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BEFORE THE

CALIFORNIA STATE WATER RESOURCES CONTROL BOARD

HEARING REGARDING PETITION FILED BY THE DEPARTMENT OF WATER RESOURCES AND U.S. BUREAU OF RECLAMATION REQUESTING CHANGES IN WATER RIGHTS FOR THE CALIFORNIA WaterFix PROJECT	**CORRECTED 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 deep 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 and biological 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 PCFFA-75.[1]

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[1] Exhibit PCFFA-75 is a true and correct copy of the document.

II. OVERVIEW OF TESTIMONY

My testimony is submitted to describe and evaluate the climate change assumptions and climate change model projections used by the Department of Water Resources ("DWR") and the United States Department of Reclamation ("Reclamation") in projecting future conditions and shifts in hydrology for the Early Long Term ("ELT") period. PCFFA-77 (presentation by Deirdre Des Jardins).[2]

III. CLIMATE CHANGE

The climate change analysis conducted for the Bay Delta Conservation Plan ("BDCP") / WaterFix has major flaws, which I believe must be remedied. In a 2014 review of the BDCP Draft Environmental Impact Report/Draft Environmental Impact Statement ("DEIR/DEIS"), the Delta Independent Science Board ("ISB") stated,

> *The potential effects of climate change and sea-level rise are underestimated.* . . . The potential direct effects of climate change and sea-level rise on the effectiveness of actions, including operations involving new water conveyance facilities, are not adequately considered. . . .
>
> In their response to our preliminary draft review, the Department of Water Resources noted that "the scope of an EIR/EIS is to consider the effects of the project on the environment, and not the environment on the project". If the effects of major environmental disruptions such as climate change, sea-level rise, levee breaches, floods, and the like are not considered, however, one must assume that the actions will have the stated outcomes. We believe this is dangerously unrealistic. CEQA requires impacts to be assessed "in order to provide decision makers enough information to make a reasoned choice about the project and its alternatives".

PCFFA-9, p. 6, emphasis in original, footnotes omitted.[3] I strongly concur with the assessment of the ISB. Some of the assumptions and analysis of climate change in the WaterFix are also dangerously out of date. *See, e.g.*, PCFFA-14 (presentation by DWR climatologist Michael Anderson).[4]

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[2] Exhibit PCFFA-77 is a true and correct copy of a presentation compiled by Deirdre Des Jardins, based on other cited references, in support of her testimony.
[3] Exhibit PCFFA-9 is a true and correct copy of the document.
[4] Exhibit PCFFA-14 is a true and correct copy of the document.

There have been significant advances in the scientific understanding of climate change since the initial modelling for the BDCP / WaterFix conveyance projects that took place from 2009-2012. PCFFA-78.[5] These advances have been driven by data collected during recent, dramatic phenomena, including the accelerated melting of ice sheets in the west Antarctic and Greenland and severe, prolonged droughts in the Southwestern United States, Midwestern United States, and California. Recent temperature deviations also make the lower sensitivity Global Climate Models, which predict less than 3 degrees of warming with a doubling of C02, appear increasingly unlikely. Exhibit PCFFA-76.[6]

Recent observations and research point towards a much hotter and potentially drier future, with the potential for much greater increases in sea level rise than were previously predicted. The most recent scientific literature and climate change modeling points toward major risks to water supply and water quality, which the model results presented by DWR and Reclamation for the WaterFix hearing do not address.

My recommendation is that the Board require that DWR and Reclamation submit modeled operations using the Q2 drier, warmer scenario for consideration in the WaterFix hearing. The Q2 scenario is the scenario with the greatest risk. Model results for the Q2 scenario were provided for the Revised Draft Biological Assessment (SWRCB-104 (Appendix 5A)), but the Revised Draft Biological Assessment was not available until after DWR had submitted exhibits for Part 1A, does not have the same operational assumptions as the CALSIM runs done for the WaterFix hearing, and does not consider model outputs related to legal users of water.

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[5] Exhibit PCFFA-78 is a true and correct copy of graphs from cited documents compiled by Deirdre Des Jardins in support of her testimony.

[6] Exhibit PCFFA-76 is a true and correct copy of the document S.C. Sherwood, S. Bony, and J. Dufresne, *Spread in model climate sensitivity traced to atmospheric convective mixing*, 505 Nature pp. 37-42 (2014), *available at* http://dx.doi.org/10.1038/nature12829.

As explained below, the sea level rise estimates used in the WaterFix modeling are out of date and no longer reflect the best available science. To take into account the current highest estimate of 14.8 inches of sea level rise at Port Chicago by 2035 (see page 8 of this testimony), I recommend that the Board require DWR and Reclamation to submit model results from the 18 inch scenario for sea level rise for consideration in the WaterFix Hearing, as well as the 6 inch scenario. The 18 inch scenario was used for the 2013 BDCP DEIR/DEIS, but the 2013 project is significantly different from the current WaterFix project. Not only have some of the regulatory assumptions changed, but there is no longer an extensive, funded restoration in the Delta, which changes the modeling of salinity in the Delta.

IV. SEA LEVEL RISE

DWR should not continue to use the assumption that there will be six inches of sea level rise by 2025-2030 (Early Long Term) and 18 inches by 2060-2065 (Late Long Term) for the WaterFix project when the best available science shows that these may be at best 50% exceedance estimates. DWR's Conceptual Engineering Report (DWR-212, p. 50) shows that these sea level rise estimates originate from 2007 recommendations by the Delta Independent Science Board ("ISB") that the Bay Delta Conservation Plan ("BDCP") use a median estimate of one meter of sea level rise by 2100, and use empirical estimates by the method of Rahmstorf. However, the ISB cautioned in their 2007 guidance that ice sheet melting could result in as much as 2 meters of sea level rise by 2100. PCFFA-8 (document p. 5, cautions of an additional meter of sea level rise from ice sheet melting).[7]

[7] Exhibit PCFFA-8 is a true and correct copy of the document.

BDCP planning documents show that DWR also did their own analysis, which reduced the values suggested by the ISB. The following is taken from an ICF International memo in Appendix 2C of the March 13, 2013 Administrative draft. PCFFA-62, p. 18.[8] The memo states:

> For water planning purpose, the California Department of Water Resources used the method of Rahmstorf (2007) and 12 climate projections selected by the California Climate Action Team (Chung et. al. 2009). The historical 95% confidence interval was extrapolated to estimate the uncertainties in the future projections (Figure 2.C-8). Mid-century sea level rise projections ranged from 0.8 to 1.0 foot, with an uncertainty range spanning 0.5 to 1.2 feet. End-of-century projections ranged from 1.8 to 3.1 feet, with an uncertainty range of 1.0 to 3.9 feet. These estimates are slightly lower than those of Rahmstorf (2007) because DWR used a more limited ensemble of climate projections that did not include the highest projections of temperature increases.

DWR's 2009 planning estimates of 1.8 to 3.1 feet by the end of the century were significantly less than the ISB's estimates. The sea level rise estimates used for BDCP and WaterFix planning appear to have been based on DWR's 2009 estimates. At the time the 2013 BDCP DEIR/DEIS was written, the best available science showed higher sea level rise. The "[b]est available information suggests a range of potential SLR from 17 to 66 inches (42 to 167 centimeters) by 2100 (National Research Council 2012). SWRCB-4 (BDCP DEIR/DEIS, Chapter 29, p. 13:24-25). Nonetheless, DWR and Reclamation rejected any update of their outdated sea level rise assumptions. According to the BDCP DEIR/DEIS, "[t]he projections from the NRC study were not used directly in the BDCP analysis for two reasons. 1) the study was published in June 2012, well after the modeling analysis for BDCP had been designed and performed, and 2) the projection years are not directly aligned with the 2025 and 2060 analysis periods used for BDCP." SWRCB-4 (Chapter 29, p. 13:27-29). Recent observations have shown not only that the National Research Council's maximum estimate of 1.67 meters (5.5 feet) may be reached by the end of the century, but also that the ISB's original maximum estimate of two

[8] Exhibit PCFFA-62 is a true and correct copy of the document.

meters (6.6 feet) may be reached. This is more than double DWR's 2009 upper estimate of 3.1 feet.

These higher estimates of sea level rise are driven by new scientific understanding of the effects of climate change on the polar ice sheets. Recent satellite observations show that the rate of melting in the ice sheets in West Antarctica and Greenland is increasing dramatically. In December 2014, the American Geophysical Union accepted a paper by Tyler Sutterly and colleagues at University of California, Irvine and NASA's Jet Propulsion Laboratory which examined satellite data estimating the annual mass loss in the Amundsen Sea Embayment. Sutterly's study showed that the acceleration of mass loss (net melting) had tripled in the last decade. PCFFA-63, p. 8421.[9] Sutterley's analysis was comprehensive and authoritative as it evaluated and reconciled data using four different measurement techniques over 21 years. Similar accelerations are being seen in Greenland.

For the National Climate Assessment in 2012, the Climate Change Program Office of the National Oceanic and Atmospheric Association ("NOAA") used empirical estimates of the rate of acceleration of ice sheet melting to derive potential values of sea level rise as high as 2 meters (6.6 feet or 79 inches) by 2100. PCFFA-10, p. 2.[10] NOAA recommended that the highest levels of sea level rise be used where there is little tolerance for risk, such as in a major new infrastructure project like the WaterFix. PCFFA-10, p. 2.

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[9] Exhibit PCFFA-63 is a true and correct copy of the document Sutterley, T. C., I. Velicogna, E. Rignot, J. Mouginot, T. Flament, M. R. van den Broeke, J. M. van Wessem, and C. H. Reijmer, *Mass loss of the Amundsen Sea Embayment of West Antarctica from four independent techniques*, 41 Geophys. Res. Lett. 8421–8428, doi:10.1002/2014GL061940, *available at* http://dx.doi.org/10.1002/2014GL061940 (last accessed Oct. 29, 2015).

[10] Exhibit PCFFA-10 is a true and correct copy of the document *NOAA Climate Program Office, Global Sea Level Rise Scenarios for the United States National Climate Assessment* (December 2012), *available at* http://cpo.noaa.gov/sites/cpo/Reports/2012/NOAA_SLR_r3.pdf (last accessed Oct. 29, 2015).

Regional sea level rise estimates for 2025-2035 show that the WaterFix's engineering design estimate of 18 inches of sea level rise is much lower than NOAA's recommended values for new infrastructure. The United States Army Corps of Engineers ("ACOE") has an online calculator for sea level rise which gives low, medium, and high estimates under projections by both ACOE and NOAA for various gauges on the east and west coasts of the United States.[11] Port Chicago is the closest gauge in the calculator to the Sacramento Delta. The regionally corrected estimates for Port Chicago show that NOAA's high estimate of sea level rise is 11.8 inches by 2030 and 34.56 inches by 2060. PCFFA-64 (Port Chicago regionally corrected sea level rise table);[12] PCFFA-65 (Port Chicago regionally corrected sea level rise projections graph);[13] PCFFA-66 (Port Chicago sea level gauge data).[14] Under the more likely scenario of project completion by 2035, NOAA's high estimate of sea level rise is 14.8 inches, and 39.4 inches by 2065. PCFFA-64. NOAA's 2035 high estimate is 8.8 inches higher than the 6 inch (15 cm) assumption used for WaterFix Hearing modeling. NOAA's high estimate of 34.56 inches by 2060 is almost double the 18 inches used for the project engineering design. DWR-212, p. 51. For this reason, I concur with the ISB's opinion that these assumptions are "dangerously unrealistic."

NOAA's empirical high estimate of two meters of sea level rise by 2100 is consistent not only with recent observations, but also with a recent study by James Hansen and 16 colleagues, published in 2015. PCFFA-67.[15] James Hansen and the other authors looked at melting in the

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[11] ACOE's sea level rise calculator is available at http://www.corpsclimate.us/ccaceslcurves.cfm.
[12] Exhibit PCFFA-64 is a true and correct copy of a document prepared by me using ACOE's sea level rise calculator.
[13] Exhibit PCFFA-65 is a true and correct copy of a document prepared by me using ACOE's sea level rise calculator.
[14] Exhibit PCFFA-66 is a true and correct copy of a document prepared by me using ACOE's sea level rise calculator.
[15] Exhibit PCFFA-67 is a true and correct copy of the document J. Hansen, M. Sato, P. Hearty, R. Ruedy, M. Kelley, V. Masson-Delmotte, G. Russell, G. Tselioudis, J. Cao, E. Rignot, I.

last interglacial period warmer than the current period, when temperatures were less than one degree centigrade greater than the current period, and sea levels rose an estimated 3-5 meters. They used inferences from this period to construct models of nonlinear disintegration of the polar ice sheets in the Antarctic and Greenland. The models imply that the rate of ice sheet melting could double every 10, 20, or 40 years, with a corresponding rise in sea level of several meters within 50, 100, or 200 years. The authors conclude that recent ice sheet melt rates have a doubling time near the lower end of the range, meaning that we could see sea level rise of several meters within 50-100 years. PCFFA-67.

In conclusion, satellite observations are showing a dramatically accelerated rate of ice sheet melting, and new studies on nonlinear disintegration of polar ice sheets shows that the rate of ice sheet melting could continue to accelerate. It is essential to take this into account in the WaterFix analysis as sea level rise has major effects on both Delta outflow requirements and water quality. Correct sea level rise assumptions must also be taken into account because they are essential for evaluating forecast project operations and the conceptual project design.

V. SHIFTS IN HYDROLOGY

In order for BDCP and WaterFix modelers to simulate shifts in hydrology due to climate change, it was necessary to select a set of global climate models to project changes in temperature and precipitation. The BDCP lead agencies selected an ensemble method of climate change modeling, using all 112 models in the Coupled Model Intercomparison Project Third Assessment Report ("CMIP3") database. According to Appendix 5A, Section D: Additional Modeling Information, "[a] total of 112 future climate projections used in the IPCC AR4, subsequently bias-

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Velicogna, E. Kandiano, K. von Schuckmann, P. Kharecha, A. N. Legrande, M. Bauer, and K.-W. Lo, *Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2 °C global warming is highly dangerous,* 16 Atmos. Chem. Phys. Discuss. 3761-3812 (2016), *available at* http://www.atmos-chem-phys.net/16/3761/2016/acp-16-3761-2016.pdf.

corrected and statistically downscaled (BCSD), were obtained from Lawrence Livermore National Laboratory (LLNL) under the World Climate Research Program's (WCRP) Coupled Model Intercomparison Project Phase 3 (CMIP3)." SWRCB-4, Cha. 5, Appendix 5A, § D, 5A-D33. Appendix 5A § D also states that "[r]ecent studies at both global and regional scales have demonstrated the superiority of the multi-model ensemble over the use of a single climate model for characterizing mean climate and climate variability (Pierce et al 2009, Gleckler et al 2008)." SWRCB-4, Cha. 5, Appendix 5A, § D, 5A-D31. Finally, Appendix 5A references the following sources for its conclusions: "Gleckler, PJ, Taylor, KE, Doutriaux, C. 2008. Performance Metrics for Climate Models. Journal of 48 Geophysical Research. 10.1019/2007JD008972." SWRCB-4, Cha. 5, Appendix 5A, § D, 5A-D45.

However, a more recent study by the Intergovernmental Panel on Climate Change ("IPCC") included evaluations of how well the CMIP3 database of global climate models represented regional climates. PCFFA-68 (Gregory Flato et. al., Climate Change 2013 The Physical Science Basis, Chapter 9: Evaluation of Climate Models).[16] This more recent study showed that, while the CMIP3 ensemble does a reasonable job of reproducing historic precipitation over Eastern North America, Europe and the Mediterranean, and East Asia, there is a significant bias for Western North America. PCFFA-68 at p. 810-812. Box and whisker plots in the study show that for the 50th percentile, the ensemble is approximately 30-40% wetter than historical conditions for October through March, and approximately 25% wetter annually. PCFFA-68, p. 812; *see also* PCFFA-78 (Figures 9-11).

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[16] Exhibit PCFFA-68 is a true and correct copy of the document Flato, G., J. Marotzke, B. Abiodun, P. Braconnot, S.C. Chou, W. Collins, P. Cox, F. Driouech, S. Emori, V. Eyring, C. Forest, P. Gleckler, E. Guilyardi, C. Jakob, V. Kattsov, C. Reason and M. Rummukainen, Evaluation of Climate Models. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 2013. Cambridge University Press, Cambridge, United Kingdom and New York, NY, US.

It is possible to estimate bias in global climate model projections by comparing the unforced outputs with the historic record. This is done by comparing outputs from the unforced models and the historical record. This was the approach used by the California Climate Action Team, supervised by Daniel Cayan at the Scripps Institute at the University of California, San Diego. The California Climate Action Team did the climate change modeling for the California Climate Change Assessments. PCFFA-69.[17] The Climate Action Team compared how well the global climate models in the CMIP3 database did in representing the California climate, and culled the set to models which performed reasonably well in matching the historic hydrology. The models were chosen "on the basis of providing a set of relevant monthly, and in some cases daily, data. Another rationale was that the models provided a reasonable representation, from their historical simulation, of the following elements: seasonal precipitation and temperature (Figure 1), the variability of annual precipitation, and El Niño/Southern Oscillation (ENSO)." PCFFA-69. Given California's unique climate, Cayan has advocated for this culling approach in future climate modeling by DWR. DWR's August 2015 Perspectives and Guidance for Climate Change Analysis states that, "[n]ot unlike mutual funds in economics, though past performance is no guarantee of future performance, the model's representation of historical climate provides a logical way to select models for regional application." PCFFA-70, p. 24.[18]

A study done by Sarah Null and Josh Viers at University of California, Davis in conjunction with the 2012 California Climate Change Assessments shows just how different the

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[17] Exhibit PCFFA-69 is a true and correct copy of the document Dan Cayan et al., "Climate Change Scenarios and Sea Level Rise Estimates for the California 2009 Climate Change Scenarios Assessment," a Paper from the California Climate Change Center, *available at* http://www.energy.ca.gov/2009publications/CEC-500-2009-014/CEC-500-2009-014-F.PDF.

[18] Exhibit PCFFA 70 is a true and correct copy of DWR, Perspectives and Guidance for Climate Change Analysis, p. 24 (Aug. 2015), *available at* http://www.water.ca.gov/climatechange/docs/2015/Perspectives_Guidance_Climate_Change_Analysis.pdf.

Climate Action Team's subset of six carefully selected global climate models is from the entire CMIP3 ensemble, which was used for the BDCP and WaterFix climate change projections. PCFFA-72.[19] Null and Vier's modeling also did not use downscaled global climate model outputs to perturb the historic hydrology, as was done for the BDCP's climate change modeling.

DWR has noted problems with using downscaled global climate models to perturb historic hydrology in a 2009 report, Using Future Climate Projections to Support Water Resources Decision Making in California. PCFFA-71.[20] In Section 4.4 of DWR's report, titled "Future Climate Variability" (p.36), the authors state that,

> In water resources planning, it is often assumed that future hydrologic variability will be similar to historical variability, which is an assumption of a statistically stationary hydrology. This assumption no longer holds true under climate change where the hydrological variability is non-stationary. Recent scientific research indicates that future hydrologic patterns are likely to be significantly different from historical patterns, which is also described as an assumption of a statistically non-stationary hydrology. In an article in *Science*, Milly et al. (2008) stated that "Stationarity is dead" and that "finding a suitable successor is crucial for human adaptation to changing climate."

PCFFA-71.

Null and Vier's use of Cayan's carefully selected set of global climate models allowed direct use of the model outputs, without bias correction and mapping onto the historic hydrology. Null and Viers performed ANOVA and t-tests using a 95 percent confidence level to compare the GCM outputs with observed 1951-2000 hydrology. The statistical tests showed the GCM outputs were not statistically different from the historic hydrology. The direct use of this subset of global

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[19] Exhibit PCFFA-72 is a true and correct copy of the document Sarah Null and Josh Viers, *Water and Energy Sector Vulnerability to Climate Warming in the Sierra Nevada: Water Year Classification in Non-Stationary Climates* (July 31, 2012), *available at* http://www.energy.ca.gov/2012publications/CEC-500-2012-015/CEC-500-2012-015.pdf,

[20] Exhibit PCFFA-71 is a true and correct copy of the document Francis Chung et. al., *Using Future Climate Projections to Support Water Resources Decision Making in California*, California Climate Center (May 2009), *available at* http://www.water.ca.gov/pubs/climate/using_future_climate_projections_to_support_water_resources_decision_making_in_california/usingfutureclimateprojtosuppwater_jun09_web.pdf.

climate models did show a marked shift in climate. Most of the models projected major increases in dry and critically dry years, and decreases in wet and below-normal years. All of the models projected a significant increase in dry and critically dry years by the latter half of the century, with a corresponding decrease in wet and above normal years. PCFFA-72.

The BDCP did originally propose a method for dealing with regional uncertainty. Appendix 5A-D of the BDCP DEIR/DEIS shows that CH2M Hill originally proposed to deal with uncertainty about regional climate scenarios by developing projections for subsets of the global climate model / climate scenario ensemble. SWRCB-4. The ensemble was divided into 4 quadrants with projections of more warming and less warming, and drier or wetter. A Central Tendency for the ensemble was also calculated. SWRCB-4 (Appendix 5A-D, p. 35-36).

Appendix 5A-D, p. 33 stated that "[t]he selected approach for development of climate scenarios for the BDCP incorporates three fundamental elements. First, it relies on sampling of the ensemble of GCM projections rather than one single realization or a handful of individual realizations. *Second, it includes scenarios that both represent the range of projections as well as the central tendency of the projections.*" SWRCB-4 (emphasis added). This would have been a reasonable approach to uncertainty about regional climate change scenarios if it was carried through to the final WaterFix modeling. It also would have provided information on possible climate shifts. Instead, only the single "Central Tendency" projection has been used for most BDCP and WaterFix modeling and model results, including the results presented for the hearing. The Central Tendency scenario provides no information about uncertainty in the BDCP / WaterFix projections of shifts in hydrology.

VI. CLIMATE SHIFTS

DWR's planning studies for its 2010 analysis of modeling of climate change noted that

> there is a lack of analysis of potential drought conditions that are more extreme than have been seen in our relatively short hydrologic record. There is significant evidence to

> suggest that California has historically been subject to very severe droughts and that climate change could result in droughts being more common, longer, or more severe. However, most current DWR approaches rely on an 82-year historical hydrologic record (1922–2003) on which GCM-generated future climate changed-hydrologic conditions are superposed. This record is likely too short to incorporate the possibility of a low frequency, but extreme, drought.

PCFFA-73.[21]

DWR did fund a study of tree ring cores by David Meko at the University of Arizona. PCFFA-74.[22] Meko's study estimated the Sacramento Four River Index from tree ring cores, back to 901 A.D. Graphs of Meko's reconstructed flows, along with the associated data set, are available at http://www.treeflow.info/content/sacramento-river-four-rivers-index-ca. The graphs show many extended periods of below average flows. PCFFA-78;[23] *see also* IFR-2.[24] In a presentation for the 2009 Extreme Precipitation Symposium, Meko stated that

> six-year droughts of the 1930s and 1980s-90s are as severe as any encountered in the tree-ring record. For longer running means the tree-ring record contains examples of drought severity and duration without analog since the start of the 20th century. For example, mean flow is reconstructed at 73 percent of normal (1906-2008 observed mean, 23.8x106 acre-feet) for the 25-year period ending in 1480.

IFR-1, p. 1.[25]

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[21] Exhibit PCFFA-73 is a true and correct copy of Abdul Khan and Andrew Schwarz, Climate Change Characterization and Analysis in California Water Resources Planning Studies, Final Report. DWR, p. xvi (Dec. 2010), *available at* http://www.water.ca.gov/climatechange/docs/DWR_CCCStudy_FinalReport_Dec23.pdf.

[22] Exhibit PCFFA-74 is a true and correct copy of David M. Meko, Matthew D. Therrell, Christopher H. Baisan, and Malcolm K Hughes, *Sacramento River Flow Reconstructed To Ad. 869 From Tree Rings*, Journal Of The American Water Resources Association, VOL. 37, NO.4, August 2001.

[23] Graphs and data from David Meko's reconstruction are presented in PCFFA-78, which is a true and correct copy of Meko's work as presented at http://www.treeflow.info/content/sacramento-river-four-rivers-index-ca.

[24] Exhibit IFR-2 is a true and correct copy of Cook et al., *Megadroughts in North America: placing IPCC projections of hydroclimatic change in a long-term palaeoclimate context*, Journal of Quaternary Science, DOI: 10.1002/jqs.1303 (2009).

[25] Exhibit IFR-1 is a true and correct copy of Meko, *Central Valley Droughts Over Last 1,000 Years*, 2009 California Extreme Precipitation Symposium (UC Davis, June 24, 2009).

Given this history, I believe it is essential to consider extended drought periods in evaluating the proposed increase in water diversions by the SWP and CVP. I recommend that the Board require DWR and Reclamation to produce detailed information on water supply and water quality under the proposed change for the droughts of 1987-1992 and 1928-1934, and would recommend this analysis for all changes that involve significant increases in diversions.

VII. MODELING

The model results submitted in support of the WaterFix petition all rely on a hydrologic / water operations model called CALSIM II. This model has never been externally validated, i.e., approved as reliable, for any use. The validation of the hydrodynamic model, DSM2, has also not been put into the record for use by the Board in the WaterFix hearing. DWR and Reclamation have implied that they validated the model for its proposed use in the WaterFix Hearing. *See, e.g.*, DWR-71, p. 8. But an examination of the 2003 peer review cited by DWR shows that DWR *never provided the information for a technical analysis to the panel,* information which was required to assess the accuracy of the model results. As stated in the report of the 2003 peer review of CALSIM II, *A Strategic Review of CALSIM II and its Use for Water Planning, Management, and Operations in Central California*:

> 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.

PCFFA-20, p. 3.[26] The 2003 report also recommended that, "[t]o increase the public's confidence in the many components and features of CALSIM II, we suggest that these components of

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[26] Exhibit PCFFA-20 is a true and correct copy of the document A. Close, W. M. Haneman, J. W. Labadie, D.P. Loucks, J. R. Lund, D. C. McKinney, and J. R. Stedinger, *A Strategic Review of*

CALSIM be subjected to careful technical peer review by appropriate experts and stakeholders. PCFFA-20, p. 2. DWR's response to the 2003 peer review did not allay these concerns, which were reiterated in a 2006 peer review. PCFFA-79,[27] PCFFA-80.[28]

Furthermore, CALSIM's reviewers expressed significant skepticism about the use of CALSIM in a comparative mode, the very mode upon which petitioners' testimony – that there will be no injury to legal users of water – is based.

> 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.

PCFFA-20, p. 9. This skepticism was never addressed through adequate documentation of CALSIM errors, testing, and calibration.

With the exception of the San Joaquin River component of the CALSIM model, it appears that none of the components of the model have had a published technical peer review. Given the concerns expressed by peer reviewers and others in the modeling community about problems with the modeling of hydrologic processes, this should be of major concern when the model is proposed to be used as evidence of "no harm" to legal users of water. For this reason, the

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CALSIM II and its Use for Water Planning, Management, and Operations in Central California,"CALFED Science Program (Dec. 4, 2003).

[27] Exhibit PCFFA-79 is a true and correct copy of the document Review Panel Report San Joaquin River Valley CalSim II Model Review, 2006.

[28] Exhibit PCFFA-80 is a true and correct copy of the document 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.

omission by Petitioners of the 2003 and 2006 CALSIM peer reviews from evidence submitted for the hearing, while repeatedly referring to the peer reviews as if they validated the proposed use of the model, is misleading and obfuscatory.

I incorporate here by reference and join in the conclusions of testimony to this point submitted directly as a party by Deirdre Des Jardins, principal at California Water Research, as part of her case in chief.

VIII. CONCLUSION

During the time period for the proposed permit, there are significant risks to water supply and water quality from sea level rise, shifts in hydrology due to climate change, and shifts in climate as have been seen in the record of flows reconstructed from tree ring data. I believe that it is essential that these risks be adequately assessed, in order to provide sufficient information for both the Board and for parties representing beneficial uses in the Areas of Origin, as well as for decisions involving water quality and public trust resources.

In summary, my recommendations are as follows:

1. The Board should require DWR to submit modelled operations using the Q2 drier, warmer scenario for consideration in the WaterFix hearing. The Q2 scenario is the scenario with the greatest risk. Model results for the Q2 scenario were provided for the Biological Assessment (SWRCB-104, Appendix 5A), but the Biological Assessment does not have the same operational assumptions as the CALSIM runs conducted for the WaterFix hearing, and did not look at model results related to legal users of water;
2. The Board should take into account current guidance based on the best available science and require DWR and Reclamation to submit WaterFix model results using the 18 inch

early long term (ELT) BDCP DEIR/DEIS scenario for sea level rise, in addition to the 6 inch scenario currently evaluated;

3. The Board should require that DWR and Reclamation submit a sensitivity analysis for the WaterFix with long term project operations at 1.4 meters (55 inches) of sea level rise, as specified in the Delta Reform Act;
4. The Board should require that DWR and Reclamation produce information on water supply and water quality under the proposed change for the droughts of 1987-1992 and 1928-1934.
5. The Board should require that DWR and Reclamation disclose, the extent such reports exist, or newly produce, if such reports do not exist, testing and calibration reports for the CALSIM model components that represent hydrologic process.
6. The Board should require that DWR and Reclamation newly produce a validation report for the CALSIM model used by petitioners to model the WaterFix project that includes appropriate input data.

Executed on this 2nd day of September, 2016 in Santa Cruz, California.

Deirdre Des Jardins