands on upstream reservoirs.
- **Export Decision Making** - The ability to export water from the Delta for municipal or agricultural 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 released 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 Estimation** - 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 either increased or decreased during the repair and recovery period. Evaporation from flooded islands may be greater than normal evapotranspiration increasing DICU. High salinity in adjacent channels may prevent normal irrigation on unflooded islands decreasing DICU.

- **Channel Scour** - The high velocity flows during initial flooding and the increased tidal prism (and flow velocities) associated with breached islands may cause channel 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 the salinity may have a significant impact on Delta water quality and on when the island can be returned to agricultural production.
- **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 throughout 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 that tributary flows take through the Delta. Changes in tidal and residual flows in the Delta channels will alter the Net Delta Outflow required to maintain Delta water quality.
- **Other Water Quality Issues** - In addition to changes in salinity, island flooding may impact other water quality parameters important to economic and environmental consequences – parameters such as temperature, dissolved or total organic carbon, dissolved oxygen, and toxic contaminants. Heating of shallow breached islands may, through exchange with the 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.

4.0 APPROACH FOR WATER MODELING

Using the most sophisticated modeling tool, and adding capabilities for modeling upstream water management and Delta water export, the analysis of the hydrodynamic response of the Delta is a computationally intensive undertaking. Due to the numerical nature of hydrodynamic analysis for a system such as the Delta, it is not possible to analytically derive a conditional probability distribution on the Delta's performance and resultant monthly water export from each pumping station (E_{SM}). Further, since the computational effort is so demanding it is also not practical to carry out a Monte Carlo simulation to obtain a dataset that could be used to derive the correlated conditional probability distributions on each E_{SM} in a sufficient range of sequences. Such an approach could easily run into many thousands, if not tens of thousands, of months-long calculations. Thus, from a practical perspective, performing the water simulations that are required to derive a distribution for each sequence is prohibitive. Nonetheless, we are still faced with the requirement for estimating the variability in the water quality and related responses of the Delta to the random effects of levee breaches.

Our task in developing the water module of the risk analysis is two fold. First, we must develop both a "water management modeling approach" and a "hydrodynamic modeling approach" (i.e., an efficient, yet accurate computational means) to evaluate the response of the water system and Delta in order to estimate each E_{SM} and the other water quality consequences needed by the in-Delta economic and ecosystem modules. The need for computational efficiency occurs because the model will be used to evaluate a potentially large number of sequences and the effects of several random factors that impact the response of the Delta. Figure 3 illustrates the relationships that must be captured in an influence diagram.

Secondly, given our water modeling approach, a probabilistic model must be developed to model the aleatory and epistemic uncertainty in E_{SM} and the other water-quality-related outputs. Two considerations apply to development of this model. First, it necessarily is a function of the random variables that affect the response of the water system and Delta and thus the water exports and other water quality consequences. In addition, the probabilistic model is a function of the approximations inherent in the water models and modeling approaches that are used.

In developing the cause-effect portion of the water model, a series of submodels will be used, as illustrated in the four flow charts presented in Figures 4 through 7. These flow charts illustrate the way in which the WAM will functioning and fit into the overall “Risk Calculator.” The more detailed idea (i.e., more detailed than Figures 1 and 3) in hooking up all the modules in a sequence within the “Risk Calculator” is:

- Hazard initiates the incident – e.g., an earthquake, flood or some other driving force,
- Levee Vulnerability defines initial breaches,
- WAM provides the initial, salinity-based priority order for flooded island repair,
- Levee Emergency Response & Repair coupled with Ongoing Damage provides actual repair progress (or lack thereof due to ongoing damage),
- Other Water Infrastructure Failures & Repair details impacts on and repair schedule for non-levee components of the water system (e.g., Delta gates, barriers, and pumping plants),
- Main WAM provides water quality impacts, Delta agriculture water use, and exports, and
- Economic and Environmental Consequence Modules estimate consequences.

Each module calculates for all the time involved in the incident (sequence) and then passes its results on to the next module. Thus, a module cannot know the results of downstream modules, even for times earlier than the present calculation step. That is why the salinity-based priority is presented as an early, one-shot calculation that is an initial contribution from WAM. It is not updated (using secondary breaches) so that we avoid a feedback loop; it just gives an initial assessment of priorities for flooded island repair based on the salinity distribution that results from flooding and initial flushing of the islands that were breached by the initiating event.

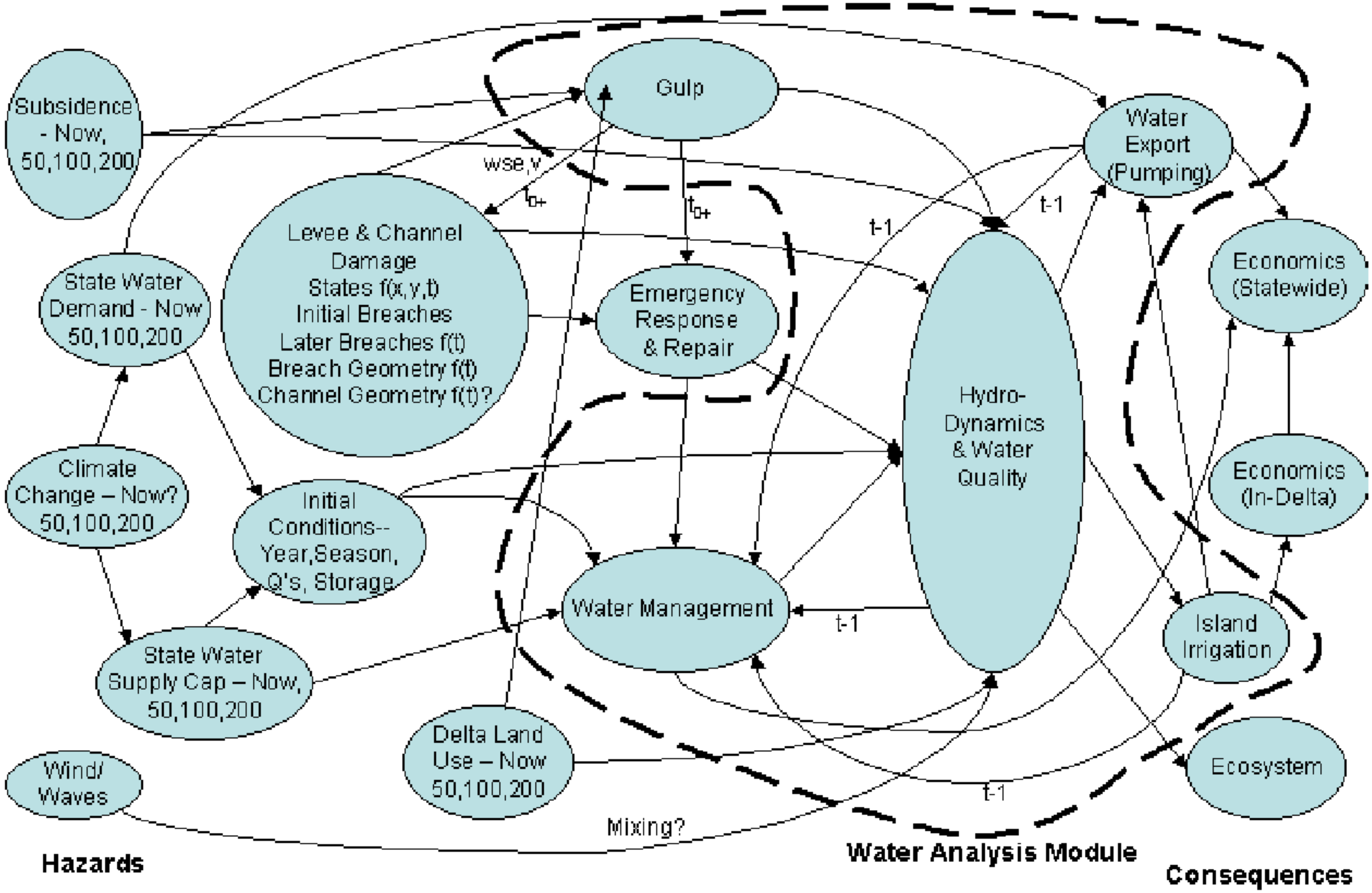


Figure 3: Water Analysis Module Influence Diagram

Flow Chart Legend:

▱	Method (subroutine) Input or Output passed as arguments or I/O files
⬭	Method (subroutine) Start/End points
⌭	Base data sets stored on disk
▭	Temporary file(s) for saving program state
⬟	Reference to method in another flow chart
◇	Program flow control
W#:	Water Analysis Module data management procedure
M#:	Reservoir Management/Operations Decision (Release/Export) procedure
D#:	Delta Operations Decision procedure
H#:	Simplified Hydrodynamic/WQ model procedure

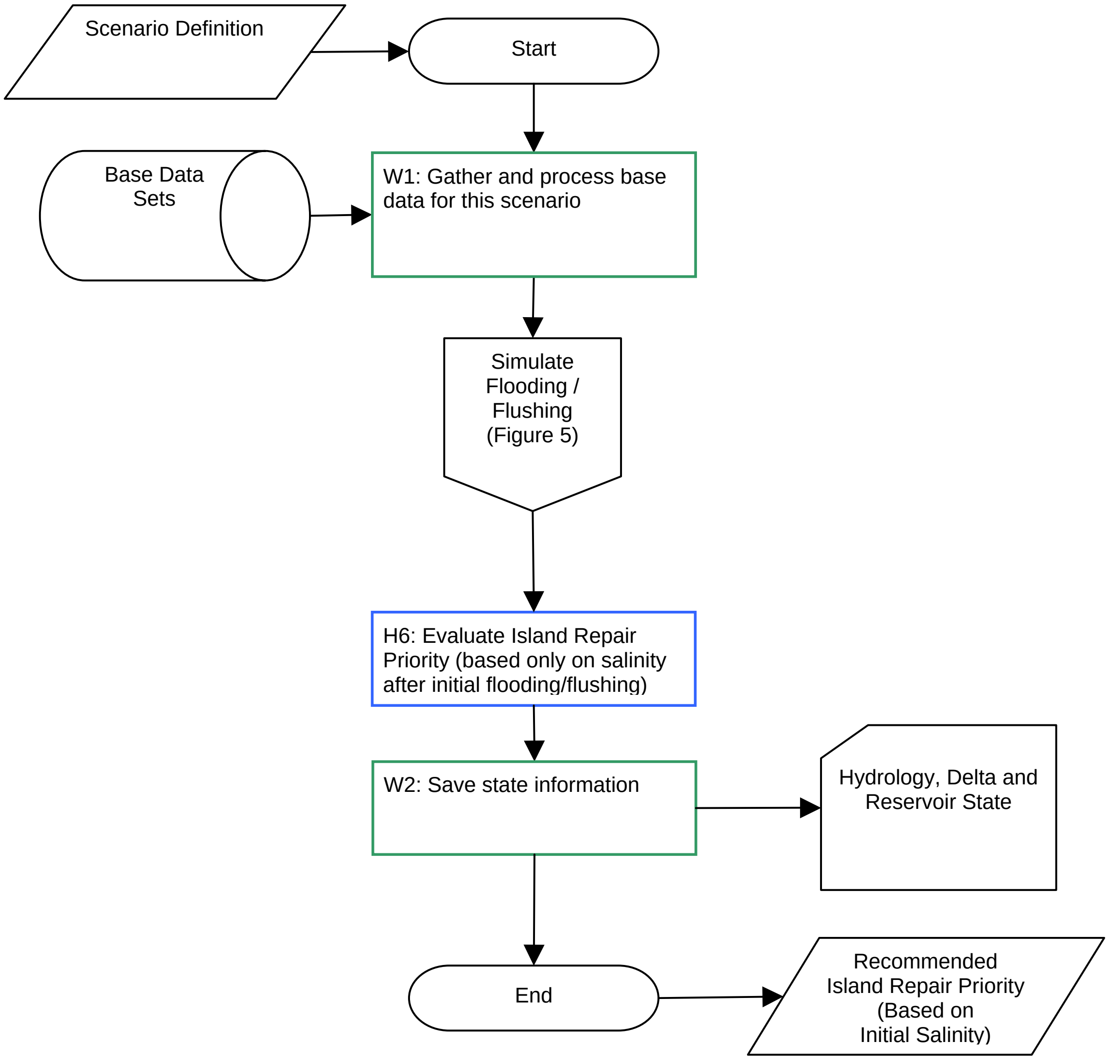


Figure 4: Initial Flooding/Flushing and Evaluation of Salinity-Based Island Repair Priority to Be Performed Before the Levee Emergency Response & Repair Module is Called.

Period simulated is the time required to flood all initially breached islands – on the order of 1 day to 1 week as determined by the hydrodynamic model and provide initial flushing up to end of first month. State information is saved for use by the Water Analysis Module later (Figure 6) – after the Levee Emergency Response & Repair Module has determined the actual repair schedule, including schedule slippage due to ongoing damage, diversion of repair resources to address ongoing damage, and inclusion of repairs for secondary breaches and additional islands flooded.

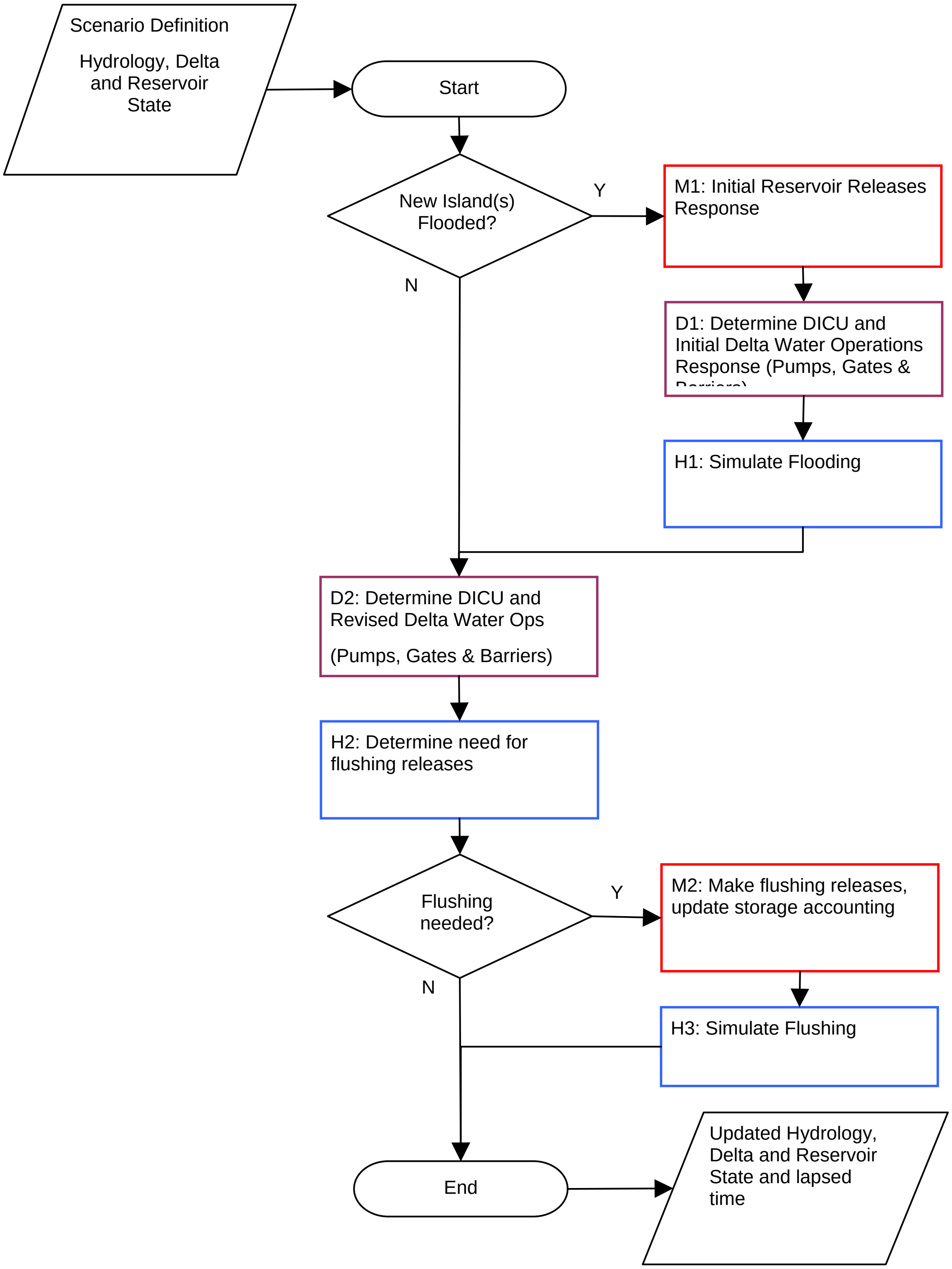


Figure 5: Simulating Flooding and Flushing with Water Operations Response.

The period simulated is the time required to fill all islands and receive flushing releases, which is expected to be on the order of 1 day to 1 month as determined by hydrodynamic model and water management model.

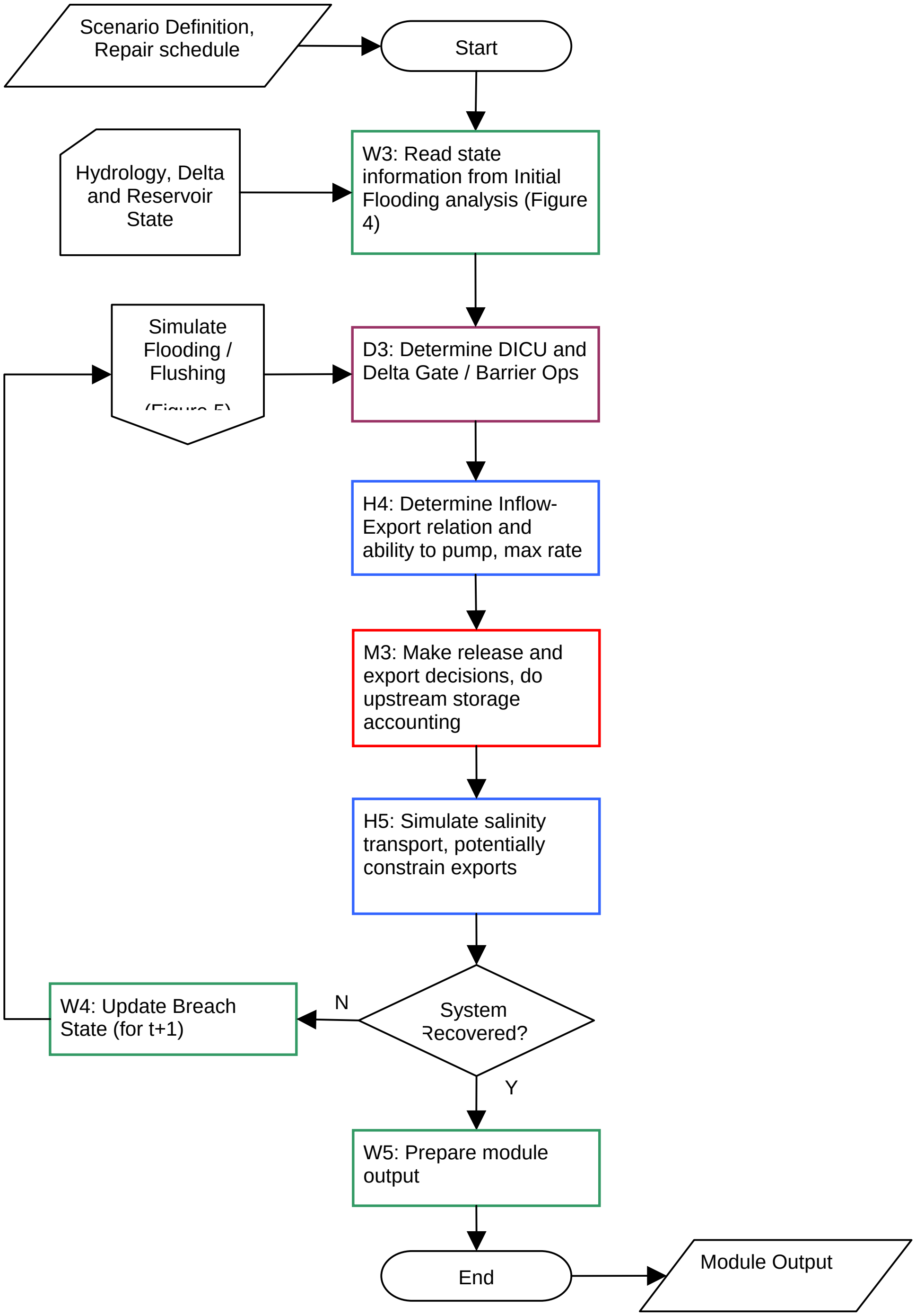


Figure 6: Main Water Analysis Module (Main WAM) Logic Flow Chart.

It is assumed that initial flooding was evaluated as a separate process (Figure 4) before the Levee Emergency Response & Repair Module determined the actual repair schedule. The state after initial flooding/flushing was saved to disk and is now retrieved. Each loop moves the simulation forward one time step (possibly 1 week, 2 weeks, or 1 month). If flooding occurs during a time step, then the time spent in “normal” operation is equal to the time step length minus the time lapsed during flooding (and flushing, if required).

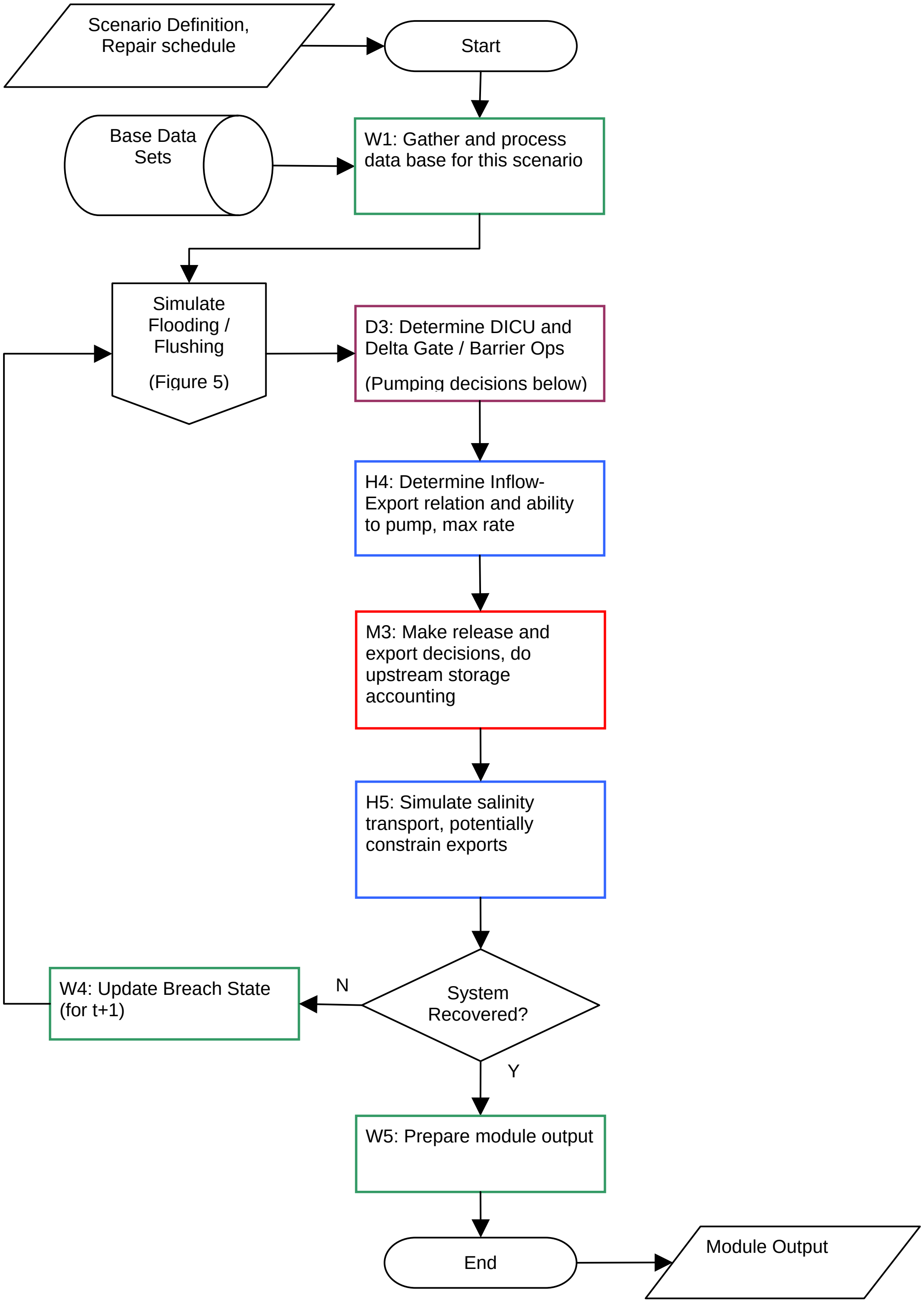


Figure 7: Alternate for Figure 6 Main Water Analysis Module Logic Flow Chart Without Reading Previously Saved State from Initial Flooding and Flushing.

(We may redo initial flooding and flushing calculations to avoid having to store/read state data, which makes sense if we are doing a batch of WAM runs independent of a specifically defined risk sequence.)

WAM must be developed as a coupled time-step simulation to capture the interaction of upstream reservoir management and Delta salinity. A great deal of interconnection and feedback will be required among these submodels in order to reflect incident progression for all the submodels and to guide the Delta toward water quality improvements until in-Delta water use and pumping are reestablished and then to provide required Delta inflows to support these uses without unacceptably degrading water quality. For this reason, Figures 4 through 7 incorporate all these submodels into the overall “Water Analysis Module” or WAM and address the need for interconnection and feedback by modeling the time series as steps – so that each temporal state can be a function of the relevant prior states represented in the other submodels.

It receives, from the Levee Vulnerability and the Levee Emergency Response and Repair Modules a schedule of secondary breaches and repair progress (updated levee breach states) on a monthly basis. The one thing that is a residual uncertainty is how to know that recovery is complete, assuming that recovery includes rebuilding south of Delta surface and groundwater storage, restoration of damages (e.g., salinity buildup in farmland), and normalization of deliveries. The status south of Delta is unknown to WAM because it is managed in the Export Economic Consequences Module, which is downstream of WAM. In an actual levee breach incident, water managers will know south of Delta status during recovery and will be able to judge when recovery is complete. WAM will need to use an artificial measure, such as providing excess post-event deliveries to make up some fraction of the delivery deficiencies caused by the incident.

Upon completion, the WAM outputs monthly average export volumes and salinities, monthly averaged salinity at key Delta locations, island status (flooded, irrigated), end of period upstream reservoir storages, and other summary information. The module will operate internally on a weekly to monthly time step, with shorter steps for periods of island flooding and short term flushing.

The flow charts (see Figure 7 for the best overview) illustrate the following basic logic for WAM:

- 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 entire simulation period. If several years are involved, different sequences of water year types will have to be considered and this will require either several or branching simulations.
- At initiation and at the beginning of every time interval, the model will update the levee breach state, as affected by secondary breaches and repair progress.
- If new islands are flooded, the model simulates immediate emergency water operations and evolution of the salinity distribution for the number of days it takes to fill the islands.
- Based on estimated conditions when the islands have filled, the model will calculate whether flushing releases are needed to satisfy Delta salinity criteria. If flushing releases are needed, the reservoir management component makes releases based on the need and water availability. The model then simulates the evolution of the Delta salinity distribution for the number of days that flushing occurs.
- Delta Island Consumptive Use (DICU), both diversions and returns, are revised based on the Delta salinity distribution and the island breach state, considering evaporation from flooded islands and decreased evapotranspiration if channel water is too salty to irrigate.

- The ability to pump for export is evaluated based on pump damage, salinity criteria, and the required Delta outflow versus exports relation (see below for more description).
- The reservoir management component makes reservoir releases and export decisions for the remainder of the time step and updates the reservoir storage accounting.
- The hydrodynamic/water quality component simulates salinity 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 developed, 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. Some additional consideration will be given to whether south of Delta surface and groundwater storage have recovered, farmland salt balances have been restored, and water deliveries have returned to normal.

Because the salinity state following the initial flooding event is expected to have an impact on island repair priority, the initial flooding analysis by the WAM will be run before the Levee Emergency Response & Repair Module (see Figure 4). In this case, it will be the WAM's responsibility to recommend the island repair priority based only on salinity concerns. The Levee Emergency Response & Repair Module will consider the recommendation along with other criteria in determining the actual levee repair schedule.

The WAM calculator will operate in time steps that vary a bit (internal to WAM), depending on what is going on. The key parts are:

The Flooding & Flushing Period – Initially, this is the time from when the earthquake occurs and causes levee breaches (or when the flood, tide or winds start breaching levees) until island flooding (and perhaps an additional period of initial flushing) is complete (see Figure 5). The key output product is a Delta salinity distribution at the end of the period. This period will vary in length base on the magnitude of the event and other context definitions. It might be only one or two days for one or two breaches, but it would be at least two weeks and perhaps much more for 50 breaches. The envisioned hydrodynamic model requires separate calculations for flooding and flushing. Water operations, in these two steps will start with the initial, immediate responses of project operators (hold reservoir releases constant and decrease pumping to one CVP pump at Tracy). Then, for the flushing period, revisions to water operations will be considered – open the Delta Cross Channel gates (if they were closed and fisheries agree to open them), shut down the final Tracy pump (if necessary) and increase upstream reservoir releases – all in response to Hydrodynamics/Water Quality model requests. The salinity distribution at the end of the flushing period will then be estimated. For this initial period, the "Salinity-Based Priority Order of Island Repair" will also be provided for consideration in scheduling repair work (see Figure 4). Flooding and flushing periods may also occur in later months, based on the occurrence of secondary levee breaches that flood new islands. Flushing periods could last for several months in major events.

Regular Periods – The first of these could be the rest of the month containing the initial period, provided that flushing is completed in less than a month. In a major event the first regular period could be delayed until several months of flushing have occurred after event initiation. The regular period is a Delta salinity maintenance, fine-tuning, and export management period. It will include Delta inflows needed to keep Delta salinity levels acceptable while permitting water exports. The needed inflows will be estimated by the hydrodynamics/water quality model. It will specify a Delta outflow versus exports relationship so that the reservoir management subroutine can recognize the water cost (extra Delta outflow) for various levels of exports and manage available storage according to present and prospective needs. Then reservoir releases will be provided to satisfy Delta outflow, in-Delta use and exports.

There are seven key subroutines that are of primary importance in the Water Analysis Module – important because they are the most difficult and represent crucial innovations that must be achieved for a successful effort. These include five subroutines that apply a simplified hydrodynamic/water quality model and two subroutines that manage upstream reservoirs to provide Delta inflow and, at the same time, retain enough storage upstream to provide for future needs.

The key hydrodynamic/water quality subroutines are:

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 to be 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, 50 breach scenarios developed in the earlier Preliminary Seismic Risk Analysis. Given the time to fill estimate, net flow rates can be determined for each island that is flooding. The salinity distribution can then be simulated with net flows and tidally average dispersion.

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 will be estimated to push the salt gradient seaward. An estimate of the flushing volume may be developed based on 1) the volume of water in the main channels that must be displaced to move the salinity gradient downstream the required distance plus 2) the flow over the flushing period required to compensate for the tidally averaged dispersive flux tending to push salt upstream.

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

H4: Estimate the required Delta outflow versus export relationship and ability to pump – The ability to pump will be a function of pump damage and Delta salinity. Conditions that will constrain pumping include the following:

- A pump has suffered damage due to seismic activity or flooding and is unrepaired,
- 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 total salt mass in channels south of the San Joaquin River is too much for south of Delta water users to accept.

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 south Delta channels can be accepted by south of Delta water users.

The model must also estimate the Delta outflow versus export relationship that is appropriate for the current breach state. This relationship will vary depending on the number and location of breaches. In general, the more islands actively filling and draining, the more tidal mixing will occur and result in greater need for net Delta outflow to combat dispersion of salt into the Delta.

H5: Simulate salinity transport - This will consider Delta inflow, 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.

The key water/reservoir management routines are:

M2: Decide what flushing releases can be provided responsive to the H2 request, considering the type of water year, time of year, available storage, and prospective needs in future months.

M3: Decide what releases to provide to Delta inflow (for DICU, Delta outflow and exports), considering the type of water year, time of year, available storage, the required Delta outflow versus export relationship provided by H4, and prospective reservoir needs or Delta improvements in coming months.

5.0 WAM CONTEXT AND INPUT REQUIREMENTS

Given the occurrence of a major incident (e.g., seismic, flood, or other) that impacts the Delta and its levees, all or the majority of the Delta's assets that have a role in water exports and that may affect Delta water quality will be simultaneously challenged, leading to the potential for multiple levee and other asset failures and a protracted period of water quality and export disruption. In the risk analysis, an evaluation will be conducted that will identify and examine ***all*** the hazard-initiated sequences that could occur and their likelihood of occurrence. The WAM must be capable of characterizing the relevant water-quality-related responses of the Delta for each sequence. Since there are likely to be more than 10,000 sequences to be calculated, with a wide variation of circumstances, the WAM must be both robust (versatile) and efficient (in terms of computation time).

When the WAM is called upon to simulate water responses in the context of levee and other failures, the specific sequence will have been defined in terms of:

- If the incident was initiated by a flood, specific information defining Delta inflows for the flood event and a recession period (from the Flood Hazard Module).
- The Delta assets/facilities that failed and, in the case of levees, which islands are flooded and where the levee failures occurred. This will include indication of any secondary levee failures with specific times of failure and, for all breaches, the fully developed breach dimensions after capping the levee ends (from the Levee Vulnerability Module and from analysis of other failures – gates, pumping plants, aqueducts, etc.).
- The elapsed time after incident initiation when each failure will be repaired including, for the levees, the time when the levee ends at each breach are capped, when each breach is closed and, thus, the time at which the final breach closure for each island is achieved. This schedule will include allowances for diversion of repair resources to address non-breach

damage and to prevent, control, or repair additional ongoing damage as necessary (from the Levee Emergency Response and Repair Module and Other Failures). Note that a preliminary WAM output will be a preferred order of repair for the flooded Delta islands based on initial salinity and it will have to be made available before the above repair schedule can be finalized.

- The rate of pumping and the elapsed time to completion for pumping out of each repaired island (from the Levee Emergency Response and Repair Module).
- If a conclusion is reached that complete repair cannot be accomplished, indication of the time when this new response strategy is adopted, what additional repairs or Delta modifications are to be completed, when these are to be finalized and what islands are to be deferred (from the Levee Emergency Response and Repair Module).
- For the time at which Delta operations return to normal, the estimated south of Delta storage deficit that must be filled to complete water system recovery (assistance from the Economics Team, possibly defining this external to the economics module based on a measure of incident duration and/or severity in order to avoid the complication of a feedback loop).

Supplementary independent variables that will be available include:

- Type of water year – At least three types of water years will be used to represent the spectrum of possibilities. These would be dry, normal, and wet water years conforming as closely as possible to definitions used in DWR Bulletin 160 studies. Further consideration will be given to using the five categories defined for the Sacramento River Index.
- Time of year (season) – At least four alternative incident initiation dates during the year will be used to represent the full spectrum of seasonal conditions that may occur. These would be January 1, April 1, July 1, and October 1. It may be necessary to consider other start times to adequately represent the flood hazard.

These variables will have the effect of creating at least twelve and as many as sixty sub-branches for each sequence on the system model event tree and will be weighted so that the frequency for each sub-branch of the sequence is quantified. They will have to be established in coordination with the Flood Hazard Team for flood events.

The above input requirements are briefly summarized in Table 1.

6.0 DATA REQUIREMENTS

The following basic input data will be required for WAM development:

1. The topography of the Delta and Suisun Marsh islands and channels so that flows through the channels and especially the volume of water required in flooding each island is accurately known. This island topography must reflect the impact of subsidence to the time being modeled. Channel alterations over time or due to the event will not be considered in the base case risk analyses. The proposed operable barriers in the south Delta will be included in defining base cases for future years. Some channel alterations or new barriers may need to be considered in the risk management phase.
2. Mean sea level and changes in tidal patterns (if any) as impacted by climate change for future analysis times.

3. Impacts of climate change and state population growth on the State’s water supply system and water demands (e.g., transfers from agriculture to urban and demand changes, if they can be estimated and are significant) for future analysis times.
4. Specific base case assumptions for any facility changes to the State’s water supply system for future analysis times.
5. Operating rules for emergency management of the water supply system, north of the Delta (to calculate Delta inflows) and in the Delta (to calculate water quality and permissible export pumping).
6. Delta water quality standards.

The following data will be required to establish WAM initial conditions: (Note that these conditions will likely be established as part of module development for the selected types of water year and seasons of year – e.g., the twelve or more combinations selected.)

7. The water resource state at the time of incident initiation. This will take the form of several quantitative measures, including north of Delta and south of Delta storage. The detail required will include south of Delta groundwater storage and local storage by federal and state contractors. The state of the resource will be a function of State water system capacity and demands, type of water year, time of year when the incident occurs, and antecedent water conditions. The several variables will be correlated. There will be a probabilistic aspect to the variables; each will have a median (or mean) and a variance.
8. Delta inflows (including salinity), from each inflow source, for the month preceding the incident.
9. Delta water quality (salinity) for the month leading up to the incident
10. Export pumping (including salinity) for the five pumping stations for the month leading up to the incident.
11. The settings of Delta gates and barriers, especially the Delta Cross Channel gates and south Delta temporary barriers.

The following input data to the WAM will be required to drive the module: (Given the selection of year type and event start date combinations, these time series will have to be established as an input for each combination.)

- Tide data (at the Golden Gate) for the duration of the incident. Changes in mean sea level as impacted by climate change will need to be reflected in this input (this will not include any storm surge component; if surge is applicable, it will need to be provided as a hazard input).
- Basin/reservoir inflow hydrology (including salinity), Delta island consumptive use and normal exports for the event water year.
- For multi-year incidents, a selection method and hydrologic data for various types of second and subsequent water years will have to be provided.

7.0 OUTPUT REQUIREMENTS

The WAM must calculate the following outputs (including uncertainty parameters, as appropriate) for any specified sequence:

- Preferred order of island repair based on Delta salinity as calculated for the end of the initial flooding and flushing period. This is to be input to the Levee Emergency Response and Repair Module for scheduling.
- Water exports and average salinity (by month) throughout the incident and recovery period at each of the five Delta water export pump stations for use in the Water Export Economic Consequences Module.
- Water availability (based on salinity) at the channel takeout points for each unflooded island for use in the In-Delta Economics Module.
- Salinity (monthly average) at key locations for the Environmental Consequences Module.

These are the primary outputs that must be provided to other modules of the calculator. There is some possibility that other module outputs will be identified as useful, so the above list may be supplemented to the extent such outputs can be calculated in a practical manner.

Supplemental water quality information (perhaps more details on salinity and including temperature and organic carbon, with uncertainty parameters) will be provided to the Environmental Consequences Team based on detailed model runs for key “anchor” sequences.

Other teams may also have additional special information needs. These will be external to the WAM and will not be part of the calculation made for each sequence.

8.0 SUBMODEL DETAILS

The following Appendices provide additional details on each of the four major types of submodels that are assembled in the flow charts shown in Figures 4 through 7. These are:

Appendix A: Hydrodynamics and Water Quality

Appendix B: Upstream Reservoir Management

Appendix C: Delta Island Consumptive Use

Appendix D: Delta Water Operations

Table 1
Water Analysis Module (WAM) Computational Processes

Process	Description	Input	Output
W1	Gather and process base data for the given scenario. This task involves selection of the hydrology for the entire simulation period and determining initial (antecedent) conditions for all reservoir storage levels and Delta salinity state.	Scenario description (module input) Base Data Sets	Hydrology Initial reservoir storages Delta salinity distribution Base DICU
W2	Save system state	Current state data for all WAM components	File with state data
W3	Read system state	File with state data	Current state for all WAM components
W4	Update breach state	Levee failure and repair schedules	Current breach state
W5	Prepare module output. Perform all required post processing to information for subsequent risk analysis modules	Current state data and time series of exports, salinity, etc	Monthly exports & average salinity Monthly salinity - select locations Island Status – Flooded? Irrigated? Monthly upstream reservoir storages
D1	Determine DICU based on date, salinity distribution/ irrigation available, and island state (flooded or not) For flooding period, use 1/30 per day of monthly DICU calculated for Delta after initial flooding is complete. Determine initial Delta Water Operations (gates, barriers and pumps) -- reduce exports to 1 pump at CVP (base case)	Date Salinity distribution Island state Base DICU data Water System Components States Delta Water Ops Status	DICU diversions and returns at specific locations Delta Water Ops Status
D2	Same as D1 with revision/refinement of decision making for Delta Water Operations – Pumps and flow control barriers/gates, in particular the Delta Cross Channel gate and Tracy single pump operation.	Date Salinity distribution Island state Base DICU data Water System Component States Delta Water Ops Status	DICU diversions and returns at specific locations Delta Water Ops Status
D3	Same as D1 & D2, but pumping decisions occur in H4, M3, & H5	Date Salinity distribution Island state Base DICU data Water System Component States Delta Water Ops Status (except pumping)	DICU diversions and returns at specific locations Delta Water Ops Status (except pumping)
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) Current Salinity Distribution	Salinity distribution at the time when all breached islands have filled. Requested changes in Water Operations (pumps, gates, releases).

Table 1
Water Analysis Module (WAM) Computational Processes

Process	Description	Input	Output
H2	Determine need for 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 (lower releases over a longer period may require more volume, but this may reverse)	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 (M3)	Levee breach state DICU, Inflow, Exports Control Structure Operation (DCC) Current Salinity Distribution	Salinity distribution at end of flushing period
H4	Determine Delta outflow versus export relationship and ability to pump based on WQ standards, predicted salinity distribution and damage to pumps	Levee breach state Current Salinity Distribution WQ Standards Pump damage state	Outflow versus export function (determines needed inflow for various levels of export). Ability to pump at each export location.
H5	Simulate salinity transport and potentially constrain exports if WQ impacts so require.	Levee breach state DICU, Inflow, Exports Control Structure Operation (DCC) Current Salinity Distribution	Salinity distribution at end of time period Actual export volume from each location
H6	Evaluate island repair priority based on salinity concerns only.	Levee breach state Salinity distribution	Recommended repair priority by island
M1	Initial estimate for reservoir operations response – hold releases	Scenario description Hydrology Reservoir states	Delta inflows and exports during period of flooding
M2	Make flushing releases and update storage accounting. Releases may be less than requested by hydro model.	Scenario description Hydrology Reservoir states Requested flushing volume (Flow-Volume relation)	Delta inflows and exports during period of flushing
M3	Make release and export decisions, perform storage accounting for upstream reservoirs considering the inflow-export relationship determined by hydro model	Scenario description Hydrology Reservoir states Inflow-export relationship	Delta inflows and exports during period Updated upstream reservoir storage

APPENDIX A
HYDRODYNAMICS AND WATER QUALITY

The detailed background, approach, and input needs for the hydrodynamics and water quality submodels are presented in a separate ITF Paper, "Hydrodynamics/Water Quality," dated September 7, 2006. To summarize the contributions of these six hydrodynamics/water quality submodels to WAM, the outputs generated from each of the submodels are detailed here. They are an integral part of the overall WAM calculation, as shown in Figures 4 through 7.

A.1 Submodel H1 – Island Flooding

This submodel provides the initial characterization of the Delta's water quality (salinity) response to any given levee breach incident by providing the following information as primary outputs:

- The distribution of salinity in Suisun Marsh and the Delta when all breached islands have filled
- Requested follow-up changes in Delta Water Operations (e.g., pumps, Clifton Court, Cross Channel, Suisun Salinity control gates, south Delta barriers) to improve the future distribution of salinity during the incident.

A.2 Submodel H2 – Flushing Need

This submodel indicates the near-term flushing flows needed to minimize prolonged damage to Delta water quality by flushing the high salinity water while it is still concentrated in Delta channels and can be flushed most efficiently. The primary output will be:

- Requested flushing flows by inflow tributary (for first several days, couple of weeks, or rest of the first month), to move the salinity interface to an acceptable location downstream. This may be provided as a flow versus volume relationship based on the idea that higher flows for a shorter period of time may accomplish flushing with less total water due to less opportunity for tidal mixing. The requested amount (or functional relationship) will be based on a specific operating configuration (e.g., Cross Channel Gates open) and a specified distribution of the flushing flows among the Delta tributaries (e.g., Sacramento River only).

A.3 Submodel H3 – Simulate Flushing

This submodel simulates the Delta's salinity response to the actual flushing releases that are decided upon by the reservoir management submodel. The output will be:

- Tidally averaged salinity at each modeled location in the Delta and Suisun Marsh at the end of the flushing period (i.e., the salinity distribution). The end of the flushing period will be when the last of the flushing flows have arrived in the Delta.

A.4 Submodel H4 – Determine Ability To Pump and Outflow – Export Relationship

This submodel uses information on pump status (whether it has been damaged and, if so, its repair status), water quality criteria for exports, the latest salinity distribution, and pumping rules to characterize the ability to pump for each pumping station. It then also considers whether and how much extra Delta outflow (carriage water) will be required (due to the increased tidal prism with the breached islands) in order to allow various amounts of pumping. The outputs will be:

- A pumping or no pumping finding (based on pump status, salinity criteria, and pumping rules) for each Delta pumping plant for the current calculation period.
- A relationship between required net Delta outflow and various rates of pumping (distributed among the pumping plants) for the remainder of the present time step.
- Additional inflow required for DICU, so that total Delta inflow requirements can be calculated for any desired level of exports. This will allow the reservoir management submodel to provide inflow to support desired pumping for this calculation period in addition to satisfying salinity maintenance and DICU requirements.

A.5 Submodel H5 – Simulate Salinity Based on Actual Inflows and Pumping

This submodel uses the actual Delta inflows provided by the reservoir management submodel to calculate the end of period Delta salinity distribution with the chosen amount of Delta export pumping. The primary outputs are:

- Tidally averaged salinity at each modeled location in the Delta and Suisun Marsh at the end of the calculation period (i.e., the salinity distribution).
- Actual pumping permitted (and the average salinity of exports) at each of the five Delta-export pumping plants during this calculation period. Note that export volumes may be cut back from the amounts chosen by the reservoir management submodel if salinity calculations indicate adverse salinity impacts.

A.6 Submodel H6 – Priority Order for Island Repair Based on Initial Salinity

This submodel establishes a priority order for Island repair based on the initial salinity distribution in the Delta after completion of initial flooding and flushing. The objective is to first repair those islands that will provide rapid salinity distribution improvement to allow an early resumption of export pumping. This submodel is run early in the calculation so that its output can be provided to the Levee Emergency Repair and Response Module.

- Priority order for island repair based on hydrodynamics and salinity distribution.

A.7 Additional Hydrodynamics and Water Quality Outputs

Additional outputs that will be considered, if needed by other calculator submodels, include:

- Water surface elevations at specified channel locations during flooding.
- Water velocities at specified channel locations during flooding.
- Volumes of Delta island and Suisun Marsh flooding.
- Elapsed time to complete island flooding.
- Volume of flooding provided by Delta inflow from tributaries.
- Volume of flooding provided by flow from Suisun Bay (volume into Suisun Marsh and a separate volume upstream past Chipps Island into the Delta).
- Approximate location of salinity interface (X2) before initial flooding.
- Approximate location of salinity interface (X2) after initial flooding.
- Approximate location of salinity interface (X2) after initial flushing.

- Net Delta outflow required for this calculation period for flushing plus salinity interface maintenance assuming no pumping.
- Estimate of where (in the Levee Emergency Response & Repair actual repair sequence) and an approximate time for when water exports (partial pumping) might begin at each pumping plant. This might be updated each calculation period.
- Salinity (average for this calculation period or at the end of this calculation period) at key locations for water export pumping decisions, in-Delta irrigation use decisions, in flooded islands, and for ecosystem consequence assessment.
- Update state variables for end of this period so they are available next period.

APPENDIX B
RESERVOIR MANAGEMENT SUBMODEL

B.1 Physical System / Problem

Following occurrence of a levee failure, particularly during events that involve multiple breaches and more than one flooded island, decisions must be made to manage Delta inflows and outflows. Hydrodynamic model simulations suggest these decisions are critical to both short-term and long-term water quality in the Delta. The impact on water quality then directly affects the consequences of ultimate concern – water exports, Delta island water availability, ecosystem functions, and economic disruption.

The most obvious immediate water management decisions focus on water operations in the Delta. For example, should export pumping continue or not? Should gate settings or barriers be altered? These decisions will be addressed in Appendix D, the Delta Water Operations Submodel.

Beyond these in-Delta actions, the water management responses focus on upstream reservoirs and the appropriate reservoir management responses are less obvious.

- Should freshwater flows into the Delta be increased?
- If increases are desired, what quantity and on what schedule?
- How should the need for additional flushing water be balanced with the need to save water for environmental needs, other water users, future exports and protection against dry years?

For any given sequence, water project reservoir operators will be faced with several, reasonable options, each with some likelihood of being most appropriate and at the same time some uncertainty regarding its short-term effects and long-term benefit. Thus, as a levee breach sequence unfolds, reservoir managers will have to choose a particular course of action.

Such operating decisions will either shorten or prolong periods of high salinity that inhibit or prevent water export and may intensify or mitigate other consequences such as stress on critical Delta species. Even the simplest concepts of "reservoir management response" imply a description of the considerations or rules used in decision-making and the related action or inaction relative to water flows. The resulting Delta inflows are a critical input to assessing the hydrodynamic response of the Delta and the estimated water quality impacts are quite sensitive to the inflows used. To quantify the ultimate consequences, it is necessary to have estimates of what the Delta inflows will be throughout an incident and during the recovery period. Hydrodynamic simulations of levee failures indicate that reservoir management decisions concerning Delta water inflows will have a marked effect on water quality and the effects are particularly important in the early stages of the incident. Reservoir management ("M") submodels are proposed to simulate these decisions, responsive to the distinct stages of the incident, as outlined in Figures 4 through 7. The three reservoir management submodels indicated are:

- M1 – Flooding Period Reservoir Releases
- M2 – Flushing Period Reservoir Releases
- M3 – Repair/Recovery Period Reservoir Releases

The three "M" submodels address Delta inflows. Other submodels address water quality, in-Delta water use, and Delta water operations.

Each levee breach scenario is, in principal, unique, with it's the consequences depending in large part on the reservoir management decisions and resulting Delta inflows. Thus, the reservoir management submodels must effectively consider several factors including, but not limited to:

- Potential duration of the incident (e.g., the number of breaches and flooded islands, the resulting repair period, and when in the repair sequence partial pumping might begin),
- Stored water available for use as Delta inflows,
- Need to reduce storage at particular times for flood protection and
- Need to retain storage at other times for future pumping and drought protection.

Such needs will have varying importance depending on specific incident (sequence) circumstances. The submodels need to include allowances for such variations. Clearly, submodels that can be practically applied in the context of each sequence will not be able to predict all factors that affect reservoir management decisions and Delta inflows, so the model will need to include a probabilistic element to represent this modeling uncertainty and the random occurrences that may result in more or less Delta inflows.

B.2 Engineering / Scientific Water Management Models

Presently available California water management models include CalSim and CALVIN. CALVIN is an optimization model oriented toward policy decisions that interact with the state's water system under normal circumstances. CalSim is the statewide water operations model presently used by the state and federal projects to simulate reservoir and other aspects of project management. However, CalSim is also designed to simulate operation under normal conditions.

With a levee breach incident in the Delta, conditions become abnormal (perhaps even extremely abnormal) and operating strategies must change. Significantly different operating rules will be required to manage reservoir operation responses to a major levee failure emergency. Submodels must be available that focus on those reservoir operation responses and interact with the submodels simulating hydrodynamics and water quality in the Delta. The CalSim structure does not lend itself to that application. Special submodels must be developed for the specific applications indicated in Figures 4 through 7. Water managers do have important criteria or rules that are implicitly used in their decision making and can be described, extended and formalized into workable submodels for a levee breach incident. Some components from the models mentioned above incorporate such rules and they can also be adapted, extended and applied.

Due to computation effort, simple tools will be required. CalSim or other "heavy" lifting models will not meet this need. The likely form for the needed submodels is water-balance models that are constrained primarily by physical factors. Interviews with operators and input from others will be used to initially represent and constrain reservoir operations. Existing, complex models, such as CalSim, will be used to assist in developing the essential, simplified relationships for creating reservoir management submodels that satisfy our need.

B.3 Information Requirements, Availability, Boundary Conditions and Basic Data

The state of the water resource system upstream and the Delta inflows at the time of the incident will be essential inputs for the water management submodel. Also, the state of the resource south of the Delta, particularly storage, at the time of the incident is an essential input to economic consequence modeling and will affect north of Delta water management. This information will be required for each type of water year modeled and, within each, the four (or more) seasonal event initiation dates. It is desirable to also have statistical properties of this information, including mean or median, variance and cross correlations. In addition, basin and reservoir inflow hydrologic data will be required for the year types being used (both north and south of the Delta). Antecedent conditions are expected to be particularly important in calculating the water availability, thus they will receive close consideration. The statistical properties of these time series will be needed as well. The uncertainty and variability of these initial water resources states and the associated following time series of flows and states are expected to be the primary sources of uncertainty in characterizing Delta inflows and also important in characterizing uncertainty in water availability south of the Delta. Thus, they will be given primary attention in developing a probabilistic approach. This section therefore describes the data that will be needed and available to the reservoir management submodel.

Boundary conditions include reservoir storage, river flows, and water deliveries throughout the CVP/SWP system and the Delta. CalSim outputs will be used to establish these boundary conditions at the time an event in the Delta occurs. CalSim output will also be used to establish boundary conditions for the Delta hydrodynamic/ water quality model. Figure B1 contains a graphic depicting main Delta channels and indicates boundary condition flows provided by CalSim. Key reservoir storage and flows that will be extracted from CalSim are displayed in a CalSim output viewer in Figure B2.

Hydrologic conditions will be characterized by water year type using one of the recognized indices such as the Sacramento River Index. It may be necessary to base conditions on the antecedent water year type as well as the incident water year type. This will be explored and decided in the model development process.

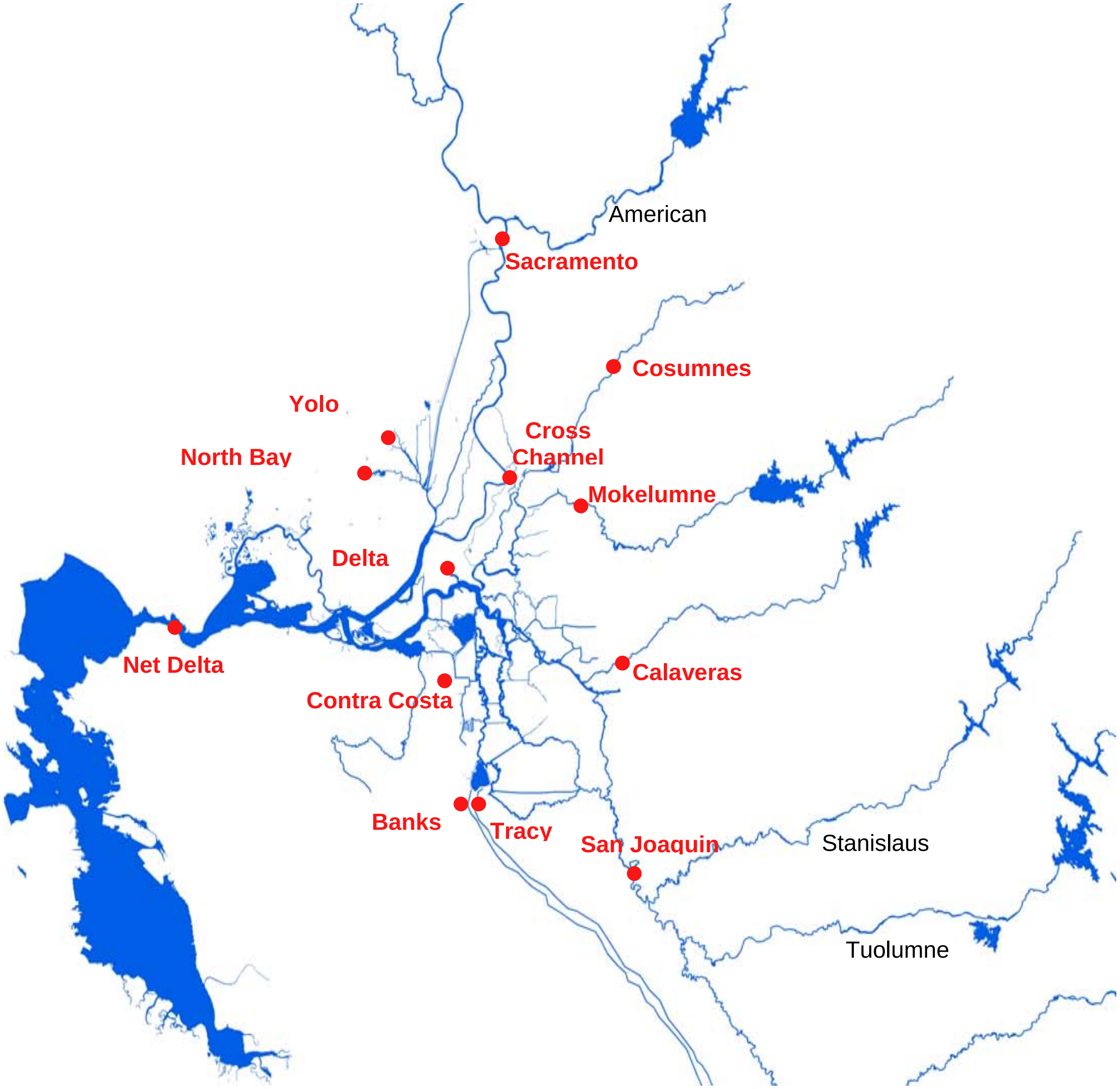
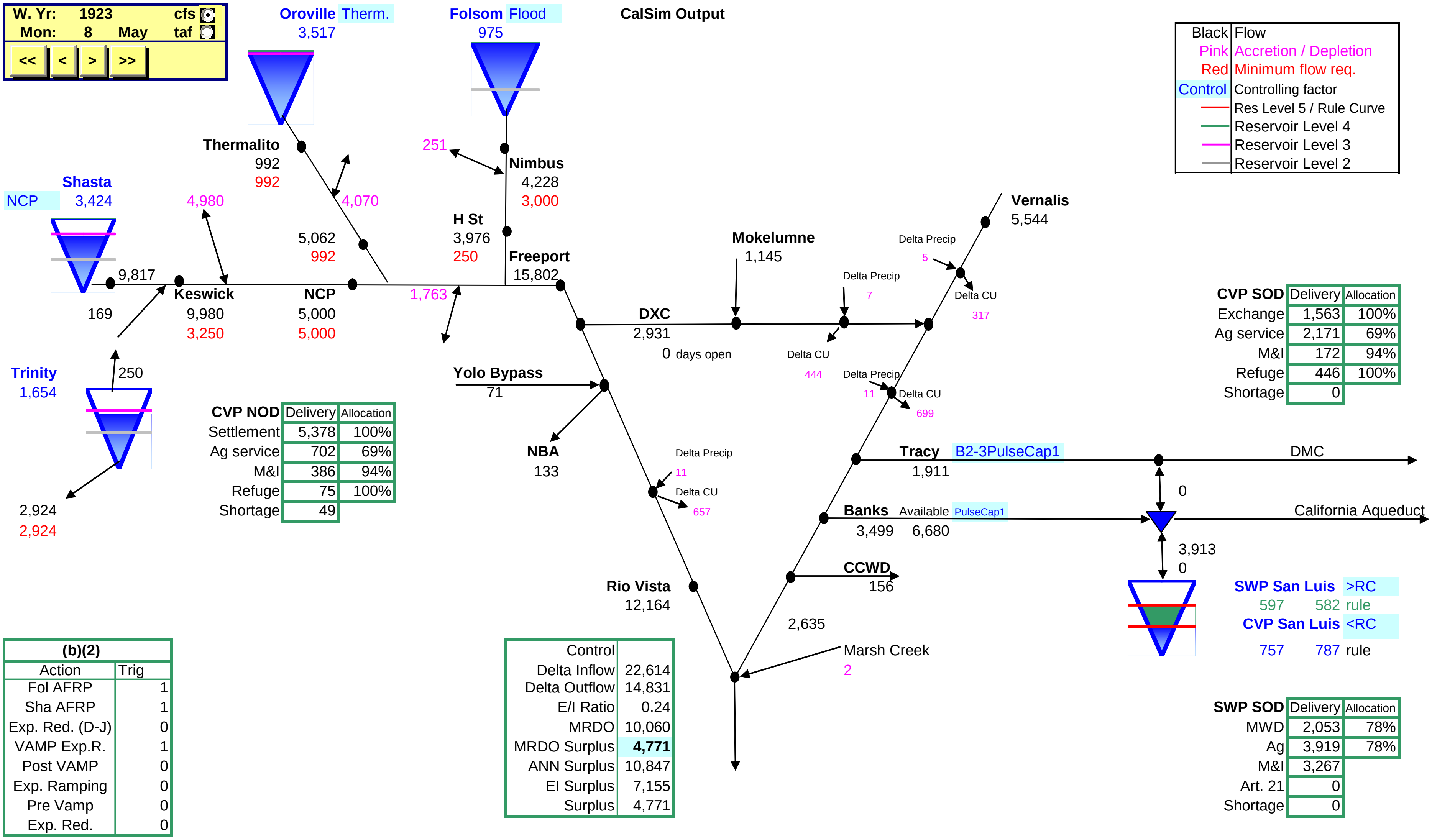


Figure B1: WAM Submodels Data Exchange Points



Black	Flow
Pink	Accretion / Depletion
Red	Minimum flow req.
Control	Controlling factor
🟥	Res Level 5 / Rule Curve
🟩	Reservoir Level 4
🟪	Reservoir Level 3
⬜	Reservoir Level 2

CVP NOD	Delivery	Allocation
Settlement	5,378	100%
Ag service	702	69%
M&I	386	94%
Refuge	75	100%
Shortage	49	

CVP SOD	Delivery	Allocation
Exchange	1,563	100%
Ag service	2,171	69%
M&I	172	94%
Refuge	446	100%
Shortage	0	

(b)(2)	
Action	Trig
Fol AFRP	1
Sha AFRP	1
Exp. Red. (D-J)	0
VAMP Exp.R.	1
Post VAMP	0
Exp. Ramping	0
Pre Vamp	0
Exp. Red.	0

Control	
Delta Inflow	22,614
Delta Outflow	14,831
E/I Ratio	0.24
MRDO	10,060
MRDO Surplus	**4,771**
ANN Surplus	10,847
EI Surplus	7,155
Surplus	4,771

SWP SOD	Delivery	Allocation
MWD	2,053	78%
Ag	3,919	78%
M&I	3,267	
Art. 21	0	
Shortage	0	

Figure B2: CalSim Output Viewer

B.3.1. Water Resource State at Time of the Incident

The state of the water resources system at the time of the incident will take the form of a collection (i.e., a vector) of correlated random variables that is a function of time – $S_i(t)$. Most of the important state variables will be storages, but a few flows will also be included. For example, project storage north and south of the Delta will be included and Delta inflow and export pumping will be included as well. The needed level of detail will be defined based on the requirements of the reservoir management sub-models, the hydrodynamic and water quality model and the economic model. The following is an example of the additional detail that may be warranted:

- North of Delta Storage
    - Federal – Shasta/Trinity
    - Federal – Folsom
    - State – Oroville
    - Other
- Sacramento Inflow
- East of Delta Storage
- Eastern Inflow
- South of Delta Storage
    - New Melones
    - San Luis
    - State WP Terminal Reservoirs
    - Friant
    - Other Federal
    - Other State
    - Other Tributary to Delta
    - Groundwater
- San Joaquin Inflow
- Contractor Local Storage
    - Contra Costa Water District
    - Metropolitan
    - Santa Clara Valley Water District
- Export Pumping
    - North Bay Aqueduct
    - CCWD – Rock Slough
    - CCWD – Old River

    - SWP – Banks
    - CVP – Tracy
- X2 Targets or Requirements

The actual detail required will be established as a first task in module development and will include needed consultations with state and federal water managers and developers of the subsequent submodels or modules that will use the data.

There are several approaches that could be taken to establish the “water resources state” at the time of the incident in terms of an appropriately correlated set of numbers. We anticipate using the approach detailed below that gives prominence to antecedent conditions.

Start of Water Year State, Sets of Random Variables Depending on Prior Water Year Type

This approach formalizes recognition of the antecedent conditions by establishing the type of the previous water year as a key input and thereby reflecting much of the needed correlation among the vector components. It is based on the fact that previous years have a marked effect on conditions in the present year. The variance of each vector component would be less, but a correlation of components would still need to be recognized. Then, to represent the resource state at the time of the incident, routine water management would need to be applied for the portion of the water year prior to the incident, given the water availability at the start and the event water year type being addressed for initiation of the incident.

DWR’s CalSim model is expected to be particularly useful in compiling information on system states for the specific water year types and event start dates pertinent to the current water system and present statewide development (population and land use) and water demands.

B.3.2. Normal Operations Projected to the End of the Water Year

The projection of normal operations, in absence of the levee-breach incident, from the time of the event to the end of the water year will provide a starting point for considering what reservoir operation modifications would be helpful and prudent. This will depend strongly on the water year type and the hydrologic record developed to represent that water year type. This should be achievable based on existing hydrologic records and normal water management protocols. Indeed, it will likely be possible and helpful to extend the “normal operations” projection through the first three months of the next water year (i.e., through December). The hydrologic conditions (e.g., wet, normal, or dry) of the next water year will not yet be known and operations are likely to be similar regardless of the next water year type. An important aspect of this will be recognition of reservoir draw down requirements in preparation for the upcoming flood season. These normal operations are also needed to provide a “without event” baseline for economic analyses.

The outputs of primary interest from this projection of routine operations are:

- Reservoir storages upstream of the Delta
- Delta inflows
- Normal exports

The above data and projections are independent of the incident; they depend only on the antecedent conditions, type of water year, and the incident start date.

The basin/reservoir inflow hydrology will be used as input (at least in summary form) to drive the WAM. The projections of normal operations beyond the incident start date, will not be actual risk model inputs, but will be used in developing model operating rules. In modeling response to the incident, the normal exports are available for reallocation to Delta flushing, retention in storage, or partial pumping (if pumping is feasible based on water quality achieved in managing the incident). Additional water might be used based on reducing end-of-year carryover storage and anticipated limitations on pumping during the next water year. These projections of normal operations may be a natural contribution from DWR's CalSim, since it basically performs normal operation of the water system using historical hydrology adjusted for current (non-emergency) conditions.

The data and projections will have to be further adjusted to reflect impacts of climate change and state water demand and the water supply system pertinent to the future calendar times that are to be modeled.

B.4 Information Requirements from Other Modules or Submodels

The following sections identify inputs needed by the reservoir management submodels from other modules or WAM submodels:

B.4.1. Requirements for Submodel M1 – Immediate Releases

For the immediate response reservoir management submodel, no special analysis is required. The initial base-case operating rule is to leave reservoir releases unchanged in response to any levee breach incident. Thus, only the following information is needed:

- Type of water year (and, perhaps, type of antecedent water year)
- Date of incident initiation
- Water system state per above parameters, including reservoir releases and Delta inflows
- Normal project operations (projected) from CalSim

B.4.2. Requirements for Submodel M2 – Flushing Releases

The following additional information inputs are required for the reservoir management submodel to respond to requests for flushing releases:

- From Submodel H1 (Initial Flooding) – Requested changes in water operations (regarding pumps, gates and reservoir releases).
- From Submodel H2 (Flushing Need) – Requested flushing volumes/flows by tributary for the flushing period.
- From Submodel H2 (Flushing Need) – An initial, approximate estimate of where in the repair sequence and when partial pumping and full pumping might begin.

B.4.3. Requirements for Submodel M3 – Repair and Recovery Period Releases

The following additional information inputs are required for the reservoir management submodel to decide on repair/recovery period operations:

- From Submodel H3 (Simulate Flushing) – Estimates of where in the repair sequence and when partial pumping and full pumping might begin.
- From the Emergency Response and Repair Module – Estimated time (as of the current calculation period) to the points in the repair sequence, where partial and full pumping might begin.
- From the Emergency Response and Repair Module – Estimated time (as of the current calculation period) until levee repairs are complete and the islands are pumped out.
- From Submodel H4 (Ability to Pump) – Refined estimates of times at which partial pumping and full pumping and in-Delta water uses are expected to resume.
- From Submodel H4 (Ability to Pump) – Delta outflows this period needed for salinity maintenance and to support various amounts of pumping (i.e., the outflow – exports relationship)
- From Submodel D3 (DICU) – Estimated in-Delta consumptive use for this period and Delta Water Operations status.

B.5 Output Requirements

The following sections identify the outputs that the reservoir management submodels must produce and identify the other modules or WAM submodels that need those outputs.

B.5.1. Output from Submodel M1 – Immediate Releases

The following outputs are required from Submodel M1:

- Reservoir releases and present and projected Delta inflows from each tributary beginning at the time of incident initiation and projecting forward through the flooding period with no changes in reservoir releases. These will be used by Submodel H1 to simulate Delta salinity during the flooding period.
- Updated state variables at the end of the flooding period.

B.5.2. Output from Submodel M2 – Flushing Releases

The following outputs are required from Submodel M2:

- Reservoir releases and projected Delta inflows from each tributary for the flushing period, specifically as affected by extra releases provided in response to Submodel H2 requests for flushing. These will be used by Submodel H3 to simulate Delta salinity during flushing.
- Updated state variables at the end of the flushing period.

B.5.3. Output from Submodel M3 – Repair and Recovery Releases

The following outputs are required from Submodel M3:

- Reservoir releases and projected Delta inflows from each tributary for the remainder of the current calculation period.

- Target export pumping amounts used in calculating the releases provided.
- Updated state variables (e.g., upstream storages) at the end of the current calculation period so that those numbers are available for input to the next period calculation.

B.6 Approach for Modeling Reservoir Management

The reservoir operations model will be responsible for determining reservoir releases and target exports following a breach event and throughout the repair/recovery period. This model relies on hydrologic data from CalSim along with information from the hydrodynamic/water quality model, and will be based on operating rules to balance upstream storage with Delta needs, the needs of other beneficial uses, and export needs. The model will only include simulation of CVP/SWP facilities and the river systems affecting or affected by their operation.

B.6.1. Model Procedure

The basic modeling procedure common to all three submodels can be characterized in three basics steps:

1. Boundary conditions for specified hydrologic year type and month will be read in from consolidated CalSim results
2. The event occurs and desired flushing flows, export limits, altered DICU, and/or an outflow-export relationship from the hydrodynamic/water quality consequence model will be read in as appropriate.
3. Delta export targets and supporting upstream reservoir releases will be calculated based on water availability, the temporal context, prospective future needs, perceived export needs, and Delta conditions.

The sub models will be designed to respond to conditions calculated by the hydrodynamic/water quality model. They will recognize and respond to initial flushing, prolonged periods of no pumping, partial pumping or operations during the repair/recovery period. The submodels will include various rules to operate reservoirs for releasing flushing flows and the substantial increases in carriage water required to support export operations in the context of a levee breach incident.

B.6.2. Operation Rules

Operating rules will be required to manage the emergency responses to the various stages of a full range of levee failure incidents, from single breaches to multiple, simultaneous breaches. Considerable input will be required from the operators and policy makers responsible for managing the State’s water system so the decision model will actually simulate their likely response to the emergency. Several rules will be developed and input to the submodels with input variables to control the operations. Rules will be structured in terms of the following categories or concepts, which are expected to have varying applicability to the three submodels:

- Available upstream supply will be based on reservoir storage levels and minimum levels required to ensure adequate water will remain upstream to meet prospective environmental requirements and upstream water deliveries. In addition, this parameter will recognize the need for meeting flood control space requirements in the fall and will establish reserves for carryover to potential dry periods.

- Maximum upstream release from each reservoir will be variable and will be based on upstream fishery requirements, hydropower needs, and the needs of water users between the reservoir and the Delta.
- Rules will be developed to balance north of Delta storage with south of Delta normal needs, cumulative deficits, and the duration to date of export disruptions. If exports are possible, Submodel M3 will attempt to meet "baseline" export levels considering upstream water availability, the outflow-export relationship ("carriage water" cost), and accumulated deficits.
- Rules will be developed to balance available upstream water supply with flushing flow requirements within Submodel M2
- Rules will be established to determine export levels based on Delta current state of repair (as reflected by carriage water costs) and prospective improvements of conditions.
- Additional rules will be developed as necessary to produce a reasonable simulation of the way in which water projects are expected to operate under current (2005) policies.

Actual rules and input parameters will be adjusted based on initial model results. For example, if releases to satisfy Delta needs result in adverse environmental upstream impacts or cause unacceptable reduction in upstream water deliveries, input rules will be adjusted to avoid the undesirable consequences.

The approach for developing the various types of rules is presented in more detail below.

Definition of available upstream supply

This definition will be based on reservoir storage levels and minimum levels required to ensure adequate water will remain upstream to meet environmental requirements and upstream water deliveries. In addition, reserves will be established for project carryover to protect against potential dry periods.

Each upstream reservoir in the CVP/SWP has unique physical makeup, location relative to the Delta, hydrologic properties, environmental requirements, agricultural demands, and M&I demands. Although the unique nature of each reservoir must be considered when developing operating rules and parameters, the form of the rule will be similar for each reservoir. It is envisioned that the storage rule will take the form shown in Table B1, where the values represent minimum acceptable reservoir levels after making additional releases:

Table B1
Sample Reservoir Level Table

Year Type	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Wet	100	110	120	130	140	150	150	150	150	140	130	120
Above Normal	95	105	115	125	135	145	145	145	145	135	125	115
Below Normal	90	100	110	120	130	140	140	140	140	130	120	110
Dry	85	95	105	115	125	135	135	135	135	125	115	105
Critical	80	90	100	110	120	130	130	130	130	120	110	100

The following descriptions of upstream reservoirs will aid in the development of rules governing additional releases during and after an event in the Delta.

Folsom Reservoir

Folsom is a CVP reservoir that holds about 974 TAF with an average annual inflow of about 2.7 MAF. Because the inflow is almost 3 times the storage capacity it has a high probability of refill each year. Folsom is operated to meet instream flows and temperature requirements, provide releases for Delta needs, and meet large M&I demands in the American River basin. Before additional releases can be made from Folsom consideration must be given to instream fisheries, where flow fluctuations can cause significant damage to spawning salmon and steelhead. In addition to fishery considerations, adequate carryover must be maintained to provide drought protection to urban water users.

Oroville Reservoir

Oroville is an SWP reservoir that holds about 3.5 MAF with an average annual inflow just under 4 MAF. Oroville is the only major upstream water supply source for the SWP and is used to satisfy large upstream agricultural demands, local M&I demands, instream flow needs, and drought year reliability for the entire SWP.

Shasta Reservoir

Shasta is a CVP reservoir that holds about 4.5 MAF with an average annual inflow of about 5.7 MAF. Shasta is the largest storage facility in the CVP/SWP system. In terms of flexibility, its operation may also be considered to be one of the most constrained. There are flow requirements just below Shasta at Keswick to protect endangered fish species and there are flow requirements down stream, just upstream from the confluence with the Feather River. There are also temperature requirements in the Sacramento River that require management of the cold water pool in Shasta in conjunction with releases. Shasta also has high carryover storage requirements (1.9 MAF) to protect endangered species. Shasta releases are also made to provide flows to senior water right holders along the Sacramento River. Operating levels for Shasta will consider the constrained nature of its operation and balance those constraints with Delta needs.

Trinity Reservoir

Trinity is a CVP reservoir that holds about 2.4 MAF with an average annual inflow of about 1.2 MAF. Annual imports from the Trinity River to the Sacramento River basin are just under 400 TAF, based on the most recent CalSim simulations. There are significant instream flow requirements in the Trinity River leaving little flexibility for meeting additional Delta needs. Trinity may be considered for additional releases but the availability of water is expected to be limited.

New Melones Reservoir

New Melones is a CVP project reservoir located on the Stanislaus River. Essentially all its water is allocated to senior water rights holders and little, if any will be available for addressing Delta levee breach incidents.

Proximity to the Delta

New Melones is the reservoir that is closest to the Delta (flow time of about a half a day) and it also has the unique advantage of providing Delta inflow via the San Joaquin River. However, since little water is expected to be available, it will not receive primary attention in our models. Folsom Reservoir is the next closest project reservoir to the Delta, releases from Folsom take approximately 1 day to reach the Delta. For this reason Folsom may be the first reservoir called on to provide flushing flows. Oroville is the next closest reservoir with a travel time of about 3 days, and Shasta releases take about 5 days to reach the delta. A rule may be developed to balance response time to an event in the Delta with water available in each upstream reservoir.

Definition of Maximum Upstream Release

Maximum releases from each reservoir will be variable in the model and will be based on upstream fishery requirements, hydropower needs, or other needs. The first objective is to prevent releases that are so high that there will be adverse impacts on fisheries. The next objective is to prevent releases so high that there will be lost hydropower benefits. This rule will consider maximum flow and may consider changes in flow from baseline and may be based on year types.

Balance of North of Delta Storage with Starting South of Delta Storage and Normal Needs

This is the most complex and important rule to be developed for the model. This rule combines information on upstream water availability and maximum releases, previously described, with information from the hydrodynamic/water quality consequence model and conditions south of the Delta (SOD). The model will be operated in an attempt to meet “baseline” export levels considering conditions describe in these rules. The rule must address the following conditions:

- High levels of upstream water available with high levels SOD
- High levels of upstream water available with low levels SOD
- High levels of upstream water available with low levels SOD and SOD water shortages. If there are health and safety issues SOD then increases in upstream release and therefore risk may be more acceptable.
- Moderate levels of upstream water available with high levels SOD
- Moderate levels of upstream water available with low levels SOD
- Moderate levels of upstream water available with low levels SOD and SOD water shortages. If there are health and safety issues SOD then increases in upstream release and therefore risk may be more acceptable.
- Low levels of upstream water available with high levels SOD
- Low levels of upstream water available with low levels SOD
- Low levels of upstream water available with low levels SOD and SOD water shortages. If there are health and safety issues SOD then increases in upstream release and therefore risk may be more acceptable.
- Flood conditions
- Short-term movement of water from upstream to export at higher carriage water cost vs long-term movement of water when carriage water cost is lower
- Others rules will be developed as issues are discovered

Balance of North of Delta Storage with South of Delta Conditions and Desire for Flushing Flows

In addition to considering conditions south of the Delta, rules will be developed to balance available upstream water supply with flushing flow requirements. There will be similar issues in balancing upstream conditions with desired flushing flows as with balancing upstream conditions with SOD conditions. Rules for determining how much water should be release to flush the Delta must also consider the time-value of flushing flows. In many cases initial high levels of flushing flows may be beneficial to longer-term water supply, while in other cases it may be adverse to long-term water supply.

Rules Will be Established to Determine Export Levels Based on Delta Salinity

In some cases it may be beneficial to maintain some level of export to improve water quality in the central and southern Delta. Export of higher EC water could be very short-term or could last for a season. Ability to export water higher in EC will depend on ability and desire of agricultural users on the DMC to use this water; their use of higher EC water will depend on length of time higher EC water will be applied, status of their crops, potential supply for blending, and possibly EC of drain water.

Additional rules will be developed as necessary to produce a reasonable simulation of the water system.

B.6.3. Determining the End of the Recovery Period

From an upstream reservoir operations standpoint recovery will be based on recovery of storage north of the Delta and a return to a normal level of delivery. There will also need to be recognition of recovery needs south of the Delta. This may be based on providing excess Delta exports for some period until a specified percentage of export deficits has been made up.

B.6.4. Necessary Reservoir Management Submodel Characteristics

The reservoir management submodels must be suitable for use in the risk analysis computation, adapted to the Delta/upstream water system, fit into the WAM calculation flow, and applicable to the full range of sequences. They will be developed in close collaboration with operation managers and include an articulation of the criteria and rules for operating decisions. A group of federal and state project operators, contingency planners, and water contractors will be assembled to provide input on example sequences and development of management rules/guidelines for levee incident reservoir operations. Reservoir management modeling will need to establish the relevant relationships for each hazard that is considered, (e.g., seismic, flood), the timing of the incident (high or low flows, season), the magnitude and potential duration of the incident, and will be in a form that can be used efficiently in evaluating each sequence. The water management submodel will be carefully defined based on its role in the risk analysis, the inputs available, and outputs desired. The task will be planned in consultation with DWR. The necessary characteristics of the reservoir management submodel are presented below.

A robust reservoir management decision model is needed. As part of the Delta risk analysis, there may be thousands (possibly tens of thousands) of sequences involving various combinations of levee breaches and island flooding. In principal, each sequence is unique. Furthermore, each may occur during any type of water year and at any time during that year. The resource state and response in managing Delta inflows will vary. The objective of each reservoir management submodel is to provide the inflow time series required for hydrodynamic and water quality modeling – for each sequence. The inflows must be responsive to both the water resource state at the time of the incident and the damage caused to water export capabilities and it must simulate the reservoir management decisions that would be taken in each sequence in order to respond. A specific reservoir operation strategy (for use in modeling) will be developed for simulating Delta inflows during the duration of the repair and recovery period.

Consider the following widely varying set of circumstances and markedly different events. For example, a breach event might occur during a period of low net Delta outflow and a significant volume of high salinity water could be drawn into the western and central Delta from Suisun Bay. In this case, the submodels might indicate increases in reservoir releases for a short period of time, responsive to the approach described in the “Sacramento-San Joaquin Delta Emergency Water Plan: Report to the Legislature” (California DWR, 1986). Once salinity intrusion from the initial island flooding has been repulsed, reservoir releases may be decreased to save the water that would have been exported until sufficient repairs have been completed to use the water to further flush the Delta and resume pumping. On the other hand, the releases may be maintained at a higher level to enhance or accelerate flushing.

As another example, the event might occur during the wet season with relatively high Delta outflows. For a modest number of levee breaches, there may be little intrusion of saline water and, perhaps, no increase in reservoir releases would be needed.

B.7 Probabilistic Approach

The Water Management Submodel will be a mass-balance model that tracks whether available water has been sent downstream or not. The main modeling uncertainty will be whether reservoir releases to downstream have been over or under calculated for a given period. If they have been over calculated in one period, they must be low in some other period. Initially these uncertainties will be set aside. This will be reviewed when the submodels have achieved preliminary operation.

B.8 Assumptions, Constraints and Limitations

These are to be developed and undoubtedly will be a substantial list. They largely depend on specific decisions taken as the submodels are developed. Principal assumptions will be in the form of stated operating criteria for event reservoir management during the various stages being modeled – the immediate response, the flushing period, the repair and recovery period.

B.9 Reservoir Management Submodel Work Plan

For each risk analysis sequence or damage state, we must have information on the state of the water resource at the time of the incident. Then we must model the management of that resource throughout the incident in order to analyze the consequences for Delta water quality. Three distinct modes of water operation need to be addressed – the flooding period (including immediate responses to salinity intrusion, if any), the flushing period, and the repair and recovery period with potential for partial or even full export pumping. This task therefore begins with establishing the state of the water resource at the time of the incident. The subsequent submodels then simulate the management of the resource throughout the period affected by the incident.

B.9.1. RM Submodel Subtasks

The following subtasks will be performed in developing the reservoir management submodel:

- **RM-1. Water Resource State Submodel (Beginning of Event)**
- **RM-2. Identify Present State/Federal Operating Criteria**
  - **RM-2.1. Prepare Scoping Sequences For Further Elicitation of Operating Criteria**
  - **RM-2.2. Establish an Operations Working Group (OWG) (Done)**
  - **RM-2.3. Distribute Summary Information to the OWG**
  - **RM-2.4. Plan, Hold and Document the First OWG Meeting (Done)**
  - **RM-2.5. Prepare Draft of Present Operating Rules**
  - **RM-2.6. Plan, Hold and Document the Second OWG Meeting**
  - **RM-2.7. Finalize the Present Operating Rules Paper**
- **RM-3. Reservoir Management Modeling ITF Paper Contributions**
- **RM-4. Routine Operations Submodel**
- **RM-5. Immediate Actions (Flooding Period) Submodel**
- **RM-6. Flushing Period Submodel**
- **RM-7. Repair and Recovery Period Submodel**
- **RM-8. Develop an Excel version of the First-Cut Reservoir Management Submodels**
- **RM-9. Debug and Test the First-Cut Submodels**
- **RM-10. Document the First-Cut Submodels for Risk Calculator Encoding**
- **RM-11. Present Initial Submodels to the WOG for Review and Comment**
- **RM-12. Address Probability and Uncertainty**
- **RM-13. Refine and Extend the Submodels and Retest**
- **RM-14. Prepare the Reservoir Management Report**

B.9.2. RM Model Resource Requirements

The resources are required to develop the Reservoir Management Submodels up through task RM-10 have been submitted to Project Management in a separate budget document.

Additional expertise will be identified as necessary to review and advise on submodel structure and operating rule formulations.

B.10 RM Model References

To be added.

APPENDIX C
DELTA ISLAND CONSUMPTIVE USE (DICU)

C.1 Physical System/Problem

Under normal circumstances (with no breaches and no normally-dry islands flooded) the loss of water form the Delta system through evaporation from channel and island surfaces and transpiration from crops and other vegetation is estimated as Delta Island Consumptive Use (DICU). This varies throughout the year and, of course, is highest in the summer irrigation and growing season. But for any given month under normal circumstances, it may be assumed to be about the same from year to year, given a relatively short period of analysis. In aggregate, DICU is a substantial amount of water. According to one source (DWR, 1986), it amounts to approximately 1.6 million acre-feet per year – which is about 25% of exports.

When there is a levee breach incident and islands flood, this stable situation is disrupted. The flooded island(s) become lakes with evaporation rather than transpiration. Per DWR (1986), the evaporation may exceed agricultural evapo-transpiration by two feet per year. Some Delta unflooded islands may lose their access to fresh irrigation water; the channels from which they draw might be impacted by saline intrusion. This could decrease consumptive use. Some flooded islands that have been repaired may have been flooded with saline water and may require salt leaching. This could increase consumptive use and saline return flows. Other islands that have been repaired may have been pumped out too late in the season to start a crop. This could reduce consumptive use until the next full irrigation season. Finally, as we address future analysis years, the temperature increases caused by climate change may substantially increase evaporation and transpiration and require further adjustment of all the base case estimates. The usual estimates for DICU are inadequate for use in this project and a method is needed to calculate more appropriate numbers.

C.2 Engineering / Scientific Consumptive Use Models

The fields of hydrology and water resources management (irrigation) provide a rich resource for models of consumptive water use and of field measurements, both for evaporation and transpiration. Review of existing models will provide an approach for estimating Delta island consumptive water use under the variety of circumstances relevant for this submodel – namely, normal irrigated crop production, loss of the irrigation water source, and island flooding. These variations in water consumption will be used with island areas to adjust normal DICU estimates in existing models such as DSM2, CalSim and RMA. The literature will be reviewed to provide functional relationships with temperature to provide adjusted results for future analysis years impacted by climate change temperature increases.

C.3 Conditions, Assumptions, Constraints and Limitations

The following are conditions and/or assumptions that will be the basis for estimating the monthly DICU adjustments:

- Islands will either have access to suitable irrigation water or not (take out points will be consolidated and represented as one per island).
- Flooded islands will be assumed to have evaporation typical of lakes as measured through pan evaporation.

- Flooded islands that have been pumped out will be assumed to immediately convert to irrigated agriculture consumptive use if acceptable irrigation water is available at that island’s takeout point. This assumption will be adopted even recognizing that it may be too late in the growing season to start a crop on that island. Also, the irrigated agriculture consumptive use will be used even though the flood waters may have been saline and require leaching that would be better represented by the flooded consumptive use estimate.

C.4 DICU Modeling Approach

As presented in the WAM flow charts, three occurrences of DICU submodels are shown (D1, D2, and D3). The DICU calculation routine will be the same in each submodel, but must be repeated because the islands that have flooded or the water quality in the channels that would be used for irrigation may have changed. Combined into the D1, D2, and D3 submodels in the flowcharts are references to Delta water operations (pumping, gates, and barriers). These also may change in the calculation flow. The details of the Delta water operations are discussed separately in Appendix D that follows below.

Within the WAM (and each of the “D” submodels) the DICU calculator will have two components. The first estimates monthly DICU and the second estimates evaporation from flooded islands. Losses from channels and normally flooded islands will also be considered.

Prior to a breach event each island is assumed to be fully irrigated. If an island experiences a levee breach, irrigation ceases and evaporation from the flooded surface area occurs. If the salinity in channels adjacent to an unflooded island is excessive due to levee failures on other Delta islands, irrigation will be terminated on the island in question until acceptable salinity concentrations occur. However, seepage and associated return flows will continue and may even increase.

To model DICU and free water surface evaporation within the WAM the following monthly information is needed:

- Diversion (pumping and seepage),
- Return flows,
- Surface area,
- Evaporation rates,
- Return flow quality (EC), and
- Channel salinity (this will be an output of the Hydrodynamic/Water Quality Model; for details see Hydrodynamics/Water Quality ITF Paper)

C.4.1. The DWR DSM2 Model

The Department of Water Resources (DWR) identifies 142 DICU sub-areas within the Delta (DWR, 1995), which encompasses the approximately 70 islands in the Delta (see Figure C1). DWR has estimated the monthly diversions to, returns from, and seepage into each sub-area. These values were subsequently used to represent monthly diversions, returns, and seepage for use within the DSM2 model. DSM2 represents the Delta through a series of related nodes. A node can have inflows and outflows from multiple sub-areas and each sub-area can divert or return flow to multiple nodes, i.e., a node does not correspond to a single sub-area or type of flow. DWR estimated flows (diversions, seeps, and return/drain) have been divided up among 257 nodes within the DSM2 framework. The percent of the total inflows (diversion and seepage) and outflows (return) for each node and the allocation to each sub-area is specified in the "DIVFCTR.DSM.2-92" and "DRNFCTR.DSM.2-92" files provided by DWR (personal comm. J. Wilde). Based on the allocation factors, the diversion and drainage/return flows for each sub-area can be computed. The difference between the total inflows and outflows represent the monthly sub-area consumptive use.

To represent DICU within WAM, the 142 sub-areas are aggregated into five groups. These groups represent the major regions within the Delta as defined by the Simplified Hydrodynamic/Water Quality Model; one group on each of the major flow paths. Each sub-area is assigned to a group and the specific sub-area's DICU is cataloged by month for multiple year-types (i.e., DICU patterns for all base case year types are required). Outlined herein is the DICU logic, which operates on a monthly basis.

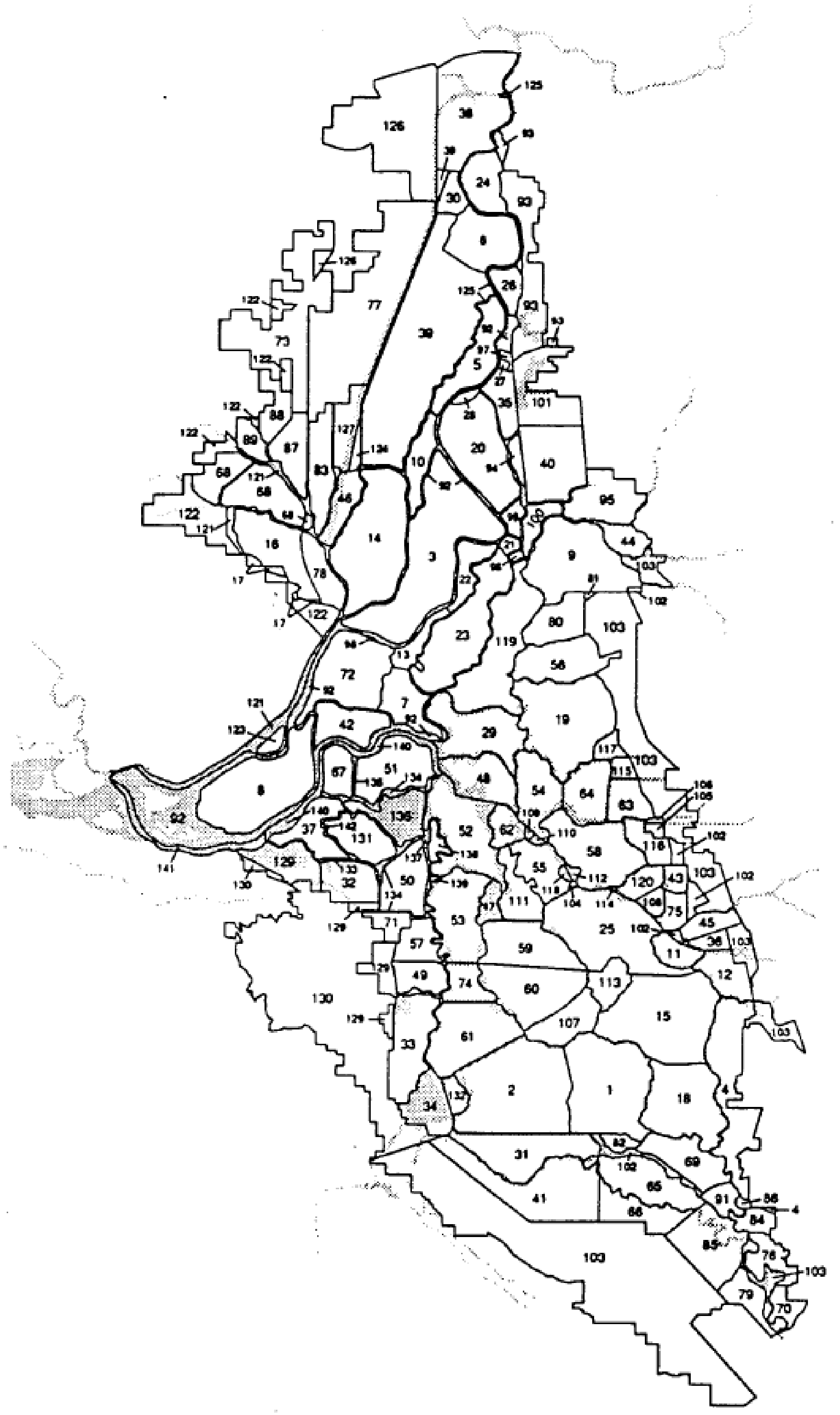


Figure C1: Copied from "Estimation of Delta Island Diversions and Return Flow," February 1995, DWR, Page 17.

C.4.2. Island Diversion, Seepage, Drain/Return Flow, and Consumptive Use

A first step in representing DICU for the simplified hydrodynamic and water quality module is determining the total diversion, seepage, and drain/return flow for each island. A representative set of islands and nodes (representing diversion, seepage, and drain/return flow) are depicted in Figure C2. Islands are represented with the subscript *i*, and nodes with the subscript *j*. An island may have a wide range of associated nodes.

In the example, island *i*=1 has 8 associated nodes. These nodes may or may not contain diversion, seepage, and drain/return flow information for adjacent island(s). For instance, a common node between two islands (*i*=1 and *i*=2) is presented in Figure C3 as *j*=2.

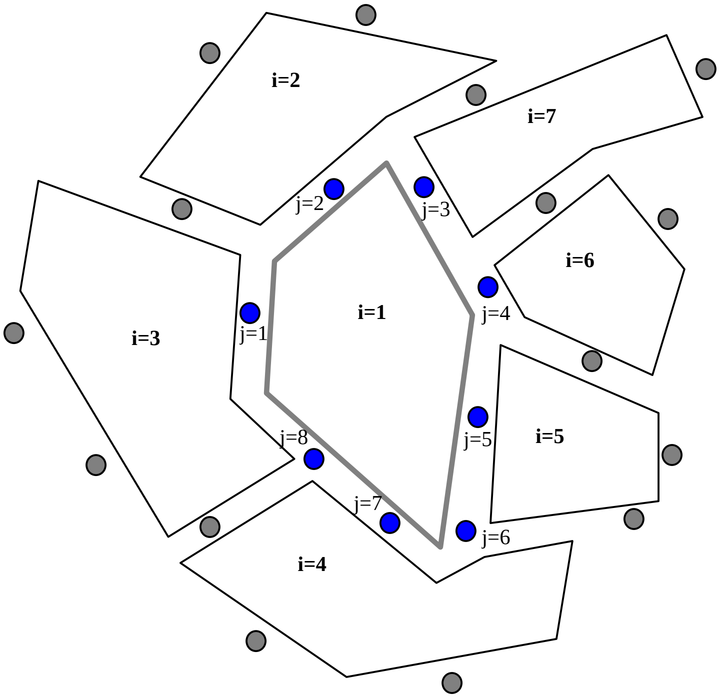


Figure C2: A Set of Representative Islands, i, and Associated Nodes, j, for Island i=1.

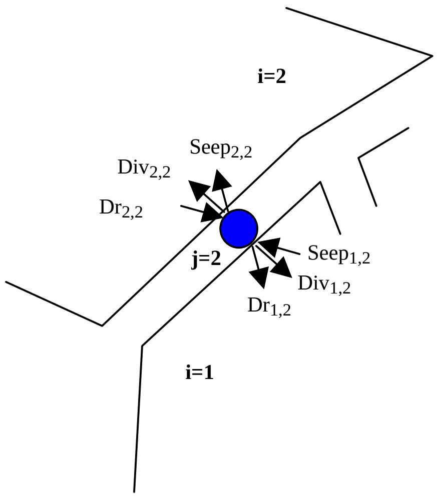


Figure C3: Potential Nodal Inflows and Outflows for Node j=2, Which Lies Between Islands i=1 and i=2.

Based on this nomenclature, the total diversion (*TotDiv*), seepage (*TotSeep*), and drain/return (*TotDr*) flows into any sub-area can be determined based on the 257 nodes included in DSM2. Namely,

$$TotDiv_i = \sum_{j=1}^{n_i} Div_{i,j}$$

$$TotSeep_i = \sum_{j=1}^{n_i} Seep_{i,j}$$

$$TotDr_i = \sum_{j=1}^{n_i} Dr_{i,j}$$

Where n_i represents the number of DSM2 nodes associated with island *i*, and $Div_{i,j}$ represents the diversion to island *i* from node *j*. Similarly, $Seep_{i,j}$ represents the diversion to island *i* from node *j*, and $TotDr_{i,j}$ represents the drain/return from island *i* to node *j*.

Total consumptive use for island *i* (($DICU_i$) is

$$DICU_i = TotDiv_i + TotSeep_i - TotDr_i$$

C.4.3. Island Drain/Return Flow Water Quality

Island return flow quality is calculated via mass

$$DICU_i(EC_{DICU}) = TotDiv_i(EC_{channel\,i}) + TotSeep_i(EC_{channel\,i}) - TotDr_i(EC_{Dr\,i})$$

Where EC_{DICU} is the EC of consumptively used water, assumed equal to zero (i.e., plants uptake water but not salt); $EC_{channel}$ is the EC of the diversion into island *i* from the adjacent channel; EC_{Dr} is the EC of island *i* drain/return flow; and other parameters are defined previously. All flow data is known and $EC_{channel}$ is an output of the hydrodynamic and water quality model, thus the equation can be solved for EC_{Dr}.

$$EC_{Dr_i} = EC_{channel_i}\left(\frac{TotDic_i + TotSeep_i}{TotDr_i}\right)$$

or

$$EC_{Dr_i} = EC_{channel_i}\left(\frac{Total\ \ Inflow_i}{Total\ \ Outflow_i}\right)$$

This formulation assumes that there is no net contribution from or accumulation of salt within an island. While the latter may be likely, this assumption is conservative with regard to potential impact to Delta water quality. Further, this formulation does not rely on historical EC conditions from individual Delta islands, the use of which may be inappropriate for application in a multiple levee breach condition. Finally, this formulation implicitly accounts for farmers who decide to apply higher than desirable, but still tolerable, levels of salt laden water to their crops.

C.4.4. Termination of Irrigation: Flooded Islands and Excessive Salinity

In the modeling representation of DICU, island irrigation can be terminated for two principal reasons: (1) a levee breach floods an island or (2) the salinity (represented by EC) in the channel adjacent to the island is unacceptable to support island crops. A criterion for limiting agriculture deliveries due to excess salinity will be developed with other technical teams

If an island is flooded due to a levee breach, irrigation ceases ($TotDiv_i = 0$, $TotDr_i = 0$), and seepage is assumed to be negligible ($TotSeep_i = 0$) due to minimal head difference in water levels inside and outside the island levees. Thus, $DICU_i$ is reduced to zero for the island(s) in question. However, evaporation from the flooded island may be appreciable. Evaporation is primarily a function of the meteorological conditions and water surface area.

$$TotEvap_i = E_i A_i$$

Where $TotEvap_i$ represents total evaporation loss for island i, E_i is the evaporation rate for island i, and A_i is the flooded surface area of island i. Surface area should be based on the physical surface area of the flooded island, which is generally larger than irrigated acreage.

If an island is not flooded, but salinity is high in adjacent channels due to levee breaches elsewhere in the Delta, irrigation is terminated until salinity is reduced to acceptable levels. Diversion to the island is terminated ($TotDiv_i = 0$), but seepage would continue. Indeed, if breaches are nearby (on an adjacent island or even one removed), seepage may increase. Thus, drainage/return flows will continue to reflect seepage into the islands. The quality in the drainage/return flows can be assumed to be approximately equal to the seepage, which reflects the salinity in channels adjacent to the island in question. Because drain/return volume and quality are assumed equal to seepage volume and quality, there is no net effect on water quality in the delta channels surrounding the island. Thus, when an island is not flooded, but irrigation is terminated due to excessive salinity at diversion points on the periphery of the island, diversion, seepage, drain/return flows and DICU are all assumed zero (to ensure proper calculation of EC at the group level, see below). Further, there is no island evaporation component assigned to this condition. Evaporation from channels and existing flooded islands will explored and incorporated as necessary.

C.4.5. Grouping Within the Simplified Hydrodynamic/Water Quality Model

Once the total diversion, seepage, drainage/return flow, DICU, and return flow quality have been determined for each island, the aggregate values for the five regional groups represented in the Simplified Hydrodynamic/Water Quality Model can be calculated.

$$GroupDiv_k = \sum_{i=1}^{l} TotDiv_i \times DivAF_i \times IrrFlag_i$$

$$\sum_{i=1}^{l} DivAF_i = 1.0$$

$$GroupSeep_k = \sum_{i=1}^{l} TotSeep_i \times SeepAF_i \times IrrFlag_i$$

$$\sum_{i=1}^{l} SeepAF_i = 1.0$$

$$GroupDr_k = \sum_{i=1}^{l} TotDr_i \times DrAF_i \times IrrFlag_i$$

$$\sum_{i=1}^{l} DrAF_i = 1.0$$

Where l represents the total number of islands in group, k. The parameters $DivAF_i$, $SeepAF_i$,and $DrAF_i$ are allocation factors for diversion, seepage, and drain/return flows, respectively. These allocation factors represent the percentage of total diversion allocated to each island and provide a means of tracking the impact of flooding an individual island or islands within a particular group. The *IrrFlag* variable is a switch with a value of either one or zero, where a value of one represents and active, unflooded, irrigated island and a zero represents an inactive, unirrigated island (may or may not be flooded). Based on the group values diversion, seepage, and drain/return flow, group DICU can be calculated.

$$GroupDICU_k = GroupDiv_k + GroupSeep_k - GroupDr_k$$

C.4.6. Group Drain/Return Flow Water Quality

Group return flow quality is calculated based on the known return flow quantity and quality (represented by electrical conductivity, EC) assigned to each island. Group return flow EC (*GroupEC*) for each group is determined using a mass balance.

$$GroupEC_k = \left(\frac{\sum_{i=1}^{l} TotDr_i \times EC_{Dr_i}}{\sum_{i=1}^{l} TotDr_i} \right)$$

Where EC_{DRi} is return flow EC for island *i* and other parameters are as defined previously.

C.4.7. Group Evaporation from Flooded Islands

Evaporation loss from a flooded island or islands within a group (*GroupEv*) is accounted for in a similar fashion.

$$GroupEv_k = \sum_{i=1}^{I} TotEvap_i \times EvapAF_i \times (EvapFlag_i)$$

Where k represents the group, $EvapAF_i$ is the allocation factor that represents the percentage of total evaporation allocated to each island and provides a means of tracking the impact of evaporation due to flooded island or islands within a particular group. The *EvapFlag* variable is a switch with a value of either one or zero, where a value of one represents and flooded island where evaporation occurs and a zero represents an active (irrigated), or inactive (unirrigated) island. Thus, for unflooded islands where irrigation is terminated due to excessive salinity in supply waters, evaporation is set to zero.

C.4.8. Year Type Determinations

DICU within the Delta will potentially vary among water year types. To reflect the variable conditions that may be expected, selected water year types (e.g., wet, above normal, below normal, dry, etc.) will be based on one of the major river indices. There are several indices, including the Sacramento or San Joaquin River indices, that will be considered with input from other members of the WAM Team. DICU values from RMA2 as well as CalSim DICU representations will be considered. The previous quantification of island and group DICU will be based on year-types.

Variability in evaporations rates based on year type may be considered as well; however, evaporation rates may or may not reflect year type conditions as identified by water year type index used for water management (e.g., Sacramento River index). If no clear year type correlation exists for evaporation, a monthly representation of evaporation (unique to each of 12 months) will be applied uniformly to all the year types.

C.4.9. Summary

At the start of a levee breach event (prior to any levee breaches), DICU (diversion, seepage, and drain/return flows) is at the full levels for each group and evaporation is zero. After a levee breach occurs, irrigation ceases on flooded islands and those impacted by elevated levels of salinity. Evaporation begins for the flooded island. DICU for a group is reduced by the percent contribution of the flooded island. Evaporation is increased by the percent that the island contributes and water quality (EC) is calculated based on the relative contribution of the flooded island.

Example

For example, for a group composed of three islands with the following characteristics:

Group 1 (units are not presented in this fictitious example):

- Number of island: 3
- Total DICU of islands in group = 175

- Total diversion to islands in group = 207
- Total seepage of islands in group = 3
- Total drain/return from islands in group = 35
- Total evaporation from islands in group = 32 (for a flooded island areas)
- EC varies from 600 to 1000 for the islands within the group

The individual island information for Group 1 is presented in Table C1, with allocation factors shown as percentages adjacent to actual monthly volumes.

Table C1
Example of available data for DICU, diversion, seepage, drain/return flow, evaporation, and EC data for a Group of 3 islands

Island ID	**Percent Contribution to Sub-Area**										**EC** (*NetEC*)
	DICU		**Diversion** (*TotDiv*)		**Seepage** (*TotSeep*)		**Drain/ Return Flow** (*TotDr*)		**Evaporation** (*TotEv*)		
Island 1	115.6	66%	124.2	60%	1.5	50%	10.1	29%	20.2	63%	600
Island 2	43.1	25%	62.1	30%	1.0	33%	20.0	57%	9.9	31%	1000
Island 3	16.3	9%	20.7	10%	0.5	17%	4.9	14%	1.9	6%	800
Total:	175		207		3		35		32		

Based on this information, the EC for the sub-area is calculated as follows:

$$NetGroupEC_k = \frac{(TotDr_1 \times NetEC_1) + (TotDr_2 \times NetEC_2) + (TotDr_3 \times NetEC_3)}{(TotDr_1 + TotDr_2 + TotDr_3)} = 857$$

If island 1 is breached and flooded, the group DICU is reduced by 66 percent (to 59.4), the group return flow is reduced by 29 percent (10.1), the group evaporation is increased to 63 percent of the total possible evaporation (to 20.2), and the EC increased 12.1 percent from 857 to 961. Values are summarized in Table C2.

Table C2
Summary of example states pre- and post-breach

State	**DICU**	**Diversion**	**Seepage**	**Return Flow**	**Evaporation**	**EC**
Pre-Breach	175.0	207.0	3.0	35.0	0.0	857
Post-Breach	59.4	82.8	1.5	25.0	20.2*	961

* Limited to Island 1

Calculations will be completed for each month in the simulation from breach event to system recover. DICU calculations will reflect conditions as islands are repaired and/or irrigation practices return to normal. For this submodel, we will assume agricultural operations (DICU) return to "normal" immediately upon pumping out of the island.

C.5 Status of Data Needs

DWR has provided considerable information:

- dicu_200506.dss – the time series of diversions, seeps, and drains for all the nodes in the DSM2 model. The time series contain monthly values for October 1921 through the present.
- dicuwq.dss – the water quality for all the nodes in the DSM2 model. The time series contains monthly values for a single unknown year (the year used for dss storage was 3001).
- DIVFCTR.DSM.2-92 – the diversion and seepage allocation factors.
- DRNFCTR.DSM.2-92 – the drain allocation factors.
- subarea-info.txt – the sub-area names, numbers, digitized USGS acreage and MWQI DOC sub-area.
- 7STAPREC.WY19XX – the monthly precipitation for seven stations (Davis, Rio Vista, Brentwood, Tracy, Stockton, Lodi, Galt) from 1922 through the present.

With the data available it is possible create a preliminary DICU calculation. However, additional data are needed to complete the DICU component of WAM. These data needs include:

- Evaporation rates – the evaporation rate for each island or sub-area will be needed to estimate the evaporation from the flooded island.
- Water quality – the current HEC DSS file for DWRSIM contains 12 values for each node (one year). Additional water quality values would be useful for determining how the return flow quality is impacted by year type. *While helpful, this may not be necessary. In lieu of more detailed information, the existing water quality will be applied to all year types or the alternate approach based on no island accumulation or contribution of salt will be used.*

C.6 Inputs

The following inputs are to be available from other modules and submodels:

- From Delta Land Use (by island or tract)
    - Acres in agriculture (assume all is irrigated)
- From the Levee Emergency Response and Repair Module (for each island)
    - Whether the island is flooded
    - When it is pumped out
- From Delta Infrastructure and Property Module – Criteria for usability of channel water for irrigation (assume one number for all islands, takeout points, crops, and months)
- From the Hydrodynamics and Water Quality Submodel (for each island)
    - Salinity of island flood water each preceding month until island is pumped out
    - Salinity of channel water at island takeout point(s) for this period (month)
- From Climate Change – Temperature change in future analysis years.
- Basic Data

- Area of each Island/Tract
- Monthly evaporation rates (Will be a function of temperature to allow for climate change.)

C.7 Intermediate Outputs (assuming adjustment to normal DICU approach)

The following intermediate outputs will be generated by the In-Delta Irrigation Submodel:

- For each island, whether the water quality at the relevant channel takeout point is acceptable for irrigation use or not for this period (monthly).
- For future analysis years, adjustments to present day DICU and evaporation and transpiration input data, as a function of Delta area air temperatures.

C.8 Final Outputs

The following are the essential outputs from the In-Delta Water Use Submodel:

- Delta consumptive water use and water surface evaporation for each of five Delta regions for this calculation period (month).
- Availability of acceptable irrigation water for this period by island or tract (or takeout point). This result will need to be reported for each period in order to show whether irrigation water is available for an entire growing season. This will be an input to the Infrastructure & Property Submodel and the In-Delta Economic Consequences Submodel.

C.9 Probabilistic Modeling Approach

In the first cut DICU submodel, only a best estimate approach will be used. However, in reviewing available approaches, we will record and tabulate uncertainty data on adjustment factors or other relevant data so that the model can be supplemented with uncertainty parameters if desired.

C.10 DICU Submodel Work Plan

C.10.1. DICU Tasks

The following tasks will be performed during DICU modeling:

DICU-1. Verify Availability of Needed Inputs from Other Submodels and Modules
DICU-2. Structure the DICU Submodel, Including Research on Basis for Flooding, Irrigation and No Irrigation Variations and Temperature Dependence

DICU-3. Develop an Excel Version of the First-Cut DICU Submodel

DICU-4. Debug and Test the First-Cut DICU Submodel

DICU-5. Document the First-Cut Submodel for Risk Calculator Encoding

DICU-6. Present the Submodel to the WOG for Review and Comment

DICU-7. Assess Uncertainty and Add Estimates If Necessary

DICU-8. Refine and Extend the Submodel and Retest

DICU-9. Prepare the In-Delta Water Use Report

C.10.2. DICU Resource Requirements

The resource requirements to develop the DICU submodel through DICU-5 were submitted to Project Management in a separate budget document. External review of the DICU submodel may be initiated.

C.11 DICU References

California Department of Water Resources (DWR). 1986. Sacramento – San Joaquin Delta Emergency Water Plan, Report to the Legislature. December

California Department of Water Resources (DWR). 1995. Estimation of Delta Island Diversions and Return Flows. February.

Marvin Jung and Associates, Inc. 2000. Revision of Representative De3lat Island Return Flow Quantity for DSM2 and DICU Model Runs. Prepared for the CALFED Ad-Hoc Workgroup To Simulate Historical Water Quality Conditions in the Delta. MWQI-CR#3. December.

Personal Communications

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APPENDIX D
DELTA WATER OPERATIONS SUBMODEL

D.1 Physical System / Problem

Following occurrence of a levee failure, particularly after events that involve multiple breaches, decisions must be made to manage Delta inflows and outflows and, in any way feasible, to influence Delta water movement to minimize adverse distributions and mixing of salinity. Hydrodynamic model simulations suggest these decisions are critical to the short-term and long-term water quality in the Delta. The impact on water quality then directly affects the several consequences of ultimate concern – water exports, Delta island water availability, ecosystem functions, and economic disruption.

Delta inflows are controlled by reservoir management decisions – discussed in Appendix B, above. Other water operating decisions are focused on the Delta itself. There are specific actions to consider, including the status of export pumping, island diversions and return flows, gate positions, (Delta Cross Channel, Clifton Court Forebay, and the Suisun Salinity Control Barrier) and whether the south Delta temporary barriers are in place.

In each case, the concern with Delta water operations is to minimize the drawing of salinity into the Delta during the flooding of islands that suffer levee breaches, maximize the effectiveness of flushing flows that are intended to repulse salinity, minimize the impacts of tidal mixing, and enhance Delta circulation to maximize movement of high salinity water from remote channels, especially in the south Delta.

The most obvious Delta water operation is whether or not export pumping is occurring. One Delta water operation decision in the context of a breach incident will therefore be whether or not to pump. Pumping is particularly significant during flooding of breached islands, since any pumping that occurs adds to the potential for drawing in saline waters from Suisun Bay. On the other hand, continuity of pumping is desirable for water project operations and customers.

Similarly, withdrawal of channel waters for Delta island irrigation use creates an additional opportunity for drawing saline waters upstream during island flooding. These diversions also will be considered.

A second type of water operation is gate operation – whether to open or close gates that control water flow in the Delta. The gates that need to be considered are the following:

- Clifton Court Forebay – the gates used to fill (on high tides) and then retain water in the Forebay in preparation for SWP export
- Delta Cross Channel Gates – the gates that allow a portion of the Sacramento River flow to divert to the North and South Forks of the Mokelumne River.
- Suisun Salinity Control Barrier – the gates that can be operated to retain fresher water in Suisun Marsh and maintain lower salinities for marsh habitat.

Each of these gates will have some effect on Delta salinity. Their effects may vary in different stages of the levee breach event; thus, they need to be considered in each submodel.

The south Delta barriers (either the present temporary barriers or the proposed operable barriers) will affect the routes taken by flushing flows and the circulation resulting from tidal action. They will need to be considered and rules articulated for their placement, removal or operation during the various stages of the levee breach incident

D.2 Engineering / Scientific Water Operation Models

The model required is a relatively simple model to simulate water management decisions, but does not now exist for this application.

D.3 Approach for Delta Water Operations Modeling

Within the context of a levee breach event, the practical timing for decision making is a significant consideration in addressing potential operating changes. Within the flow of submodels indicated by Figures 4 through 7, Delta water operations are addressed in three separate submodels with differences based primarily on the time required for decision making. The three submodels and their time considerations are:

- D1 – Initial Delta Water Operations Response (Figure 5), standing orders implemented immediately (within 3 hours) of a confirmed report of a breach.
- D2 – Revised Delta Water Operations (Figure 5), refinements to operation that require operations management input and/or consultation with other agencies (expected to require as much as three or four days for decision making and implementation) and are particularly pertinent to flushing periods or periods with no pumping, and
- D3 – Delta Gate/Barrier Operations (Figures 6 & 7), additional operating actions responsive to the longer term strategy for managing incident impacts throughout the repair and recovery period.

In each of the three submodels identified above, a straightforward decision submodel will be developed to establish the appropriate operating status of each facility for the circumstances presented. The facilities will include Delta export pumps (which may be curtailed or stopped in Submodels D1 or D2), gate positions, and temporary barrier placement or removal. Note that initiation and rates of pumping are addressed in Submodels H4, M3, and H5.

D.4 Conditions, Assumptions, Constraints and Limitations

The following are conditions and/or assumptions that will be the basis for the Delta water operations model:

- Given occurrence of an event with levee breaches, it will be assumed that Delta exports are curtailed (consistent with standing orders) for at least two days to allow completion of island flooding while minimizing drawing of salt into the Delta, to assess damage, to conduct facility inspections, and to establish an incident management plan. This assumption may be relaxed for incidents during high flows and/or with only one or two breaches, depending on actual project operating rules. Present project standing orders appear to keep one CVP export pump operating during any levee breach event. If confirmed, that will be incorporated in the Delta water operations Submodel D1. Current standing orders for the SWP require closure of Clifton Court Forebay gates (if open) and prohibit opening the gates (if closed) as the mechanism for ceasing SWP Delta withdrawals.
- It will be assumed that in-Delta water users do not have administrative or management limitations on their withdrawals for irrigation (or for leaching of salt from their land) or on their return flows.

- Pumping will not be resumed or increased at a pumping station (beyond the amounts indicated in Submodel D1 or D2 output), or even maintained during the repair and recovery phase, except in conformance with the rules established in Submodels H4, M3 and H3.
- The Cross Channel gates should usually be opened, if they are closed, but this will require consultation with fisheries agencies and accommodation of fisheries concerns. Open gates would allow fresh Sacramento River water to be available for flooding of northeastern islands that have levee breaches and would lessen the migration of salts into the north central Delta. Of course, the gates should not be opened if the Sacramento is at high stage where flows through the Cross Channel would cause additional damage. Because consultation with fish agencies will be necessary, opening of the Cross Channel gates will not be considered in Submodel D1, but will be considered in Submodel D2 for flushing.
- Operation of the Suisun Marsh Salinity Control Barrier is not expected to have significant impacts on Delta salinity and would be beyond the resolution of the simplified hydrodynamic submodels. It will not be addressed in the Delta water operations submodels for the risk calculator.
- The south Delta barriers are of two types; three are water level maintenance barriers for benefit of south Delta irrigators (to protect against water surface draw down by SWP and CVP pumping) and one is a fisheries barrier. It will be assumed that the water level maintenance barriers may be breached/removed to enhance circulation (in Submodels D2 and D3), provided that there is no export pumping from CVP or SWP pumps. They must be reinstalled in conformance with their normal schedule if pumping is resumed. The fish barrier will be assumed to remain installed on its normal schedule.

(These assumptions need to be reexamined and further developed; for example, some may be too restrictive and exceptions need to be explicitly articulated).

D.5 Input Requirements, Operating Rules

The following operating rules must be elicited:

- Rules for pumping station response to levee breach incidents.
- Rules for Cross Channel gate operation.
- Rules for south Delta barrier installation and removal.

D.6 Input Requirements, Basic Data

The following basic data are required by the water operations submodels:

- Delta water operation status at initiation of the incident (pumping, gates, and barriers)

D.7 Input Requirements, Other Modules

The water operations submodels require the following inputs:

- The damage and repair status of each pumping and gate facility for which operations may be considered.

D.8 Input Requirements, Other WAM Submodels

The water operations submodels require the following inputs from other WAM submodels:

- From Submodel H1 – Requested changes in Delta water operation status (for flushing).

D.9 Output Requirements

Given a sequence involving one or multiple levee breaches, the Delta water operations submodels must produce the following outputs for the current calculation period, where calculation periods cover the duration of the incident, including the recovery period:

- Submodel D1 – The immediate responses to a levee breach incident conforming to standing orders:
  - Operation status of each pumping plant and pumping rate, if operating
  - Position of Delta Cross Channel gates
- Submodel D2 – The follow up responses based on requested operation changes from Submodel H1 and operator consultations with management and relevant agencies for the flushing period:
  - Operation status of each pumping plant and pumping rate, if operating
  - Position of Delta Cross Channel gates
  - Status of south Delta temporary barriers for water level control.
  - Status of south Delta temporary barriers for fish control
- Submodel D3 – The repair and recovery period responses conforming to operating rules established for the incident situation (no pumping, partial pumping, etc.):
  - Position of Delta Cross Channel gates
  - Status of south Delta temporary barriers for water level control.
  - Status of south Delta temporary barriers for fish control

D.10 Probabilistic Modeling Approach

Since most of the Delta water operations outputs will be in the form of on/off or open/closed decisions in response to articulated operating rules, the primary uncertainty will be whether the articulated operating rules accurately anticipate the operation that would actually occur. Initially, we will assume that this uncertainty is minimal. When the submodels have been developed, they will be reviewed to reconsider whether some incorporation of uncertainty features is warranted.

D.11 Delta Water Operations Submodels Work Plan

D.11.1. Water Operations Subtasks

The following subtasks will be performed as part of water export modeling:

WO-1. Verify Availability of Needed Inputs from Other Submodels and Modules
WO-2. Define Representative Operating Rules for Each Facility and Submodel

WO-3. Develop a First-Cut Version of the Water Operations Submodels

WO-4. Debug and Test the First-Cut Submodels

WO-5. Document the First-Cut Submodels for Risk Calculator Encoding

WO-6. Present the First-Cut Submodel to the Water Operations Group for Review and Comment

WO-7. Assess Uncertainty and Add Estimates If Required

WO-8. Refine and Extend the Submodels (if needed) and Retest

WO-9. Prepare the Delta Water Operations Submodel Report

D.11.2. Water Operations Submodel Resource Requirements

The resources required to develop the Delta Water Operations Submodels through WO-5 were included in a previously submitted budget for more extensive work that has subsequently been partially redistributed to other submodels. No need for additional overall budget is foreseen.

D.12 WO References

To be added.