BUREAU OF RECLAMATION

Peer Review Report

Implementation Effects of New Evaporation Coefficients for Lake Mead and Lake Mohave

Date

February 4, 2022

Originating Office

Bureau of Reclamation, Lower Colorado Basin Region, Boulder Canyon Operations Office, PO BOX 61470, LC-4000, Boulder City, NV 89006-1470

Reclamation Roles

Director or delegated manager: Jacklynn Gould, Regional Director, Lower Colorado Basin Region, Bureau of Reclamation

Peer Review Lead: Noe Santos, Civil Engineer (Hydrologic), Lower Colorado Basin Region, Bureau of Reclamation

Peer Review Scope

Reviewers were to consider the implementation of new (static) monthly evaporation coefficients in operations models. Reviewers were asked to consider the sensitivity analysis results and whether any further analysis was necessary. The following questions were the focus of the reviewers:

1. Was the sensitivity analysis performed by Reclamation a thorough investigation to understand the impact to model projections and 24-Month Study annual determinations?
2. Are the conclusions of the sensitivity analysis reasonable and valid, given the analysis and results provided in the report?

Reviewers were asked to provide comments solely on the scientific information being reviewed and not on any agency decision or policy.

Peer Reviewers

Peer reviewers were selected based on having at least 3-years of experience with expertise in hydrology, natural sciences, engineering, or water/reservoir management. Reviewers also had to be

part of Reclamation but situated outside of the Lower Colorado Basin Region. Selected reviewers had general knowledge regarding Colorado River Basin operations and guidelines and were not involved with the study. The public was not asked to participate in the peer reviewer selection process. The three selected reviewers are listed below:

- Jennifer M. Johnson, P.E., PhD, Supervisory Civil Engineer, Columbia Pacific Northwest Region
- Dagmar Llewellyn, Supervisory Civil Engineer, Albuquerque Area Office – Upper Colorado Basin Region
- Jonathan Rocha, Civil Engineer, Columbia Pacific Northwest Region

Summary of Reviewer Comments

Reviewer 1 was the only reviewer that directly answered the questions identified above for the peer review scope. The summary of input from the other reviewers is noted below. Reviewer numbers do not directly correspond to the reviewer list above in order to retain anonymity with respect to their comments.

Reviewer 1 Response:

1. Yes, the analysis seems to be very thorough and addresses the most high visibility and consequential use-case for the updated evaporation coefficients. That use-case being its impact to Colorado River operations.
2. Given the data that was presented, the conclusion that "evaporation was being over-projected" is very well established and defensible. The other conclusion that "[c]apturing a more accurate temporal distribution and evaporation magnitude... is critical for determining accurate operational conditions" however, is relatively not as well established in my opinion. Results from the modeling show that there were minimal differences in the operating tiers using intervening flows and evap coefficients derived from the USGS study vs the USBR coefficients. This suggests that the old USBR coefficients were not doing that bad in terms of determining accurate operational conditions which undermines the criticality of using a more accurate temporal distribution and evap magnitude. Despite that, I do think that it is very important to "provide stakeholders with the knowledge that the best available technology is being used correctly to determine future operating conditions at Lake Mead and Lake Powell".

Reviewer 2 General Response:

Reviewer 2 provided constructive feedback which allowed for better explanation regarding the Lower Colorado Basin Region's (LCBR) operations model, model architecture, and coordinated operations decisions between Lake Powell and Lake Mead.

Reviewer 3 General Response:

Reviewer 3 provided constructive feedback regarding the LCBR's approach to modeling evaporation using static evaporation coefficients. The feedback allowed for greater clarity on the use of static coefficients and to denote the interest in continuing the data collection process. This would allow the LCBR to better understand the impacts of regional climate change on evaporation at the two study sites.

Based on the reviewers' comments, the following general changes were made:

- Additional text and supporting figures were added to better explain the 2007 Interim Guidelines and their role on the coordinated operations between Lake Powell and Lake Mead.
- Additional text and supporting figures were added to better explain the purpose and architecture of the LCBR's operations models.
- Additional text was added throughout the document to clarify that the new/old evaporation coefficients are static and are based on the average evaporation measurement by month in feet.
- Tables showing results from the Colorado River Mid-Term Modeling System: Ensemble Streamflow Prediction mode were cleaned up to increase readability.
- The conclusion section was improved to better reflect the outcome of the study following the constructive comments received by all the reviewers.

Specific reviewer comments and LCBR responses are listed in the following table.

Comment	Reviewer	Original Page Number	Original Line Number	Reviewer Comment	Response
1	Reviewer 1	10	1	Starting on Pg3 line-53, it states that "It is important to note that evaporation in the Hoover Dam to Lake Mohave reach is not explicitly modeled; rather, evaporation in the reach is lumped into the mass balance for Lake Mohave's intervening flow calculation". Pg10 line-1 seems to use Evaporation as an input into the calculation implying that the value is being estimated (modeled via a coefficient and surface area?) somehow. Propose reconciling/clarifying the difference.	Extra text was added to Page 4 (Lines1-4), Page 10 (Lines 12-13), and the evaporation term in Equations 1 & 2.
2	Reviewer 1	12	3	"Figure 5 and Figure 6 and Table 3". Propose Figures 5 and 6, and Table 3 or maybe Figure 5, Figure 6, and Table 3?	Comment incorporated.
3	Reviewer 1	14	10	Initial use of R-Squared term. In these kinds of reports, I think it is customary to introduce it in some form. Something like "R2, the coefficient of determination, is a measure of the goodness of fit given two independent variables. An R2 value of 1 denotes a perfect fit, and a value of 0 denotes no relationship."	Comment incorporated.
4	Reviewer 1	16 & 17	Fig 8 & 9	Legends on Figures 8 & 9 doesn't clearly show that the USGS coefficients are the dashed lines since there is only 1-dash on the legend icon for them	Comment incorporated.
5	Reviewer 1	19	1	Initial use of ICS Surplus. Not sure who the target audience is but people not well-versed in Colorado Ops will not know what this means unless you explain it. Ditto for all the Shortage tiers. Propose more genelarized language on whether differences in the senstivity analyses result in a different operating criteria/tier rather than pointing out the specific criteria/tiers without context.	Added some text and a new Figure 7 to illustrate the operating tiers in the CRMMS 24-MS section. Some clarifying text in the CRMMS-ESP results section was added to point readers back to the supporting information.

Comment	Reviewer	Original Page Number	Original Line Number	Reviewer Comment	Response
6	Reviewer 1	21	Table 6 & 7	See comment above this one. Operating tiers with no context for the Colorado-Ops-uninitiated. Since the sensitivity analysis seems to be very closely tied to looking at the tier differences, maybe spend a paragraph discussing the ops tiers and triggers at a very high level... This would be easier if you don't make special distinctions between the within-tier conditions such as >8.23,=8.23, & <8.23	Incorporated. Added a new Figure 7 to better show the release/operational tier differences.
7	Reviewer 1	21	Table 6 & 7	I was getting cross-eyed evaluating why the 2024 column wasn't reconciling (summing to zero) until I realized that one of the '3's is nested under a parent tier. Some creative formatting should fix this unless you do away with the within-tier distinctions as mentioned in the comment above this one	Comment incorporated.
8	Reviewer 1	Replies to specific review scope questions	Question 1	Yes, the analysis seems to be very thorough and addresses the most high visibility and consequential use-case for the updated evaporation coefficients. That use-case being its impact to Colorado River operations.	Comment noted

Comment	Reviewer	Original Page Number	Original Line Number	Reviewer Comment	Response
9	Reviewer 1	Replies to specific review scope questions	Question 2	Given the data that was presented, the conclusion that "evaporation was being over-projected" is very well established and defensible. The other conclusion that "[c]apturing a more accurate temporal distribution and evaporation magnitude... is critical for determining accurate operational conditions" however, is relatively not as well established in my opinion. Results from the modeling show that there were minimal differences in the operating tiers using intervening flows and evap coefficients derived from the USGS study vs the USBR coefficients. This suggests that the old USBR coefficients were not doing that bad in terms of determining accurate operational conditions which undermines the criticality of using a more accurate temporal distribution and evap magnitude. Despite that, I do think that it is very important to "provide stakeholders with the knowledge that the best available technology is being used correctly to determine future operating conditions at Lake Mead and Lake Powell".	Comment noted. Updated the conclusions to note that the temporal distribution assists in better seasonal projections of intervening flow for the reservoirs instead.

Comment	Reviewer	Original Page Number	Original Line Number	Reviewer Comment	Response
10	Reviewer 2	8	Table 2	Given the large change in elevation for the EC-1 through EC-4, it seems as though these should be broken out in to difference USGS site locations, or the data should be corrected for the elevation difference. Please consider adding text that explains how the change in elevation was addressed for this data.	We are unable to instruct the USGS to change how the Site IDs were assigned to each EC station unfortunately. At this point, our models are not set up to take in a "dynamic" approach to evaporation (e.g. having evap coefficients vary by elevation); however, this is something we are interested in pursuing after this study is finalized. We haven't taken a close enough look at the hourly/daily data to make an educated statement regarding the effect of elevation on evaporation at this time.
11	Reviewer 2	9	5	We have been instructed to use the following format to reference RiverWare with the version number: RiverWare® ver. 8.2.3 rather than using the Zagona citation	Our research group centered at the CADSWES HQ has provided us some different guidance on how to reference the system.
12	Reviewer 2	9	2	For someone who is not familiar with the Colorado River Basin and its models, it was hard to follow which model was being described, its relative timestep, data inputs, etc. Suggest starting the Reclamation modeling section with a short description of each model and maybe a table describing the relative differences.	We've added a new Figure 5 and Figure 6 to provide a visual for the different uses/architecture for each type of model used in this report. Each model's use is described in the "Reclamation Modeling" section and it's sub-components as well.
13	Reviewer 2	9	23	Might also want to mention that this term includes all potential error in any of the other measurements, including evap, which becomes apparent later in the results of the sensitivity analysis.	Incorporated

Comment	Reviewer	Original Page Number	Original Line Number	Reviewer Comment	Response
14	Reviewer 2	9	43	Seems like a pretty old method for Bank storage and wonder how accurate it is given all of the changes in the reservoir system. Could it be better included in your gain/loss term?	Due to the nature of bank storage, it would be quite an expensive study to better incorporate bank storage. Any variability/error in bank storage gets lumped in to the intervening flow calculation with our current methods.
15	Reviewer 2	10	21	Should Study Mode be Study Model? Maybe this just my misunderstanding of the models and how they are used, hence my previous comment.	"Mode" is correct. A new section was added above the 24-ms mode and esp mode descriptions that describes the combined model and the different modes in which it can be run
16	Reviewer 2	11	24-36	Seems like a new section would help here since this doesn't seem to be describing a model, but rather how it was used for this study.	This section was moved to the results section to be more in-line with how the CRMMS-ESP section is structured.
17	Reviewer 2	14	16-26	To make sure I am tracking, you remove historical estimated evaporation to get your gains/losses, then uses the monthly pattern for analysis? Reasonable approach, but you might want to spell it out for readers.	That is correct. This is explained in the Gain/Loss Model section under Results and Analysis.
18	Reviewer 2	Figure 8		You have been referring to the flows as intervening flows throughout the document but switch back to side flows here - for consistency, it might be good to pick one term for the document.	The term is interchangeable but the Figure will be updated in the final version to be consistent.

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19	Reviewer 2	17	19	Because there is Mead is releasing more to backfill higher evap from Mohave and vice versa?	Correct! Mohave is operated with a seasonal guide-curve so releases are adjusted to account for higher/lower evap. The guide curve reference is found a bit lower below Figure 13.
20	Reviewer 2	17	25	This paragraph is unclear to me. Wouldn't your gain/loss model do this? Or are you saying that it did and it resulted in an inverse relationship?	The latter is correct. Some adjustments to the text were made to clarify.
21	Reviewer 2	18	12	This is the first mention of "operational tiers". Please explain what these are and why they are important to the study.	Figure 7 was added with additional text to better support this statement.
22	Reviewer 2	Table 4 and 5		Are these a summary of the 117 runs simulating the years 2016-2020 each or are these a single model run resulting in the differences for these years? If the later, I am not sure this really displays the results of a "sensitivity" analysis, but rather its a scenario. If my understanding is not corrects, some additional explanation could help alleviate that concern.	The original Table 4 and 5 are from individual runs using the 24MS from recent years. Due to the deterministic setup of the model, individual runs had to be compared to the baseline model. A broader time period would use models from when Lake Mead is at slightly higher elevations and far from any operational tier shift as well. This technical report wanted to report on how sensitive our models were to changing evaporation coefficients and whether new coefficients would have resulted in different operations tiers in the past.

Comment	Reviewer	Original Page Number	Original Line Number	Reviewer Comment	Response
23	Reviewer 2	18	21	Please explain Level 1 shortage, mid-elevation release tier, ICS surplus.	Figure 7 and supporting text was added on Page 12.
24	Reviewer 2	Table 6		what are the units in the table? %?	Yes. Percent is referenced in the table caption.
25	Reviewer 3	Executive Summary	-	It would be helpful if you added a statement indicated what portion of this work is covered in this report. Are you reporting the work that has also been reported in Moreo and Swancar 2013, and in Earp and Moreo, 20211?	Good point, some additional text was added to the Disclaimer section to provide more details. Outside of the Methodology section, all text and figures were created by Reclamation. Appropriate references to the USGS are in place when referring to their studies' findings.
26	Reviewer 3	1	6	I suggest explaining what "implementing new coefficients" means. Are these coefficients to multiply by reservoir surface areas to get total evaporation losses from each reservoir? Are these coefficients static, or will they change into the future. The term "coefficients" is often used in our operations planning for evaporation as the value that we use to multiply the measured evap values from Class A pans, so it would be helpful to clarify whether that is what you are talking about (so the values are not static), or whether it is just the value that you multipy by the lake area to get total evap losses.	We wanted to keep the Introduction section short and discuss the objective of the report. The main concerns in this comment are covered in the "Reclamation Modeling" subsection of the report. The evaporation pans history is also brought up in the Executive Summary and Introduction sections. Additional text was also added to better explain what the coefficients represent in terms of the average value of evaporation from the reservoir by month (in feet).

Comment	Reviewer	Original Page Number	Original Line Number	Reviewer Comment	Response
27	Reviewer 3	4	18-19	I suggest providing dates of installations. Is this the instrumentation installed in 2010? The portion of the overall monitoring effort that is being included in this analysis is a bit unclear to me.	Some clarifying text was added to better explain how the instrumentation was moved around and that all of the data was used from each station location. Table 2 provides the dates and locations of the monitoring. The paragraph below Table 2 also discusses how the Lake Mohave monitoring phase used the same equipment as the Lake Mead monitoring phase.
28	Reviewer 3	7	4 to 5	I suggest describing what is meant by "turbulent flux source area"?	Definition added.
29	Reviewer 3	7	10 to 11	This is confusing to me- you say the EC sensors were installed at "exposed rock outcrops" (plural) at Lake Mead, and the map of Lake Mead shows 4 EC locations and a floating platform, for a total of 6 locations. It seems that the four EC locations might be for the same instrumentation, which moved over time. Are there two floating platforms? Either way, there are at least 2 setups at Lake Mead…	"Sensors" was removed and replaced with "station" to clarify the use of a single station. The remaining text in the paragraph states the use of a single station at both reservoirs.
30	Reviewer 3	8	4	We haven't been told the distances from shore. Also, the fetch distance of 2,000 m to 16,000 m doesn't flow logically from this statement. It might help to add the distance from shore and the fetch distance for each location to Table 2.	Fetch is defined as the distance from the measurement point to the shore in the report; however, we were not provided with the fetch for each station location.

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31	Reviewer 3	8	19 to 22	I suggest adding a table linking the equipment and locations and dates to the reports in which the data are reported. This is getting confusing.	The supporting USGS reports and websites with data are referenced in the report and References section. Table 2's supporting text better explains how all of the data was used for this study and there was no period without data for Lake Mead.
32	Reviewer 3	9	2 through 5	I suggest listing in this paragraph all of the operations models that are used by the River Operations Group. Are those the Daily Operations Model, the Gain/Loss Model, the CRMMS (24-month study and ESP forecasting modes), the Natural Flow Model, and the Colorado River Simulation System? The subsections below are mostly these models, but the first section, Reservoir Mass Balance, applies to all of these models, making it tricky to keep track of what all of the models are.	List of models added.
33	Reviewer 3	12	3 through 8	As I noted in a previous comment, I think that the use of "coefficients" warrants additional explanation. Are these coefficients to multiply times the surface area to get an estimate of total evaporation losses from the reservoirs? If so, then these are static coefficients. Or are they coefficients for multiplying measured evaporation rates from Class A Evaporation Pans, which are then, in turn, multiplied by the reservoir area, and therefore are part of a method that will adjust as the air and water temperatures warm?	Additional text was added to better explain the use of coefficients for the Basin's operations models. The use of the static coefficients is described in the second paragraph of the "Reclamation Modeling" section. The pan coefficient history is described in the executive summary.

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34	Reviewer 3	17	19 to 20	Is this because water has to be released from Mead to make up for the evaporation losses from Mohave? Otherwise, it seems backwards to say the evap losses from the lower reservoir drive the releases from the upper reservoir, since so many other factors play in to the Lake Mead releases, including Hydropower demand, and calls for irrigation water out of Mohave…I suppose this could be resolved if you said "all other factors being equal" before this statement.	The statement is true since Hoover releases also target reservoir regulation downstream of Lake Mead. Lower losses = lower release to arrive at the same target elevation. It is a minor difference in the end. Some additional text was added to explain this.
35	Reviewer 3	17	21	I don't understand what is meant by "the decision-making year". Figure 10 shows multiple decision-making horizons, with decision points in September of year 1 or December of year 2 (or maybe this means September when the 24-MS is run in April and December when it is run in August – that isn't clear to me).	Some clarifying text was added to point to Tables 5 and 6 instead which summarize the sensitivity runs that were referenced on this line.
36	Reviewer 3	17	21	What is the "calendar year outyear"? This is the first introduction of the term "outyear" in this paper. Is this the second year of the 24 month study, or the year after the 24 months that are included in the study?	Yes, this refers to the second year of the study. Some additional text was used to better explain this.

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37	Reviewer 3	24	4 through 12	Hmmm, so the difference in total evaporative loss volumes between the two simulations is significant (the new values are about 18% lower for this month), but in the daily operations model, this difference is taken up into the "side inflows", which is an error term – the model just assumes that this water that we previously thought was lost to reservoir evaporation was replaced by rain on the reservoir or inflow from tributaries that discharge directly into the reservoir. So to me that says that these new evaporation volumes provide new information about the water budget, but the daily operations model is not sensitive enough to account for them. Is that fair?	That is correct. Since the beginning and end points of the reservoir mass balance isn't changing, the daily water accounting shifts from one variable (evap) to another (side inflow/gain-loss).

Comment	Reviewer	Original Page Number	Original Line Number	Reviewer Comment	Response
38	Reviewer 3	25	16-24	It is still unclear to me whether these projections out to 2060 include the impacts of changing air and water temperature associated with our changing climate. You say earlier that this study does not include characterization of changing hydrology (except through the use of the "stress test hydrology" which is made up of more recent years. However, if the coefficients are static multipliers for reservoir area used to compute total volume losses, rather than multipliers for Class A pan values, then the values will not change as the climate warms. If that is the case, I think it should be made clearer here that this analysis is just an exercise to see how the effects of changing coefficients compound over time, and is definitely not a projection of reservoir conditions, since it does not include the key factor leading to changing reservoir evaporation rates in the future. Also, if this is the case, I question the validity of this approach for longer-term planning. It seems more appropriate to continue the EC monitoring to track how reservoir evaporation changes over time, and incorporate that knowledge into our river and reservoir operations.	We are continuing to fund the EC site at Lake Mead to get a better picture of how evap is changing with respect to climate and reservoir elevation. In general, CRSS is used to determine the risk of hitting critical elevations. The evap coefficients are a small aspect of this model but their impact compounds as different traces are run through the model. The compounding effect is also discussed in the CRSS section. The analysis was done to indicate how likely a shift in projection frequency could have occurred with new evap coefficients. Climate change impacts will need to be done under a separate analysis since it wasn't in the scope of. Some additional text was added to the conclusions to indicate our continued interest in updating the coefficients in the future as we gather a longer term record of evaporation at Lake Mead. Further edits were added throughout the report to clarify the use of static coefficients and that they represent an average evaporation value (in feet) per month.