State of California DEPARTMENT OF WATER RESOURCES California Natural Resources Agency

OFFICE MEMO

TO: Cathy Crothers	DATE: 8-22-13 DRAFT
FROM: Parviz Nader-Tehrani, Erik Reyes, Francis Chung, Tara Smith	SUBJECT: CalSim II and DSM2 Modeling for BDCP (16-years versus 82-years)

SUMMARY FOR CONSULTANT REVIEW

I. Introduction

Contra Costa Water District (CCWD) raised concerns that the CalSim Artificial Neural Network (ANN) results showed that BDCP Alternatives increased chlorides at CCWD's intake locations at Rock Slough, Old River south of Highway 4, and Victoria Canal when compared against a No Action Alternative. DWR technical staff has confirmed modeled increase in chlorides (salinity). However, the CalSim ANN water quality results are only used as guidelines to drive project operations, such as changes in export levels. Instead, the better tool to use is DSM2, which produces results that more accurately reflect the actual water quality impacts that might occur due to project operations. DWR staff reviewed the DSM2 results and found that there was a chloride increase, averaged over 16-years[1], but it was smaller than the increase seen in the average CalSim ANN results, which rely on data from an 82-year time period.

All of the existing analysis for the BDCP Draft EIR/S has used 16-year DSM2 results. CCWD's inquiry led DWR staff to investigate whether 82-year DSM2 results showed greater changes in chlorides, or salinity, than the 16-year results. DWR staff ran an 82-year DSM2 simulation for the No Action Alternative and for Alternative 4 to examine if there are indeed significant differences in chlorides when comparing 82-year results against 16-year results. DWR staff found that there is at times greater increases in chlorides in the 82-year simulation period than there are in the 16-year period when looking at the average monthly results. Even so, DWR staff believes that the conclusions based on the 82-year time period do not add any additional accuracy or value to the analysis. In fact, the hydrology that is used in the CalSim simulations that provides input to DSM2 is not as accurate as in the 16-year period. This memo briefly describes CalSim and DSM2 and their appropriate applications and addresses whether CalSim and DSM2 82-year simulations are the "best available model" for the BDCP process. Also discussed at the end of this memo are the Potential impacts to BDCP and other DWR efforts if there is a move to DSM2 82-year simulations. The points below summarize the findings and are explained in the following text.

- 82-year CalSim simulations were designed to evaluate system performance from a probabilistic perspective, whereas 16-year DSM2 simulations are designed to investigate the detailed physics of the hydrodynamics and water quality, such as the

1 DSM2 uses Electrical Conductivity (EC) to model salinity. The simulated EC values are converted to chlorides using empirical relationships developed from historical data at various locations in the Delta.

movement of chlorides, in the estuary system. In other words, DSM2 can show salinity (chloride) changes in all of the Delta channels in short time steps (daily or less) in relation to changes in flows and tidal movement of water, which can help understand how salinity moves within the system with more accuracy than CalSim.

16-year DSM2 simulations have adequate data (over half a million time-steps) to evaluate the detailed physics of the system. 82-year DSM2 simulations do not appear to add any value to these evaluations and are less accurate due to a less accurate hydrology in the earlier historical periods.

- The use of 16 year DSM2 simulations can be analogized to the use of a microscope that renders a close examination of a focus area, the Delta, on a fine time scale, 15 minutes.

- The distribution of year types in the 16-year period is similar to the distribution in the 82-year period (i.e., a wide range of hydrological conditions is reflected in both data sets).

- Data to develop DSM2 Boundary conditions is more readily available for the 16-year period because the time period is more recent.

  Historic data of more recent periods is of better quality when used to develop the historic hydrology used in CalSim and DSM2. Data representing historic flows, tidal stages, and water quality, etc. for periods before the 1950's is often estimated rather than from recorded gage data.

- The 16-year simulation period for DSM2 contains the driest two-year drought and also an extended drought (1987 – 1991), and provides sufficient information for necessary confidence in the modeling results.

- 16-year DSM2 simulations have been used for several programs, including SDIP, Franks Tract, Storage Investigations, and OCAP.

- An 82-year DSM2 simulation was developed to look at expanded Los Vaqueros storage investigations and was an appropriate use of the model for that specific analysis. A longer simulation period was needed to properly evaluate salinity results over the time needed to fill the reservoir. Since filling the reservoir occurs over a number of years, 16 years was too short to properly look at how the water quality in the reservoir might change over time due to variable hydrologic conditions.

- 82-year DSM2 simulations need additional development if they are to be used for constituents other than salinity, such as organic carbon, dissolved oxygen, or temperature.

- Choosing 16-, 82-, 25-, or 50-year simulation periods will generally provide different period average results despite them having similar year type distributions. This is because the sequence of years plays a large role in physical and operational system responses. However, the difference in length of the modeling period may not add value or confidence in results.

II. CalSim and DSM2

(What is CalSim II and for what purposes is it used? What is DSM2 and for what purposes is it used?)

CalSim and DSM2 focus on different aspects of the system, with different levels of detail in relation to project operations. In Appendix 5A of the BDCP documentation, section A.3 (pages A-10 through A-23) has a detailed description of CalSim II (input and output) along with the assumptions and how it was used to simulate the system operations. In section Section A.5 (Pages A-32 through A-49), there is a detailed description of DSM2 (input and output) and how it was used to simulate the hydrodynamics and water quality in the Sacramento San Joaquin Delta. For reference, both of these sections are attached to the end of this memo.

CalSim II uses a monthly time step for inflows and exports. CalSim II looks at system performance over larger time scales and thus 82 years of data enhances the evaluation process. DSM2 is a hydrodynamic[2] and water quality model and looks at finer details of the physical system and uses a 15-minute time–step, for such functions as salinity, water levels, flows, organic carbon, and dissolved oxygen. CalSim II is run at a monthly time-step for a total of 984 time-steps in an 82-year simulation period. DSM2 runs at a 15 minute time-step for a total of 560,640 time-steps in a 16-year simulation period. For an existing condition simulation, CalSim uses historical hydrologic data as its input and applies current water regulatory requirements and level of development in order to determine the operation of the state and federal projects. DSM2 is calibrated[3] using historical data at several locations in the Delta. For planning studies, its inflow and export input come from CalSim's monthly output. Because DSM2 is a model of the physical system, if actual flows into and exports and diversions from the system matched that of CalSim, DSM2 would be able to determine water levels, flow patterns, and salinity throughout the channels in the Delta within the confidence levels as determined by the historical calibration. CalSim can only determine salinity at select locations in the Delta. This is explained more fully in the paragraph below.

A. CalSim

1. Artificial Neural Network

The Artificial Neural Network in CalSim is the module that calculates the amount of

2 A hydrodynamic model is a tool that is able to describe or represent the motion of water using numerical solutions to the complex governing equations of conservation of momentum and mass within a fluid.

3 In Calibration, model parameters (knobs) are adjusted in order for model output to match observed data. Validation of the model follows. In validation, another historical time period is chosen, the model is run again and the results of the simulation are matched with observed data without adjusting the model parameters.

water needed to be released into the Delta or exported in order to meet the water quality objectives in the Delta at a few specific locations. The CalSim ANN does not adjust the flows to meet water quality levels in other Delta locations. The CalSim ANN is not a physics-based model, but a mathematical model that finds patterns in data and is trained to fit those patterns with equations that provide the best estimate of salinity, using output from DSM2. The inputs into ANN include major inflows, tidal magnitudes, cross-channel operation and Delta-wide consumptive use. The inputs for training do not include salts coming from agricultural returns. Because of this lack of detailed input for land salts and regional diversion and returns, the ANN is limited in its accuracy to represent the physical system.

Appendix 5A, Section C, starting from page B-185, includes specific CalSim II and DSM2 Modeling results. End of Month Storage values at major reservoirs are analyzed in detail for each of the listed BDCP alternatives. These include Trinity, Shasta, Oroville, Folsom, San Luis, and New Melones. Los Vaqueros storage, however, has traditionally never been a part of the standard CalSim II output. In summer of 2009, at the request of CCWD, DWR agreed to allow Dan Easton (MBK) to insert the LV (Los Vaqueros) module inside BDCP CalSim studies. According to CCWD, this addition would allow a better representation of CCWD operations of its three intakes (Rock Slough, Old River, and Victoria Canal). The accuracy of the LV module relied on the accuracy of the ANNs developed for these three intakes. DWR has been in charge of developing ANNs for all the scenarios studied for BDCP. Although DWR has routinely generated ANNs designed to simulate water quality conditions at 11 locations (including all the three CCWD intakes), we performed a "ANN Full Circle Analysis" only for the four major locations; Emmaton, Jersey Point, Old River Rock Slough, and Collinsville. These were the locations that primarily affected the operations (such as reservoir releases or export levels) simulated within CalSim II. In addition, it has always been understood that ANNs perform the best[4] when the ocean salt is the primary source of the salt. As a result, the accuracy of the ANNs to simulate water quality conditions at the other two CCWD intakes (Old River and Victoria Canal) should be considered questionable. In fact, in an E-mail exchange in October 29, 2009, Matt Moses (CCWD) acknowledged that "**Use of ANN to estimate water quality at CCWD intakes can at times result in operational flutter between cycles and inaccurate estimates of CCWD delivered water quality. CCWD will likely use pre-processed water quality time series input for CalSim studies related to Los Vaqueros Expansion".**

2. CalSim II Daily Data

CalSim II has routines for estimating Fremont Weir flows and North Delta Diversions that transform monthly flows into daily historic patterns. The daily historic patterns provide for better estimates of flow and diversion at the Fremont Weir and North Delta Diversion facilities. Daily historic patterns are assumed[5] from recorded gage data for Sacramento River at

4 When performing best, salinity determined by the CalSIM ANN more closely matches the DSM2 simulated salinity for the same conditions.

5 CalSim II is a monthly model and for most locations assumes that flow is uniform for every day in a given simulation month. Two places that are different are the Fremont Weir and the Hood NDD. At these locations it was necessary to introduce the daily variability of real-time hydrographs to get more realistic estimates of flow over the weir and diverted at Hood NDD. Daily variability is introduced into the model by assuming that the monthly water volume at Fremont weir occurs on a daily pattern that matches the daily pattern that occurred historically.

Freeport for the period of 1955 – 2003. There is insufficient gage data for the period of 1922 – 1954 and thus the daily patterns here are estimated from daily patterns of years with gage data (1955 – 2003) for years in 1922 - 1954 that are hydrologically similar. The period with gage data is obviously a more accurate depiction of daily flows and thus gives more accurate results that feed into DSM2. From an accuracy and quality of data point of view, the 16-year period of 1976 – 1991 is better than the 82-year period of 1922 – 2003.

3. CalSim II Hydrology Data

Similar to the point above, in general the quality of hydrologic data is less reliable the further back in time one goes. The input hydrology for the 82-year CalSim simulation period consists of good gage data from about the 1950's to 2003; however, this data only provides a "best estimate" of data from the 1950's back to 1922. For CalSim, which is run on a monthly time-step and analyzes system performance, it helps to have more data with which to evaluate the performance. Traditionally, the early period has been thought to be desirable to simulate for the evaluation of system performance because it contains an extended drought period (1928 – 1934). There is also, however, an extended drought period (1987 – 1991) in the more recent years with more accurate gage data, which is used in DSM2 as discussed above. The driest two-year drought also occurs in the later period with more accurate gage data. Thus, while using estimated input data allows for longer simulations, the data for the early years of simulation (1922 – 1950's) is acknowledged to be of lower quality. In contrast, DSM2 models the 16-year period with recent high quality data and includes hydrologic variability similar to the 82-year period, as discussed above.

B. DSM2

1. Historical Development of Delta Simulation Model Planning Studies

The modeling purpose of the operation model is to show system-wide changes to flow and exports related to SWP and CVP operational scenarios. The modeling purpose of the hydrodynamic and water quality models is to show more detailed changes to physical constituents, such as salinity, in the Delta due to the changes in flows from the operations model (CalSim), tidal variations, gate operations, structural changes (such as a tunnel) and in-Delta diversions and returns. Flows from the systems operations models, such as DWRSIM and CalSim, have been used as input to Delta hydrodynamic models, such as DSM (a predecessor to DSM2), since the early 1990s. DSM used flow and export output from DWRSIM to make analysis for various DWR programs, including the North and South Delta Programs. At that time, computing power was expensive, so running several years of time, such as 16 years, could take up to two weeks of computer run time. Years simulated represented various year types in order to allow modelers to see the impact of proposed changes to the Delta on the hydrology and salinity in the Delta.

DSM2 modeling uses daily and 15 minute data from 16 years, 1976 –1991. CalSim modeling uses monthly data from 82 years, 1922-2003. Because the hydrodynamic models and the operations models have different purposes and use different temporal types of data (monthly versus daily or less), the length of the time period to use in the model must be chosen in consideration of the data available during the time period. This is an important consideration because the quality of the input data affects the confidence to be given in the modeling results. Section II.A.2 and II.A.3 above discusses the quality/resolution of flow data from

CalSim that is used as input to DSM2. Available data, purpose of modeling, and representative hydrologic time periods are all factors that determine the best available model to use in an analysis, as discussed further below.

2. DSM2 16-Year and 82-Year Planning Studies

a) DSM2 16-year-Year Planning Studies

In 1998, DWR released DSM2, which was an improvement over DSM in several respects, including improved channel bathymetry and the use of a real tide that included spring neap variations[6]. One of the first studies for which DSM2 was used was evaluating the CALFED alternatives. At that time, the operations model provided output, for use as input to DSM2, through 1994. The engineers making the simulations chose a series of years that represented the full spectrum of year types: Wet, Above Normal, Below Normal, Dry, and Critical. The years 1976-1991 fit the spectrum of year types and also were contained in a continuous series of years that could be run as one study. Since hydrodynamics and water quality from one year affect the results of the following year, a sequence of years that contained all needed year types was chosen. The sequence of years was bracketed on either side by two critical years, 1976 and 1977 at the beginning of the sequence of years and 1990 and 1991 at the end of the sequence of years. Critically dry years are an area of focus when looking at alternatives due to potentially larger impacts to water quality. The table below shows the relationship in year types between the 16 years and 82 years.

	82 Year - year type percentage	16 Year - year type percentage	82 Year - number of years in year type	16 Year - number of years in year type
Wet	32	25	26	4
Above Normal	15	13	12	2
Below Normal	17	6	14	1
Dry	22	25	18	4
Critical	15	31	12	5

The DSM2 16-year simulation period has an ample amount of data to look at the finer details of the physical system. The 16-year period contains the driest two-year drought on record and it also has an extended drought period (1987 – 1991). There is adequate variation of year types and drought periods to evaluate the physical system and the impacts of operational and structural changes to that system. The accuracy of the model would not be improved with the addition of more years. It is important to understand the processes causing the differences in water quality between alternatives. DSM2, with 16 years, is able to do that due to a finer scale time step and a simulation that models the physical movement of water

6 Prior to using a Spring Neap tide, DWR used a 19-year mean tide that repeated every 25 hours with the range of water levels being somewhere in-between the Spring and Neap ranges. Spring tide is the highest energy tide that contains the widest range of water levels. It is caused by the sun and the moon being aligned and creating a greater force. The neap tide contains the smallest range and occurs when the moon and the sun are at 90 degrees and the solar force partially cancels out the moon's force.

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and salinity. Accuracy of the model would not be improved with additional years because 16 years contains the variability in year types and enough data to determine why there are differences in water quality results.

In putting together DSM2, DWR developed boundary conditions, which are not provided by operation models. These boundary conditions include water levels at Martinez, salinity at Martinez, and multiple agricultural diversions, drainages, and water quality. In order to develop some of these boundary conditions, historical data was necessary. A more complete set of historical data for development for the 16 years was available due to the facts that the period chosen was more recent and that the data was available in a public data base. Since 1998, DSM2 16-year simulations have been used for several programs, including the following:

- South Delta Improvements Program (http://baydeltaoffice.water.ca.gov/sdb/sdip/index_sdip.cfmhttp://baydeltaoffice.water.ca.gov/sdb/sdip/index_sdip.cfm),
- Franks Tract (http://www.water.ca.gov/frankstract/) ,
- Surface Storage Investigations (http://www.water.ca.gov/storage/common_assumptions/index.cfm)
  - including the In-Delta Storage (http://baydeltaoffice.water.ca.gov/sdb/sdip/index_sdip.cfmhttp://baydeltaoffice.water.ca.gov/sdb/sdip/index_sdip.cfm),
- and Operations Criteria and Plan (OCAP) biological assessments (http://www.usbr.gov/mp/cvo/ocap_page.html).

b) DSM2 82-Year Planning Studies

DSM2 82-year simulations were also developed as part of the Surface Storage Investigations work to look at the salinity in the expanded Los Vaqueros Reservoir as it was filled. Due to the filling taking several years, 16-year simulations were not sufficient to do the analysis. A longer simulation period was needed to properly evaluate salinity results over the time needed to fill the reservoir. Since the filling of the reservoir occurs over a number of years, 16 years was too short to properly look at how the water quality in the reservoir might change over time due to variable hydrologic conditions. As part of this effort, boundary water levels at Martinez were developed for the 82-year simulation. These water levels were adjusted to account for sea level rise. Additionally, gate/barrier operations and agricultural diversions and returns were developed over the 82-year period. Simulations had to be run in sections covering shorter periods due to file size limitations and increases in computer run time over the 16-year simulation

3. Are 82-year DSM2 simulations right for BDCP?

a) Is more better?

Although the DSM2 was able to look at 82-year simulations for the above Surface Storage Investigation work, the question is whether the 82-year DSM2 simulation is the best available model for all analyses for the BDCP?

In modeling, it is not appropriate to assume that using more years in the model is necessarily better. It is more important to determine the requirements of the project first before determining the best available model. Often, when the amount of input used by a model is increased beyond what is needed or beyond the capability of the model, people reviewing the modeling results may wrongly assume they are more accurate or dependable than they really are. The following illustrates these points for the analysis of BDCP alternatives:

- Different hydrologies (all year types) are represented in the 16-year studies in a daily time-step.

  The process causing the difference in EC between alternatives is understood. With low export pumping in the south Delta in Alternative 4 , land salts are not quickly removed from the system after a dry year. Salinity levels in the south Delta will increase due to higher San Joaquin salinity, higher salinity in agricultural returns and/or lower flows in the San Joaquin River. Higher agricultural return salinity, representing leaching of fields, can also occur during winter months impacting water quality. Project exports, when high enough will remove that concentrated salinity from the south Delta. The exports also bring fresher Sacramento water into the south Delta area. In Alternative 4, since there are less exports than in the No Action Alternative, flows from the San Joaquin River and salinity due to concentrated agricultural returns make up a greater portion of the water diverted by Contra Costa Water District.

- The magnitude of the differences will vary due to different factors:

  - Different year types following each other will impact the magnitude. Whether it is 16 years, 25 years, 30 years, or 82 years, there is not a pattern of year types that history follows. Because of this fact, it is not a good assumption that the magnitude of the difference in EC levels would follow the 82-year average in the future. It could be more or it could be less. What is important is to determine what is behind the increase in EC and understand how that magnitude would be affected by that physical process. In this situation, the physical process is the higher concentration of land salts (from agricultural drainage) as compared to ocean salt, that is causing the increase in salinity.

  - The magnitude of the difference is affected by how ocean salts and land salts are modeled. In the case that is examined here (higher salinity from a dryer year followed by lower exports), land salt is not moved out of the system as quickly as in the base condition.

Because the salt coming from agricultural returns is estimated and not measured, there is uncertainty in values produced in studies that will affect the proper interpretation of the difference in water quality magnitude between No Action Alternative and Alternative 4. Agricultural water quality and diversions and drainages are boundary conditions for DSM2 and are supplied by another model, the Delta Island Consumptive Use (DICU) model, because measured values are not available. Calibration of DSM2 using historical conditions has shown that when DSM2 is not matching salintity well in the south Delta (in dry periods), it is due to the lack of adequate boundary conditions from agricultural boundary conditions. So when land salts become an important factor in the water quality results, care should be taken with interpreting the resolution and accuracy of results.

The physical processes behind the water quality differences between the No Action Alternative and Alternative 4 are understood. In this particular case, the differences are primarily due to agricultural diversions and returns. Because of this understanding of the impact of agriculture and because of understanding the relative accuracy of this impact, the accuracy of the DSM2 results cannot be improved by increasing the number of years of simulation. Thus, the 16-year DSM2 model is the best available model for the BDCP analysis. 82-year DSM2 results will not add additional value to this project.

b) DSM2 82-year simulations need additional development

82-year simulations of other constituents, such as organic carbon, dissolved oxygen, or temperature in the Delta, have not been developed. Additionally, the likelihood of developing boundary conditions for these constituents with an acceptable level of confidence is very small due to the limited amount of historical data. The further in time one gets away from the availability of data, the accuracy of the results becomes worse because an estimation is used instead of actual data. In developing the 82-year simulations for salinity, relationships for boundary conditions for Martinez and inflows could be more easily developed. Other constituents do not follow easily defined patterns and are much more difficult to develop.

4. Model Run time

In making a decision for the best available model, run time for obtaining results is a factor. One reason for using a combination of multi-dimensional[7] (multi-D) models with DSM2 in BDCP was because the multi-D models could not perform studies quickly enough to model 16 years. For example, to complete a 16-year study using the multi-D model RMA without combining it with DSM2 would have taken a computer run time of approximately one month. In addition to this practical concern of model run time, 16-year long multi-D model simulations are not deemed to produce additional or useful findings that are not afforded by 16-year DSM2 simulations. However, for a refined detailed analysis, refined both in space and in time, multi-D models have a place and have been deployed as an industry standard. For instance, multi-D models were needed and used to model flow into the habitat areas because the multi-D models were better in generating necessary information than DSM2. Information

7 Mult-Dimensional models model flow in two or three dimensions. In DSM2, a one dimensional model, flow is modeled as either moving upstream or downstream. In a two dimensional model, flow directions and magnitudes in a wide but shallow channel can be modeled.

from those multi-D runs modeling the habitats was fed into DSM2. Each alternative in this process is often run several times due to new changes in how that alternative is configured based on dialogue between stakeholders or technical problems in running the study. Model run time, in addition to the time it takes to process and analyze the information, has to be considered. If using a multi-D model does not provide added value to the studies and is more cumbersome, then using the simpler model is better.

For 82 years, the current run time for DSM2 is one day (24 hours), so run time is not the issue. It is a little more cumbersome to process the results due to the increased output per study (about 5 GB output for 16 years and 20 to 25 GB for 82 years), but that cumbersomeness also is not the main concern. The concern is that the additional years added would not add value to the analysis in all cases , so that the time added to run and process the results, even if not overly burdensome, would not be justified.