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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	SUR-REBUTTAL TESTIMONY OF BENJAMIN S. BRAY, Ph.D., P.E.

I, Benjamin S. Bray, do hereby declare:

I. Introduction

I am a Senior Civil Engineer employed by the East Bay Municipal Utility District ("EBMUD"). I hold a Bachelor of Science in Environmental Resource Engineering from Humboldt State University (2000) and a Master of Science (2002) and Doctor of Philosophy in Civil Engineering with an emphasis in water resources and minors in operations research and linear statistical models (2006) from the University of California at Los Angeles. I am a registered Civil Engineer in the State of California (C78883), and I have over ten years of experience with EBMUD. A true and correct copy of my statement of qualifications is submitted as EBMUD-127. My case-in-chief testimony is submitted as EBMUD-152 and EBMUD-101.

The purpose of my sur-rebuttal testimony is to respond to the rebuttal testimony offered by DWR witness Dr. Parviz Nader-Tehrani in response to my case-in-chief testimony. (See EBMUD-152 [Bray case-in-chief testimony]; May 4, 2017 Transcript, vol. 39, pp.143:7-152:12 [Nader-Tehrani direct rebuttal testimony]; May 11, 2017 Transcript, vol. 43, pp. 137:21-141:5, 151:16-154:24 [Nader-Tehrani re-direct rebuttal testimony].)

II. The DSM2 Model Used by Petitioners Consistently Under-Predicts Significant Reverse Flow Events at Freeport Because It Inaccurately Simulates Tidal Influence at Freeport in Low-Flow Conditions.

On cross-examination following his direct rebuttal testimony, Dr. Nader-Tehrani was asked whether he knew of a systematic under-prediction of peak velocities in the DSM2 model. (May 5, 2017 Transcript, vol. 40, p.206:19-21.) He testified in response that he is not aware of any systematic problem with the model at Freeport. (*Id.* at p.206:21.) To the contrary, there is overwhelming evidence that DSM2 systematically and consistently under-predicts tidal amplitude at Freeport – particularly the older version of DSM2 used by Petitioners for this hearing. This deficiency in the model is caused by the proximity of Freeport to the model's upstream boundary condition. That problem causes Petitioners' modeling to significantly underestimate the frequency and magnitude of Significant Reverse Flow Events (SRFEs) at

Freeport. This is evident by comparing the model's historical simulation to actual historic Freeport Gage data.

A. A 2009 Recalibration Report Documents a Known Deficiency in DSM2 Simulation Near the Upstream Boundary Condition at Freeport.

The 2009 DSM2 recalibration report prepared for DWR documented a deficiency in the then-current version of the DSM2 model with serious implications for the accuracy of DSM2's simulation of tidally influenced low-flow conditions at Freeport. That report has been admitted into evidence in this hearing as Exhibit Brentwood-105. Section 2.2.2 of the recalibration report discusses this issue. That section of the recalibration report notes that the Freeport Gage is used as the upstream boundary condition for the model where the upstream node is located at the City of Sacramento. The report identified a deficiency in DSM2's representation of tidal amplitude in the upper portions of the Sacramento River during low-flow periods near Freeport due to its proximity to the upstream specified flow boundary condition. The model's upstream specified flow condition does not allow for tidal variation at the boundary, and allows for only attenuated tidal variation in close proximity downstream of the boundary, relative to the actual hydrodynamics in that portion of the river. Under low-flow conditions, simulated tidal amplitude is deficient, or not representative of actual conditions due to the model discretization and associated boundary conditions.

The 2009 recalibration report documents the state of the DSM2 model as it existed at the time, and an effort was made at that time to address this deficiency and improve the model's simulation near the upstream boundary on the Sacramento River by further extending that upstream boundary. (See Brentwood-105 at §2.2.2 [describing change], Fig. 2-2 [depicting extended upstream boundary].) However, the recalibration report stated that this modification only "partly mitigate[d] the errors." (Brentwood-105, §2.2.2.) In fact, the figures included with the recalibration report show that the recalibration-related improvements to simulated flow amplitude are most pronounced well downstream from Freeport. For example, the 2009 recalibration significantly improved the model's simulation of flows at Rio Vista. (Brentwood-105, Fig. 4-4.) By contrast, the 2009 recalibration resulted in only a very slight overall

improvement of DSM2's flow simulations at Freeport. Notably, the model's performance actually *declined* following the 2009 recalibration in the only month during the recalibration period with monthly average flows below 10,000 cfs, which is October 2001. (Brentwood-105, Fig. 4-6.) Therefore, the 2009 recalibration cannot be said to have significantly improved the accuracy of DSM2's simulated velocity at Freeport during reverse flows.

B. The Deficiency Identified in 2009 Appears as a Systematic Bias within the DSM2 Data Provided by Petitioners for this Hearing, which May Be Corrected by Applying a Bias Correction Offset.

The 2009 recalibration report documents DWR's awareness of this problem with the model, and the relative lack of success in improving it at Freeport. Nevertheless, Petitioners chose to perform modeling for this hearing using a version of DSM2 that contains the same systematic bias in representing tidal variation at Freeport in low-flow conditions. Petitioners used version 8.0.6 for this hearing. (EBMUD X-3 [screenshot of model file provided by Petitioners showing version number]; May 12, 2017 Transcript, vol. 44, pp.9:21-10:4 [Nader-Tehrani declined to dispute version number].) When reverse flows occur and velocities are negative, DSM2 version 8.0.6 consistently "over-predicts" velocity relative to gage data at Freeport. By "over-predicts," I mean simulated velocity is relatively more positive than velocity measured by the Freeport Gage. A consistent over-prediction of this kind represents a bias inherent in the model. It demonstrates the model's inability to simulate the full tidal range in velocity under these conditions.

I have depicted an example of this systematic bias in slide 6 of my summary sur-rebuttal testimony (EBMUD-103). This graph shows two exceedance curves representing DSM2's error in simulating minimum negative daily velocity. Each curve plots a series of simulated minimum negative daily velocity data. The vertical axis represents deviation from Freeport Gage data during the same period that was simulated using DSM2. The red line plots uncorrected DSM2 output from version 8.0.6. Each and every data point plotted on the red exceedance curve over-predicts minimum negative daily velocity relative to the Freeport Gage. The blue line depicts the effect of applying a bias correction offset to the uncorrected DSM2 data. As the blue curve

illustrates, application of the offset removes the bias, resulting in roughly half of the days over-predicted and the other half under-predicted. For purposes of analyzing SRFEs at Freeport, the bias-corrected result leads to a more accurate comparative analysis of project effects.

Slide 7 of my summary sur-rebuttal testimony illustrates this systematic bias from another perspective by showing how the bias is expressed during a specific period of time. It plots uncorrected DSM2 model output from version 8.0.6 provided by Petitioners for this hearing against Freeport Gage data over the same time period: February 9-17, 1991. The DSM2 output plotted on Slide 7 reflects the model's consistent bias to over-predict minimum velocity, despite Dr. Nader-Tehrani's assertion on rebuttal that he is not aware of a systematic bias at Freeport. This over-prediction of minimum velocity can be addressed by applying a bias correction offset.

III. My Case-in-Chief Testimony Documents the Time Period I Used to Calculate My Bias Correction Offset.

Dr. Nader-Tehrani testified in the rebuttal phase on re-direct examination that he did not have enough information to "fully understand" how I modified the DSM2 results to present the analysis in my case-in-chief testimony. [1] (May 11, 2017 Transcript, vol. 43, p.138:9-14.) He testified: "Specifically, what is missing here is what time period did he consider for his bias correction and specifically also what version of – calibrated version of DSM-2 he used for his analysis." (*Id.* at p.138:18-22.)

The first piece of information mentioned by Dr. Nader-Tehrani – the time period considered for my bias correction – is documented in my case-in-chief testimony. (Exhibit EBMUD-152, pp.9:23-26–10:1 and p.10, fn. 7.) There, I explained that "I calculated the optimal offset by minimizing the sum-of-square error between model simulation and historical Freeport gage data over 15 months of historical low-flow periods in which reverse flow events occurred." (*Ibid.*) A footnote to that sentence listed the months: "October and November 1990, February

[1] The May 11, 2017 hearing transcript repeatedly refers to Dr. Bray as "Dr. Bourez" in error during the colloquy between Dr. Nader-Tehrani and Mr. Berliner regarding EBMUD's testimony. (*See, e.g,* pp.138:9, 138:11, 139:20, 140:24, 151:18-19, 152:2-3, and 153:18.) All references to "Dr. Bourez" in this portion of the transcript were actually references to Dr. Bray.

1991, May 1991, May through August 1992, October and November 1992, April through June 1994, December 2008, and November 2009." (*Ibid.*)

IV. I Used Version 8.1.2 of DSM2 to Calculate the Bias Correction Offset, Which Expanded the Pool of Simulation Data Available for Offset Calculation While Avoiding Any Inappropriate "Overcorrection" of the Model Results.

Dr. Nader-Tehrani testified on rebuttal that he could not fully understand my bias correction in part because he did not know which calibrated version of DSM-2 I used for my analysis. (*Id.* at p.138:18-22.) I used version 8.1.2, the most recent publicly available version, because that version contains an extended historical simulation dataset that includes more recent low flow conditions. I compared V8.0.6 output with V8.1.2 output to verify that using V8.1.2 to calculate the bias correction offset would actually result in a more conservative offset than using the older V8.0.6.

A. Version 8.1.2 is More Up-to-Date than Version 8.0.6.

DWR's DSM2 web page makes four versions of the model available to the public.[2] Version 8.1.2, which I used for bias correction, was released in November 2013. The website also provides earlier versions of the model, including version 8.0.4, used for BDCP modeling by Petitioners, and version 8.0.6 (released November 2010), used by Petitioners for subsequent analyses including their simulations for this water rights hearing.[3] When the DSM2 model versions are downloaded, typically benchmark or reference simulations are provided which allow a user to test the model and validate its results against results provided for a complete and predetermined set of model inputs. In the case of DSM2 V8.0.6, a historical simulation is provided that simulates the historical conditions between January 1990 and December 2006.

My goal was to remove bias to enable more accurate identification of SRFEs in the modeled data. SRFEs occur in extreme low-flow conditions. Therefore, it would be helpful to

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[2] *See* http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm (accessed June 8, 2017).

[3] I am not aware that Petitioners have provided any justification for their decision to use the older version 8.0.6 for this hearing instead of version 8.1.2, which became available in 2013. Petitioners described various modeling efforts for the BDCP/WaterFix Project in their May 11, 2016 letter to the Hearing Officers, but that letter lacks specificity or justification regarding Petitioners' choice of DSM2 model versions for this project.

be able to choose from a reasonable selection of model output for months with extreme low flows at Freeport, ideally across more than one time period. Unfortunately, the historical simulation provided with DSM2 V8.0.6 contained no suitable months after 1994. Had I limited myself to the same model version used by petitioners for this hearing (V8.0.6), I would have faced a limitation where *all* the months in my dataset would have been during the 1990-1994 period. This data would represent a historical drought condition with different regulatory regime – for example, before D-1641's adoption. Using data exclusively from 1990-1994 also would have limited me to a period before certain morphological changes such as the Liberty Island flooding, which is a concern expressly raised by Dr. Nader-Tehrani in his redirect rebuttal testimony. (May 11, 2017 Transcript, vol. 43, pp.139:7-140:8; *see also* Brentwood-105, §1.2 [explaining DSM2 "shortcomings" associated with Liberty Island flooding].)

Using the more recent V8.1.2 alleviated this concern. Version 8.1.2 has an extended historical simulation available with capability of simulating October 1990 through March 2012. This is a longer and more recent data set than found in V8.0.6, and it includes relatively recent extreme low-flow conditions in 2008 and 2009. Using V8.1.2 allowed me to consider 2008-2009 data along with low flow months in the period 1990-1994 when calculating the offset. The 2008-2009 data better approximates the current regulatory and morphological conditions, which Dr. Nader-Tehrani stressed the importance of in his redirect rebuttal testimony. (May 11, 2017 Transcript, vol. 43, pp.139:7-140:8.)

B. The Bias Correction Offset Calculated with Model Output from Version 8.1.2 Was Conservative and Did Not "Over-Correct" Because Version 8.1.2 is Somewhat Less Biased at Freeport than Version 8.0.6.

As Dr. Nader-Tehrani noted on rebuttal, successive model versions may be changed in a way that affects their output. (May 11, 2017 Transcript, vol. 43, pp.139:9-140:8 [citing Liberty Island as example].) Because different model versions may yield different output, I considered it important to verify that using V8.1.2 to calculate a bias correction offset would not result in an inappropriate "over-correction" of the model output that Petitioners generated using V8.0.6. I verified this by directly comparing the output of both model versions to each other and to the

Freeport Gage dataset during low-flow conditions. This analysis showed that: (1) both versions of the model displayed a consistent and systematic bias towards over-predicting minimum negative daily velocity, a parameter that is closely associated with SRFEs, but (2) V8.1.2 is consistently *less* biased than V8.0.6, relative to Freeport Gage data, with respect to simulation of minimum negative daily velocity. This relationship is illustrated on slide 14 of my summary sur-rebuttal testimony. (Exhibit EBMUD-103.) Because V8.1.2 is consistently less biased, the bias correction offset calculated using its output (-0.23 ft./sec.) is less aggressive than the bias correction offset that would have been calculated with V8.0.6 (-0.55 ft./sec.). I used the -0.23 ft./sec. offset to perform the analysis in my case-in-chief testimony.

On cross-examination during rebuttal, Dr. Nader-Tehrani expressed an opinion that my bias correction "introduced events that are falsely identified as reverse flows." (May 5, 2017 Transcript, vol. 40, p.207:13-22.) If it did so, it resulted from normal model variability and not any flaw in the bias correction. It is true that models will tend to over-predict in some instances and under-predict in others. For example, a model may sometimes simulate a reverse flow incident that did not actually occur, just as it may sometimes fail to simulate a reverse flow incident that did occur. This variability is inherent to modeling; models generally do not precisely simulate actual conditions with perfect consistency. A well-performing model will tend to exhibit a balance between under-prediction and over-prediction. On the other hand, if a model displays a consistent and systematic bias in a single direction for a given output parameter, that model may not be suitable to use for analyzing that parameter, unless the bias is first removed.

That consistent bias is exactly the problem with using uncorrected DSM2 model output to analyze reverse flows at Freeport. My bias correction removes some, but not all, of the bias from the model data Petitioners provided for this hearing using V8.0.6. In no case does my offset "over-remove" bias, which would have been the equivalent of introducing a new bias into the model data. Any events that are "falsely identified as reverse flows," as Dr. Nader-Tehrani claimed, are the result of normal variability in prediction, rather than systematic bias. Given normal model output variability, I would expect any "false positives" found in the bias corrected

output to be roughly offset by "false negatives" found elsewhere, at least in the case of DSM2 V8.1.2. The same cannot be said of the Petitioners' uncorrected model output.

V. There Is No Evidence that Liberty Island Flooding Significantly Affected Tidal Influence at Freeport or the Frequency of SRFEs.

In his rebuttal redirect testimony, Dr. Nader-Tehrani speculated that the flooding of Liberty Island could have affected Delta hydrodynamics in a way that reduced tidal influence at Freeport, which in turn could affect the frequency of reverse flow velocities. (May 11, 2017 Transcript, vol. 43, pp.139:9-140:8.) He appeared to imply that I may have calculated the bias correction offset using model data to that did not reflect the impact (if any) of Liberty Island flooding. He presented no evidence to support his speculation.

The time period I considered included low-flow months both before and after the Liberty Island flood, as I explained above in Section IV.A. Furthermore, I reviewed Freeport Gage data to determine whether the Liberty Island flooding resulted in any discernible impact to the range of tidal velocities observed at Freeport. I compared flow data from two months with similarly low monthly average flows: August 1992 (8,669 cfs monthly average flow) and December 2008 (8,893 cfs monthly average flow). I chose these months for several reasons. First, gage data was readily available. Second, because flow rates correlate with the extent of tidal influence, I chose two months with similar flows to control for the expected variability in tidal impacts and better isolate any impact on tidal influence caused by non-flow factors such as Liberty Island. Third, I selected a pre-flood month and a post-flood month for comparison. I did not identify any clear difference in tidal range at Freeport from this comparison. (*See* EBMUD-103, slide 17.) Rather, tidal range is consistent and daily minimum velocity is similar in both months. In sum, I am not aware of any evidence that Liberty Island should be considered a significant factor for purposes of my bias correction or analysis of SRFEs at Freeport, and my comparison is some indication that it is not a significant factor during low-flow periods of interest.

VI. The Least-Square Minimization Method Removes Bias, Rather than Creating It.

During rebuttal cross-examination, Dr. Nader-Tehrani conceded that it is acceptable to perform bias correction before analyzing model output data if the modeler is aware of a bias

within the model that would affect the analysis, as long as the analyst is fully aware of the consequences of applying the bias correction. (May 5, 2017 Transcript, vol. 40, pp.206:23-207:6.) However, he contended the sum-of-square methodology (also known as least-square minimization) was not "the appropriate way." (*Id.* at p.207:7-16.) Dr. Nader-Tehrani argued that "there are times you would underestimate and you have lower error and at times you have *[sic]* overestimate." (*Id.* at p.207:11-14.)

I responded to this argument in Section IV.B above. Some degree of underestimation and overestimation can be reasonably expected following bias correction. Bias correction is important not because it results in a perfect simulation, but because it removes a model's systematic bias towards one particular direction. Dr. Nader-Tehrani's argument, taken to its logical conclusion, appears to be that it is preferable to systematically underrepresent SRFEs than to perform an unbiased simulation with near-zero mean error that nevertheless over-predicts SRFEs in some instances and under-predicts them in others.

I do not believe Dr. Nader-Tehrani has offered a valid criticism of least-square minimization, but his focus on this issue calls for a more detailed explanation of my bias correction methodology. To develop the bias correction offset parameter, I employed a Euclidian or L2-norm minimization procedure. This is a common procedure of minimizing the sum of square-error, also known as the least-squares minimization technique in statistics and regression analysis. The analytical solution to the least-squares objective under certain assumptions is typically called the "normal equations" that result in parameter estimates that are "B.L.U.E." or the "best least unbiased estimator" of the parameter set.[4] In this case, I estimated only the intercept parameter, which I then applied as the bias-correction offset to the DSM2 velocity output. Other candidate objective functions sometimes used are the L1-norm, which is the minimization of the sum of the absolute values of the error set, and the Linf-norm, which is minimization of the maximum error.

[4] *See, e.g.*, Triola, Mario F., *Essentials of Statistics* (Addison-Wesley Inc., 2005), at p. 475.

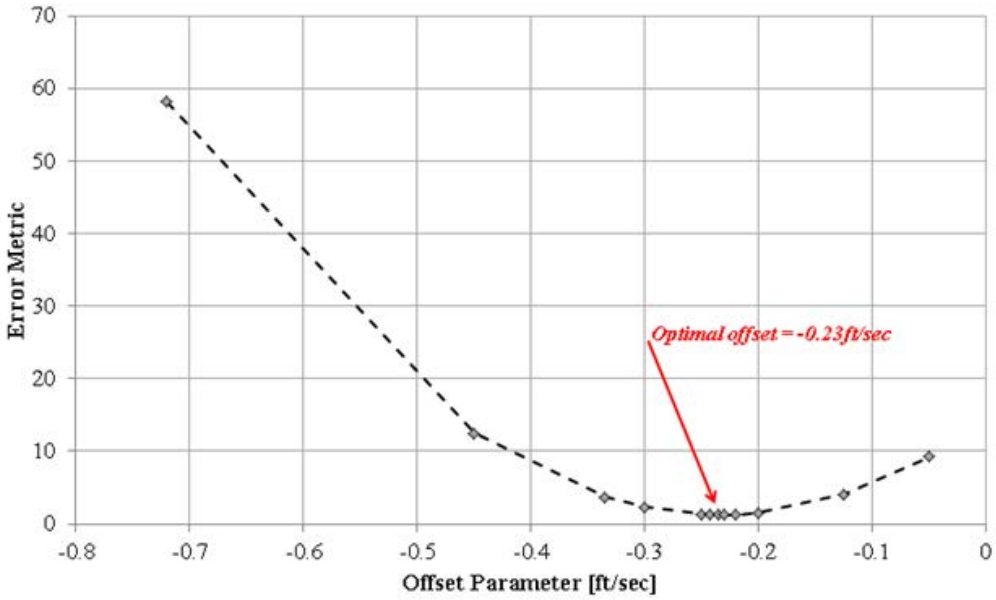

Figure 1: Least-Squares Minimization Convergence to Optimal Bias-Correction Offset

The convergence of the least-squares minimization procedure is shown in Figure 1 above.

In this particular instance, the L1- and L2-norms result in the same optimal offset value equal to -0.23 feet per second. I also tested the Linf-norm and obtained a slightly more negative optimal offset equal to -0.275 feet per second. This latter procedure minimized the spread of minimum and maximum error, as expected, to roughly ±0.21 feet per second, but the resultant offset would have tended to over-correct where bias-corrected peaks would tend to show up *more* negative than the corresponding minimum velocities *more* than half of the time.

Figure 2 presents the distribution in minimum daily velocity error for the raw DSM2 V8.1.2 results with the results obtained after applying the L1, L2, and Linf-norm minimization procedures:

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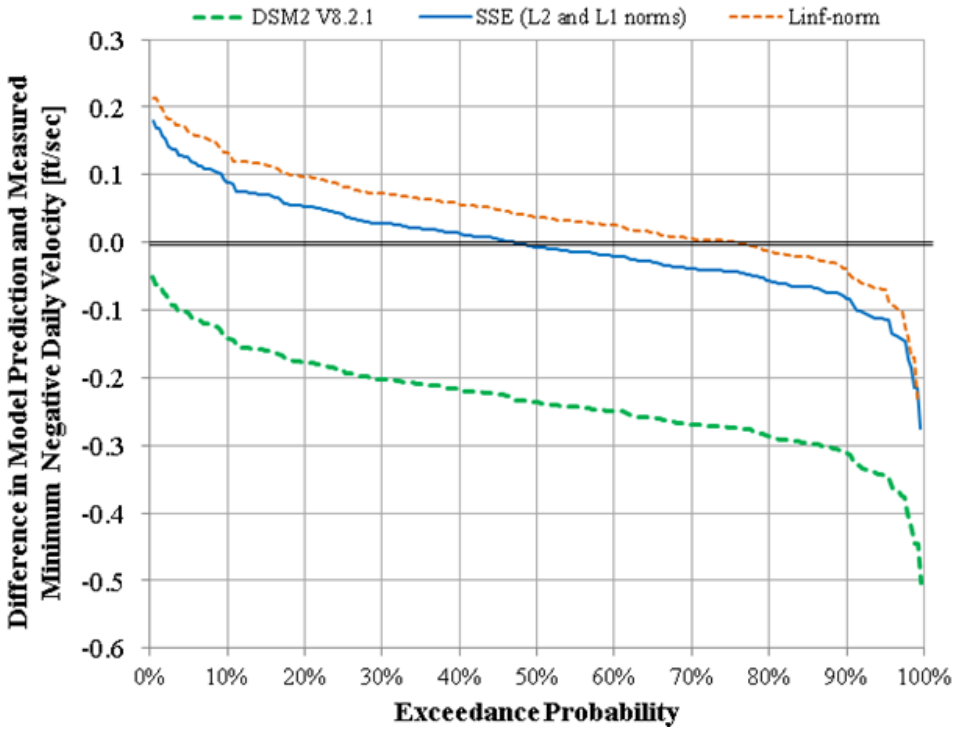

Figure 2: Change in Simulated Daily Minimum Velocity Error Distribution relative to Freeport Gage Velocity with Optimal Offset Parameters for L2, L1, and Linf Norms with DSM2 V8.1.2 Raw Output.

Based on the analysis described above, I believe my bias correction methodology yielded an appropriate bias correction offset that must be applied to DSM2 output to analyze SRFEs to improve the comparative analysis of Petitioners' modeling of the CWF project with the no action alternative.

VII. Conclusion

Even if, as Dr. Nader-Tehrani stated, he is unaware of DSM2's significant systematic minimum velocity over-prediction bias at Freeport, that bias does exist. Petitioners' modeling includes this bias and, therefore, under-predicted SRFEs under simulated future conditions. It is proper to use DSM2 V8.1.2 to calculate a conservative bias-correction offset using the least-squares minimization method. This offset improved (without entirely eliminating) the bias inherent in Petitioners' modeling, thereby improving DSM2's representation of SRFEs.

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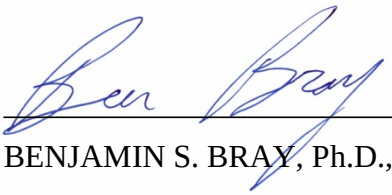
Executed this 9th day of June, 2017 in Oakland, California.



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