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Party to the WaterFix Hearing
Principal, California Water Research

BEFORE THE

CALIFORNIA STATE WATER RESOURCES CONTROL BOARD

HEARING IN THE MATTER OF CALIFORNIA DEPARTMENT OF WATER RESOURCES AND UNITED STATES BUREAU OF RECLAMATION REQUEST FOR A CHANGE IN POINT OF DIVERSION FOR CALIFORNIA WATER FIX	TESTIMONY OF DEIRDRE DES JARDINS

I, Deirdre Des Jardins, do hereby declare:

I. INTRODUCTION

My name is Deirdre Des Jardins. I am the principal of California Water Research. I have performed independent research and analysis relating to California's developed water supply since 2010, including analyses for a wide range of environmental and fishing groups in California. I have a comprehensive background in computational modeling, physics, and applied mathematics, which allows me to read and synthesize information from a wide range of scientific literature, agency reports, and technical and environmental documents. I also analyze complex physical and operational systems and associated modeling, and produce analyses of hydrologic and other data as needed. My background in theoretical physics allows new insights into the complexities of California's state and federal water projects.

As a principal at California Water Research, I have also done research on the three major drivers of change to California's developed water supply and uses: climate change, soil and groundwater salinization, and population growth and associated growth in urban water use. My comments to the Delta Stewardship Council ("DSC"), the Department of Water Resources ("DWR"), and the State Water Resources Control Board ("Board") have regularly raised concerns about the risk of increased frequency and severity of droughts due to climate change prior to 2014.

My scientific background involved the development and application of a wide range of different computational models of physical systems, as well as work with some of the leading research groups in the world in their fields. I did research and modeling at the Center for Nonlinear Studies at Los Alamos National Laboratory as well as the Advanced Computing Laboratory at the National Aeronautics and Space Administration's ("NASA's") Ames Research Center. The Center for Nonlinear Studies was preeminent in the world for research in nonlinear dynamics and Chaos theory at the time I did research there. I later did research with the Computational Mechanics Research Group at the Santa Fe Institute,

which was the preeminent research center in the world in Complex Systems Theory. I also worked with the Bioinformatics Research Group at the University of California, Santa Cruz, which was renowned for assembling the Human Genome sequence.

I received a bachelor's degree in applied mathematics from the University of California, Santa Cruz in 1992. I was a fellow with the National Physical Science Consortium for six years, and worked toward a doctorate in Computer Science at the University of California, Santa Cruz, with studies in Machine Learning, Bioinformatics, and Complex Systems Theory. My statement of qualifications is attached as Exhibit DDJ-100.[1]

REFERENCE DOCUMENTS

The following documents are referenced in this testimony. I hereby declare that on this day I have submitted true and correct copies of the following documents to the State Water Resources Control Board.

EXHIBIT DDJ-101 ("2003 Peer Review") Close et. al., report of the Strategic Review of CALSIM II, sponsored by the Bay-Delta Authority Science Program, entitled, "A Strategic Review of CALSIM II and its Use for Water Planning, Management, and Operations in Central California," (December 2003) Obtained from http://www.waterboards.ca.gov/waterrights/water_issues/programs/hearings/daviswoodland/daviswoodland_cspa_es9.pdf. (Previously submitted for use in procedural motions and cross-examination.)

EXHIBIT DDJ-102 ("2004 Peer Review Response") Department of Water Resources and US Bureau of Reclamation, August 2004 response by the to the 2003 Strategic Review, entitled, "PEER REVIEW RESPONSE: A Report by DWR/Reclamation in Reply to the Peer Review of the CalSim-II Model Sponsored by the CALFED Science Program in December 2003," (August 2004) Obtained from

[1] Exhibit DDJ-100 is a true and correct copy of the document.

http://baydeltaoffice.water.ca.gov/modeling/hydrology/Peer%20Review%20Response%20(August%202004).pdf (Previously submitted for use in procedural motions and cross-examination.)

EXHIBIT DDJ-103 ("2006 Peer Review") David Ford et. al., report of the review of the CalSim II San Joaquin River module, entitled, "Review Panel Report San Joaquin River Valley CalSim II Model Review," (January 2006) obtained from http://science.calwater.ca.gov/pdf/calsim/calsim_II_final_report_011206.pdf (Previously submitted for use in procedural motions.)

EXHIBIT DDJ-104 ("Analytical Tools") Jay Lund et. al., Report of the scientific panel on "Analytical Tools for Evaluating the Water Supply, Hydrodynamic, and Hydropower Effects of the Bay-Delta Plan," entitled, "Analytical Tools for Evaluating the Water Supply, Hydrodynamic, and Hydropower Effects of the Bay-Delta Plan," (2012) obtained from http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/docs/comments111312/jay_lund.pdf (Previously submitted for use in procedural motions.)

EXHIBIT DDJ-106 ("35th Annual Progress Report") California Department of Water Resources, 35th Annual Progress Report to the State Water Resources Control Board on Methodology for Flow and Salinity Estimates in theSacramento-San Joaquin Delta and Suisun Marsh, (2014) obtained from http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/AR2014/AR-2014-All.pdf (Previously submitted for use in procedural motions.)

EXHIBIT DDJ-105 ("DOD M&S instruction") US Department of Defense, Instruction 5000.61 on DoD Modeling and Simulation (M&S) Verification, Validation, and Accreditation (VV&A), (2003) obtained from http://www.public.navy.mil/cotf/OTD/DoDI_MS_VVA_5000.61.pdf. (Previously submitted for use in procedural motions.)

EXHIBIT DDJ-107 ("NRC Review Ch 4") National Research Council, Chapter 4 of the Report of the 2010 National Research Council Committee on Sustainable Water and Environmental Management in the California Bay-Delta, entitled, A Scientific Assessment of Alternatives for Reducing Water Management Effects on Threatened and Endangered Fishes in California's Bay Delta, Chapter 4, Use of Models. (2010) Obtained from http://www.nap.edu/catalog/12881/a-scientific-assessment-of-alternatives-for-reducing-water-management-effects-on-threatened-and-endangered-fishes-in-californias-bay-delta

OVERVIEW OF TESTIMONY

The model results submitted in support of the Petition all rely on a hydrologic / water operations model, CalSim II. No report documenting the validation of the full model has been submitted for the hearing. No report documenting the validation of the hydrodynamic model, DSM2, has also not been presented for use in the hearing.

Request for validation, testing, and calibration by Modelling Community in 2009

In 2009, a group of 24 members of the CALFED hydrodynamics modeling community sent a letter to Joe Joe Grindstaff, the Director of the California Bay-Delta Authority, and Clifford Dahm, the Chief Scientist. The letter was titled "Re: Improved Modeling Capabilities Needed for the Bay-Delta Planning Effort." It was included in the report of the 2012 panel on Analytical Tools, Exhibit DDJ-104. The letter stated in part,

> By agreeing on the most appropriate directions for expanding existing modeling capabilities, our proposed program will permit the development of intermediate products while working toward longer-term objectives. We recommend that the proposed program include the following:
>
> […]
>
> Proper mathematical verification of model codes and calculations, field testing of models, and peer-review of model algorithms and documentation
>
> An external review committee to provide outside scientific advice, oversight, and quality assurance, drawing on expertise from other estuaries
>
> Model codes and documentation made freely available in the public domain
>
> Identification of a caretaker of model codes and documentation
>
> (p. 15)

Shortly afterward, the Delta Reform Act dissolved the Bay-Delta Authority. As detailed below, these requests may never have been implemented for the CalSim hydrologic model and DSM2

hydrodynamic model. If so, it is unfortunate, because these models have been the foundation for the entire Bay Delta Conservation Plan / WaterFix planning process.

In 2010, the National Research Council Peer Review (Exhibit DDJ-107) also noted that the CalSim model had not been adequately calibrated and tested:

> *It is a standard practice to ensure the appropriate use of models through the processes of calibration and testing (ASTM, 2004; NRC 2008)*. Validation of CalSim-II is described in Appendix U of the OCAP BA (USBR, 2008), which provides a comparison of Study 7.0 (existing condition) with the recent historical data. A review of those results shows that there are significant deviations of the historical data from the simulated storages and exports that may be of the same magnitude as the differences between the scenarios being evaluated. Thus, while the tool itself performs well, some questions remain regarding the gross nature of generalized rules used in CalSim-II to operate CVP and SWP systems, relative to actual variability of dynamic operations (USBR, 2008, pages 9-4). In their peer review of the CalSim-II model, Close et al. (2003) suggested that "Given present and anticipated uses of CalSim-II, the model should be calibrated, tested, and documented for "absolute" or non-comparative uses." It is not clear if the agencies that developed the model have responded to this suggestion in a comprehensive manner. (EXHIBIT DDJ-107, NRC Review, Chapter 4, Use of Models, p. 11)

I concur with the opinion of the 2010 National Research Council review that calibration and testing is a standard engineering practice. The CalSim model can and should be tested, calibrated, and validated.

Criteria for Acceptance of Model Results for use in Board Proceedings

The State Water Resources Control Board has not set objective criteria for acceptance of computer model results for use in Board proceedings. In the past, the Board appears to have simply used Government Code § 11513 (b) to determine whether to accept model results for Board proceedings. The criterion in Government Code § 11513 (b) is "the sort of evidence on which responsible persons are accustomed to rely in the conduct of serious affairs." Because of the status of the Department of Water Resources and the US Bureau of Reclamation, this criterion can be circular when applied to their models. That is, models developed by DWR and the Bureau can be regarded as "the sort of evidence on which responsible persons are accustomed to rely in the conduct of serious affairs," regardless of whether the computer models meet any objective engineering standards for reliability.

The Board's 2012 panel on "Analytical Tools for Evaluating Water Supply, Hydrodynamic and Hydropower Effects" (Exhibit DDJ-104) referenced the 2009 letter by modelers, and made clear, specific, and objective recommendations for assessment of the reliability of computer models and model results in Board proceedings. I requested that the Board take official notice of those recommendations, because it was clear that an objective standard was needed for the WaterFix hearing.

There appears to have been no complete, technical peer review of the CalSim or DSM2 models, nor has the Board arranged for any independent review of the CalSim and DSM2 modelling and model results proposed for use in the WaterFix hearing. DWR and USBR are instead submitting testimony from two engineers who oversaw the development and application of the BDCP / WaterFix CalSim and DSM2 model versions, Armin Munevar and Parviz Nader-Tehrani. The testimony by these two engineers is proposed to certify the suitability of the model results for the hearing.

On reviewing the testimony by Armin Munevar (DWR-71), I noticed significant omissions and inaccuracies in statements about the peer review status of the CalSim II model, as well as in statements about the agency's ability to calibrate and validate the model. Some of Munevar's statements were in contradiction of recommendations by the CalSim peer review panels. Some statements by both engineers were also in contradiction to the recommendations of the Board's 2012 panel on Analytical Tools (Exhibit DDJ-104.) I have attempted to explain some of the discrepancies below.

The Board needs to carefully weigh these discrepancies, and the failure to implement the recommendations requested by the modelers in 2009, when evaluating whether the model results are acceptable for use in the hearing. The refusal by the Petitioners to provide basic information on the existence of model documentation, version control, quality control, testing, and calibration information, and previous external technical reviews,[2] is also relevant and needs to be considered.

Evaluation of Written Testimony by Armin Munevar on CalSim model reliability

Armin Munevar testified on the hydrologic modelling for the Petitioners. Mr. Munevar's resume states that he was the Integration Lead in the development and application of the physical modelling. Mr. Munevar's written testimony in DWR-71 is what was originally proposed to support the proposed uses of the CalSim model in the hearing.

Many statements in Munevar's written testimony about the CalSim model were contradicted by statements by the qualified and disinterested experts who served on the 2003 and 2006 peer review panels, and even by statements by the Petitioners, as outlined below. The following compares Munevar's written testimony with excerpts from reports by the 2003 and 2006 peer review panels, the 2004 response to the peer review reports by DWR and USBR, and the 2008 FWS Biological Opinion on Delta Smelt.

I. Acceptance of the model

Output from the CalSim model has not been accepted as reliable by experts in the field, in large part because of the failure by the Petitioners to document adequate model testing and calibration. The 2003 Peer Review (Exhibit DDJ-101) stated:

> Better quality control is needed both for the model and its current version and the input data. Procedures for model calibration and verification are also needed. Currently many users are not sure of the accuracy of the results. A sensitivity and uncertainty prediction capability and analysis is needed. (p. 8)

The 2006 Peer Review of the San Joaquin River component of the model (Exhibit DDJ-103) stated:

[2] I reference my June 9, 2016, letter, "Request for Extension and Missing Modeling Information."

> CalSim II work fails to adequately report technical results that would give knowledgeable readers some sense of the quality, accuracy, sensitivity, or uncertainty present in the results. This issue was prominent in the previous CalSim review panel report (Close, et al., 2003). (p. 10)

Mr. Munevar states in his testimony (DWR-71),

> It is a well-accepted model and has been used in multiple planning and regulatory processes, including but not limited to, the 2008 Fish and Wildlife Service and 2009 National Marine Fisheries Service Endangered Species Act consultation on coordinated operations of the CVP and SWP ("2008 FWS BiOp" and "2009 NMFS BiOp"), and the related federal litigation. (p. 7)

This statement is misleading. While the CalSim model was used in the 2008 and 2009 Biological Opinion, the lack of calibration of the model was an issue for the Fish and Wildlife Service biologists, who found that the models of interior Delta flows were too inaccurate for use. The following is from the 2008 Fish and Wildlife Service Formal Endangered Species Act Consultation on the Proposed Coordinated Operations of the Central Valley Project (CVP) and State Water Project (SWP) (Exhibit SWRCB-87):

> The biological assessment suggested using CALSIM II study 7.0 as the current baseline, and 6.1 as the historical baseline but the CALSIM monthly simulation model does not capture a precise Delta operation. When Study 6.1 was modeled, changes were expected between Study 6.1 and Studies 7.0 and 7.1 but the results in the August 2008 biological assessment were nearly identical. (p. 204)

The biologists also stated that the previous CalSim model runs (May 2008) had shown a difference between the historical baseline and the current baseline. The discrepancy between the May 2008 and August 2008 model runs was apparently never adequately explained by Reclamation. The biologists decided to instead use actual historical data to construct a baseline:

> The inaccuracies in CALSIM lead us to use actual data to develop an empirical baseline. We also developed historical time series data for hydrologic variables used in this effects analysis based on the DAYFLOW database (http://iep.water.ca.gov/dayflow/index.html) and OMR data obtained from USGS. We calculated monthly or multiple month averages or medians based on these daily hydrology data sets. The historical time series are intended to show where changes in water project operations have caused or contributed to changed Delta hydrology and to serve as an empirical baseline of SWP and CVP operations for comparison to proposed futures modeled using CALSIM II. (p. 206)

The Fish and Wildlife Service biologists' use of actual, empirical Delta flow data for the Biological Opinion was disputed by Petitioners. Petitioners asserted that the model results could not be compared with historical data. Mr. Munevar has reiterated this assertion in his testimony:

> Because it is a simulation, based on a combination of historical hydrology, the current regulatory environment and projected changes to the hydrology due to climate change, CalSim II cannot be calibrated and therefore, should not be used in a predictive manner. (p.12)

As documented below, this statement is inconsistent with recommendations by peer reviewers, and with previous statements by the Petitioners in the 2004 Peer Review Response.

II. State of the Art

Mr. Munevar referred in his written testimony to an opinion by the 2003 peer review panel that CalSim is "state-of the art." The 2003 Peer Review (Exhibit DDJ-101) did confirm that the general modelling approach of using a constraint language and a linear optimization solver was comparable to other models of major water basins. But this was only validation of the Simulation Conceptual Model, which is very different than validation of the model itself. The following statements were quoted in the 2004 Peer Review response (Exhibit DDJ-102), and Mr. Munevar's testimony (EXHIBIT DWR-71) on p. 8:

> We believe the use of an optimization engine for simulating the hydrology and for making allocation decisions is an appropriate approach and is in fact the approach many serious efforts of this kind are using.

And,

> CalSim II represents a state-of-the art modeling system that is similar in general concept, while differing in specific details, to other data driven river basin modeling systems such as ARSP, MODSIM, OASIS, REALM, RiverWare, and WEAP.

Mr. Munevar should have been clear that this statement was a validation of the CalSim Simulation Conceptual Model. The conceptual model of a simulation includes the choice of a general modelling approach, and the overall structure of the model. Validation of the full model requires testing and calibration of the components of the model, not just review of the general approach and overall structure. This testing and calibration of the model components was recommended by the 2003 Peer Review panel (Exhibit DDJ-101). Mr. Munevar also states,

> CalSim II has also been peer reviewed as part of the publication of the model. See, Draper, A.J., Munévar, A., Arora, S. K., Reyes, E., Parker, N.L., Chung, F.I., Peterson,

L.E. 2004. CALSIM: Generalized Model for Reservoir System Analysis, Journal of Water Resources Planning and Management, 130:6(480) (p. 8)

A review of the journal article shows that it is a description of the model at the Simulation Conceptual level. The review for publication of a general description of the model and modelling approach is not the same as a technical peer review of the model. Since Mr. Munevar is the Integration Lead for the BDCP / WaterFix physical modeling, his confusion on these points raises significant issues about the reliability of the entire model process.

Mr. Munevar and the Department of Water Resources did appear to have forgotten that the 2003 Peer Review was only at a strategic level. The 2003 Peer Review panel noted that the information provided for review "precluded a thorough technical analysis," and stated that such a technical review should be carried out (Exhibit DDJ-101):

> The information we received and the shortness of our meetings with modeling staff precluded a thorough technical analysis of CALSIM II. We believe such a technical review should be carried out. Only then will users of CALSIM II have some assurance as to the appropriateness of its assumptions and to the quality (accuracy) of its results. By necessity our review is more strategic. It offers some suggestions for establishing a more complete technical peer review, for managing the CALSIM II applications and for ensuring greater quality control over the model and its input data, and for increasing the quality of the model, the precision of its results, and their documentation. (p. 3)

The 2003 review panel also recommended:

> To increase the public's confidence in the many components and features of CALSIM II, we suggest that these components of CALSIM be subjected to careful technical peer review by appropriate experts and stakeholders. (p. 2*)*

However, except for the San Joaquin River component of the model, a "careful technical peer review" appears never to have been done, and there have been continuing questions about the reliability of the model, particularly by stakeholders.

The 2006 Peer Review of the San Joaquin River component of the model (Exhibit DDJ-103) noted some significant issues, and stated,

> The panel does not in any way certify or endorse the model presented. On the other hand, we do not disapprove of or discourage its use by knowledgeable users. […]
>
> Users must take responsibility for model selection and application, and they must accept the responsibility for decisions that they make with information produced by the model. Relying on an external body to provide a blanket endorsement covering all possible applications is a dangerous practice. It tempts users to avoid accountability for their work. It tempts decisionmakers to place responsibility on general model reviews which

> are remote from a particular application. *Further, it opens the door to intentional and unintentional abuse, negligence or complacency by model users and developers, or their managers who may shift responsibility to tools or some external general review panel for decisions made or actions recommended based on their use of a model*. (p. 8, emphasis added.)

DWR's reliance on the 2003 Peer Review for implied endorsement of the use of the CalSim II model for the WaterFix hearing raises significant questions about the reliability of the model.

III. Reservoir, Demand, and Operations modelling

A. Historical Period

Mr. Munevar's testimony (DWR-71) states,

> DWR completed a quasi-validation of the CALSIM II model in 2003. […] The CalSim II Simulation Study showed that CalSim II could approximate historic trends suggesting that CALSIM II was a reasonable tool for water resource planning. The CalSim II Simulation Study results that are summarized in Exhibit DWR-514, p.3, Table 2 show that simulated SWP Table A and CVP south-of-Delta deliveries during the drought (1987-1992) were within 5 percent of historical values, suggesting a close fit between simulated and actual values. (p. 8)

However, the 2003 Peer Review panel noted some issues with the "quasi-validation," stating (Exhibit DDJ-101):

> Because the SWP south of delta demands were set to historical deliveries in many years, comparison with the historical deliveries in the validation report is of limited validity. (p. 68)

The 2003 Peer Review panel (Exhibit DDJ-101) recommended a full calibration and validation of the model:

> A Calibration/Validation report should be very useful in demonstrating the accuracy of the model. However there are a number of elements in the CALSIM II validation run and the validation report which reduce that confidence including:
>
> - State Water Project (SWP) demands south of the Delta were set at historical deliveries in years with no restriction and at the contractor's request level in restricted years. Neither of these pieces of information is available to a production run which calculates demand based on crop areas. Therefore the validation run does not provide reliable information on how well the model can represent these demands.
>
> […]
>
> - The DWR (2003) report produces estimates of SWP and Central Valley Project (CVP) deliveries south of the Delta but then adjusts them for changes in storage before presenting comparisons of those results with observed deliveries. This process merely checks that the model is preserving a water balance and does not present a legitimate validation of model deliveries.
> - The report provides statistics on long term average deliveries and flows but no statistics on the fit for individual years. Additional analysis of the output would assist stakeholders to assess whether the estimate of water supply

reliability and in particular the modeled volumes of water available in the most restricted years are accurate.

- In some instances, such as the examination of water quality in the Delta, the ability to accurately model monthly flows and deliveries will be important. The validation report contains no information that would enable the ability to model monthly flows to be assessed.
- A key model output is the water quality in the Delta. It would assist the validation of the model if a comparison of parameters such as the location of the X2 boundary was provided. (p. 31)

It should be noted that some of the recommended validation elements are essential to validating the proposed use of the model in the hearing to show "no harm" to other users of water. This includes accurate modelling of monthly flows and water quality in the Delta.

The reviewers also noted:

> Most successful applications of optimization that attempt to simulate the behavior of a system have calibrated their objective functions (i.e., set the weights that prioritize flows over time and space) so that the model results correspond to what actually happens or would happen under a particular hydrologic and demand scenario. In these cases the model's decisions correspond to those the operators would make, as often prescribed by rules that have been worked out in a legal/political process. It does not appear that such a calibration of the objective function weights in CALSIM has yet been completed. (Exhibit DDJ-101, p. 4)

The Petitioners responded that historic validation was not desirable, stating that reservoir operations were subject to change, stating in part:

> …DWR and Reclamation suggest that a more reasonable approach to defining behavioral parameters is through discussions with system operators to define current operational policy or rules. California's water system, especially with regard to the Delta, has undergone many changes in the 1990s (Delta Water Quality Control Plan, CalFed, ESA actions, CVPIA (b)(2), Environmental Water Account) so that calibration to historical practice has limited value. It would appear more reasonable to define operating rules in conversations with operators and subsequently use a recent wet, normal and dry year in a validation exercise. (Exhibit DDJ-102, p. 19, emphasis in original)

However, since 2004, no limited validation has been reported.

B. Current Period

As indicated in the 2004 Peer Review response, all that is required for testing of the CalSim model is a version that simulates existing biological conditions. These versions were produced for the Preliminary and Administrative Drafts of the Bay Delta Conservation Plan Draft EIR/EIS, as well as for the 2015 Delivery Reliability Report, on which the WaterFix hearing model was based. These models

could have been tested with a data set for the years since the Biological Opinion (2009-2015) However, the only publicly available input data set for CalSim is from 1922 to 2003.

Failure to produce a current period data set not only precludes testing of the current operations model, it also makes it extremely difficult for independent experts to assess the validity of any given model version. Mr. Munevar's testimony (DWR-71) states,

> One noteworthy difference in the current modeling is that CalSim II results show that the September upstream reservoir releases are consistently lower in the drier years compared to the historical values. Although there are detailed model inputs and assumptions, the CalSim II results may differ from real-time operations given that not all of the regulatory requirements (e.g. upstream temperature requirements, reservoir release ramping rates, etc.) or real-time operational adjustments to Shasta operations are modeled in CalSim II. (p.11)

Without documentation of the "detailed model inputs and assumptions" and the current year validation proposed by DWR and USBR in the 2004 Peer Review response, it is difficult to even evaluate this statement.

C. Future Period

Mr. Munevar admits that the modelling of future reservoir operations during extended droughts is not realistic. His testimony (DWR-71) states,

> When system wide storage levels are at or near dead pool, also described as stressed water supply conditions, the CalSim II model results should only be an indicator of stressed water supply conditions and should not necessarily be understood to reflect actually what would occur in the future under a given scenario. (p. 12)

The embedded parameters in the simulation include the objective function, the weights on storage zones in the reservoirs, and delivery targets when storage is low. Without detailed documentation of the settings of these parameters, and sensitivity analyses comparing different parameter settings, it cannot be determined whether this failure to accurate model reservoir operations during "stressed water supply conditions" is due to modelling assumptions or to model limitations.

IV. Hydrologic modelling

A. Mass Balance

Mass balance in hydrologic models concern whether water is conserved in the model, i.e., whether errors cause the model to create or lose water. The 2003 Peer Reviewers noted (Exhibit DDJ-101):

> Large simulation models using optimization and procedural rules both need to have internal checks to ensure to the extent possible that errors in mass balances, for example, do not occur due to errors made when the model is being defined or created. Such internal checking is not apparent to us in our admittedly brief review of CALSIM II. Nor were calibration procedures well defined. (p. 5)

There are still significant questions about internal error checking and calibration procedures.

V. Relative use

In his submitted testimony (DWR-71), Mr. Munevar states that the CalSim II model can be used in relative mode:

> CalSim II results are intended to be used in a comparative manner, which allows for assessing the changes in the SWP/CVP system operations and resulting incremental effects between two scenarios. The model should be used with caution where absolute results are needed in instances such as determining effects based on a threshold, prescribing seasonal operations, or predicting flows or water deliveries for any real-time operations… In summary, the CalSim II and DSM2 results should only be used comparatively" (pp. 12-13).

However, the 2003 Strategic Review panel was "somewhat skeptical" of this proposed use of the model by the Petitioners, and stated that the feature would need to be "documented rather than merely assumed":

> Modelers sometimes make a distinction between the use of a model for absolute versus comparative analyses. In an absolute analysis one runs the model once to predict an outcome. In a comparative analysis, one runs the model twice, once as a baseline and the other with some specific change, in order to assess change in outcome due to the given change in model input configuration. The suggestion is that, while the model might not generate a highly reliable absolute prediction because of errors in model specification and/or estimation, nevertheless it might produce a reasonably reliable estimate of the relative change in outcome. The panel is somewhat skeptical of this notion because it relies on the assumption that the model errors which render an absolute forecast unreliable are sufficiently independent of, or orthogonal to, the change being modeled that they do not similarly affect the forecast of change in outcome; they mostly cancel out. *This feature of the model is something that would need to be documented rather than merely assumed*. (Exhibit DDJ-101, p. 6, emphasis added.)

The 2006 Peer Review panel also recommended documentation of model assumptions and error analyses. (Exhibit DDJ-103.) Under "Uncertainty in Model Results," the reviewers noted:

> Currently no general guidance is available to indicate whether differences of 1 taf, 50 taf, 100 taf, or 500 taf are significant enough to rise above the level of error and noise inherent in the model. (p. 13.)

and recommended

> At a minimum, error analyses should be conducted, combining a sensitivity analysis of critical model results to some of the largest and least well supported model assumptions with an assessment of the likely range of error in these major model parameters and assumptions. (p. 13.)

As discussed below, the submitted documentation of model assumptions, and the error analyses are insufficient to support the proposed use of the model results in the hearing.

VI. Submitted Documentation of Model Assumptions and Error Analyses

The table of model assumptions presented by the Petitioners as Exhibit DWR 15 is at the Simulation Conceptual Model level of detail, i.e., it serves to document the specification of assumed regulatory and operating requirements for the model. It does not document the detailed assumptions used by the model components in simulating the operations to meet these requirements, or the detailed assumptions used in setting of model parameters.

The error analyses presented by the Petitioners also do not meet the recommendations in the report of the 2012 scientific panel on "Analytical Tools for Evaluating Water Supply, Hydrodynamic and Hydropower Effects in the Bay Delta Plan" for use of model results in Board proceedings (Exhibit DDJ-104). The panel made very specific recommendations with respect to calibrating and testing model representations of the Delta, reproduced below. Some of the underlined flows and diversions below are represented by CalSim II.

Some Key Aspects in Calibrating and Testing a Delta Hydrodynamics Model
In the testing and calibration of a Delta hydrodynamic and water quality model, the panel suggests several key aspects to examine. These include:

- Matching point observations of Stage, Flow, Salinity (EC) on tidal and tidally averaged (net) basis
- Matching key interior net-flow splits: Sacramento River to Sutter and Steamboat Sloughs; Sacramento River to Delta Cross Channel and Georgianna Slough; San Joaquin River to Old River at Head; San Joquin River to Old River and Middle River; net flows around Franks Tract; flow between the Sacramento River and San Joaquin through Threemile Slough
- Representing gate/barrier operations: DCC, Suisun Marsh Salinity Control Gate, south Delta barriers, Clifton Court Gates
- Representing Delta Island Consumptive Use
- Representing Delta Exports
- Representing low flow, high flow, and transition periods
- Representing the yearly cycle of salt intrusion and flushing
- Representing spring-neap tidal variation

(p. 5)

Mr. Munevar's testimony (DWR-71) includes an attempt to do an error analysis for flow at Freeport, for the Net Delta Outflow Index, and for the Delta exports:

> A comparison of Sacramento Valley inflow to the Delta (flow at Freeport) is a good measure of how well Sacramento Valley hydrology is simulated by CalSim II. Exhibit DWR-514, p. 3, Table 2 shows that for this quasi-validation run CalSim II simulated Delta inflows were 0.3 percent greater than historical, a reasonably close fit between simulated and actual values. Comparison of the Net Delta Outflow Index, a measure of how well the Sacramento-San Joaquin Delta is represented by CalSim II, also show a close fit between simulated and actual. Exhibit DWR-514, p. 3, Table 2 shows simulated values are 3.5 percent less than historical during the 1987-1992 time-period. This exhibit also shows that simulated long-term (1975-1998) average deliveries compare quite well and are within 7 percent of historical values, suggesting a reasonably close fit between simulated and actual values. (p.9)

There are three issues with this error analysis.

1. The analysis is incomplete, in that it does not include analysis of interior Delta flow splits. The analysis also only compares long term averages. It includes no statistics on the fit for individual years. The 2003 Peer Review panel recommendations (Exhibit DDJ-101, cited in part A), indicate that these statistics are required to evaluate the accuracy of the model for the most restricted years. The analysis also provides no information on the ability of the model to match monthly flows under different year types.
2. The CalSim model has changed since the Historical Operations Study was done in 2003, so the error analysis is not be relevant to the 2015 version of the model. The statement by DWR and USBR in

the 2004 peer review response (Exhibit DDJ-102, cited above) indicates that operating rules for the reservoirs may also have changed. Both demands and reservoir operations clearly affect inflow to the Delta, as well as the Net Delta Outflow Index.

To be relevant, the Historical Operations Study would need to be redone using the current version of the model, and the current operating parameters, including actual export demand settings, WSI-DI curves, and reservoir rule curves. This requirement to use the actual operating parameters for validation was previously noted by the 2003 Peer Review panel (Exhibit DDJ-101).

VII. Sensitivity analyses and climate change

Although sensitivity analyses have been done for reservoir inflows, they appear to use very small perturbations. The sensitivity analyses for the San Joaquin River component of the model only tested the model for inflows of +/- 3%. This may be much smaller than perturbations to inflows under climate change. The Petitioner's graph of the 3 year average of the Eight River Index, which includes the San Joaquin Valley, showed that it was the lowest in the historic period in 2015.

Executed on this 1st day of September, 2016 in Santa Cruz, California. (Errata on 17th day of October, 2016.)

Deirdre Des Jardins