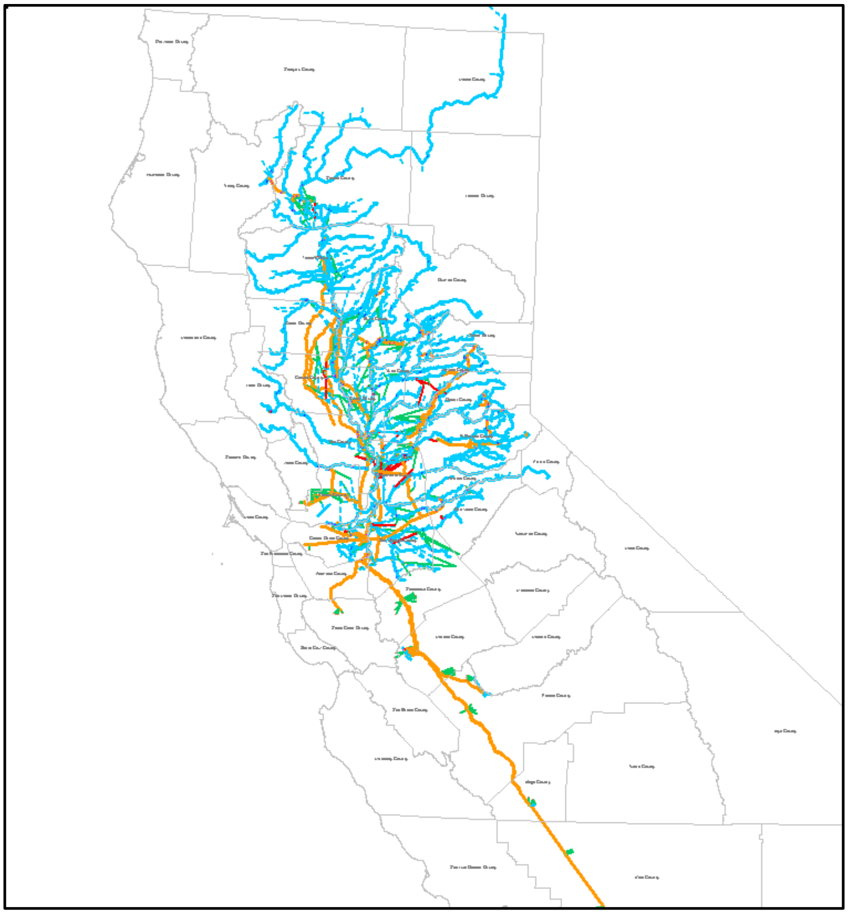
# Independent Peer Review of the Sacramento Water Allocation Model (SacWAM)



**A report for the**

**Delta Science Program**

## Prepared by


**William Fleenor (co-lead author), Samuel Sandoval-Solis (co-lead author), Deanna Sereno, Laura Condon, and Joshua H. Viers (chair)**



**December 2016**

**Delta Stewardship Council**
**Delta Science Program**

## Table of Contents



**Suggested citation:**
Fleenor[1], W.E., S. Sandoval-Solis[2], D. Sereno[3], L.E. Condon[4], and J.H. Viers[5]. 2016. Independent Peer Review of the Sacramento Water Allocation Model (SacWAM): a Report to the Delta Science Program. Delta Stewardship Council, Sacramento, California. 31 pp.

[1] Civil & Environmental Engineering, UC Davis, retired (wefleenor@ucdavis.edu)
[2] Land, Air, Water Resources, UC Davis (samsandoval@ucdavis.edu)
[3] Consultant (dsereno@gmail.com)
[4] Civil & Environmental Engineering, Earth Sciences, Syracuse University (lecondon@syr.edu)
[5] Environmental Engineering, UC Merced (jviers@ucmerced.edu)

# Executive Summary

The peer review panel (Panel) has examined the Sacramento Valley Water Allocation Model (SacWAM) and its documentation at the request of the State Water Resources Control Board (State Water Board). The State Water Board contracted with ICF International, Stockholm Environment Institute (SEI) and MWH Global to produce a Sacramento Basin model application using the Water Evaluation And Planning (WEAP) proprietary software for its use in the update of the 2006 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Bay-Delta Plan). The review included an in-person presentation of SacWAM by SEI and MWH Global representatives and hands-on use of the model. The Panel has discussed their individual concerns with SacWAM and here provides a summary of the questions posed to them and the Panel's findings:

1. Is the SacWAM model a suitable tool to assist in the analyses being undertaken by the State Water Board as it updates the Bay-Delta Plan?

The Panel finds that the approach taken with SacWAM is appropriate. However, the Panel has identified concerns regarding the calibration and validation of the model especially for low flow periods (see questions 5 and 6), the lack of sensitivity studies (question 6) and uncertainty analyses (question 2), the need for additional model enhancements and documentation (question 4), and the limitations of both, stream-aquifer interactions (question 2), and the temporal and spatial scales (question 7). Due to these shortcomings the Panel suggests using the model with great caution until these issues are addressed.

2. What are the limitations, uncertainties, and impediments associated with the use of the SacWAM model? Can you suggest ways to improve SacWAM to address those concerns?

The Panel is comfortable that SacWAM can provide guidance in wet and above normal water years for major project operations. However, the Panel is uncomfortable at this time in endorsing SacWAM for use in dry or critically dry years, and smaller "non-project" tributaries (see Appendix A). The current inability of the model to incorporate regulatory operational options (e.g., temporary urgency change petitions approved by the State Water Board in 2015 to relax Delta outflow objectives in order to preserve Shasta storage) and the approach to stream-aquifer interactions may limit its use in dry and critically dry years, or at least result in large unquantified uncertainties.

3. Under what circumstance(s) would SacWAM or CalSIM II be more scientifically justified?

SacWAM includes non-project systems and output at additional locations along the tributaries, it will be more useful in planning efforts that require streamflows at those locations. However, since many of these locations lack historical measurements of streamflow, the accuracy of the SacWAM model to simulate the additional non-mainstem tributaries cannot be determined.

4. What additional information or capabilities could be added to the SacWAM model, post-run processing, or documentation to improve its usefulness to the State Water Board?

The Panel finds that the documentation still needs to be significantly improved within SacWAM and in detail in a separate document. There are several informational output files that the software could provide to reduce user errors or misuse. The post-processing tool that was provided to the Panel should be completed and refined.

5. Is SacWAM calibration and/or validation appropriate and sufficient for the intended use to evaluate potential changes in flows, and environmental and economic impacts under different regulatory requirements?

Since SacWAM uses current regulatory and operational criteria and infrastructure (*i.e.* it does not reflect historical changes in operations), it is not conducive to an actual **calibration** where model performance is analyzed against historical measured data that reflect regulation and infrastructure change over time. Instead, various components used within SacWAM are **corroborated** against other models or regressions. The lack of observations and true model calibration is clearly a limitation, although it is likely unavoidable. Still, it is the opinion of the Panel that additional work is needed to sufficiently demonstrate that the model will provide realistic results in dry years and under the range of operating conditions that will be included in planning scenarios.

6. What, if any, additional sensitivity analysis, calibration and/or validation is recommended for SacWAM?

The Panel finds several areas in which further work with SacWAM would reduce uncertainty of the model predictions. The areas include applying the model to more recent time periods where understanding is more relevant to what is needed from the model, investigating and documenting model bias that may exist for wet and dry years separately, improving upper watershed estimates (if later incorporated), examining seasonality of valley floor ET and runoff, and verifying the model is correctly allocating water from the appropriate source(s) in both operation and non-operation areas by respective experts and operation manuals.

7. Are SacWAM temporal and geographic scales and resolutions appropriate for the intended use?

The Panel is concerned that the monthly timestep will not be sufficient for future decisions on environmental limits during droughts and water quality assessments. Also, the lack of feedback from the San Joaquin system and sparsely represented Delta channels will challenge any effort to estimate water quality within the Delta.

## Foreword

To assist in its water quality control planning process, the State Water Board needs a flexible, user-friendly simulation tool to assess the impacts of various regulatory scenarios on flows into the Delta, within the Delta, and exported from the Delta. The State Water Board has identified the following modeling capabilities are necessary to assist in its analyses and decision-making but do not exist in the current water resources planning model CalSIM II:

- the ability to predict flows at the mouths of tributaries to the Delta;
- the ability to simulate water diversions on non-mainstem tributaries and creeks; and
- the ability to simulate the operation of local agency reservoirs that are not part of the State Water Project (SWP) or Central Valley Project (CVP) systems

SacWAM was designed to provide these capabilities while maintaining most of the CVP and SWP operations logic found in CalSIM II. The overall purpose of this review is to answer the question "is SacWAM an appropriate tool to assist the State Water Board with the analyses associated with the Bay-Delta Plan update?". The model was reviewed by an Independent Review Panel (*i.e.*, the authors of this report) in a public forum in order to assure transparency and confirm the adequacy of SacWAM to simulate water balance for comparative purposes for applications related to updates to the Bay-Delta Plan. The Panel was given the charge as follows:

**Charge to the Panel -** The independent review panel was asked to answer the following questions after attending a presentation on the model and having a short period of time to work with the model.

- Is the SacWAM model a suitable tool to assist in the analyses being undertaken by the State Water Board as it updates the Bay-Delta Plan?
- What are the limitations, uncertainties, and impediments associated with the use of the SacWAM model? Can you suggest ways to improve SacWAM to address those concerns?
- Under what circumstance(s) would SacWAM or CALSIM II be more scientifically justified?
- What additional information or capabilities could be added to the SacWAM model, post-run processing, or documentation to improve its usefulness to State Water Board?
- Is SacWAM calibration and/or validation appropriate and sufficient for the intended use to evaluate potential changes in flows, and environmental and economic impacts under different regulatory requirements?
- What, if any, additional sensitivity analysis, calibration and/or validation is recommended for SacWAM?
- Are SacWAM temporal and geographic scales and resolutions appropriate for the intended use?

The Panel was provided with the timeline depicted in Figure 1 for completing the model review. However, the Panel held no fewer than five conference calls and two additional meetings where three or more members were present.

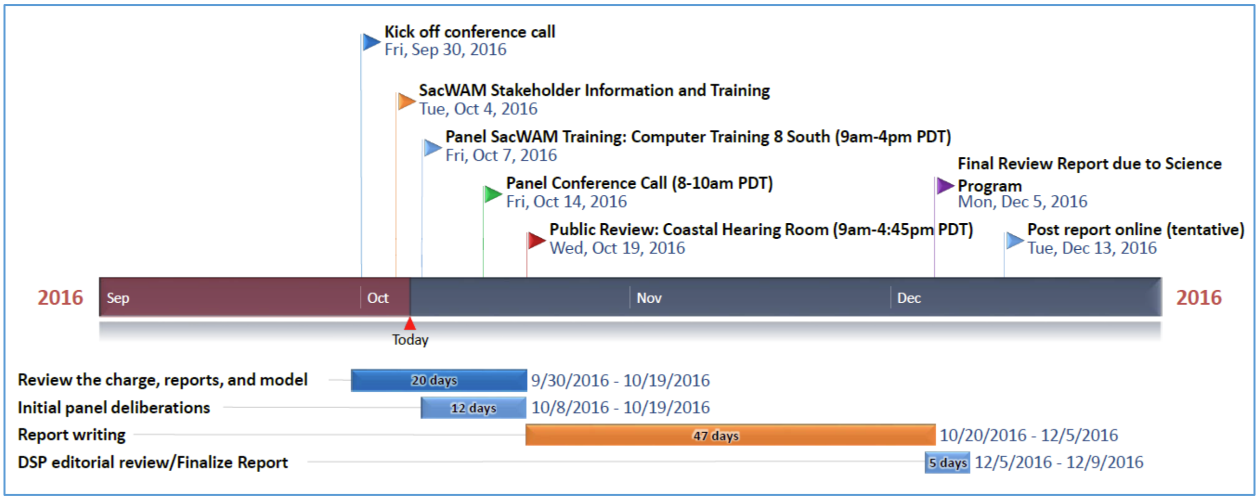



*Figure 1 Initial timeline for review Panel*

## Background

Sacramento Water Allocation Model (SacWAM) is a hydrologic and system operations model developed by Stockholm Environment Institute (SEI) and State Water Resources Control Board (State Water Board) to assess potential revisions to instream flow and other requirements in the 2006 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (2006 Bay-Delta Plan). SacWAM was developed using the Water Evaluation And Planning (WEAP) modeling platform and is intended to be user-friendly and to easily accept various scenarios. The Delta Science Program is conducting an independent peer review of SacWAM to assure transparency and confirm the robustness of SacWAM for applications related to updates of the Bay-Delta Plan, and as part of the Delta Science Program's mission to provide the best possible unbiased scientific information to inform water and environmental decision-making in the Bay-Delta system.

The WEAP system uses water balance accounting, where both the engineered and biophysical components of a water system are represented, to facilitate multi-stakeholder water management dialogue on a broad range of topics, including sectoral demand analysis, water conservation, water rights and allocation priorities, reservoir operations, hydropower generation, pollution tracking, ecosystem requirements, and project benefit-cost analysis. WEAP informs management strategies through scenario-driven analyses of possible water futures where the influences of climate, land use management, demand, regulation, and planning objectives can be explored. These analyses can be conducted at any number of scales, from municipal water systems and the local watersheds to regional, transboundary river systems.

The State Water Board's periodic review of the 2006 Bay-Delta Plan was initiated with the 2008 Strategic Plan, which prioritized Bay-Delta planning activities, and the 2009 Periodic Review Staff Report (2009 Staff Report), which recommended further review of the following: (1) Delta outflow objectives; (2) export/inflow objectives; (3) Delta Cross Channel Gate closure objectives; (4) Suisun Marsh objectives; (5) potential new reverse flow objectives for Old and Middle Rivers;

(6) potential new floodplain habitat flow objectives; (7) potential changes to the monitoring and special studies program; and (8) other potential changes to the program of implementation.

The State Water Board water quality control planning process for approving amendments to the Bay-Delta Plan must ensure the reasonable protection of beneficial uses, which requires balancing competing beneficial uses of water, including municipal and industrial uses, agricultural uses, fish and wildlife, and other environmental uses. The State Water Board process will include an analysis of the effects of any changed flow objectives on the environment in the watersheds in which Delta flows originate, in the Delta, and in the areas in which Delta water is used. It will also include an analysis of the economic impacts that could result from changed flow objectives. Computer modeling will assist in these analyses and decision-making.

The California Department of Water Resources (DWR) and the U.S. Bureau of Reclamation (Reclamation) have developed and extensively used the CalSIM II model for planning, managing, and operating the State Water Project (SWP) and Central Valley Project (CVP). Potential modifications to the 2006 Bay-Delta Plan may affect Central Valley and Delta operations that are included in the CalSIM II model, such as inflow, Delta outflow, export/inflow ratio, Delta Cross Channel Gate closure, as well as Old and Middle River reverse flows. However, for its review of the Bay-Delta Plan, the State Water Board will need the following additional modeling capabilities that are not part of CalSIM II functionality: (1) the ability to predict flows at the mouths of tributaries to the Delta; (2) ability to simulate water diversions on non-mainstem tributaries and creeks; and (3) ability to simulate the operation of local agency reservoirs that are not part of the SWP or CVP. The State Water Board also needs a flexible, user-friendly simulation tool to rapidly assess the impacts of various regulatory scenarios on flows into the Delta, within the Delta, and flows exported from the Delta. The WEAP modeling software system allows for rapid assessment of alternative water development and management strategies. As a policy analysis tool, WEAP can evaluate a wide range of water development and management options, and it takes into account multiple and competing uses of water.

SacWAM was designed to estimate stream flows at Sacramento River tributary mouths, locations on the Sacramento River, Delta Eastside tributaries and key channels within the Delta. To achieve this, it was designed to include most of the CVP and SWP operations logic found in CalSIM II. It was designed to run on a monthly timestep in order to estimate seasonal variation in water demands, supplies, and streamflow important to aquatic species of interest. Its temporal and spatial discretization is meant to provide a tool useful for assessing all of the Sacramento River Hydrologic Region within a continuous hydrological and system operations model. Impacts on processes that occur on a sub-monthly time scale will need additional study using more refined models.

Stream flows estimated by SacWAM may be used to inform the following types of analyses as part of the State Water Board's assessment of potential alternative regulatory requirements:

- Estimates of flow conditions under a range of alternative regulatory requirements.
- Estimates of changes in water diversions for use in an evaluation of the impacts of alternative regulatory requirements on agricultural resources, water suppliers, and groundwater.
- Estimates of changes in reservoir storage for use in an analysis of the impacts of alternative regulatory requirements on hydropower generation, recreation, and fisheries.

- To inform other analyses or models, such as delta hydrodynamics, temperature, economic, and fisheries benefits models.

SacWAM will be used in a comparative manner in which a model scenario is compared to a model base condition and the difference in model outputs is used to assess potential impacts of proposed regulatory actions. Additionally, conclusions may be derived from broad statistical measures of model output and not particular model output in a single month or single year.

## Regulatory Context

The State Water Resources Control Board and the nine Regional Water Quality Control Boards (Water Boards) have broad responsibilities to protect surface and groundwater quality and balance competing demands on California water resources through programs that allocate water rights, adjudicate water right disputes, develop statewide and regional water quality control plans and implement and enforce those plans. The State Water Board allocates water rights through an administrative system that is intended to maximize the beneficial uses of water while protecting the public trust, serving the public interest, and preventing the waste and unreasonable use or method of diversion of water. The State Water Board protects water quality by establishing water quality control plans, implementing those plans and enforcing that implementation. Water Quality Control Plans identify existing and potential beneficial uses of waters of the state and establish water quality objectives and implementation measures to reasonably protect the identified beneficial uses along with surveillance and monitoring requirements. While most water quality control planning is done by the Regional Water Quality Control Boards, the State Water Board has authority to adopt statewide Water Quality Control Plans and adopts the Bay-Delta Plan because of the overlapping water quality and water rights issues of statewide significance in the Bay-Delta.

The Bay-Delta Plan includes beneficial uses that fall into three broad categories including: fish and wildlife, agricultural, and municipal and industrial uses. The current Bay-Delta Plan includes water quality objectives to protect the three categories of beneficial uses including: inflows from the Sacramento and San Joaquin Rivers; Delta outflows; water project operations; dissolved oxygen; native salmon protection; and various salinity objectives for the protection of fish and wildlife, agriculture, and municipal and industrial uses. The program of implementation identifies actions needed to protect beneficial uses and implement the water quality objectives, including actions the State Water Board will take, actions that the State Water Board will take with other entities, and actions that other entities should take, including non-flow and water quality actions.

The Bay-Delta Plan like other Water Quality Control Plans is not self-implementing and requires additional actions to be implemented. The primary mechanism for implementing the Bay-Delta Plan in the past has been through the State Water Board water rights authorities. The water quality control planning process and water rights implementation processes are separate processes governed by separate statutory and regulatory requirements. The water quality control planning process is a quasi-legislative planning process, whereas the water rights process is a more formal evidentiary quasi-judicial process.

Pursuant to state and federal law, the State Water Board is required to regularly review the Bay-Delta Plan to determine what, if any, changes should be made to the Bay-Delta Plan to protect beneficial uses. The State Water Board conducted a review of the current 2006 Bay-Delta Plan in 2009. As a result of several species declines in the Bay-Delta that may be associated with Bay-Delta Plan requirements the State Water Board determined that Delta outflows and other requirements for the protection of fish and wildlife beneficial uses should be considered for potential amendment to ensure the protection of fish and wildlife beneficial uses. The State Water Board started the process of updating the Bay-Delta Plan with Phase 1 in 2009 and Phase 2 in 2012. The update process is being conducted in compliance with applicable statutory and regulatory requirements, including the California Environmental Quality Act (CEQA). The Water Quality Control Planning process is a Certified Regulatory Process pursuant to CEQA. Accordingly, the State Water Board is exempt from preparing an Environmental Impact Report (EIR) for its review. Instead, the State Water Board is preparing a Substitute Environmental Documentation (SED) that is functionally equivalent to a programmatic EIR.

In addition to the evaluation of environmental impacts, the SED will also evaluate economic effects and other public interest considerations at a programmatic level. All of this information will be used along with public comments from the public to inform the State Water Board decisions regarding changes to the Bay-Delta Plan. Prior to implementation through water rights and other measures, additional project specific environmental documentation will be prepared as necessary and other statutory and regulatory requirements will be met.

## Panel Analysis

This section provides detailed responses to the seven charge questions. Note that many of the responses provided may seem repetitive, but it is the intent of the Panel to answer each question completely.

### Question 1:

> Is the SacWAM model a suitable tool to assist in the analyses being undertaken by the State Water Board as it updates the Bay-Delta Plan?

SacWAM is a complex model developed with a proven software tool (WEAP) that allows the creation of new scenarios for answering 'what-if' type questions and comparison of results to a base case. The Panel finds the SacWAM model to contain many advantages over CalSIM II for use as a water planning and management tool. The advantages of the SacWAM model include added non-project tributaries and operations, and finer spatial representation, which therefore allows for simulation of flow at locations not included in CalSIM II while maintaining fidelity to existing data representations and specific nodes of interest to the water management community.

The Panel finds that the approach taken with SacWAM is appropriate. However, the Panel has identified concerns regarding the calibration and validation of the model especially for low flow periods (see questions 5 and 6), the lack of sensitivity studies (question 6) and uncertainty analyses (question 2), the need for additional model enhancements and documentation (question 4), and the limitations of both, stream-aquifer interaction (question 2), and the temporal and spatial scales (question 7). Due to these shortcomings the Panel suggest use with great caution until these issues are addressed. In the **Recommendations** section of this report, the Panel segregates its recommendations into those that should be completed before the tool is used for the Bay-Delta Plan update and those that could be delayed.

### Question 2:

> What are the limitations, uncertainties, and impediments associated with the use of the SacWAM model? Can you suggest ways to improve SacWAM to address those concerns?

The SacWAM documentation devotes a chapter to the proper uses and limitations of the model (Chapter 11). As stated in the **Background** section, the model was developed to assist in the assessment of potential regulatory alternatives:

1. Estimates of flow conditions under a range of alternative regulatory requirements.
2. Estimates of changes in water diversions for use in an evaluation of the impacts of alternative regulatory requirements on agricultural resources, water suppliers, and groundwater.
3. Estimates of changes in reservoir storage for use in an analysis of the impacts of alternative regulatory requirements on hydropower generation, recreation, and fisheries.

4. To inform other analyses or models, such as delta hydrodynamics, temperature, economic, and fisheries benefits models.

The Panel is comfortable that SacWAM can provide guidance in the first three areas of inquiry above in wet and above normal water years for major project operations. The Panel is uncomfortable, however, in endorsing SacWAM for use in dry or critically years for those three areas, or for smaller non-project operations (see Appendix A). The inability of the model to provide regulatory operational options (*e.g.*, modify priority between Delta outflow and Shasta coldwater pool storage) and the assumptions about stream aquifer interactions may limit its use in dry and critically dry years, or at least result in large unquantified uncertainties. To date, the uncertainty of the results has not been quantified, especially for anomalously wet or dry years, and this limits interpretation and potential use. Further, the Panel urges extreme caution in the use of SacWAM for the fourth area of inquiry. While its use should be determined on a case-by-case basis, there are a number of limitations outlined in responses to other questions below and the lack of calibration described further here, that will often preclude its use in its current form.

By definition, model calibration is a process of adjusting model parameters to predicted results from a model, comparing these results with observed data of known uncertainty over the full range of input variables that are expected to occur, and then determining if the degree of discrepancy between the model results and observed data is acceptable for the intended purpose of the modeling exercise. The model is then validated by simulating the calibrated model for a separate set of input data over the same full range to see if the agreement of the predicted results from the model and the observed data holds true. Using statistical analysis of the results versus the measured data of known uncertainty, the uncertainty of the model results is extrapolated. Corroboration is the process to verify that the algorithms and logic declared in a model follow an intended system behavior, which for SacWAM can be to replicate CalSIM operations, algorithms and logic. In this case, the models are compared among themselves and not with observed data, though statistical measures of performance are also used.

The northern California system being modeled is highly complex and thus, without adequate historical data (*e.g.,* unimpaired flow measurements), SacWAM cannot be calibrated *per se*. Consequently, much effort has gone into comparing SacWAM with CalSIM II to corroborate SacWAM operations, without consideration of the shortcomings of the current CalSIM II model version. For instance, CalSIM II is shown to drawdown upstream project reservoirs in drier years, yet the current regulatory requirements prevent such operation. In the end, both are modeled approximations of a complex system with numerous interdependent decision rules.

Also, in the areas that are not simulated by CalSIM II there is even less to compare. The State Water Board is considering flow regulations at a number of locations that do not have historical measurements of streamflow (SWRCB 2016). The State Water Board should work with other agencies to install flow measuring devices at each of the potential compliance locations as soon as possible. In addition, a thorough sensitivity analysis would bring some understanding of the internal uncertainty of the model and could provide more quantitative guidance on appropriate applications even when observations are lacking.

The Panel considers exclusion of recent water years through 2016 from the comparisons another significant limitation. These later water years are better understood and reflect how the system operated for a range of water year types under current regulations, current water management operations. Also this period covers a significant drought and can also be used to test the more restrictive decisions made to react to shortage. A greater effort and emphasis should be placed on simulating these recent historical data to demonstrate the model's efficacy and provide greater confidence in results.

It was outside the scope of this Panel charge to verify the coding and implementation of the logic in the model itself. Nevertheless, the members of the panel did a cursory examination of one region of SacWAM, Kellogg Creek. Here the logic declared in SacWAM was found to be inaccurate for allocating water from the adequate sources and the operations of a reservoir, resulting in inaccuracies in the Delta flow balance (See Appendix A for details), and unknown implications for cascading decision rules downstream. This is just one example and, due to model complexity, it is likely that not all system parts within SacWAM will be fully verified until individuals with full knowledge of each component have had an opportunity to exercise the model. As with all such models, assumptions and simplifications will limit representativeness in certain cases.

There are additional limitations in the physical representation of the system in SacWAM. Stream-aquifer interactions are heavily parametrized and rely on annual correlations. The lumped parameter approach employed greatly simplifies the physical hydrology and will always have some inherent limitations especially for simulating extreme events outside the calibrated range of the model. The implementation of a seasonal regression with C2VSim for stream-aquifer interaction suggested here would likely reduce uncertainty, although it will not improve the ability to quantify the uncertainty. Furthermore, these correlations are dependent on the calibration of other model applications, C2VSim, making this approach highly dependent on other tools which will have their own limitations. Consideration of recent years through 2016 for valley floor rainfall runoff-infiltration will also reduce uncertainty. Using the more recent ET work that has been done, and is currently underway, will improve uncertainty. The long-needed improvements to Delta Island Consumptive Use (DICU), along with improved ET would certainly improve uncertainty and is most needed in the drier years.

A further consideration is that the desired model transparency is limited since the base software (WEAP) is not open-source and the complexity of the model requires the use of a commercial numerical solver. In other words, the true nuts-and-bolts of the model *vis-a-vis* its numerical and computational formulation cannot be known. Further, the choice of proprietary software and commercial solver will limit use by casual users.

The fact that one must have some expertise in both project and non-project operations to effectively use the model is an impediment to its use. As new scenarios are developed (*e.g.*, adding/modifying flow requirements), the user will need to review the results to ensure that the modifications don't have any unintended consequences. Improved model corroboration and the addition of sensitivity analyses will reduce the risk of significant errors but will not remove the need for expert review. An additional post-processor would be helpful to assist in the evaluation of modeling scenarios to more readily identify any unintended consequences of scenario development.

Another potential impediment to model use is that users will require policy direction for certain operational conditions. For example, in dry years when available water supply is unable to meet all regulatory requirements, both CalSIM II and SacWAM place preferences on meeting Delta outflow requirements rather than Shasta storage requirements, which results in simulated Shasta operations that are inconsistent with current regulations. However, in recent years, Delta outflow has been sacrificed to meet Shasta storage requirements. An alternative approach was used in the Draft Hydrological and Operations Modeling Considerations for the Phase II Update of the 2006 Bay-Delta Plan – State Water Board staff implemented measures to reduce the amount of irrigated agriculture and reduce the allocation of CVP and SWP project water to senior settlement contractors in drier water years to limit groundwater pumping and reduce the demand on upstream storage. Such policy decisions are highly controversial, may be an impediment to model use, and are an additional source of unquantified uncertainty in the model results.

Finally, as the State Water Board evaluates new flow and water quality objectives, the model must include logic as to the responsibility for meeting those objectives. For the portion of responsibility that accrues to DWR and Reclamation as holders of the water right permits for the SWP and CVP, the correct division of that responsibility is unknown and thus is a source of uncertainty. For example, the existing SacWAM logic splits responsibility for upstream reservoir releases necessary to meet in-basin use, such as Delta outflow, between Reclamation and DWR by allocating 75% of the responsibility to Reclamation. However, the agreement that serves as the basis for that division of responsibility was signed in 1986 and does not address any regulations beyond the State Water Board water rights decision D-1485 (August 1978). SacWAM has incorporated logic for more recent regulations, based upon recent operations, but there is no formal agreement that specifies the split in responsibility for meeting the current post-1978 regulations or any future regulations. SacWAM could be used to run sensitivity studies that evaluate the effects of potential responsibility splits on upstream streamflow and water supply. However, the lack of clear definition regarding the delegation of responsibility and its follow-on effects means that the results of the SacWAM model must be used with caution in the State Water Board Bay-Delta planning process until this definition of responsibility splits has been clarified. Furthermore, as discussed in question 4, the assumptions and interdependencies of the model are not always transparent in its current form.

## Question 3:

Under what circumstance(s) would SacWAM or CalSIM II be more scientifically justified?

Since SacWAM includes non-project systems and output at additional locations along the tributaries, it will be more useful in planning efforts that require streamflows at those locations. However, since many of these locations lack historical measurements of streamflow, the accuracy of the SacWAM model to simulate the additional non-mainstem tributaries cannot be determined. SacWAM can be calibrated against naturalized and unimpaired streamflow data from other model applications (DWR 2007) or analysis that uses publicly available data (Lane *et* *al*. 2016). WEAP provides a better scenario comparison tool than CalSIM II; however, the SacWAM application is highly detailed and consequently the tool often takes considerable computer resources and time to generate comparisons, and differences between scenarios can be difficult to track.

Both CalSIM II and SacWAM will likely continue to evolve as they each have strengths. Maintaining synchronization between the models for management operations will require significant cooperation across agencies, but is an important step to ensure that useful comparisons can still be carried out. Both models will continue to suffer from the same limitations in model corroboration since they both basically use the same input data and current operation logic. Agencies involved with project operations are more likely to maintain their use of CalSIM II and any future versions, i.e. CalSIM III. The prolonged development of CalSIM III, and further the lack of agency disclosure with respect to the details of CalSIM III, are problematic as its release could obviate SacWAM utilization or run counter to SacWAM results. Resolving the programmatic and implementation differences in these competing models should be a high priority, but it is beyond the scope of this review.

### Question 4:

> What additional information or capabilities could be added to the SacWAM model, post-run processing, or documentation to improve its usefulness to State Water Board?

While the software for the SacWAM model is based on a graphical user interface (GUI), which can depict different objects such as demand nodes in both map and hierarchical form, the extraordinary complexity of this particular system means that the GUI can be cumbersome for analysis and requires near expert level use for proficiency. It would be helpful if some key assumptions, such as whether the model simulated upstream hydrology or simply a pre-processed input file, were obvious in the GUI and if modal switches were depicted more readily. Model logic is all technically available from the GUI; however, it is often not intuitive and must be pieced together by going through multiple related objects. Understanding model logic in its current form will require users to educate themselves with model formulation and node interdependencies. Allowing a user to generate a summary of all logic that is relevant for a given model object (*e.g.*, demand node, transmission link, *etc.*) would improve transparency. Without ready access to tracing and post-processing tools, users will be required to delve more deeply into results to ensure that the logic performed as intended. Users will need to be familiar with the operational system and the concept of priority ranking, model depicted object relationships, and how rule sets are implemented to adequately judge if results are reliable. At present, these concepts and model components can be difficult to decipher. SacWAM model results and their presentation *via* the software are not intuitive and occasionally buggy. Short of a full redesign of the WEAP GUI, a 'WEAP-lite' interface for key model components would help future users explore the model without having to be WEAP experts.

The SacWAM application of WEAP is extensive; consequently, using the WEAP interface to view results can be extremely time intensive (*e.g.*, some results take over 30 minutes to load in a view). Enhancements should be made to the WEAP interface to allow more efficient result queries. For example, when in the Schematic view, the user can right click on an object and see the object name and select "View Results." This action should simply load results for the object that was selected on the Schematic view; however, currently this action appears to either load results of all similar objects (if this is the first time that the user requested to load results of this result type (*e.g.*, streamflows) since the program was launched) or load results from the previous queried objects of this result type. Similarly, clicking on the "Map" tab in the results view generates a map showing the full extent of SacWAM rather than simply limiting the extent to the objects selected on the chart view. The SacWAM developers have defined a number of "favorite" result groupings for display, which facilitates review. However, there is no documentation of these "favorites" and many are not intuitive.

The ease of modifying scenarios is a great strength of SacWAM. However, there remains difficulty in interpreting the results from the model interface. While two or more scenarios can easily be graphed together, there is currently no easy way to track logic differences to determine what might be driving model result differences. Currently, one must investigate the whole GUI to determine what changes were made from one scenario to another, and there are few clear mechanisms to evaluate differences in results without extensive post-processing. It would be helpful if the model could generate a summary specifying the assumptions used in the base case and the modifications for each scenario in addition to the numerical results of such model runs.

Additionally, the model should include common automatic quality control checks. For instance, the model "injects" small amounts of water to overcome "relaxation of constraint errors" caused by numerical rounding and iterative WEAP solution techniques. While the errors may be small, each new simulation needs to be checked to ensure they are not significant. If the model 'injects' the flows, then it can surely identify them and assess their significance so the user does not have to search and analyze them. There are a number of standard approaches to assess model performance, such as ramp-up or initialization time and long term accretion from annual carryover, that do not appear to be standard diagnostic features of SacWAM. Some suggested improvements follow.

The Panel found the post-processing spreadsheet to be most helpful addition to the GUI output and would encourage that it be fleshed out and provided with the model. The Panel would also encourage the development of two additional types of post-processing tools. The first tool would be used assist in the evaluation of the model results. The second tool (or suite of tools) would transform SacWAM output into the format required as input for subsequent models (such as DSM2). These tools have been created for CalSIM II and could be rather easily adapted for use with SacWAM.

The SacWAM documentation needs improvement. A detailed summary of what facilities, regulations, and operations are consistent with CalSIM II and what is modified, additional, or not included, would be helpful (*e.g.*, demands based on MABIA (agriculture), historical or full contract demands, what operations are not included, *etc.*). While some decisions are specified in the documentation, few have full citations for their basis and leave one without knowing why the parameters were chosen. For example, Section 7.2.5.2 provides a table of coefficients (at p. 7-26) used to determine the split of flow at the Head of Old River; however, the discussion lacks the following: (1) a reference for the coefficients; (2) an explanation of the priority between conditions listed in the table (the conditions are not mutually exclusive, yet no priority is given);

and (3) an explanation of why the table is inconsistent with CalSIM II and the current regulations, which prevent the Head of Old River Barrier from being installed in the spring (represented in the SacWAM table as the “April, May AND Qvernalis<5,000 cfs” condition). Similarly, additional documentation is needed to clearly identify where SacWAM logic differs from CalSIM II (and in the future, from CalSIM III as the models progress).

WEAP has the capacity to store “notes” for each variable created in it, and in the initial model development this documentation was not included. Putting the documentation of SacWAM in a broader context, there have been other efforts in similarly complicated river systems, such as the Colorado River Simulation System, where extensive documentation of the inputs, water allocation logic and infrastructure operations have been put together into user manuals and model application manuals with the objective to make the tools more transparent and understandable (Zagona *et al.* 2001, USBR 1995). The Panel suggests adding detailed documentation of this sort to both the model and to an expanded user manual.

### Question 5:

> Is SacWAM calibration and/or validation appropriate and sufficient for the intended use to evaluate potential changes in flows, and environmental and economic impacts under different regulatory requirements?

As a planning model, SacWAM uses current (or future) regulatory and water management operational criteria forced by historical hydrology. Calibration of simulated flow in regulated streams to historical flow data is not possible because regulations and operational criteria have changed over time. Similarly, calibration of simulated reservoir storage to historical reservoir levels is not possible. For example, regulatory criteria for CVP and SWP facilities were modified significantly in 2008 and 2009 and thus historical data prior to 2009 are not relevant for calibration purposes. This limitation is recognized in Appendix B of the SacWAM documentation in discussion of CVP and SWP project operations (section B.6), which relies upon a comparison with the CalSIM II model for corroboration of CVP and SWP operations.

Comparison to CalSIM II is a good starting point for regions that are largely influenced by CVP and SWP operations; however, the validation relies upon results over long-term averages without examining wet and dry years separately. Preliminary analyses by the Panel indicate that, although the model may perform adequately when comparing long-term averages, certain results are biased by water year type (*e.g.*, Net Delta outflow compares well over the 82-year period, but SacWAM is high in drier years and low in wetter years). This bias will affect the ability of the model to evaluate the potential flows in extremely dry years when the environmental and economic impacts are likely to be most significant. Additionally, CalSIM II has known limitations and uncertainties, and simply mimicking CalSIM II operations may not be appropriate for the State Water Board’s purposes (see question 2).

Calibration of non-mainstem tributaries or creeks are uncertain and need further evaluation. It was beyond the charge of the Panel to verify that the model was solving each piece of the system correctly. In a quick examination of one part of the system the Panel found an obvious error (see Appendix A). Each part of the system should have scrutiny by those who are expert in that part of the system (*e.g.,* project operations examined by project experts and each non-project system examined by local experts).

Although regulated streamflow and reservoir storage could not be calibrated directly for the reasons discussed above, various components of SacWAM processes are corroborated for the upper watershed and valley floor. The upper watershed hydrology was corroborated for the largest 21 of 38 streams by adjusting the Soil Moisture Method hydrological parameters to match the "DWR reported unimpaired flows" – but no information is provided regarding the source of those flows, and no uncertainty analysis was completed.

Another significant area of concern is that the corroboration (and model formulation) uses a monthly timestep. A monthly timestep not only limits the feasibility and accuracy of modeling snowmelt and environmental flows and qualities, but limits model applications to other desired benefits such as the potential for estimating hydropower generation.

Valley floor evapotranspiration (ET) is corroborated to replicate the DWR CUP model, although only one example was provided. There is more recent, including currently ongoing, ET work that should be considered. Baseflow should not be ignored for the valley floor. Valley floor rainfall runoff-infiltration is based on a curve number approach with curve numbers fit to historical Sacramento Valley accretions data. Stream-aquifer interactions are based on regressions from C2VSim simulations over annual periods. Seasonal examination of these interactions could reduce error and should be completed.

There are additional concerns and limitations to SacWAM. To date, there has been no sensitivity analysis performed or effort to quantify SacWAM model uncertainty (see question 2). While the corroboration was incomplete (as acknowledged by the SacWAM developers at the October 19, 2016, public workshop), the need for additional corroboration is not acknowledged in the documentation or the model itself. Furthermore, extending the hydrologic period of analysis until 2016 (see Question 6) will allow for additional model evaluation under current operating conditions, which can improve the trust of SacWAM for water supply and demands estimation, water allocation logic and results.

Taking into account the above limitations it is the opinion of the Panel that the current corroboration and validation of the model is incomplete and attention should be given to the limitations described here and the suggestions in the **Recommendations** section.

## Question 6:

> What, if any, additional sensitivity analysis, calibration and/or validation is recommended for SacWAM?

As a planning model, SacWAM applies current regulatory and operational criteria to historical hydrology. This combination makes it impossible to perform a true calibration as discussed in the response to question 5. Consequently, different components of SacWAM are corroborated and/or validated by separate means, as described in Appendix B of the SacWAM documentation. At the October 19, 2016, public workshop, the SacWAM developers indicated that validation and model refinement are on-going. The Panel provides the following discussion and recommendations to inform that additional work.

> **Recent Time Periods**. First, all corroboration, calibration, and validation would be significantly improved by including the most recent historical data through 2016 – this is particularly true for operational validation as discussed later in this section. Extending through 2016 is important because 2016 is a relatively wet year following an extended

drought; this condition is necessary to evaluate if SacWAM is adequately simulating the rewetting of the soil profile and further that the operational decisions related to drought recovery are appropriately reflected.

**Bias Corroboration**. Second, the corroboration and validation analyses should consider model performance by hydrologic conditions, analyzing wet and dry years separately (*e.g.*, present monthly statistical boxplots by water year type). Since recent years have been operated under current regulations, corroboration and validation against these years (2009-2016), and closer comparison against extreme events (wet and critical) is important. Preliminary analyses by the Panel indicate that although the model may perform adequately over long-term averages, certain results are biased by water year type (*e.g.*, Net Delta outflow compares well over the 82-year period, but SacWAM is high in drier years and low in wetter years). Distinguishing the corroboration and validation plots by hydrology may allow the developers to determine the cause of this bias and adjust model parameters as necessary.

**Upper Watershed Corroboration and Calibration**. At the public workshop, SacWAM developers acknowledged that the corroboration and/or calibration of upper watershed catchments would need to be refined before it is ready for use. The upper watershed catchments can be corroborated from unimpaired streamflow data from other hydrologic models (DWR 2017) or by using time series data publicly available of naturalized and unimpaired streamflow data (Lane *et al*. 2017). State Water Board staff indicated that the upper watershed catchments are not intended for use in the Bay-Delta Phase II update; instead, the State Water Board is relying upon pre-processed hydrology time series. The upper watershed catchment corroboration and calibration deficiencies need to be clearly stated in the documentation, and if possible, this functionality should be disabled within the model until it is sufficiently corroborated and verified (currently, users can turn on the catchment objects by modifying the Key Assumption "Simulate Hydrology"). With that said, the Panel recommends that the corroboration of the upper watershed catchments be completed. To adequately simulate snowmelt and runoff, SacWAM should incorporate a finer elevation delineation (currently 500-m contours). Also, a weekly timestep would be preferred and improve upon the current monthly timestep. The hydrologic improvements gained by a finer timestep may exceed the inaccuracies introduced by the lack of hydraulic routing, though this is dependent upon location and discharge.

**Valley Floor Corroboration**. The SacWAM water demand estimation component is based on the methodology for estimating water requirements presented in the publication from FAO 56 (Allen *et al.* 1998). The water demand estimations of FAO 56 are scientifically sound and adequate for the planning purposes of SacWAM, although updated methods have existed since 2012, FAO 66 (Steduto *et al.* 2012). Valley floor evapotranspiration (ET) is calibrated to replicate the DWR CUP model, although only one example was provided. There is more recent, including currently ongoing, ET work that should be considered. Furthermore, baseflow should not be ignored for the valley floor. Following corroboration of ET, the valley floor surface water diversions were corroborated for 15 of the largest water users in the Sacramento Valley by apparently adjusting one rice irrigation parameter to match historical surface water deliveries. The total diversions do not appear to indicate a large bias, but large biases are apparent for specific locations with strong seasonal patterns. Accounting for additional water sources, such as historical groundwater pumping could be a source of error – there is no mention in the documentation of whether historical groundwater pumping was included in the corroboration, nor is there discussion of what other parameters could be adjusted to better match seasonal diversions. The final step to valley floor corroboration was the division of precipitation into infiltration and surface runoff using a modified curve number approach, with literature-based curve numbers adjusted to match historical Sacramento Valley accretions. The documentation only provides a long-term average bias, but it would be good to evaluate the corroboration by water year type. Simulation of more recent years where operations are replicated would provide more useful information for each of these areas. Stream-aquifer interactions are based on regressions from C2VSim simulations over annual periods. Seasonal examination of these interactions would reduce error. A seasonal representation of the surface/groundwater relationship is also needed with baseflow in the valley floor included.

**Operational Verification**. As discussed in the response to question 4 and 5, the approach to validating operations is a good first step, but ultimately incomplete. The best method to evaluate a planning model is to convene a workshop of experts, including system operators and modelers, to determine if the model performs in a realistic manner (*i.e.*, simulates operational decisions by system operators for specified conditions). Additionally, for the CVP and SWP, regulations have been fairly consistent since 2009. Therefore, the Panel recommends that SacWAM be updated through 2016 to allow comparison of operations for years of consistent regulations. Extending through 2016 is important because 2016 is a relatively wet year following an extended drought; this condition is necessary to evaluate if SacWAM is adequately simulating the rewetting of the soil profile and operational decisions related to drought recovery. For smaller pieces of the system (such as the operational problem identified on Kellogg Creek, a small Delta tributary, see Appendix A of this report), the best approach is to conduct outreach to local experts.

There are several areas where a sensitivity analysis is required. The WEAP model is designed around priority allocations; a formal analysis is needed to be certain the model is performing properly given the existing priority assignments. Sensitivity studies for San Joaquin River inflow and water quality is necessary to address the lack of integration with the San Joaquin valley. Sensitivity studies of key operational parameters might reduce uncertainty. A flow comparison of the SVI 4-river Index against the model along with a distribution of water year types is needed. Analysis of reservoir antecedent storage conditions and carryover is needed. Additionally, full sensitivity and uncertainty analyses are necessary for any variables examined for comparison of base case and 'what-if' scenario to be fully understood.

## Question 7:

*Are SacWAM temporal and geographic scales and resolutions appropriate for the intended use?*

Temporal resolution (*i.e.*, monthly timestep) is as good as what has been available to date for statewide CVP and SWP water resources planning, but monthly time steps will not suffice for environmental limits during drought conditions nor inform many water quality assessments (see cautionary statement in answer to question 2). This caveat is especially true given recent confusion over the vernacular usage of unimpaired flows and "functional flows", which are not interchangeable. Functional flows are managed releases to meet specific biophysical process needs over timeframes shorter than one month (Yarnell *et al*. 2015). Additionally, a monthly timestep will not likely perform well on snowmelt calculations, which are also compromised by the 500-m vertical resolution. Annual reset of upstream reservoir storage might be adequate for planning purposes but adds to the difficulty in calibrating and validating the model.

The geography included does not take into consideration any feedback from the San Joaquin River system and its parallel but integrated management. Diversions from the Delta to the San Joaquin Valley affect the water quantity and water quality in the San Joaquin River at Vernalis. At least a sensitivity analysis should be performed to see how San Joaquin valley changes would affect the larger system. Additionally, lack of representation of many Delta channels and control (barriers, *etc*.) pose future issues for water quality estimations.

## Recommendations

### Required Prior to Phase II Use

A more thorough corroboration, validation and sensitivity analysis needs to be performed prior to use in Phase II management decisions. The more recent data through 2016 should be included in SacWAM to allow calibration and validation, even for a small period of time. Including this data will also allow corroboration with the model performance examined statistically by water year type.

Stream-aquifer interaction has been incorporated using an annual linear regression against C2VSim. In the short term, a seasonal consideration should be applied to reduce error and uncertainty. However, it should be noted that with this approach the SacWAM streamflow-aquifer interactions are still dependent on the calibration of other model applications, C2VSim, making this approach highly dependent on other tools. In the long term the Panel recommends that WEAP developers also consider directly coupling with a physically based groundwater model.

Valley floor rainfall runoff-infiltration is based on a curve number approach with curve numbers from historical data. Infiltration is treated as though it goes straight to groundwater which eliminates all baseflow. The Panel recommends modifying this approach to incorporate baseflow into the valley floor simulations.

Valley floor water diversions were corroborated with a focus on one rice parameter. Crops and demands with large seasonal and inter-annual demands should be examined. Including other demands should assist in defining uncertainty.

Valley floor evapotranspiration was compared to the DWR CUP work, but only a single example was provided in the documentation. A more thorough evaluation should be shown in the documentation and a comparison with more recent measurements and analysis of ET in the valley would better define the uncertainty.

Phase II documentation indicates the intent to use the upper watershed functionality that is available in SacWAM. Prior to its use it is necessary to corroborate with other models (DWR 2007), or calibrate against publicly available data (Lane *et al*. 2016) and validate its efficacy. If this is not performed, then upper watershed functionality should not be used in Phase II and should be disabled before SacWAM is distributed to prevent misapplication by others.

Sensitivity analyses should be performed on the variables that are expected to be manipulated in Phase II scenario work. Other sensitivity analyses should be done on the many parameters within the model where mostly default values have been applied. In particular, since Phase II is to be run without feedback from the San Joaquin River system, sensitivity to changes in the San Joaquin boundary condition should be better understood. Certainly various WSI-DI curves should be included in the sensitivity analysis.

It was not the charge of the Panel to verify the water allocation logic for every water demand, water source, and piece of infrastructure throughout the system. However, a cursory inspection to understand how the model functions uncovered one such error (see Appendix A). It is unlikely that this was the only such error in the complex system that the model covers. Significant efforts should be made for both the project operations and the non-project operations to involve experts in each of the various areas to assure that SacWAM is representing the systems as intended.

As funds are available, the State Water Board should work with the U.S. Geological Survey to install flow meters at the locations that the State Water Board is considering for new flow regulations. It is critical to start building a historical time series at these locations.

### Helpful Prior to Phase II Use

It would facilitate the use and minimize errors in the use of SacWAM if the model would output a list of differences between scenarios that are being compared. Further, a list of the significantly high 'injected' flows that are added to overcome "relaxation of constraint errors" caused by numerical rounding and iterative WEAP solution techniques is needed.

Documentation should be supplemented with summary tables of facilities, operation, and demands that are consistent with CalSIM II; what differs from CalSIM II (*e.g*. COA implementation, WSI-DI curves); what new implementations (*e.g*., demands refined and based on MABIA or historical or full contract; and what is still not included (*e.g*., operational adjustments during droughts). Documentation should also define which reservoirs are dynamically operated and which are reset at historical levels each simulation year. It would further be useful to define all parameters, their default values or ranges and what has been modified to match CalSIM II output.

The post-processing spreadsheet tool provided to the Panel was quite helpful and should be completed and supplied with SacWAM to assist users in analyzing output. Additional functionality of the post-processer would be helpful as well as pre-processing of SacWAM output for future use in other models (*e.g.*, DSM2).

### Recommendations after Phase II

As SacWAM and CalSIM mature there will be a need to coordinate SacWAM development along with any further development of CalSIM.

A deeper analysis of the monthly timestep is needed to determine any bias associated with such an averaging approach. Examination of using a shorter timestep, biweekly or weekly, could benefit many modeling variables. Shorter time steps can result in travel time issues without some type of routing algorithm, but still might not introduce any more error than monthly aggregation. Also add greater vertical resolution to better estimate snowmelt.

SacWAM, and CalSIM as well, would better serve the public need with a public domain solver. The current proprietary solver requirement is a burden and impediment to their use.

Every model of the Delta, whether it is a monthly timestep planning model or a 3D hydrodynamic model running time steps of minutes, suffers from in-Delta consumptive use estimates (*i.e.*, Delta Island Consumptive Use, DICU). DICU is highly influential to Delta outflows in dry years and drought conditions. Changes to DICU would require subsequent recalibration of DSM2 and the ANN used for salinity intrusion calculations.

The Panel did not include climate change considerations and the Panel has not given thorough consideration to all SacWAM shortcomings in climate change modeling. At the point when climate change is being considered it will be necessary to directly evaluate the functionality that such modeling requires and it likely additional model improvements will be needed.

## Materials provided for review:

### Reports:

1. SacWAM model documentation and calibration report
2. Hydrological and Operations Modeling Considerations for the Phase 2 Update of the 2006 Bay-Delta Plan

### Additional Recommended Materials:

WEAP Water Evaluation and Planning System Tutorial, August 2015.

http://www.weap21.org/downloads/WEAP_Tutorial.pdfhttp://www.weap21.org/downloads/WEAP_Tutorial.pdf

http://www.weap21.org/downloads/WEAP_Tutorial.pdf

2006 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary

2009 State Water Board Staff Report - Periodic Review of the 2006 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary

State Water Board Supplemental Notice of Preparation and Notice of Scoping Meeting for Environmental Documentation for the Update and Implementation of the Water Quality Control

Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary: Comprehensive Review, January 24, 2012.

http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/environmental_review/docs/notice_baydeltaplancompreview.pdfhttp://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/environmental_review/docs/notice_baydeltaplancompreview.pdf

http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/environmental_review/docs/notice_baydeltaplancompreview.pdf

State Water Board Informational Workshop on Analytical Tools for Evaluating Water Supply, Hydrodynamic and Hydropower Effects held on November 13 & 14, 2012
Revised Public Notice for 2012 Informational Workshops

http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/docs/pubnot_phs2wrkshps.pdfhttp://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/docs/pubnot_phs2wrkshps.pdf

Public Comments Received

http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/comments111312.shtmlhttp://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/comments111312.shtml

Final Workshops Summary Report

http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/docs/bdwrkshprpt070813.pdf

http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/docs/bdwrkshprpt070813.pdf

State Water Board San Joaquin River Flows and Southern Delta Water Quality Draft Substitute Environmental Document Chapter 4 – the end of this chapter provides a short example of how hydrologic modeling results are used to evaluate impacts.

http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/water_quality_control_planning/2012_sed/docs/2012ch_04.pdf

## Supplemental Documents

Peer-reviewed Publications on WEAP model

Joyce, B., Purkey, D., Yates, D., Groves, D., and Draper, A., 2010, Integrated scenario analysis for the 2009 California Water Plan update: California Department of Water Resources technical memorandum, 97 p.

Mehta, V.K., D.E. Rheinheimer, D. Yates, D.R. Purkey, J.H. Viers, C.A. Young and J.F. Mount, "Potential impacts on hydrology and hydropower production under climate warming of the Sierra

Nevada," Journal of Water and Climate Change, Vol. 2, No. 1, pp. 29–43, doi:10.2166/wcc.2011.054, 2011.

Thompson, L.C., M.I. Escobar, C.M. Mosser, D.R. Purkey, D. Yates and P.B. Moyle, "Water Management Adaptations to Prevent Loss of Spring-Run Chinook Salmon in California under Climate Change," Journal of Water Resources Planning and Management, doi:10.1061/(ASCE)WR.1943-5452.0000194, August 2011.

Yarnell, S. M., G. E. Petts, J. C. Schmidt, A. A. Whipple, E. E. Beller, C. N. Dahm, P. Goodwin, and J. H. Viers (2015), Functional flows in modified riverscapes: Hydrographs, habitats and opportunities, BioScience, 65(10), 963-972.

Yates, D., Purkey, D., Sieber, J., Huber-Lee, A., Galbraith, H., West, J., Herrod-Julius, S., Young, C., Joyce, B., and Raye, M., 2009, Climate driven water resources model of Sacramento Basin, California: Journal of Water Resources Planning and Management, v. 135, no. 5, p. 303–313.

Yates, D., J. Sieber, D.R. Purkey and A. Huber-Lee, "WEAP21--A Demand-, Priority-, and Preference-Driven Water Planning Model: Part 1, Model Characteristics," Water International, 30 (2005), pp. 487-500.

Yates, D., D.R. Purkey, J. Sieber, A. Huber-Lee and H. Galbraith, "WEAP21--A Demand-, Priority-, and Preference-Driven Water Planning Model: Part 2, Aiding Freshwater Ecosystem Service Evaluation," Water International, 30 (2005), pp. 501-512.

## Other References from the Panel

Allen, R.G., Pereira, L.S., Raes, D., and Smith, M., (1998). Crop Evapotranspiration - Guidelines for Computing Crop Water requirements. FAO Irrigation and Drainage Paper 56, Rome, Italy.

California Department of Water Resources (DWR) (2007). California Central Valley Unimpaired Flow Data. Bay-Delta Office. Fourth Edition

Lane, B.A., Dahlke, H.E., Pasternack, G.B., and Sandoval-Solis, S. (2016). Revealing the diversity of natural hydrologic regimes in California for environmental flows applications. J. American Water Resources Association. Accepted. August 2016.

Steduto, P., Hsiao, T.C., Fereres, E., and Raes, D. (2012). Crop Yield Response to Water. FAO Irrigation and Drainage Paper 66, Rome, Italy.

SWRCB, (2016). Working Draft Scientific Basis Report for New and Revised Flow Requirements on the Sacramento River and Tributaries, Eastside Tributaries to the Delta, Delta Outflow, and Interior Delta Operations.  Prepared by State Water Resources Control Board with assistance from ICF.

U.S. Bureau of Reclamation (USBR). June, 1985. Colorado River Simulation System Documentation, Colorado River Simulation System Overview.

Young, C. A., M. I. Escobar-Arias, M. Fernandes, B. Joyce, M. Kiparsky, J. F. Mount, V. K. Mehta, D. Purkey, J. H. Viers, and D. Yates (2009), Modeling the hydrology of climate change in California's Sierra Nevada for subwatershed scale adaptation. Journal of the American Water Resources Association. 45(6) 1409-1423

Zagona, E. A., T. J. Fulp, R. Shane, T. Magee, and H. M. Goranflo (2001), RiverWare: A generalized tool for complex reservoir system modeling, Journal of the American Water Resources Association, 37(4), 913 – 929.

# Appendix A. - Kellogg Creek Review

The State Water Board chose to develop SacWAM, in part, because the existing water resources planning model, CalSIM II, does not have the ability to predict flows at the mouths of tributaries to the Delta, the ability to simulate water diversions on non-mainstem tributaries and creeks or the ability to simulate the operation of local agency reservoirs that are not part of the State Water Project (SWP) or Central Valley Project (CVP). Thus SacWAM domain is extended significantly beyond the Sacramento Valley representation of CalSIM II. Additionally, SacWAM includes runoff from over one million acres surrounding the Delta that are not accounted for in DWR DAYFLOW model or CalSIM II. Although the Panel was not charged with reviewing the intricacies of the SacWAM model, a quick review of one of the Delta tributaries (Kellogg Creek) revealed an error which is detailed in this appendix.

Kellogg Creek is an ephemeral tributary to the Delta. Land use in the approximately 21,000-acre watershed consists primarily of open space and agriculture; less than five percent of the watershed is impervious. Approximately the upper 12,000 acres of the watershed drain to the Los Vaqueros Reservoir – a drinking water reservoir owned and operated by Contra Costa Water District (CCWD). CCWD has a water right to store water from Kellogg Creek in Los Vaqueros Reservoir (State Water Board Water Right Permit 20750), while requiring flow to pass through the reservoir to satisfy downstream senior water rights and to maintain perennial pools. Additionally, CCWD pumps water from its Delta intakes up into the Los Vaqueros Reservoir to store high quality Delta water, which is later delivered to CCWD service area in the summer or fall when salinity at its Delta intakes is relatively high. More than 95% of the water stored in Los Vaqueros Reservoir originates from the Delta; less than 5% originated from the Kellogg Creek watershed.

Downstream of the reservoir, the foothills are grazed by cattle, and the plains are primarily used for agriculture. Flows in Kellogg Creek are influenced by natural hydrology, reservoir operations, and irrigation practices. Reservoir releases vary seasonally, dependent on the natural flow of Kellogg Creek into the reservoir; releases are generally less than 1 cubic foot per second (cfs) with normal peak releases of approximately 5 cfs during winter storms. Although it is likely that the lower reaches of Kellogg Creek were historically dry during summer months, flows are now sustained by agricultural tailwater. Irrigation return flows are typically highest during the months of May through July, with a median discharge of Kellogg Creek into the Delta of about 8 cfs.

In CalSIM II, Kellogg Creek unimpaired flow enters the Los Vaqueros Reservoir directly and the reaches of Kellogg Creek below Los Vaqueros Reservoir are not simulated. Since the peak winter release of water from the reservoir into Kellogg Creek is 5 cfs and summertime irrigation return flows in lower Kellogg Creek are typically 8 cfs, neglecting Kellogg Creek has a very small effect on Delta inflow.

SacWAM represents the entire length of Kellogg Creek, from its headwater to its discharge into the Delta (represented as Old and Middle Rivers in SacWAM, see Figure A - 1) and includes the Kellogg Creek discharge as part of the Delta flow balance.  SacWAM also represents CCWD facilities, including Los Vaqueros Reservoir.  Per the documentation provided to the review panel, SacWAM prescribes diversions from the Delta at each of CCWD intakes based upon CalSIM II results.  SacWAM then dynamically simulates other aspects of CCWD operations (*e.g.*, filling of Los Vaqueros Reservoir from CCWD Delta intakes and releases from the reservoir to meet demand in CCWD service area).

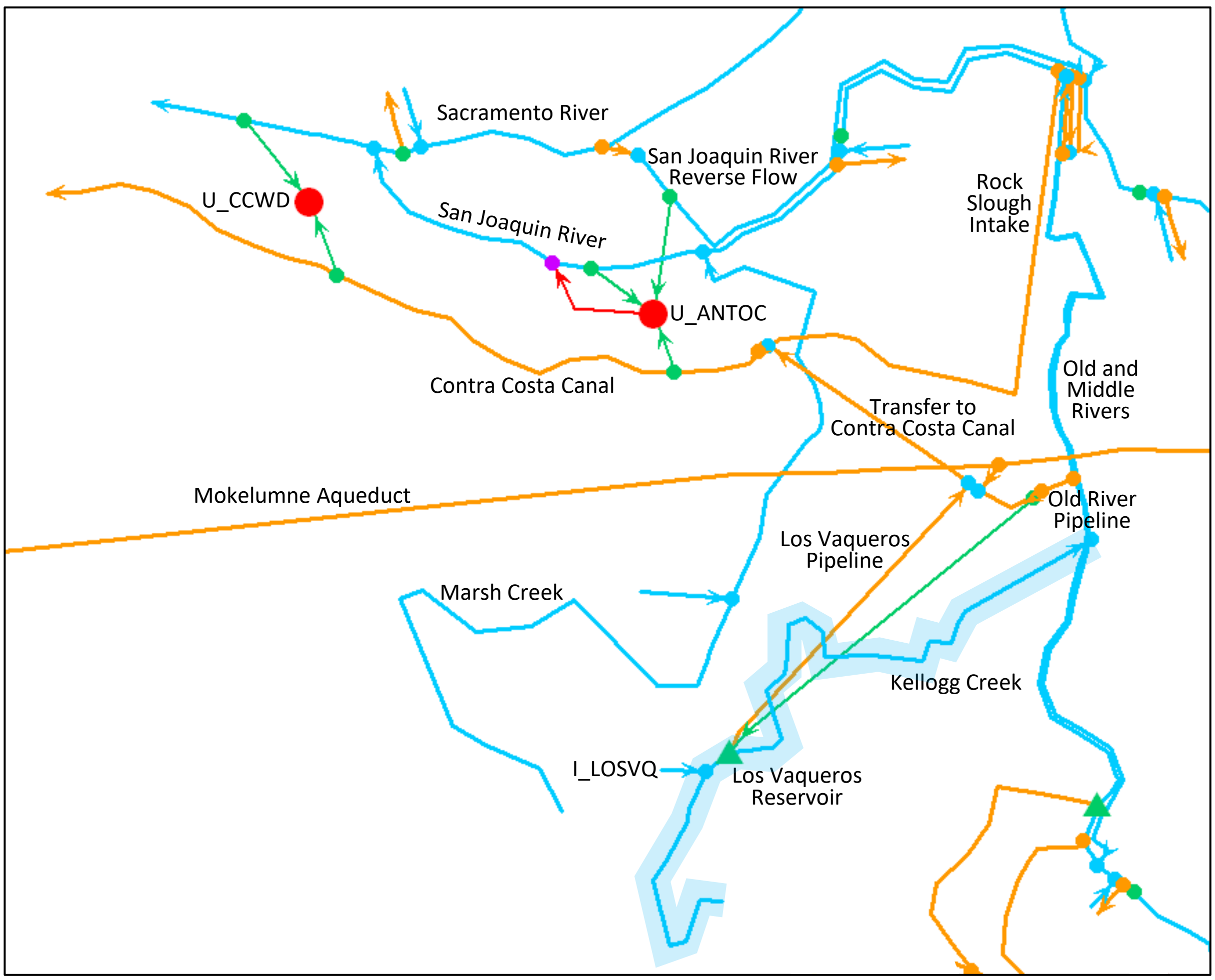



*Figure A - 1 SacWAM schematic of Kellogg Creek (highlighted) and surrounding area*

Quick inspection of SacWAM results for the discharge of Kellogg Creek into the Delta reveals an unusual flow pattern (Figure A - 2) with routine discharge between 150 cfs and 200 cfs, which is often orders of magnitude greater than, and temporally inconsistent with, the unimpaired flow in upper Kellogg Creek above Los Vaqueros Reservoir (represented as I_LOSVQ in SacWAM). These streamflow results are also contradicting the observed streamflow patterns of 5 cfs in winter season and 8 cfs in summer season. Thus, the discharge of Kellogg Creek into the Delta appears to be in error.

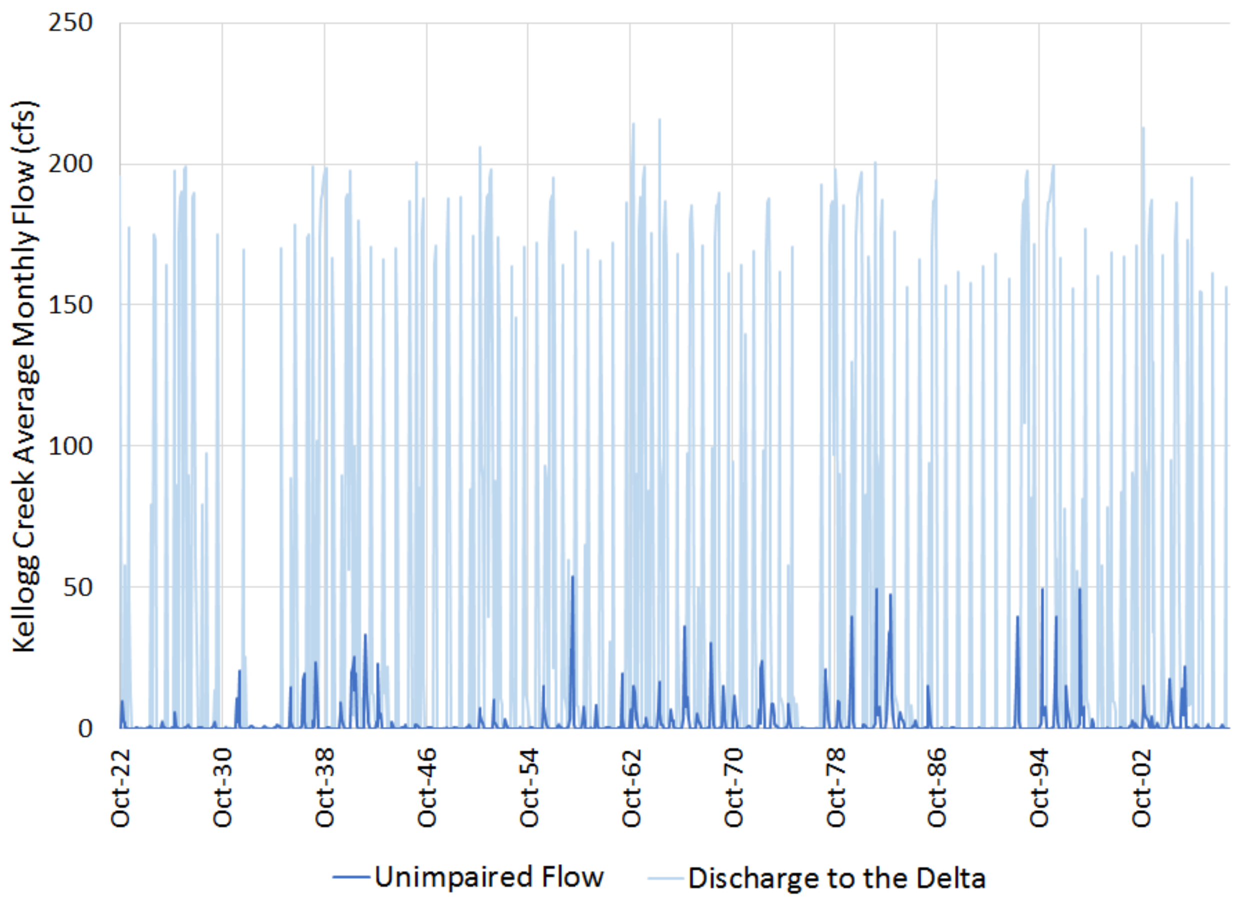



*Figure A - 2 SacWAM Monthly Average Flow in Kellogg Creek*

Examination of the long-term monthly average SacWAM results illustrates the unusual seasonal pattern (Figure A - 3) – the discharge from Kellogg Creek to the Delta peaks in the summer near 150 cfs, while unimpaired flow peaks in the winter and spring around 10 cfs. In addition, the annual volume of water produced by the unimpaired flows upstream of Los Vaqueros reservoir is much smaller than Kellogg Creek outflow into the Delta. This indicates that the unimpaired flows are not the source of water in Kellogg Creek that is discharged to the Delta in the model. In other words, the simulated Delta inflow from Kellogg Creek did not originate in the Kellogg Creek watershed.

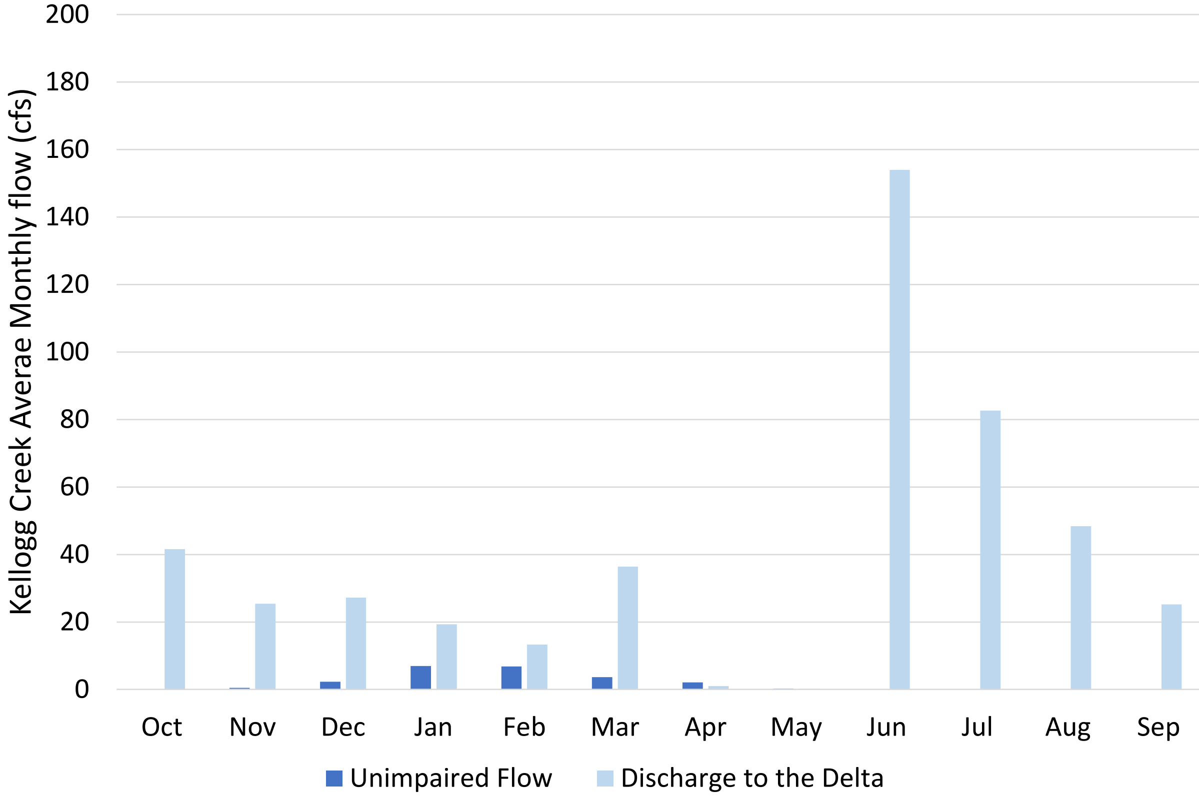



*Figure A - 3 SacWAM Long-term (1922-2009) Average Monthly Flow in Kellogg Creek*

Further investigation of SacWAM results reveals that the flow in Kellogg Creek that discharges to the Delta originates as releases from Los Vaqueros Reservoir. This is an inaccurate operation that is not practiced by CCWD. As mentioned above, almost all of the water stored in Los Vaqueros Reservoir is pumped from Delta channels. CCWD does not go to the expense of pumping water from the Delta up to the reservoir only to release it back to the Delta. This is evident by looking at historical flows (Figure A - 4(a)). CCWD reports the daily average Kellogg Creek inflow into Los Vaqueros Reservoir and the releases from the reservoir into lower Kellogg Creek to the State Water Board as part of its annual water right reporting requirements. The daily average flows from 2006 (a wet year) are presented in Figure A - 4(a), while the SacWAM results are shown in Figure A - 4(b). The measured Kellogg Creek inflow to Los Vaqueros Reservoir peaks in the spring around 12 cfs daily (about 6 cfs monthly averaged), with a corresponding outflow from Los Vaqueros Reservoir to Kellogg Creek of about 5 cfs. In contrast, SacWAM results for Kellogg Creek inflow to the reservoir peak around 20 cfs in April, yet releases from Los Vaqueros Reservoir to lower Kellogg Creek exceed 170 cfs in both June and October 2006, when there is virtually no inflow from Kellogg Creek.

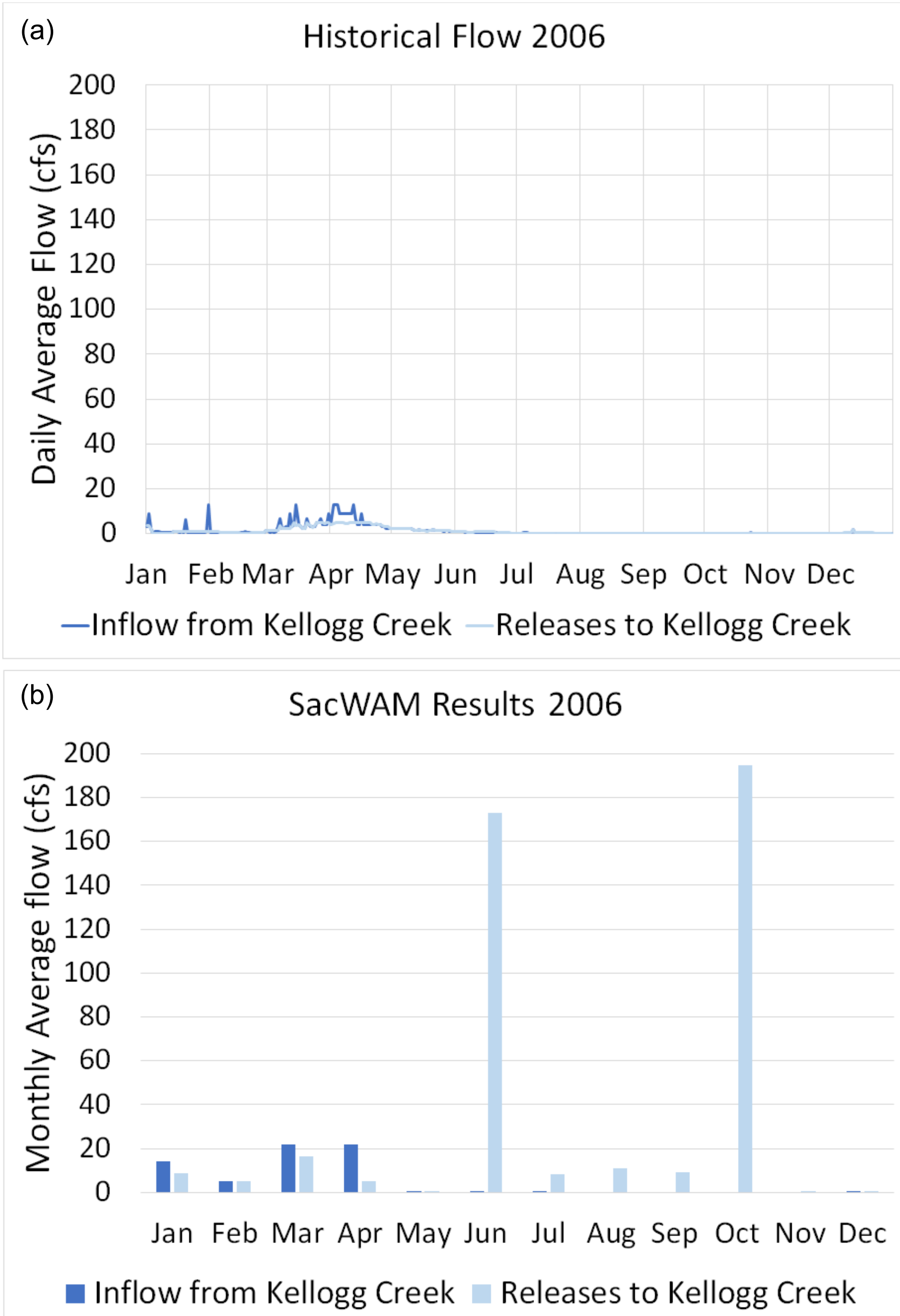



*Figure A - 4 Inflow from Kellogg Creek and Releases to Kellogg Creek from Los Vaqueros Reservoir in 2006: (a) historical daily average flow and (b) SacWAM monthly average results*

SacWAM releases from Los Vaqueros Reservoir to lower Kellogg Creek appear to be flood control releases as Los Vaqueros Reservoir remains nearly full at conservation storage capacity (160 thousand acre-feet or about 52,000 million gallons (MG)) at all times. Figure A - 5 shows that reservoir storage in Los Vaqueros (LV) remains close to conservation pool capacity, while deliveries from Los Vaqueros Reservoir to meet CCWD demand are infrequent (long-term average for the entire SacWAM simulation period is 0.3 million gallons per day (MGD)). This implies that SacWAM is not calling on water from Los Vaqueros Reservoir to meet CCWD demand (U_CCWD). **The consequence of this improper operation is that CCWD total deliveries are often modeled as insufficient to meet CCWD demand, while a portion of CCWD water supply remains in Los Vaqueros Reservoir and another portion flows back into the Delta.**

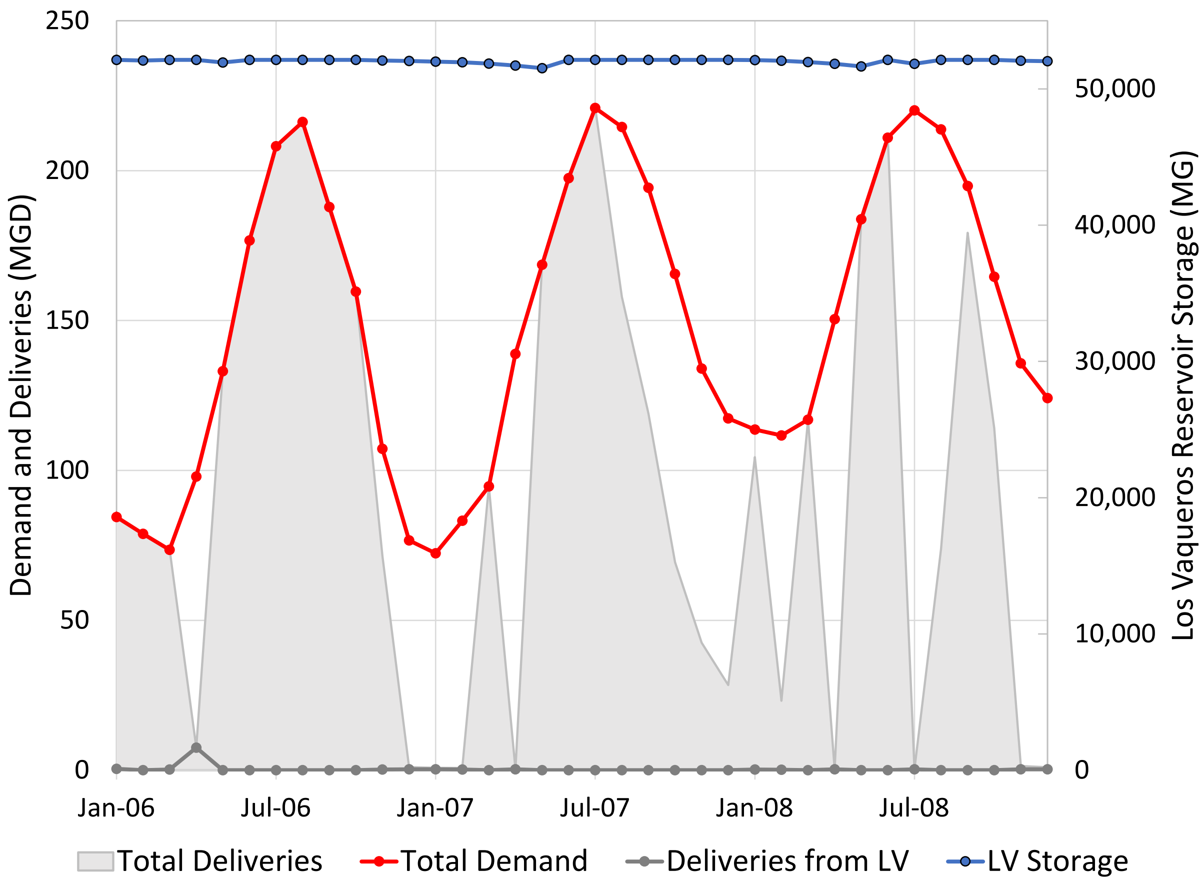



*Figure A - 5 Total Demand and Deliveries to U_CCWD and Storage in Los Vaqueros Reservoir*

In expanding the domain, SacWAM simulates Kellogg Creek as a tributary to the Delta, contributing to the Delta flow balance. The incomplete implementation of CCWD operations creates the error in Kellogg Creek discharge into the Delta, which then affects Delta outflow and salinity, which in turn may affect CVP and SWP reservoir releases and Delta exports. **The identification of this error highlights the need for expert review of the SacWAM model implementation across the model domain.**