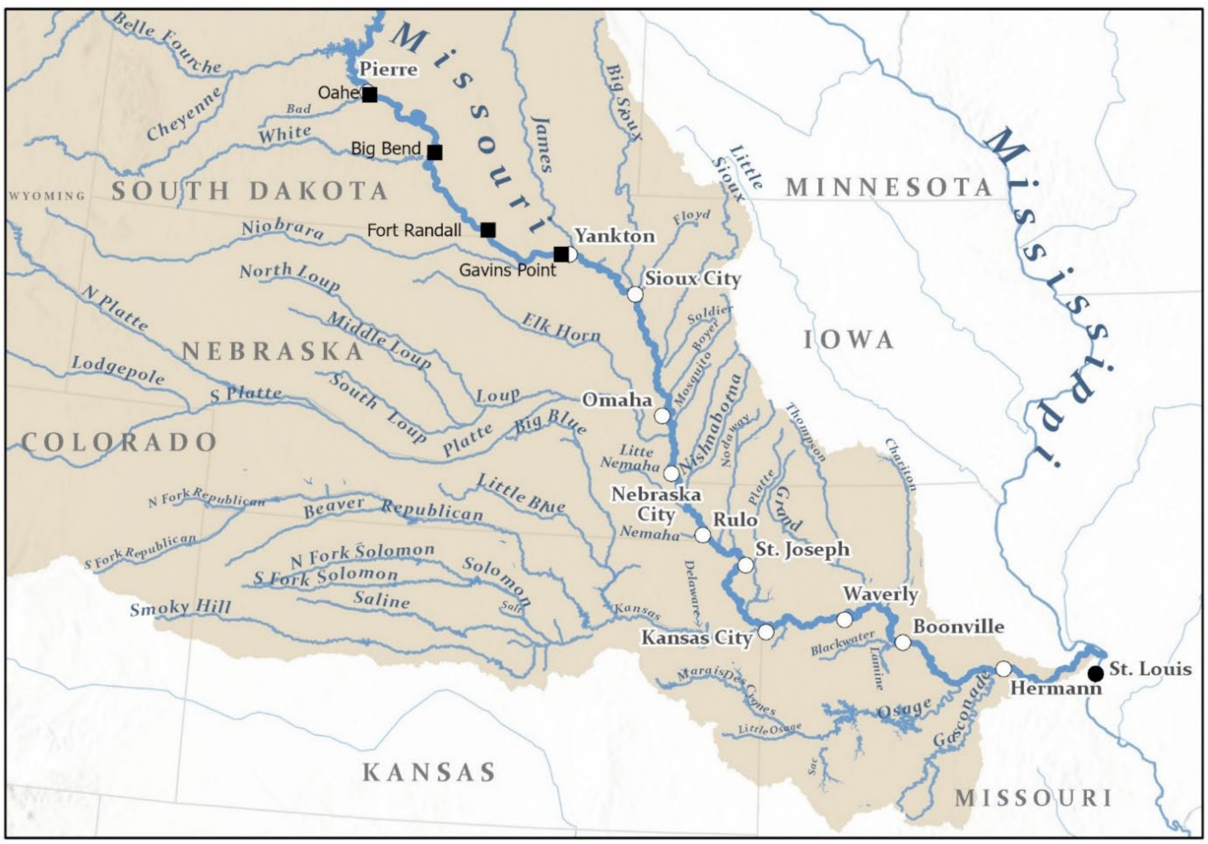
# Missouri River
# Flow Frequency Study

## Yankton, South Dakota to Hermann, Missouri

## *Appendix K: Summary of Technical Review Group (TRG) and Research Triangle Institute (RTI) Meetings and Comments*




U.S. Army Corps of Engineers
Northwestern Division
Omaha District, Kansas City District, and
Missouri River Basin Water Management
June 2023

# Introduction

Research Triangle Institute International (RTI) supported the USACE flow frequency team by providing technical review of the flow frequency analysis, review of the final report and facilitating meetings with the Technical Review Group (TRG). The TRG was established to provide external review from experts and agencies outside of USACE. This ensures that the employed methods are acceptable based on the current state of practice. The members of the TRG are presented in Table 1.

Methodology, work products and results were presented to the TRG in a series of four meetings. The presentation of the draft report, which was reviewed and commented on by the TRG, commenced after TRG Meeting #4. This appendix documents the comments provided by the TRG in the meetings as well as on the final report, and also includes an external review by the RTI team. The meeting agendas and review comments are compiled in the following sections.

- **TRG Meeting #1:** Introductions, basin overview and analysis methods
- **TRG Meeting #2:** HEC-WAT results, HEC-RAS updates for routing, draft unregulated flow frequencies at gauge locations, Qualitative Climate Assessment
- **TRG Meeting #3:** Climate assessment results, Bulletin 17C analysis, unregulated flow frequency analysis, HEC-RAS vs. HEC-ResSim routing, Unregulated to regulated flow transformation, HEC-WAT analysis, comparison of results.
- **TRG Meeting #4:** Justification for adoption of the HEC-WAT method and presentation of results
- **External Review by RTI**: Initial review of data and analysis in preparation for report
- **Draft Report Comments:** TRG and RTI Comments from the draft report

**Table 1.**
**Members of the TRG**

| External TRG Members | | |
|---|---|---|
| **Name** | **Agency** | **Expertise Group** |
| Kellan Strauch | NE Water Science Center – USGS | Flow Frequency - Hydrology |
| Kevin Low | Missouri Basin Forecast Center – NOAA | Flow Frequency - Hydrology |
| Dr. Nate Young | Iowa Flood Center – IIHR - University of Iowa | Flow Frequency - Hydrology |
| Dr. Nancy Barth | Dakota Water Science Center - USGS | Flow Frequency - Hydrology |
| Dr. Drew Loney | WRE&M – Bureau of Reclamation | Flow Frequency - Hydrology |
| Rick Nusz, PH | Risk Analysis - FEMA | Flow Frequency - Hydrology |
| Dr. Jery Stedinger | Cornell University | Flow Frequency - Hydrology |
| Chris Murray | MBRO – Bureau of Reclamation | Climate Assessment |
| Dr. Greg Pederson | Northern Rocky Mountain Science Center - USGS | Climate Assessment |
| Dr. Jeff Arnold | Senior Climate Scientist - USACE | Climate Assessment |
| Michael Crouch | Research Triangle Institute (RTI) | Facilitation/Hydraulics |
| Jamie Martin | Research Triangle Institute (RTI) | Facilitation |
| Noah Friesen | Research Triangle Institute (RTI) | Flow Frequency - Hydrology |
| Jon Quebbeman, PHD | Research Triangle Institute (RTI) | Flow Frequency - Hydrology |

## TRG Meeting #1 – 14 August 2020

TRG meeting number 1 was conducted prior to RTI's involvement with the project. The agenda from the meeting is presented below.

**INTRODUCTIONS AND BACKGROUND**

| | |
|---|---|
| 0900-0915 | USACE Team Introductions |
| 0915-0930 | TRG Introductions |
| 0930-0945 | Missouri River Basin Overview and USACE Management History<br>*Melliger/Boyd* |
| 0945-1000 | Missouri River Flow Frequency Study (MoFF) and TRG Expectations<br>*Boyd* |
| 1000-1020 | Upper Mississippi River System Flow Frequency Study (UMRSFFS)<br>*Kay* |

**CURRENT STUDY TASKS AND ANALYSIS**

| | |
|---|---|
| 1020-1030 | Overview of MoFF Study Steps<br>*Boyd* |
| 1030-1100 | ResSIM Modeling of Regulated and Unregulated Flows<br>*Larsen/Poluektov* |
| 1100-1130 | Flow Routing Methodologies<br>*Poluektov(ResSIM)/Chestnut(RAS)* |
| 1130-1210 | Lunch break |
| 1210-1240 | Synthetic Flood Events<br>*Poluektov/Melliger* |
| 1240-1250 | Climate Assessments Update<br>*Giovando/Krause* |

**GROUP DISCUSSION AND FEEDBACK**

| | |
|---|---|
| 1250-1400 | Group Discussion and Feedback |

Notes and comments from this meeting are shown below.

### *General Meeting Comments*

- We need to follow up on regional studies done in the basin – Rock Island -Dan – it does not update FF, just for analysis. Do we know of any other districts doing FF updates?
- USACE will push forward with ResSim and look for gages not well represented by the ResSim results, take a stair step approach.
- A split approach (routing?) is not ideal – pick one method and go with.
- Can we develop a list of actions to support ResSim
- Look at the unregulated FF from ResSim, and the transform, so see what we need to look at.
- Route to 5 historic floods through each model and look at timing and peak levels. What is the unregulated peaks and FF curve between the two methods.

### *Action Items*

- Follow up on getting NWK depletions into the model – can be calculated after the fact, a problem into the ResSim model – follow up with Allen C. and Twombly. Have Ilya connect with Twombly to incorporate holdout data from NWK in the ResSim routing.
- Have RAS models use the incremental flows from ResSim to make this consistent, then we can compare the two models. Get an estimate from the RAS team on the effort needed here.
- Do the ResSim routing
- Get a comparable RAS solution – Dan – take another incremental step – take ResSim incremental flows and route through RAS and check. If that shows RAS is superior, then we need to update the RAS in a big effort.
- Talk about Breach vs. overtopping discussion in our next call. Maybe include in upcoming

### *Comments During Meeting*

Note that these comments have been edited and re-ordered slightly based on topic. These are presented to document the discussion that occurred to arrive at the logic used for the analysis. These comments are not inclusive of all the discussion.

- We need to list where the most important damage sites are.
- Comment on Levees: There are a combination of private and federal levees from Omaha downstream to the mouth, both Ag and urban areas.
- 1930-2019 is the POR for the analysis. Pre-1930 was demonstrated as needing too much work to have higher confidence
- … the UFDM and DRM models were developed for other purposes, but were the best available tools to develop unregulated and regulated flows for UMRFFS

- Are the models integrated into a CWMS product?
- The ResSim model is integrated into CWMS to run a short-term (3-week) reservoir forecast, and a longer-term (monthly/calendar year) reservoir forecast.
- [in comparison to ResSim] RAS has finer time step, right?
- Both use daily data. RAS has a finer computational time step.
- Are there reaches with 2D models in place these have been compared against?
- … Omaha Districts experience similar to what was relayed for KC. The 1D model did fine routing calibration events. There is some concern about the model geometry to handle the really high unregulated volumes, especially for synthetic events.
- In terms of updates, are you taking in consideration of the updates in the next version of HEC-RAS. Namely ability to account for instream structures? FEMA has also contracted with HEC Center to add encroachment analysis capabilities.
- FEMA would certainly support HEC-RAS for its use in risk analysis and mapping. It also agrees with what is currently being done to update the MS River.
- USACE has not specifically examined an update to these models to the next RAS version. That should be considered, but I would be concerned about when that would be available and our project schedule.
- [Regarding the hydrograph Kansas City] had a double hump for RAS
- Response - For the 1952 flood there was a double hump in the ResSim results, but not the RAS or observed. It's an example where the routing coefficients were not great and the event probably got routed too quickly. And the incremental inflows were computed on the observed, which created the second peak in ResSim that had the same timing as observed.
- …One thing to consider about routing models: at the end of the day, the unregulated/regulated results will inform the transform and ultimately the regulated flow frequency. The study team has not gotten to the point where they could determine how impactful the routing model assumption has on the ultimate regulated frequency. It might make sense to carry results forward on both models at some select locations to determine impacts before expending significantly more time and effort on RAS adjustments. Tendencies of each model could play into the engineering judgment required on the transform relationship (forthcoming presentation).
- To add to Josh's comment, the bottom line is how much can we reduce uncertainty in the results by using a theoretically more accurate routing method that costs more. Is

there really that much less uncertainty in hydraulic vs hydrologic routing on a basin of this size?

- What if we split the flow frequency effort into two parts? Part one would be done with ResSim. The ResSim is used to develop the unregulated / regulated datasets and preliminary scaled floods and transform. This would be done with the understanding that the flow frequency would be updated once we move to part two. Part two will be stage frequency with RAS which will necessitate revising the ResSim dataset and transform and flow frequency to account for overbank storage / hydraulics, etc. Might be too confusing for stakeholders? I don't love this idea, but if time and money are the issue it may be a work-around.
- What if scaling reflected standard deviation for floods in different catchments?
- Lower basin is not as influenced by transform as upper
- What about the option of adding several scenarios for attenuating major flood events by breaching levee's ACE would prefer to breach if given the option and time? A "design levee breach" so to speak to inform management decisions...
- I am not too worried about the levee status. I feel there is no way we can determine when such-n-such a levee will breach, and if the duration of the flood is long enough, then chances are the floodplain will fill (or as Jean says flow behind), so that the flow-frequency at a given station will not be "wrong" whether we assume levee holds or not holds. Does make me feel that trying to capture "peaks" between stations is probably not within the realm of reason (not in leveed reaches anyway, for extreme events).
- Rain-on-snow risks during early spring are increasing in probability in the upper basin with warming. 2011 was the most recent event, but another historic rain-on-snow event were the 1964 floods in the upper basin.
- …this is definitely something we found in the climate change study for Columbia R. Another example (less extreme than 1964) was the Nov 2006 flood in the N. Rockies

## TRG Meeting #2 - July 15th, 2021

The agenda from the meeting is presented below.

| | |
|---|---|
| 09:00-09:10 | Introductions<br>*Boyd* |
| 09:10-09:20 | Review of the Study, Expectations, and last Meeting<br>*Boyd* |

| | |
|---|---|
| 09:20-09:40 | Using the WAT to develop a Regulated Flow Frequency<br>*(Larson)* |
| 09:40-10:10 | Updates made to HEC-RAS Models to run the unregulated POR<br>*(Reed/Cieslik)* |
| 10:10-10:40 | Comparison of Selected Peak Flood Events – ResSim vs. Updated RAS<br>*(Cieslik/Reed/Kenney)* |
| 10:40-10:50 | Break |
| 10:50-11:30 | Unregulated flow-frequencies at gage locations using ResSim and RAS flows<br>*(Poluektov/Chestnut)* |
| 11:30-11:45 | Qualitative Climate Assessment for the Missouri River Basin<br>*(Giovando)* |
| 11:45-12:00 | Discussion and Identification of Feedback Requested by TRG<br>*(Boyd)* |

A compilation of comments from the TRG meeting #2 is presented below.

### *Comments During Meeting*

Note that these comments have been edited and re-ordered slightly based on topic. These are presented to document the discussion that occurred to arrive at the logic used for the analysis. These comments are not inclusive of all the discussion.

#### *Using the WAT to develop a Regulated Flow Frequency*

- How are the autocorrelations preserved in the sampling process? Would like to see plots to ensure that autocorrelations are preserved in the sampling process. The bias may need to be adjusted to ensure that modeled events represent reality.
- Are you running the Osage and Kansas Basin Reservoir ResSim models in the WAT right now? The Kansas is wide enough it is probably considered to have a couple regions, w/ flood risk driven more by the downstream region and lower 7 (of 18) dams.

  Response - Will get these into the mainstem model for this study.

#### *Updates made to HEC-RAS Models to run the unregulated POR*

- Please check the Rulo plot on the results Rulo to mouth slide. Question - in the 2011 flood routing did hitting the USGS peak at Rulo result in too high of flows at St. Joseph? Curious on implications for the three locations with uncertain peaks.

- Model accuracy and realism of a physically based model…"is incredibly important for synthetic events that are larger than those in observed record: more Facilities start failing." These impacts can have a big impact on peak flow and timing.
- You could consider hydraulic uncertainty (i.e. levee breaches) for larger events or at least evaluate sensitivity on the 17c results.

*Comparison of Selected Peak Flood Events – ResSim vs. Updated RAS*

- ResSim is a model focused on reservoir operations so the routing has been calibrated to observed events where most of the events are contained within the levees. For these extremely large unregulated events, ResSim will usually be faster because it doesn't account for levees overtopping and the subsequent attenuation. Changing the ResSim routing coefficients would impact how the model simulates reservoir operations because we have several flow targets in the lower river.
- ResSim results look high for 1952, almost 500,000 cfs? Did Fort Peck and other dams in construction make that big of a difference? Looks like ResSim is better matching the results from UMRSFFS for the 1952 event
- …a method such as Variable LagK could be used in ResSim to have different routing characteristics at different flow rates to account for differences due to overtopping of levees or similar for more extreme unregulated events.
- Routing/timing will become increasingly important in peak flow calcs as you move below Big Sioux and Platte due to interaction between flow on tributaries and flow on the mainstem. This would be a benefit of using HEC-RAS for routing, which would be able to account for storage and peak flow lag in the system for large events where downstream tributaries also contribute.

*Unregulated flow-frequencies at gage locations using ResSim and RAS flows*

- Why the difference between two models at median flows? The model differences at this range will impact the slope of the frequency curve.

  <u>Response</u> -The RAS focused on the annual peaks, the low flows might be skewed due to flows input to the model for stability. Some stability fixes might impact the peak in this range

- Only recommend using RAS model for higher flows, where you have more confidence in the annual peak. Jery recommended a definition of break point between ResSim and RAS routing

  <u>Response</u> - RAS team will circle back with an answer of whether the annual peaks are impacted

- 17B was originally designed for unregulated basins, no levees, etc. There are bends in the outflow vs. frequency due to structures. Boonville, MO has extreme divergence. Jery recommends exploring this issue further.
- Concerns that Bulletin 17C may not be appropriate for regulated flows because of discontinuous changes.
- Below the Kansas River the 1993 flood sticks out a fair amount no matter if computing unregulated with ResSim or RAS, from flood history we believe it to be the largest unregulated event dating back prior to 1700 on the Missouri River below the Kansas River in terms of "unregulated" event (1844, 1785 provide some uncertainty with this but 1993 appears larger if dams had not been present). RAS shows a couple other events as being a fair amount higher than ResSim below KC, we can look into why that is also.
- 1941 was the first flood after a major drought...

  End of the dust bowl and start of the mid-20th century pluvial… It's a clear change point shifting from low snowpack in the 1930s to high snowpack through most of the 1970s

*Qualitative Climate Assessment for the Missouri River Basin*

- The USGS has an effort going on in the upper mid-west with climate change. Have you guys talked with them about that effort?

  <u>Response</u> - Yes, have been connecting with USGS staff
- Since mainstem dam regulation is a function of volume, this is interesting. Effects will also be compounded by reservoir sedimentation and storage loss.
- You can use gauges outside of the drainage basin for temperature and precipitation
- Is there an effort to modify flows given these trends to asses current conditions used in frequency analysis? Modify flows to account non stationarity. Modify flows to look at contemporary flow frequency based on what flows would be at this time.

  <u>Response</u> – can be looked at with WAT and look at changes to stream flow out to 2100.
- Would there be multiple future time horizons considered? Shorter horizons (e.g., 2050) would seem helpful for people making decisions on nearer-term infrastructure improvements than 2100.

  <u>Response</u> - yes, I think we have multiple future time horizons in the scope, 2050, 2085, and 2100 come to mind

*Discussion and Identification of Feedback Requested by TRG*

- Primary feedback from group – Did modifications to the RAS model influenced the peaks on the dry years?
- Need to justify use for RAS or ResSim further. Seems that USACE is less confident in RAS because there are many complexities that could influence the result.

### *Post Meeting Comments*

One of several important updates in B17C for performing flood frequency analysis (FFA) is generalizing the annual peak flow series. We are now able to more accurately describe annual maxima and are no longer bound to having to use a single-value point estimate or one non-exceedance threshold, for example. We can now use interval estimates to describe annual maxima. Was there any discussion about using interval flow values that capture the difference between the ResSim and HEC-RAS flows estimates in the FFA? Using that approach would capture some more of the uncertainties because we don't know the truth.

***Response*** *we will be rerunning his initial 17C with the 'interval' method next week. I expect we can share the results with the TRG in two weeks.*

## TRG Meeting #3 – February 2nd, 2022

Comments from the Technical Review Group (TRG) on the Bulletin 17c analysis presentation given by the US Army Corps of Engineers on 2/2/2022 are presented in this section. Topics are listed below:

1. ECB 14-18 Climate Assessment
2. Flow Frequency Study Update
3. Summary of Initial Results and Next Steps
4. Discussion and Identification of Feedback Requested by the TRG

### *Comments During Meeting*

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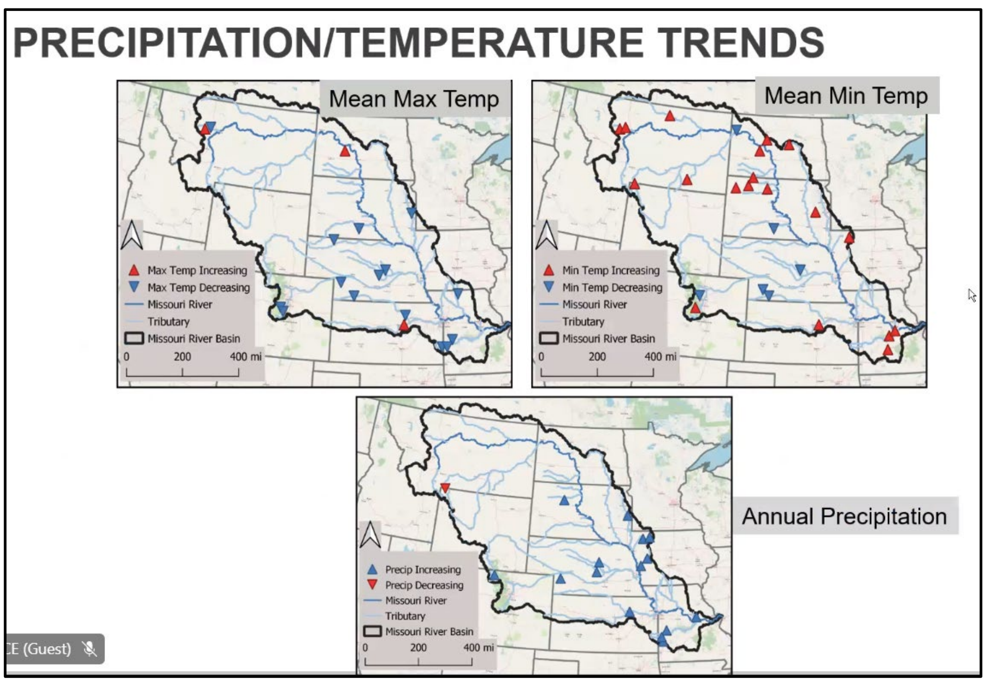
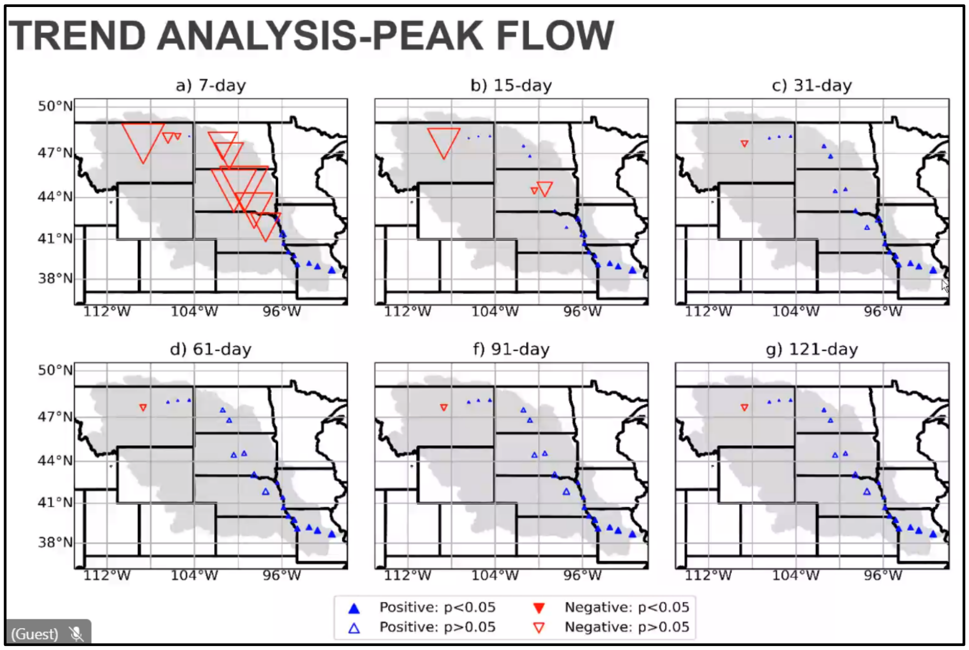
*ECB 14-18 Climate Assessment Process and Results*

- On the following figure, add dots to indicate all of the locations with non-significant trends.

5. …Add-on: suggest using consistent symbology with the streamflow trends.




6. Similarly, on the following graphics, the open triangles indicate statistically insignificant trends. Suggest using a single sized triangle for all of the statistically insignificant trends and make them smaller than the statistically significant trends (or use different colors as well to avoid confusion). The graphics currently draw the reader's attention to the large triangles (in particular the upper left graphic), which are statistically insignificant, rather than the locations with statistically significant trends.




7. I'd like to see the statistics summarized as an area weighted average for contributing area above each river mile. That would give a sense for tradeoffs between increase/decreasing contributing areas.
8. A similar climate change assessment is underway on the Upper Plains, and this also goes beyond the baseline guidance requirements. These two studies should coordinate so consistent methods are used to present information.
9. The trend analysis suggests a statistically significant trend in flows on the lower main stem. However, it appears this is for gages along the Missouri River main stem, correct? In this case, the sites would be highly correlated, so the information is somewhat misleading.

- Consider messaging of portrayed by showing sites in sequence that show essentially the same information
- It may be more informative to consider stream gages on major tributaries in different areas so that the gages are not directly up/downstream of one another to remove some of the correlation between locations, although we recognize this would be a larger effort (potentially something to consider in the future phase of the climate assessment).
- In the presentation, Jon asked if any consideration was made to see what the impacts of trends are on the present-day risk (i.e., considering an analysis that accounts for the trend). We do not recollect getting a clear response to this question.
- Can the USACE provide a high-level overview of what the next steps are in considering a climate-adjusted analysis, either extrapolating historical trends or accounting for information from GCM projections to adjust the flow frequency results?

## *Bulletin 17C Analysis*

Unregulated Flow Frequency Analysis

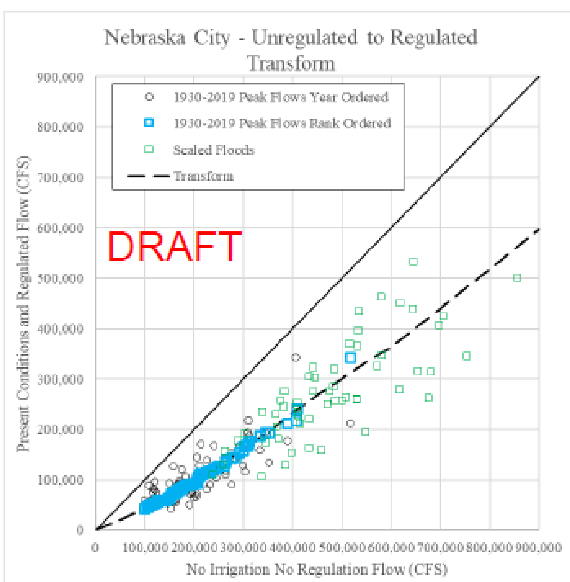
1. HEC-RAS and HEC-ResSim present different methods of computing the annual maxima series. We recognize that there are pros and cons to both datasets, and neither represents the "true" estimate of annual maxima. Rather than treating them as two separate analyses with no uncertainty on the observations, what about treating the two estimates of the flow as data points to inform a representation of each year's annual maxima as an uncertain observation? The range of uncertainty per observation could expand beyond the HEC-RAS and HEC-ResSim observations. This could potentially allow the datasets to be combined and avoid two independent sets of results.

## *HEC-RAS vs. ResSim Routing*

1. Suggest further work with HEC-RAS models to route unregulated and regulated flows for 2011 and 2019 to verify proposed transformations. Furthermore, including one or two larger synthetic events seems like it would be valuable to evaluate the differences in the two routing methods

## *Unregulated to Regulated Flow Transformation*

1. For extremely large events in the upper basin, the reservoirs will not have much additional capacity to regulate flow. Based on RTI's study of the 2011 event on the Missouri River, the volume of the event was such that reservoir regulation could not have reduced flooding any further. It seems that the unregulated to regulated transform should plateau at a high flow and start trending back to 1:1 rather than trending to suggest a greater amount of regulation occurs at extreme flows (see figure below). Peak regulated flows from 2011 suggest that this might begin to occur at flows around 200,000 cfs at Sioux City and approximately 230,000 cfs at Nebraska City, although this event had an uncommon antecedent condition. The variability in on unregulated vs. regulated flows due to uncertainty of initial conditions for individual events further justifies the use of the HEC-WAT method. Suggest verifying transformations using recent extreme events and HEC-RAS models to route unregulated and regulated flows through the system.



2. Transform ratios should generally decrease moving downstream due to lessening percentage of regulated drainage area. For many of the high flow events in the last 15 years, releases from Gavin's point account for less than 20% of the total peak flow at locations downstream of Omaha. Unable to verify this trend based on data in the presentation.
3. As expected, there is significant scatter in the relationship between unregulated to regulated flows at different locations based on observed data because of operational flexibility between years. A lot of effort went into deciding how to draw a single line through the dataset. Instead, the uncertainty in the transformation could be characterized and used to reflect the range of variability that could occur in the regulated flows. Alternatively, the HEC-WAT analysis provides a greater diversity of events—this could be used to help inform how to extrapolate the relationship beyond the observed range (recognizing the limitations from the following point).
4. The HEC-RAS unregulated to regulated results showed substantial differences from the HEC-ResSim transform, even though this could only be completed for a limited number of events. Similar to the previous comment, consider how this uncertainty could be incorporated into the transformation.

*HEC-WAT Analysis*

1. The 50-year HEC-WAT simulations all start from the same starting conditions. If this is done, it seems the first year (or multiple years) should be dropped from the analysis. Alternatively, the starting conditions could be set based on the historical range of starting pools for every reservoir in the starting month.
2. The bootstrap analysis considers different combinations of early spring/late spring/remainder for different parts of the watershed. However, this does not consider the potential for variability within each season per region, which seems like a significant limitation.

- It would help to better understand the sampling method used to characterize serial correlations, cross correlations between sub-regions, and the method used to sample between years to maintain correlations.
- A relatively small step to further improve the dataset generation would be to not just shuffle historical years, but allow scaling of years to create more unique and extreme conditions to increase variability. Distributions of seasonal volumes per region could be used to draw volumes for each season for scaling purposes.
- Alternative synthetic time series generation approaches could be used to create greater variability within seasons. For instance, the PRSIM.wave method can be used to generate synthetic streamflow to maintain correlations between multiple sites and across time and has been used by others performing similar analyses (e.g., Hydro Quebec).[1]
- From the HEC-WAT analysis, the plot depicting the HEC-ResSim unregulated to regulated transform shows much more limited variability in comparison to the observations over the observed range of flow. This suggests that the flexibility in operations is not reflected in the simulations (which is not surprising because of the complexity in operations and difficulty in fully representing this flexibility in the context of HEC-ResSim). This would also suggest that the uncertainty resulting from

[1] M. I. Brunner and E. Gilleland, "Stochastic simulation of streamflow and spatial extremes: a continuous, wavelet-based approach," *Hydrology and Earth System Sciences,* vol. 24, p. 3967–3982, 2020.

the HEC-WAT simulations is underrepresented, particularly for the observed range of flows. A statistical noise model could be used on the tail end of the simulations to increase/decrease the simulated annual maxima calculated for each year to re-introduce the variability in operations without making any changes to the ResSim model. If the noise model were applied to the individual simulations, the post-processing tools in HEC-WAT could still be used to compute frequency curves. We would expect this would improve the representation of uncertainty coming out of the HEC-WAT analysis, as well as the mean frequency curve.

- As mentioned earlier, at some high flow level, we would expect that the flood storage of the reservoir system to be overwhelmed, at which point the variability in the unregulated to regulated transform would decrease substantially, approaching a single-value curve (i.e., with minimal uncertainty) and eventually trending back to a 1:1 curve. Is this beyond the range of flows considered for this analysis, or within the range? A knowledge of the physical system could help inform the formulation of the noise model. This knowledge could also help in describing the confidence we have in the results for different flow ranges because of different certainty in the transform for different ranges.

*Analysis and Comparison of Results*

3. In some cases, there is a substantial change in flood results between the prior UMRSFSS (2003) analysis and the current analysis. Our opinion is that understanding and explaining why results changed at different locations is an important piece of the study to help give end users confidence in the results—for instance, attempting to break out the fraction of the change due to different sources (e.g., the addition of 16 years of flow observations vs. different methodological changes).
4. The USACE suggested that the study needs to result in a single set of frequency curves. We agree with this sentiment. At this point, the three analysis approaches (Bulletin 17C HEC-ResSim, Bulletin 17C HEC-RAS, and HEC-WAT) all represent different means of arriving at a final answer. Each has pros and cons. It seems that it would be preferable to create a blended combination of the different estimates, either through a manual combination of curves or otherwise, with the final result reflecting the combined uncertainty of the different estimation methods. Weighting factors between different methods could potentially be varied for different flow ranges or for different locations based on the opinions of the modelers involved in the analysis. The assumptions underlying the blending approach should be clearly defined in the methodology description.

### TRG Meeting #4 - September 28, 2022

This meeting presented the HEC-WAT analysis that was ultimately used for the flow frequency calculation. At the time of the meeting there were still refinement to be performed on the WAT sampling routine. The TRG comments from this meeting are in the form of the final report comments presented below. The agenda from the meeting is as follows:

13:00-13:10 Introductions (Boyd)

13:10-13:30 Review of Flow Frequency Process

13:30-14:00 Ongoing Revisions to Methods (Chestnut & Larsen)

14:00-14:20 Draft Results and Next Steps (Larsen & Krause)

14:20-15:00 Discussion and Identification of Feedback Requested by TRG (Boyd)

## External Review by RTI:

RTI performed a review on the unregulated and regulated flow data, HEC-ResSim model and draft report section for the Omaha District (NWO) reach of the Missouri River. The review was completed with the understanding that the holdouts and depletions provided by the US Bureau of Reclamation (Reclamation) may be updated, which will impact HEC-ResSim results. The comments on the data and analysis are presented below.

***Review Comments:***

*Seasonal Split*

The previous analysis uses a seasonal split for the NWK portion of river, however is the distinction justified? How is the spring vs. summer flow frequency used in practice? Jan-April contains the plains snowmelt and winter rain events (like the bomb cyclone a couple years ago). May-Aug has mountain snowmelt and summer rain.
Both periods contain snowmelt and rain, however the dates for the periods seem reasonable based on visual analysis of historic flow data.

*Non-Stationarity*

We note there is a special committee for the assessment of climate impacts – we would encourage evaluation and significant of trends on the data sooner than later, with an attempt to differentiate between potential meteorological variance, hydrological responses possibly from varying temperatures, and/or impacts from land use changes. Discussion should follow regarding possible mitigation measures for adjustment to the naturalized flow sequences should these shifts be significant and violate any required independent and identically distributed assumptions for fitting distributions.

*Unregulated and Regulated Flows*

Regulated and Unregulated data presented in the report are different lengths. Suggest presenting only data from 1930 onward since this is what is being used in the update.
The report indicates that while adjustments were made to depletions to represent current conditions for the full period, no adjustments were made for runoff impacts from land-use changes. It would be good to verify that land-use change over the period is not significant enough to affect the basin hydrology.

***Conversion of Maximum Daily Mean Flows into Instantaneous Flows***

Daily mean to instantaneous peak conversion factors look reasonable, less than 5% for all. However, the snowmelt season vs. rainfall season factors look odd. It seems rainfall events would be more peaked than snowmelt events, but the factors are the other way.
Are all daily max and instantaneous max that are not on the same day identified (Yankton, 1972 for example)? The validity of comparing daily mean and instant from 2 months apart is questionable. The computed factor is irrelevant for answering the question of what the instantaneous peak is for the day that the maximum mean discharge occurs. Suggest removing these events entirely from the analysis.

***ResSim Model Review***

Model: MR_System_2020-10-06
Network: MR_Mainstem

***Model Setup***

We assume that the MM_2018PC alternative is being used to generate regulated flows, and the MM_2018N alternative is used for unregulated flows.
Check: Daily timestep used for computations.
Operation set: MM2018 for all reservoirs for both alternatives.
Checked: Depletion time series for 2018N and 2018PC alts look correct, time series are linked accurately.
Simulations

- Natural: Natural flows (unregulated, MM_2018N alt), 01Mar 1930 - 01Mar 2020)
- PC_Forecasts: Present conditions (regulated flows, MM_2018PC alt), 01Mar 1930 - 01Mar 2020 but lookback is 1 month shorter than natural simulation

Natural flow simulation still operates the reservoirs according to the MM. Only difference is the depletion time series and multipliers. Depletions are multiplied by -1 to add the depleted water back into the system.

### *Depletions*

For natural alternative, input depletion time series (F part = REV-USBR-HISTORIC) are mainly negative in the summer, lightly positive in winter. Some are relatively consistent over the POR, others get much more negative over time.

- OMAtoNCNE has a larger negative outlier in 2011. Please ensure that that these values are real.

  SUXtoOMA has a similar negative outlier in 2012.
- 2018 and 2019 appear to be copies of 2017.

We would like more clarity on how depletions, inflows, and local flows were calculated.

<u>Assumptions from review:</u>

- Inflows and locals are observed, calculated from measured data. Pre-reservoirs, upstream inflow is stream gage data, locals are calculated as stream gage flow minus upstream routed gage flow. Post-reservoir, use reservoir outflow/calculated inflow in place of gage data.
- "Historic" depletions represent the amount of water actually removed from the river in each year.
- "PresentIncremental" depletions are the amount of water that would have been removed each year if the diversions, returns, and reservoir evaporation were similar to 2017.
- To get the total depletion at a point for present conditions, add Historic and PresentIncremental depletions together.
- The Natural alt adds the historic depletions to the measured flow (subtracts if the depletion is positive). This results in undepleted flow.
- The Present Conditions alt adds/subtracts the incremental difference only. This turns the observed depleted flow into what the depleted flow would have been with present conditions.

If above assumptions are true, no issues with setup of the model.

Questions:

- Is reservoir surface evaporation considered in the depletion data?
- What is the difference between TotalWithReservoir and TotalWithoutReservoir time series?
- Are upstream/tributary reservoir holdouts included in depletion data?
- If so, what percentage of the upstream reservoir regulation is included (roughly)?
  - How much confidence is there in the accuracy of the depletions? They are a primary determinant of the unregulated flows.

### *Unregulated Results*

To evaluate the performance of the model in computing unregulated flow from Gavin's Point Dam to Nebraska City, the physically unregulated period from 1931 to 1952 was used. ResSim unregulated results were compared to gauge measurements plus approximated depletions for Yankton, Sioux City, Omaha and Nebraska City (Figures 1-4). It appears that the ResSim model performs well at Yankton, but there is more scatter in the results at Nebraska City. This may be due to limitation in the HEC-ResSim routing used to develop the results. Suggest using HEC-RAS to route large flows downstream of Sioux City. Results indicate that the unregulated flows produced by this analysis are generally higher than UMRSFFS for flows exceeding 200,000cfs at Sioux City and Omaha. Again, suggest analyzing HEC-RAS results to determine how much storage and attenuation occurs at this level. If attenuation is causing this discrepancy, then suggest using HEC-RAS to route large flood events.

**Figure 1. Yankton ResSim Unregulated Flows vs. USGS + Depletion**

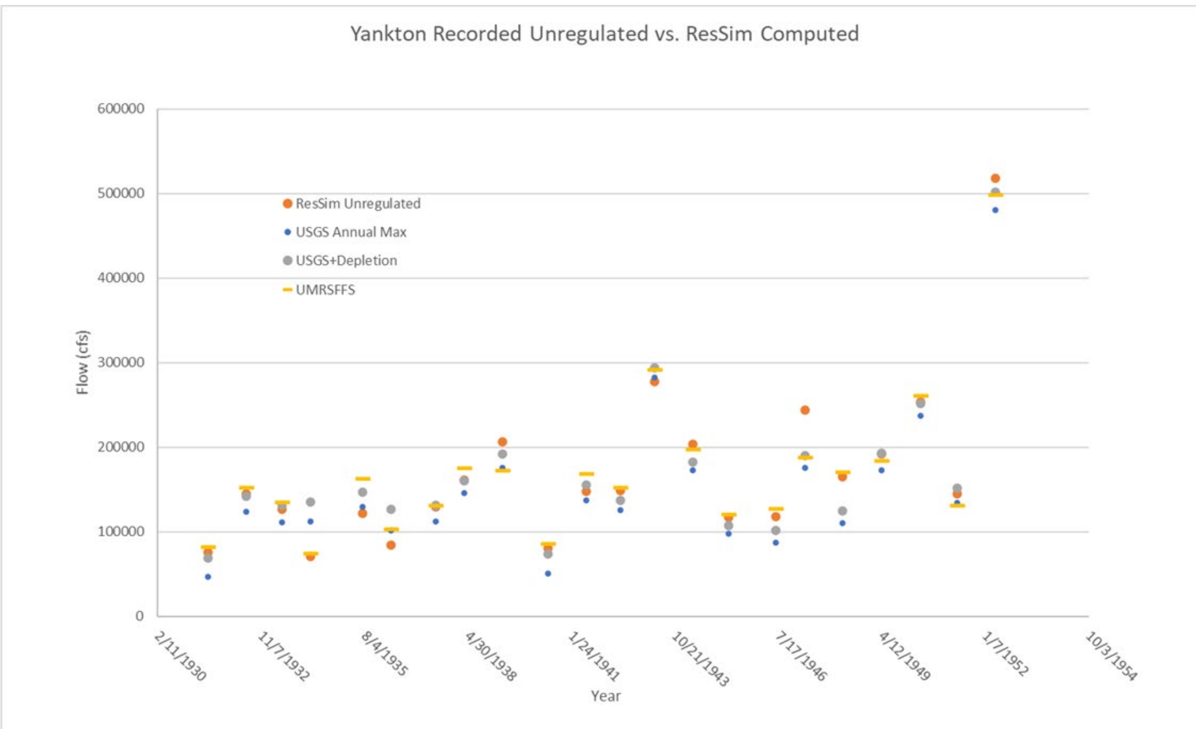


**Figure 2. Sioux City ResSim Unregulated Flows vs. USGS + Depletion**

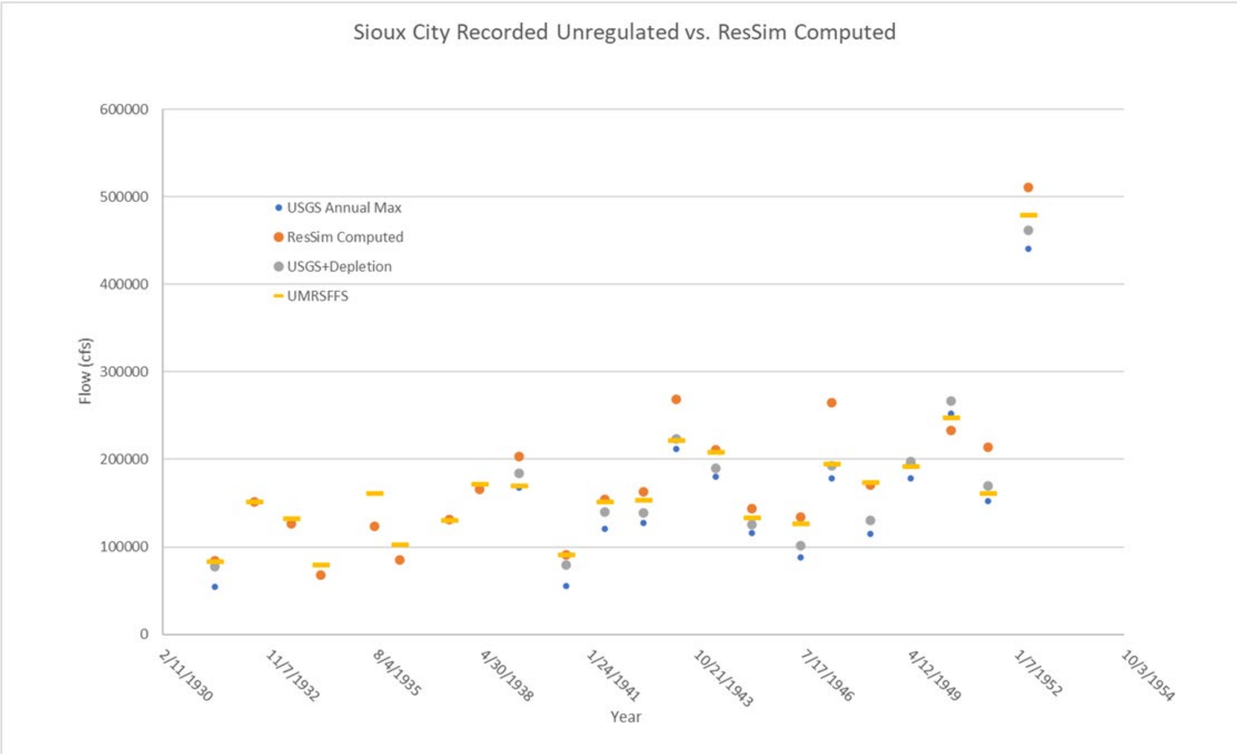



**Figure 3. Omaha ResSim Unregulated Flows vs. USGS + Depletion**

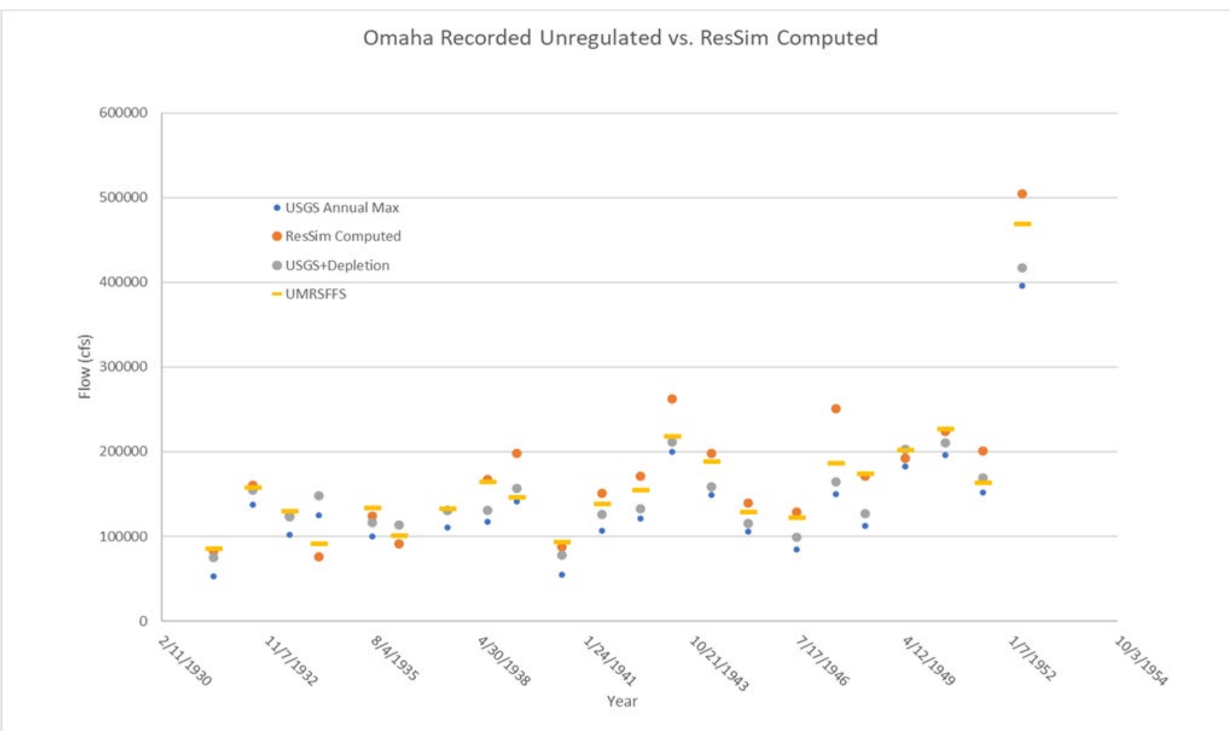
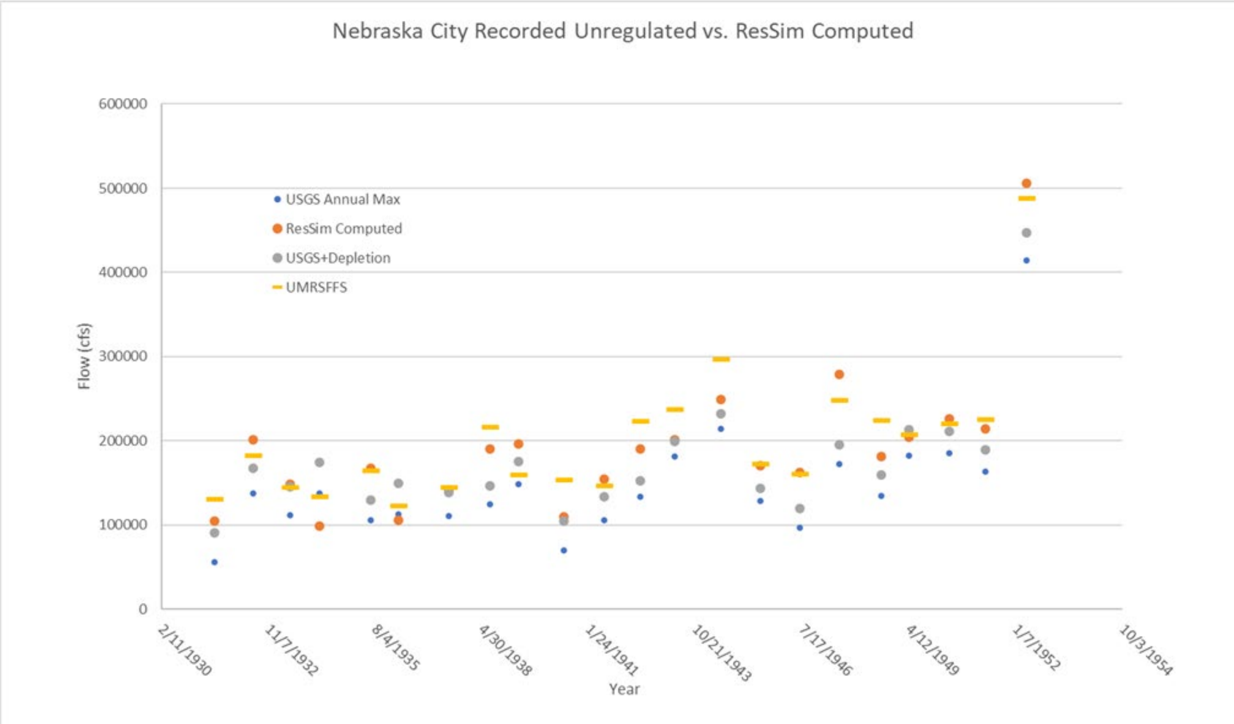


**Figure 4. Nebraska City ResSim Unregulated Flows vs. USGS + Depletion**




## Bulletin 17c Review

This section documents RTI's review comments from the review of the Bulletin 17C analysis performed by the US Army Corps of Engineers for gauge locations on the Missouri River in the Omaha and Kansas City Districts, respectively.

### *Omaha District Review Comments*

*Bulletin 17c*

- Analyses for all four locations used station skew only. Was any investigation of regional skew performed?
- Historical peaks are included in the analyses with exact peak magnitudes. NWO staff could consider adding uncertainty to these older events by adding lower and upper values based on confidence in the event estimation.
- Splitting the peaks into two populations is justified by the different causes of peaks, namely plains snowmelt and later mountain snowmelt. However it would be good to verify that the chosen split date (end of April) reliably sorts events by cause. It could be possible to have events primarily caused by plains snowmelt occur after April in cooler springs, and mountain snowmelt peaks earlier than May in warmer years. Mis-categorized events could be fixed manually.
- Overall the analyses seem well done and produce reasonable results.

*Transformation to Regulated Flow*

- Final regulated frequency curves see flows for the same exceedance value increasing as locations get further downstream, as expected.
- Input unregulated flow time series have negative values at times. Care should be taken to ensure calculations are justifiable.
- Higher exceedance portions of the transformed curves are based on 5th-order polynomials fitted to rank-ordered historical events. What went into the choice of 5th-order vs. other options such as a lower-order fitted curve or directly interpolating between each plotted historical event?
- It appears that the lower exceedance portions of the transformed curves were defined by blending two straight lines to the fitted polynomial. Were these lines defined visually or quantitatively?
- The historical (systematic) events are plotted in rank order to provide a cleaner curve to fit a transformation to, but the larger scaled events are only plotted in pair order. What is the reasoning behind combining the two different ordering methods?
- It was unclear if confidence bounds were being calculated on the regulated frequency curves (bounds are shown at GAPT but not other locations). Including some measure of uncertainty around the regulated frequency curves could be beneficial. Possible uncertainty sources could be ResSim model operations uncertainty and transformation curve definition uncertainty.
- Comparison and explanation of difference between UMRFFS values and current study values will be valuable and interesting.

***Kansas City District Review Comments***

  - The Excel sheets used parameters manually input for the LP3 distribution, but it was unclear where / how these parameters were developed.
  - In review of the accessible Macros, one of the parameters should be reviewed further. The Alpha and Beta look correct, but the Tau parameter looks to use a different approach than I have seen in the past – it is worth further review to be sure that the Tau is correct in the calculations

- The approach is using annual maximums which appear to be based on calendar year – is it more appropriate to use annual water year maximums instead?
- There is an instantaneous peaking coefficient that appears to be developed from regulated records. After transformation to unregular values, the same peaking factor is then applied – is this appropriate, or should some adjustment factor on the peaking side be used?

These comments and review provided by RTI were addressed in development of the final report after the fourth TRG meeting and presentation. Once a draft of the report was available, both the TRG and RTI staff compiled the comments provided in the following section. The USACE team provided resolution feedback for 184 comments as part of this review phase.

## Final Report Comments

Final Report Comments from the TRG and RTI are presented in the table below.

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| 1 | 0 | 0-0 | Title Pages - "Missouri River" appears too often in subtitle | Jery Stedinger | Concur | Removed the last "Missouri River" |
| 2 | 0 | 0-15 | Regulated to what year of depletions? Are these adjusted for "2020" levels of activities? Are there "2050" series? | Jery Stedinger | Concur | Added "2017" to glossary entry |
| 3 | ES | ES-1 (17) | Master Manual includes what? | Jery Stedinger | Concur | Added this text to clarify what the Master Manual is... "that documents guidance on the operation and maintenance of the Missouri River system " |
| 4 | ES | ES-1 (17) | NICE Ex. Summary | Jery Stedinger | Concur | Thanks |
| 5 | ES | ES-3 | figures would be a more interesting way to present the information | Jery Stedinger | Dissent | That would be an option, thank you. Tabular data is preferred. |
| 6 | ES | ES-3 | Why are some values highlighted? | Jery Stedinger | Concur | Final values are in the table and highlights are removed. |
| 7 | 1.1 | 1-1 | Present tense is recommended for the report. The report, especially section one needs an edit to improve readability. | Michael Crouch | Concur | CJB - I concur w/ this comment on Section 1, I revised the paragraph a fair amount for clarity. The tense was also adjusted here, but overall you will largely see past tense in the report for things previously completed. |

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| 8 | 1.1 | 1-1 | The first sentence references the "Hydrologic and Hydraulic Analysis," but I assume this is carryover from a previous report and that the sentence should reference the 2022 Missouri River Flow Frequency Analysis. | Michael Crouch | Concur | This section has been revised for clarity. |
| 185 | 1.2 | page 1-1 | "A regulated dataset was developed by applying the current level of depletions and holdouts to the entire period of record." Comment: Should not the depletions/holdouts be dependent on the given year? And given the length of the period of record, would it not seem reasonable to believe depletions/holdouts to have increased in more recent history than in distant past? | Kevin Low | Concur | You are correct. Depletions do increase as you move through the POR. Historical flows all represent flows that occurred during a snapshot in time, which means the basin development is for the historical year. We adjusted the flows with the depletions datasets so they represented flows as they would have occurred under the current/present basin development. For example, observed flows in 1930 would likely be even lower because there are a lot more irrigation intakes, water supply intakes, etc. in the basin now than in 1930. |
| 9 | 1.2 | 1-1 | the scope section should discuss the Monte Carlo analysis as well. It comes in as a surprise in section 6. | Michael Crouch | Concur | Added "A Monte-Carlo analysis was performed utilizing HEC-WAT to compute regulated flow frequency directly." |
| 10 | 1.2 | 1-1 | Study captures new methodology AND updated "estimates of water uses or depletions" + 2011 & 2019 flood values. When you say the effect of two major floods, I assume you mean their effect on the freq. distributions of unregulated flows and NOT of physical characteristics of the rivers (?). | Jery Stedinger | Concur | Added "on peak flow frequency" to clarify |

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| 11 | 1.3 | 1-2 | "along over a long period of time" delete *along.* | Jery Stedinger | Concur | Done |
| 12 | 1.3 | 1-2 | First paragraph, needs an ending sentence that reflects what was done because there is error in the transformation - transformation not exact. | Jery Stedinger | Need Clarification | This section is high level objectives. The details are later in the report. E.g. we expanded and re-named Chapter 5 to mention this is Regulated, Transform method, and cover this point in the introduction of the Transform method up front before presenting it. |
| 13 | 1.3 | 1-2 | Figure 1-1 should include the location of Gavins Point Dam. | Jery Stedinger | For information | In the text preceding the figure, we made it clear that Yankton, SD and Gavins Point Dam are generally used interchangeably. |
| 14 | 1.4 | 1-3 | Please indicate what year the Missouri River Levees study was published | Jery Stedinger | | Modified text to: 1947 Missouri River Levee System Definite Project Report (USACE 1947) |
| 15 | 2 | 2-1 | Define NGVD acronym and other acronyms throughout the report | Greg Pederson | Concur | Added definitions for acronyms throughout report. |
| 16 | 2 | 2-1 | Need to refer to a map for text to be effective. Would be nice to see these distinct subareas outlined on map. | Jery Stedinger | Concur | Map of physiographic characteristics was added to the report. |
| 17 | 2 | 2-2 | Occasionally, summer rainfall floods having high, sharp peaks occur in the lower mountainous areas in small catchments, such as the Rapid City flood in June 1972 and the Big Thompson River flood in July 1976. | Jery Stedinger | Concur | I believe this to be linked to the following comment in terms of linkage to the Missouri River. See comment #18 (excel line 24). |

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| 18 | 2 | 2-2 | Enjoyed this discussion, but the descriptions does not link peak flood flows in these tributaries to flood flows in the Missouri. Can you perhaps reflect on whether the tributary drainages with their peaks has much impact on the mainstem. Maybe a table? | Jery Stedinger | Concur | These events far upstream are not linked to major flooding below Gavins Point. I edited this section quite a bit to make it more comprehensive and linked to the Missouri River. The changes were made through text edits, I found no need for a table when working through it. |
| 19 | 2 | 2-2 | Paragraph 2 - Consider mentioning the potential for rain-on-snow flood events. These can be major and highly destructive. See the 1964 floods in the Upper Missouri / Milk St. Mary Rivers and the recent 2021 floods along the Yellowstone River, Red Lodge and Yellowstone National Park. | Greg Pederson | Concur | Added a mention of this without specific years. We touch on a few select years in the flood history section now also were this is also discussed, e.g. as in 2019 flood. |
| 20 | 2.1 | 2-3 | Need a map of regions. | Jery Stedinger | Concur | Several maps have been added to Chapter 2 for reference. |
| 21 | 2.3 | 2-5 | Final paragraph should discuss how expected changes to the climate might impact the results of the study. | Michael Crouch | Concur | Added text provided by Jeremy Giovando, and provided a summary in Section 2.6. |
| 22 | 2.4 | 2-5 | /Upper Mississippi River System Flow Frequency Study / This is the 2003 study UMRSFFS ? Add date. | Jery Stedinger | Concur | Added citation with date |
| 23 | 2.4 | 2-5 | End section 2.4 > "since the publishing of 'the 2003' report. " | Jery Stedinger | Concur | text modified as suggested |
| 24 | 2.4.1 | 2-5 | large amounts of rainfall in the spring of 2011 **where**? | Jery Stedinger | concur | added "in the upper basin" |

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| 25 | 2.4.1 | 2-6 | "communities downriver of the dams"<br>above Gavins Pt or below? | Jery Stedinger | concur | changed text to "communities downstream of the mainstem dams as well as downstream of the system below Gavins Point Dam" |
| 26 | 2.4.2 | 2-6 | TWICE> "of water equivalent " | Jery Stedinger | Concur | changed text to " 2-4 inches of snow water equivalent across the entire lower Missouri River Basin. " |
| 27 | 2.4.2 | 2-6 | where is "all over the basin"? Rockies? | Jery Stedinger | Concur | throughout the Missouri river basin |
| 28 | 2.5 | 2-6 | Should appendix F include information about Levee development? | Michael Crouch | Concur | I pulled information from the appendix in and expanded this section. It was previously just pointing the reader to UMRSFFS Appendix F (Omaha) from 2003, and I found some information that was not either comprehensive for Kansas City or was updated or out of date for this study. |
| 29 | 3.1 | 3-1 | "were performed on computed estimates of unregulated | Jery Stedinger | Concur | text modified as suggested |

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| 186 | 3.1 | page 3--1 | "The peak flows used were maximum daily flows computed using the Missouri River mainstem HEC-ResSim model, and were converted to peak flows using instantaneous peak to daily....." COMMENT: Understanding the caveats presented on the limitation of daily stream discharge data provided in Section D.1 on page D.1, was there any "spot-checks" made to validate the ResSim daily flow values to actual gage observations within the observed period? Given known model bias, how well was ResSim simulations (year to year) able to replicate what limited historic gage data is known? | Kevin Low | Concur | We added reference to the reports for ReSim model development in Section 3.2 of the report, and included them for tributary reservoir system updates. ResSim results were calibrated to current floods (see 2012 report, link provided in the document). The period of record run was validated against flow records also, and checked with newer flow data (through 2019). Changes and additional work done to that model and how it was used for timeseries development were added to the report. |
| 30 | 3.1 | 3-1 | "Yankton, SD – near Gavins Point" Yankton is BELOW the dam? | Jery Stedinger | Concur | Changed to "below" |
| 31 | 3.1 | 3-1 | "and were converted to peak flows using instantaneous peak to daily average flow ratios. " Where can I see these numbers? I suspect on main stems they are close to one and thus not a great concern. CORRECT? | Jery Stedinger | Concur | Appendix B documents the Qp/Qd ratios. 2-4% range of difference |

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| 32 | 3.1 | 3-2 | Table 3-1. This must be a wonderful table. I see as one moves down stream, river miles decrease to zero, and total drainage goes to the maximum. But what does below dams mean where there is no dam at the site, and should it not decrease to zero rather than increase. Makes no sense to me - clearly I do not understand the table. | Jery Stedinger | Concur | The table headings were altered during formatting and have been edited to resolve. The "total drainage area" column is still as it was. The other two columns were labeled on the top line as "drainage area", and bottom line as "regulated" on the left side and "unregulated" on the right side. These two columns add up to the total drainage area and are cumulative instead of incremental. For example at Gavins Point Dam (sometimes also referred to at the Yankton, SD gage), there is an unregulated drainage area of 0 sq miles (area below the dams) and the regulated drainage area equals total area. At Hermann, the regulated drainage area is the sum of drainage areas upstream of all dams included in the footnote (including the mainstem dams), whereas the unregulated area is the total area minus the regulated. |
| 33 | 3.1 | 3-2 | Table 3-1. Not clear what superscripts mean. Particularly 1-2-3. | Jery Stedinger | Concur | The confusion here is mostly because the table footnote text was formatted to look like a regular paragraph body text instead of a table footnote. I corrected the formatting so that it looks like part of the table now. The letters indicate which dams were added to the cumulative total "regulated" drainage area. The numbers indicate which year between 1993, 2011, and 2019 produced the highest USGS flows at each gage. Notes were added to further clarify. |
| 34 | 3.2 | 3-3 | Could seasons be explained with a table please. | Jery Stedinger | Concur / lower priority | We added plots showing seasonality to Section 3.2, time series, and also expanded the discussion in Section 3.3. |

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| 35 | 3.2 | 3-3 | Table 3-2. HELP. Daily means were 2-4% of instantaneous flows? | Jery Stedinger | Concur | Qp was 2-4% higher than Qd. Text Clarified |
| 36 | 3.3 | 3-3 | I assumed we were comparing 24-hour mean to instantaneous and ratios should be very close to one. You cannot be comparing the seasonal mean to the instantaneous peak ??? Your simulations must use daily flows, or perhaps weekly. Not seasonal flows. | Jery Stedinger | Concur | Midnight to midnight daily mean compared to instantaneous. We computed ratios for the years we had data. So sometimes we had an early spring daily maximum and early spring inst. peak, sometimes a late spring daily maximum and late spring inst. peak. Please see Appendix B. |
| 37 | 3.4 | 3-3 | The following should not be the first sentence. Put at end of the section - "Unregulated flow frequency analyses at Gavins Point, Sioux City, Omaha, and Nebraska City were performed by Omaha district staff, while the analyses at Rulo, St. Joseph, Kansas City, Waverly, Boonville, and Hermann were performed by Kansas City district staff. " | Jery Stedinger | Concur | placed sentence at end of section 3.4 |
| 38 | 3.4 | 3-4 | what time step? "modeled data from the Missouri River Mainstem HEC-ResSim model (USACE, 2018)" | Jery Stedinger | Concur | added "derived from flow data at a daily timestep" |
| 39 | 3.4 | 3-4 | Looks like daily flow models. Right. What is table 3-2? | Jery Stedinger | Concur | Table 3-2 shows the peak to daily flow ratios. Changed title to "Conversion Percentages of Maximum Daily Means to Instantaneous Peak Flows" |

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| 40 | 3.4 | 3-4 | As an author of Bulletin 17C, I do not understand: "To use regional skews, an estimate of mean square error is required. At all gages where regional skews were used, at station MSE was applied." - would someone please show me the details of what was used for a regional skew, and then what was smoothed and how it was used. Such details could go in a memo rather than the public report. But I request to see the details. | Jery Stedinger | Concur | changed "regional" to "smoothed". The details are plotted in Figures 3-2 through 3-5. The discussion on smoothing was expanded also a bit to clarify and figures were updated. |
| 41 | 3.4 | 3-5 | To use regional skews, an estimate of mean square error is required. At all gages where regional skews were used, at station MSE was applied. | Jery Stedinger | Concur | The text of this paragraph was expanded to address how MSE was determined, and also how we didn't entirely regionalized but smoothed the skews along the river. |
| 42 | 3.4 | 3-5 | My HEC contact said that there was no use of regional skew.<br>It was felt that these extremely large basins would not be well served<br>by mixing them with the skew of much smaller catchments.<br>I would also add that the at-site record lengths here are 100-150 years whereas a good regional skew may be worth 50 years of data. Thus, regional skew is unlikely to have a dramatic impact on flood-quantile precision. | Jery Stedinger | Concur | We did some skew smoothing along the streamline. We found that the regional skew method was not computing expected probability correctly yet for Bulletin 17 editor in SSP. Therefore, all smoothing of skew in the final report was done using the "general frequency" analysis in SSP, which we found produced identical results for station skews as the Bulletin 17C editor. This method allows smoothing using only the skew and does not require input of MSE of skew. Text of Section 3.5 explains these updates. |

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| 43 | 3.4 | 3-5 | Note I talked Wednesday to Beth Faber at USACE-HEC about a number of my projects, and I asked what she knew about statistical methods used in this report. I shared no text or figures. However, she had several of the FFA figures already, so we discussed a couple she had already. | Jery Stedinger | Concur | Acknowledged |
| 44 | 3.4 | 3-5 | Figure 3-2. DA makes more sense than River Mile | Jery Stedinger | Concur | Plots have been expanded and updated to include some of the sensitivity analysis, adding total drainage area, and retaining river mile and comparison of skew versus mean. |
| 45 | 3.4 | 3-5 | Figures 3-2, 3-5. Nice figures. You really owe audience some additional explanation. | Jery Stedinger | Concur | We have added to the section to better explain and have introduced the figures. |
| 46 | 3 | 3-7 | Figure 3-3. Add units to Y axes for the these figures. | Greg Pederson | Concur | Plots were updated, units are log of flows in cfs for Mean and Std. Dev. Explanatory text was added in the paragraph above to say that it was logs and "The statistics were separated into the early and late spring season from Gavins Point to St. Joseph, but are annual from Kansas City to Hermann. " Also added text into the paragraph above to keep the caption from being too long that river mile zero is the confluence.  Also added in the figure name that mean is the log of the flow. |

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| 47 | 3.4 | 3-8 | I think this are the log space mean and standard deviation. Probably common logarithms. Please make that clear. The units are not CFS. RIGHT? And please, use accumulated drainage area, not river mile (unless too late to change). Can you indicate, maybe in just a footnote, which sites have the longer records. | Jery Stedinger | Concur | Yes, Log space mean and standard deviation. Plots are updated and expanded - see comment responses for comment #44 (excel line 51). We expanded a table with gaging dates and moved it up to Section 3.6.1, and have the second table in the same section that summarizes locations providing historical flood information after that. The text introducing the figures also includes a description of the gages with the best information, and those have been highlighted on the figures (in my view Kansas City has the most reliable historic peak information, followed by Boonville and Hermann, St. Joseph, and Omaha). |
| 48 | 3.4 | 3-9 | I can find no discussion of figure 3-5. What do you see? | Jery Stedinger | Concur | The figure has been introduced in the text. It was a second way to look at the skew as suggested by Beth Faber (to plot vs the mean). |

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| 49 | 3.5 | 3-11 | figure 3-6 through 3-25. Please enlarge the text-legend describing what each line represents. -- Where do I find the equations to define how you computed the combined frequency. ( can guess how you got that). But how did you computed the confidence intervals for the combined frequency curve. (Do not know how you got that. | Jery Stedinger | Concur | Added this text in section 3-5 (note previously was 3-3, we added two sections): "The mixed population combined expected probability flow frequency curves were computed by means of the combined probability equation P(C)=P(A)+P(B)-P(A)*P(B)." The confidence intervals were computed by means of order statistics using 90 equivalent years of record within HEC-SSP. For the computation, the expected probability was computed for each season in Bulletin 17C in HEC-SSP, then copy-pasted into the mixed population analysis in HEC-SSP. As such, the computed curve as shown and used in the analysis is correct. However, we agree the confidence limits are not going to match those from Bulletin 17C, which should be a little wider. Used the same computation for a lower confidence limit for Nebraska City and found the tails to be marginally wider. Since these were ultimately not used in the regulated frequencies, but we want to plot them consistently, we explained this in the report that these are the ordered statistics for all mixed population gages. The annual series gages the confidence limits are from Bulletin 17C. |

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| 50 | 3.5 | 3-13 | Figure 3-10. What is - - - EXP_01 Gavins HIST--2019; this is a nice example showing the need for a mixed population model. But need to at least cite the equations you used for frequency curve and confidence intervals.<br>I DO NOT believe the confidence intervals are very good. they fail to flair at 0.99 in Fig. 3-10; see appropriate behavior in Figs 3-8 and 3-9.<br>I thought that the dark line was the expected probability combined curve. Beth said it was just the combined curve without expected probability. But the legend calls it EXP_. Does that not suggest expected probability? And how did you get it. | Jery Stedinger | Concur | See response to comment #49 on excel line 56. It is expected probability. |

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| 51 | 3.5 | 3-13 | Figure 3-10. Is it a good assumption that floods in the two periods are statistically independent ??? | Jery Stedinger | Concur | Please refer to Section 3.2 and 3.3 of the report, which we have expanded to address this question, and see also the expanded flood history section. In terms of it being a good "overall assumption", this has two parts. First independence, then also whether the time periods are appropriate as a proxy for flood mechanism. While not directly checking for independence, guidance from EM 1110-2-1415 points us to consider this as we have distinct flood mechanisms. Discussion was added to Section 3.3 to mention these points (so that it covers all mixed population gages). Not perfect to rely on a firm date to separate different types of events but overall this works very well (above KC) based on the flood history information. This was assumed during the 2003 UMRSFFS study also, and we found the analysis to still be sensitive to this above Kansas City (influence of the Kansas River; and generally wetter drainage in the east). Generally, many years, such as the 1952 early spring plains snowmelt flood, do not have major second peaks later in the season. In 2019, we saw March flooding from plains snow (and rain on snow), then smaller flooding later in the year driven by rain upstream of KC. Further downstream from KC, the largest 2019 peaks were driven by late spring rains. At KC, the four largest events including historical record were all late spring and summer rainfall events as in 1993, 1844, 1951, and 1903. Though not adopted, two mixed population analysis (systematic period and full historic period) was also added to the KC gage narrative. |
| 52 | 3.5 | 3-13 | Sorry, I do not believe this figure is correct. CI need to widen as one moves below 50%. At 50%, expected probability should cross computed curve. There is no | Jery Stedinger | Concur | Please see the response to comment #49. The report has been updated accordingly for clarity. |

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| | | | expected probability adjustment for the highest floods. Just not right. Beth said that there is no expected probability curve in 3-10, and black line is just the combined risk. Okay that could be. Then it would only be the confidence intervals at the low end that seem to be unreasonable and should flair. | | | |
| 53 | 3.5 | 3-13 | Figures 3-11 through 3-26. I looked at other sites. Same issues as Gavin Pt. | Jery Stedinger | Concur | Please see response to comment above |
| 54 | 3.6 | 3-21 | This is a great and very interesting section. Results are presented downstream to upstream, whereas the Omaha information is presented upstream to downstream. Suggest being consistent. Upstream to downstream might be more intuitive since the Omaha District information is presented first. | Michael Crouch | Concur | While the Kansas City gages were written in this section from downstream to up as it flowed better with how development progressed and correspondingly the quality and quantity of historical flood information, this comment was noted by several reviewers and was adopted. To mitigate this, a historical flood section was added and some information moved higher in the report to explain that. This full Section 3 has been rearranged and edited accordingly. |

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| 55 | 3.6 | 3-21 | Kansas City District starts. / FILLING in intermediate flows is a great idea. How did you interpolate? I hope using drainage areas of upstream and downstream sites ? | Jery Stedinger | Concur | In this text introducing Table 3-5 (summary of gage data for KC District by year) a sentence was added to explain the UMRSFFS routing filled in flows at Waverly and Rulo: "The general method to fill in flow records in the 2003 UMRSFFS involved routing flows from the Missouri River and gaged tributaries from the gage upstream to the gage downstream and apportioning incremental ungaged flows by drainage area. ". Since we did not re-do this for the period prior to 1930, I did not spend much time on this in the write up. For missing periods after 1930, a similar process was followed for this study. in this section I was mostly focused on availability of records for analysis (as opposed to routing details). NOTE: this table was also expanded to catch Omaha gages and reordered upstream to downstream. |
| 56 | 3.6 | 3-21 | Good job trying to obtain historical-flood data. | Jery Stedinger | Concur | Thanks you. We have further refined and expanded this information. Including Section 2.4, 3.6, and site-specific information in Sections 3.7 (expanding the historic period of Omaha District sides) and 3.8. Appendix A includes all historic flood information used in the final frequency curves and variation of estimates of 1844, 1881, and 1903 as presented in different documents. |

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| 57 | 3.6 | 3-24 | Good job. Waverly seems to have the weaker record - should it get less weight in the smoothing? | Jery Stedinger | Concur about Waverly, added Rulo, Gavins etc. to this comment | Report has been updated in Section 3.5, 3.7 and 3.8 to reflect that while less detailed data is available at the Rulo, Waverly, and Gavins Point/ Yankton gages (also Sioux City and Nebraska City to a lesser degree), effort was made to generate reasonable and consistent estimates of major historic events and historic periods as feasible to make computations at those locations as consistent as possible with gages with more detailed information. This was plotted in several ways to verify results. More detailed sensitivity analysis to different time periods and data sources was done at the 5 gages with the best (most detailed and most reliable) historical information, (KC, Hermann, Omaha with the most sensitivity analysis ran, also St. Joseph and Boonville). |
| 58 | 3.6.2 | 3-25 | What was the correlation? | Jery Stedinger | See text later in the paragraph. | This text was later in the paragraph and following table also: "Using the 2003 UMRSFFS unregulated peak flows, correlation of the Missouri River sites data to St. Louis from 1898 to 1997 is 92% for Hermann, 84% for Boonville, 72% for Kansas City and 58% for St. Joseph." I pointed the reader down at this location so as to not leave people hanging (two commented on it). |

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| 59 | 3.6.2 | 3-26 | Could you comment on why the 2022 RC shown in Figure 3-26 varies from the historic unregulated data? Sedimentation? Levees? Wing dikes? | | Concur | This text is in the preceding paragraph and matches my findings: "According to USGS SIR 2009-5232, with the primary shift in the rating curve correlates construction of the Alton-Gale Levee System on the Illinois side of the river as completed in the 1960's (Huizinga 2009)." Not much evidence that dikes or sedimentation is a factor. Added a statement affirming the SIR conclusion in the paragraph discussing the figure. |
| 60 | 3.6.2 | 3-27 | Figure 3-26. deserves more explanation in legend | Jery Stedinger | Concur | Moved the text at end of the section about 1844 to be before the figure, made the figure a little bigger, and replaced the note on the figure with the following: "Data Series legend: "pks 1862-1903" reflect USGS peak flows exceeding 600,000 cfs paired w/ NWS peak stages, except for 1844, where the "308 Report" flow was utilized. "Hist pk estimates" reflect values from the preceding Table. All others reflect all USGS peaks for the stated years." |
| 61 | 3.6.2 | 3-27 | Table 3-9. I do not understand the table. What is going on? | Jery Stedinger | Concur | Added to the beginning of the footnote: "Numbers expressed as a decimal reflect the Missouri River flows divided by St. Louis flows." Intent was to establish typical comparisons of the peaks at different Missouri River gages to the Mississippi River, which has the best historical records overall. |

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| 187 | 3.6.4 | page 3-32 | "The historic rating curve for Hermann was further validated using stage data at St. Charles...." COMMENT: I would be leery of using St. Charles stage data due to possible influence of the Mississippi River on the St. Charles gage. | Kevin Low | Concur | Switched the word "validated" to "investigated" and expanded this paragraph significantly to clarify this potential impact. I did not see any events that would indicate clear problems from the graph, but this was an important distinction and caveat to include. Hopefully the revised wording clarifies. General purpose is to show that 1) the historic peaks are pretty similar between Hermann and St. Charles and 2) that the St. Charles stage info (new and old) seems to uphold that the historic flows estimated at Herman are reasonable." No adjustments were made to Herman flows as result of this comparison. |
| 62 | 3.6.4 | 3-30 | Table 3-11 The sensitivity analysis seems to be great. But I do not understand the column headings. Where are they explained, or can an explanation be provided with the tables. A skew of -0.72 is often excessive. Is that number correct? Here there is no regional skew, because I this there was no regional skew. How did you force the skew to be the smoothed value? In which column do the results appear. | Jery Stedinger | Concur. | Added footnote: "Table column headings reflect data used as follows: The 1930-2019 data is the HEC-ResSIM based routings except for the column labeled "1930-2019 RAS" which are HEC-RAS based routings. Flows from 1898-1929 reflect UMRSFFS data. Where historic events were used the earliest date of the historic period is indicated. The "1930-2019 low outliers" was the raw computation from HEC-SSP, which generated 40 low outliers and unreasonable negative skew." Similar footnotes were added at comparable tables for Boonville, KC and St. Joseph. |

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| 63 | 3.6.4 | 3-32 | I think you are using the new **multiple** Grubbs-Beck test. I do not see that you are using an regional skew. "larger region back to 1699 " Is 1699 a typo? | Jery Stedinger | Concur | Yes, used the new multiple Grubbs-beck test for the low outliers and no regional adjustment at Hermann. We made the case to use 1699 as a sensitivity analysis to the historic period knowing that 1785/1844 were not exceeded below the confluence dating back to the date Cahokia, IL was established (1699), and considering reasonable ratios of the Missouri River peak to Mississippi River peaks. To address, I struck "for the larger region" and added the sentence after to say: "For the period back to 1699, given even reasonably low contributions of flow on the upper Mississippi River, the establishment of Cahokia, IL and soon after Kaskaskia, IL provides a case that the major floods of 1785 and 1844 would not have been exceeded at Hermann dating back to at least 1699." |
| 64 | 3.6.4 | 3-33 | figure 3-29. Nice job | Jery Stedinger | Concur | Acknowledged |

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| 65 | 3.6.7 | 3-40 | What is this: "A test of the regional skew from the 2003 UMRSFFS of 0.17, as obtained in the station skew for the Waverly analysis, was also conducted. "? What test?> What results? | Jery Stedinger | Concur | This reflected a Bulletin 17C sensitivity analysis using previously established regional skew values from the 2003 study. Ultimately we didn't use a regional skew or a smoothed skew at Kansas City but we wanted to see the sensitivity to it. I struck the reference to Waverly as it isn't really relevant and added text to clarify in the paragraph and footnote to the table (added as result of a comment on a similar comment for Herman) hopefully clarifies which column heading it was ("1930-2019, pks to 1844 Reg skew"). And moved this skew of 0.17 w/ 17B and 17C from the 2003 study to the second table for the KC gage. |
| 66 | 3.6.8 | 3-47 | Figure 3-44. Just not right | Jery Stedinger | Dissent | We assumed this is a comment consistent with #49 (excel row 56), #50 and #52. Information on how the curves were calculated in the mixed population analysis (computed curve and confidence limits) were added to the report to clarify. With these clarifications, this comment should be addressed. See the more detailed comment response to #49 (excel row 56) for more information. |

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| 67 | 3.6.9 | 3-48 | When you smoothed LP3 parameters, did you take into account that the effective record at Rulo was shorter? | Jery Stedinger | Concur | See comment 57 response, where I grouped Rulo with Waverly on this front. Hopefully the text additions clarify this for both gages (and similar concern at some Omaha District gages). Neither gage impacted any smoothing applied. With work to include historic peaks documented in each gage narrative / striving to use consistent events as in nearby gages with better records, they both plotted reasonably well with other locations as shown in the smoothing section. |
| 68 | 3.6.9 | 3-51 | Not right | Jery Stedinger | Dissent | We assumed this is a comment consistent with #49 (excel row 56), #50 and #52. Information on how the curves were calculated in the mixed population analysis (computed curve and confidence limits) were added to the report to clarify. With these clarifications, this comment should be addressed. See the more detailed comment response to #49 (excel row 56) for more information. |
| 69 | 3.8 | 3-51 | Could we have a 1-2 sentence introduction about what this section is about. This is a major changes from previous discussions. | Jery Stedinger | Concur | This refers to the section on limitations of HEC-ResSIM. The paragraph has been re-written clarify the purpose of the section and also the limitations. Overall added 2 sentences and revised a few others. Considering other comments on organization, this text for ResSIM limitations was moved to the introduction for Section 4 and combined with that text, as it seems to fit better in helping to introduce the "why" behind the HEC-RAS report section. |

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| 69 | 3.8 | 3-51 | "Ungaged" rather than "ungauged" is used in other report sections. Suggest updating the entire report for consistency. | Michael Crouch | Concur | I did a control F and found this was the only instance of "ungauged", therefore it was changed to "ungaged" as suggested. Note that we moved this text to Section 4, as it fit better there. |
| 70 | 4 | 4-1 | Suggest including this section as 3.9 since it is part of the unregulated flow analysis. You could potentially summarize this section and put the details in the appendix since this method was ultimately not used. | Michael Crouch | Partially adopted. | We considered this comment and ultimately decided to move the section from part 3 about ResSIM limitations into Section 4.0 as it better introduced the "why" behind the HEC-RAS modeling. In the Bulletin 17C sensitivity analysis for some gages in Section 3, the RAS routings were used for some of those, and a note pointing the reader to Section 4.0 was added. While yes, we ultimately did not adopt the HEC-RAS routings, it was a significant effort to verify the routings we ultimately used in HEC-WAT were reasonable, given ResSIM limitations. Therefore, we felt it warrants a stand-alone Section. |
| 71 | 4 | 4-1 | Intro could include more information on the outcome of the testing and why ResSim was ultimately chosen. | Michael Crouch | Concur | Concur, text has been added (it helped to combine the ResSIM limitations text in here also as discussed in Comment #72). Paragraph has been significantly expanded as a result. |

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| 72 | 4.2 | 4-2 | Some of the gauges seem to be located far away from water. | Jery Stedinger | Concur | Text added: "As seen in Figure 4-2, several streamgages from smaller tributaries generally smaller than 300 sq miles were added as lateral flows, even though they may be some distance from the river. During the 2018 Man Plan study, these tributaries were modeled using HEC-RAS and the river routing results were not sensitive to the differences in routing from the gage to the Missouri River versus just adding daily flows directly to the Missouri River. Therefore, hydraulic routing along smaller tributaries was not conducted for this study, but the flows were utilized." |
| 73 | 4.2 | 4-7 | Need title // what do column headings mean? What are the first 3 columns? | Jery Stedinger | Concur | Edited: Title changed to "Depletion Ratio per Reach". First column edited to "Reach". |
| 188 | 4.2.1.1 | page 4-8 | Would like more information as to how depletions were estimated. | Kevin Low | Concur | a slightly more detailed explanation on how depletions are estimated was added as well as summarized by BoR in appendix C. In general, depletions are estimated by the USBR using their Regional Depletions Model. |
| 74 | 4.3 | 4-9 | Need legend that describes the two lines and is big enough to read. | Jery Stedinger | Concur | Added Legend to the plot. |

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| 190 | 4.3 | page 4-9 | "Ungaged flows for the POR were calculated using two different methods." COMMENT: Was consideration given to requesting modelled ungaged flows from the NWS? Though simulated, the NWS attempts to maintain continuity of mass between gaged locations in their 6-hourly time step model, and may have been able to provide ungaged tributary volumes as well as riparian (locals) contributions. | Kevin Low | For Information | For this study, HEC-ResSIM back-calculated the ungaged flows at each gage from observed records. So, using a similar missing flow method in RAS is consistent with the ResSim methodology. We have confidence in the results at the gage locations, and use of a similar ungaged methodology allowed for better comparison of routing differences at mainstem gage locations between HEC-RAS and ResSim. However, based on a check of the NWS rainfall/runoff boundary conditions in the 2019 flood simulation we believe using NWS modeled ungaged flows could be an improvement for HEC-RAS, which needs more detailed flow inputs than HEC-ResSIM. In the next phase of the effort as we move to developing stage frequencies using the HEC-RAS model we will need more detailed flow inputs to better account for stage differences longitudinally along the river and believe it will be worth checking this data as an option for the ungaged flows. As such, we are planning to request the data from NWS and incorporate some analysis of it into the stage frequency scope of work. |

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| 189 | 4.4.1 | page 4-11 | "...as the uncertainty is compensated for in the ungaged flow calculations." COMMENT: But is this the correct way to account for uncertainty? HEC-RAS modeling incurs at least three sources of uncertainty. (1) natural uncertainties inherent in hydraulics (usually accounted for by varying the n value), (2) uncertainties due to the method of hydraulic modeling chosen (not well defined, but often assumed to be equal to the natural uncertainties), and (3) uncertainties in the geometry/terrain (i.e. mapping errors). So the question I have is whether there was an attempt to quantify uncertainties in the HEC-RAS computed flows (POR, unregulated, or regulated)? (Section 4.5 "Model Limitations" acknowledged.) | Kevin Low | Concur | Agreed, the disadvantage of this method of accounting for ungaged is that much of the uncertainty is hidden in the ungaged flow, while the results look good at the gage location. Potential impacts of this are on the regulated/unregulated results, and on the stages along the river. It would be very interesting to try to quantify the impact of different model parameters on the ungaged flow, and in turn on the mainstem gage results. I suspect the ungaged flow hydrograph would change, but the result at the gages would still match, given a reasonable model inputs. This is not feasible with today's RAS software and computer processing speed. It took approximately 6 weeks from start to finish to calculate the ungaged inflows to just one of the two models. Some edits were made to this section to better describe the purpose, as that is why we didn't go further at this time. And to better clarify uncertainty in the way the calculations were made. |
| 75 | 4.4.1 | 4-11 | DID NOT UNDERSTAND: "The HEC-RAS modeled annal peaks are centered on the largest value in the USGS daily average record, rather than the instantaneous peak, as this was the target value for the ungaged flow computation. " | Jery Stedinger | Concur | This was presented in a confusing way and the report has been edited for more clarity. The ungaged flow computation was made with USGS daily average flow hydrographs, which essentially meant the flows in the RAS model were calibrated to the highest value in the daily average flow record, which is typically lower than the instantaneous peak. This probably explains why the RAS peaks tended to be about 2% on average lower than the USGS annual peaks. |

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| 76 | 4.4.1 | 4-11 | WHY SO BIG> "At most, HEC-RAS annual peaks vary from USGS annual peaks by 43% too low and 28% too high. "? | Jery Stedinger | For Information | These are individual annual peaks that we had a difficult time matching in the observed simulation, even with the ungaged flow computation included. To call out the specific years, the HEC-RAS peak was 43% lower than the observed peak for the year 1934 (rank #12) at the Omaha gage, and the HEC-RAS peak was 28% higher than the observed peak for the year 1971 (rank #36) at Nebraska City. This does sound big, but they are outliers. Most years at most gages matched well to observed, and when the HEC-RAS simulated peak is compared to the observed peak and plotted on a 1:1 the scatter is centered on the 1:1 line, plots included in the Appendix. Outliers can most likely be attributed to using a present-day river and floodplain geometry and routing, while comparing to historic observed flows. Report has been updated to include this information. |
| 77 | 4 | 4-12 | First paragraph - "whereas there is more disperse in the results for less frequent events." awkward sentence, rephrase. | Greg Pederson | Concur | Agreed, this was a bit awkward and also doesn't exactly match what we see in the 1:1 plots in the appendix. Changed the report text to say: "As seen in the appendix, the more frequent events tend to plot closer to the line of equal agreement, whereas for the less frequent floods there was more scatter in the comparison. The floods of record (1993, 1952) had good agreement to the USGS recorded peak." |
| 78 | 4 | 4-15 | figures 4-6 and 4-7. Axes titles are too small and areas to read. Consider enlarging font. | Greg Pederson | Concur | Increased the size of the figures for easier visibility. Added legend. |

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| 79 | 4.4.1 | 4-13 | Figure 4-4 Cannot read legend defining lives in figure. | Jery Stedinger | Concur | Increased the size of the figures for easier visibility. Added legend. |
| 80 | 4.5.1 | 4-16 | Section title could be "Historic River Configuration" | Michael Crouch | Concur | Changed. |
| 81 | 4.5.3 | 4-17 | Section title could be "Ungaged Flow" | Michael Crouch | Concur | Changed. |
| 82 | 4.5.3 | 4-17 | Section title could be "Levee Breaches" | Michael Crouch | Concur | Changed. |
| 191 | 4.7.3 | page 4-24 | "Therefore, the flow frequency analysis was continued with HEC-ResSim routed flows." COMMENT: I concur. | Kevin Low | Concur | No changes. |
| 83 | 5.1 | 5-1 | Comments Chap 5. Had so many, typed them into text. SEE TEXT. | Jery Stedinger | | Acknowledged |
| 84 | 5.1 | 5-1 | Depending on how one interprets the works, this sentence is true or false. So either expand so what is meant is clear, or delete first sentence. | Jery Stedinger | Concur. | I found the text to be a little too short and even mis-leading, and re-wrote this section entirely to better introduce what this is and isn't. And cite to the guidance that drives this more directly. Hopefully this addresses the comment. Also we re-named this section to denote it is only the "transform method" to aid in clarity as the WAT reflects the final regulated frequencies. |
| 85 | 5.2 | 5-1 | TEXT added. Warning of use of scaled flood added. | Jery Stedinger | Acknowledged | EM 1110-2-1415 outlines the process for using scaled floods. When these results from the scaled floods didn't make sense, they were not included. We found that the appendix explaining this was unfortunately not included. Main pieces were added to explain and we have included the appendix. |

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| 86 | FIG 5-2 | 5-3 | I am not convinced the transformation is correct. | Jery Stedinger | For information / partially concur? / TBD | Please see the text added to Section 5.0 that cites to the Engineering Manual 1110-2-1415 which we followed in deriving this method, also this mimics the 2003 analysis which was extensively reviewed and coordinated across USACE as best we could with fresh eyes, and more data. There is no perfect method. This one meets our EM, but ultimately we decided the WAT values provided a more representative description of the risk we are facing. If needing to extend flows later, it is possible we could adapt the transform using the WAT results. However, this would need to be done at a later date. |
| 87 | 5.2 | | Please can we get Omaha and Kansas City distributes to talk to each other so that the results seems consistent. What I have is not, and I think KC has a lot to teach the Omaha District. | Jery Stedinger | Concur | This section was revised significantly. I added a lot to the intro and moved the basin ResSIM figure and common procedures to section 5-1. Then deleted the duplicate text later. Overall methods wise though, things should be pretty consistent, though the writing styles are different. And NWK gages included a lot more of the details of all of the sensitivity analysis ran. However, as noted in the text, Omaha ran several similar analysis as NWK, but ultimately just published the final curves. This was noted in the text along with how both districts shared results and methods on calls as part of developing these curves. NOTE: Section 3 now reads much more consistent for both districts, which should also help with this comment. |

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| 88 | fig 5-2 | 5-3 | In this and many other figures results are given for fitted polynomials functions. To report 6 digits as absurd. Engineers should understand significant digits even if writers of EXCEL do not. | Jery Stedinger | Dissent | It is absurd, but if you want to plug the function in and use it, you need the significant digits otherwise the output of the function won't be right. Major errors in flows will result if these are not included. As such, these need to remain as is. |
| 89 | 5.1 | 5-1 | In thinking about this whole chapter, I would like to request two additions to the material provided. | Jery Stedinger | | Note adding to #1 below (comment 92, excel row 103), we have ran a lot of synthetic floods in varying methods. See also the KC gage discussion where we looked at other rain/runoff based models from previous studies as well as the HEC-ResSIM used here. We do not really see the regulated flows bending back hard towards the unregulated flows at extreme values in most cases. I think this is due to how spread out the dams are and the size of the basin. It’s hard for a big enough storm to hit where they miss all dams, and even in surcharge, we see some attenuation from the dams (which are sized to pass very large events). |

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| 90 | 5.2.3 | 5-3 | 1. To explore what the transformation functions look like with increasing unregulated flows, consider this. Select a "scaled: multisite hydrographs corresponding to the 100-year flood. Then increase the scaling factor so it goes 1, 1.25, 1.5, 1.75, 2, 2.25, ..... and create a continuous line on the regulated versus unregulated plots. So how does this relationship change (along a scaled flood access) as the unregulated flood get bigger - does it curve back toward the 45 ° line. Instead of creating one point create a whole line for a fixed inflow pattern. Several lines could be created for different initial patterns and then the scale factor "continuously": increased. The results could be displayed for several sites. What does this suggest the transformation function looks like? | Jery Stedinger | Neither concur nor dissent | Yes, this is almost exactly what was done in UMRSFFS for various historical floods, and is also exactly what we did, only we scaled by standard deviation per TRG suggestion. Unfortunately for the Missouri River stations downstream of Gavins, it's very difficult to get any results that 1.) can be scaled without making extreme surcharges happen at the dams (we don't know what would really happen in those cases), 2.) cause the peak unregulated-to-regulated flow pairs to even begin to curve back to the 45 ° line, and 3.) even if the first two conditions could be met, it still doesn't tell us a whole lot about the 0.2% ACE flood at many locations because it depends so much on runoff distributions and their probabilities and how coincident they are, even if we are very judicious about choosing which floods to scale. We don't know what proportion of floods would happen downstream of the dams and not be regulated versus which proportion would be upstream of them, although we can sort of guess based on the POR, but it's such a shotgun blast with the transform method it's hard to tell if we're improving things. That is why we favor the Monte-Carlo approach. Because what is asked for in this comment has already been done, we can discuss those results if you would like. |

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| 91 | 5.2.3 | 5-3 | 2, We have 500 years of MAX floods. What does the transformation function look like when the sorted regulated floods are plotted against the sorted unregulated floods at various sites? Do the results agree with the transformation function we developed with the PoR data and some scaled floods? If not, what when wrong? | Jery Stedinger | Concur | We have done this. We called it the "WAT Transform". Tony Krause had asked for this earlier on. The two did agree. Ultimately we didn't include these plots (but did include results from both methods that can be compared). |
| 92 | | | I would love to see what happens if one uses the WAT derived percentile transformation function with the distribution of unregulated flood peaks derived by a Bulletin 17C analysis of the historical unregulated flood record. That would be a solid analysis. | Jery Stedinger | Tentative | We tried this earlier in the study. At the time, our WAT unregulated results were not well-matched to the Bulletin 17C unregulated results, and so using WAT-derived transformation wasn't apples to apples with the Bulletin 17C unregulated curve and regulated peak flow record peaks. With the post-processed results, we did re-look at Gavins Point, adding a figure to Section 5 with all of the scaled floods on it to see if we could better predict the shape found in the WAT with the flat part corresponding to operations for Oahe Spillway, and did compare the WAT results to the graphic. Ultimately, there was no way to predict that shape from the WAT with the transform without foreknowledge of the WAT. And we felt the Monte-Carlo results straight from WAT should stand alone as presented in Section 6 of the report. |

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| 93 | 5.3 | 5-7 | The two districts should be using the same method, so can we have one description. And I made suggestions on this first appearance of this test/description of the method. | Jery Stedinger | Acknowledged | The write up of Chapter 5 was updated for consistency. The overall method between districts was closely coordinated, it appears KC wrote up a lot more of the analysis than Omaha did, but the overall methods should be consistent. |
| 94 | 5.3 | 5-9 | I am uncomfortable as to whether the theory works to support this approach. The scaled flood examples are not from a random sample. | Jery Stedinger | For information | Unfortunately we did not transmit the appendix that explained what we did, which we have now included. We added a reference to EM 1110-2-1415 which guides the use of scaled large floods in the analysis and summarized key points of the analysis from the appendix in the main report. While the selection wasn't entirely random, the events chosen were to get a variety in terms of the type of event, volume, duration, and location of runoff. We put considerable effort in running a large number of floods to help identify uncertainty in the analysis. 18 events as opposed to 5 in the 2003 study which didn't include runs for the Kansas and Osage. Generally, all of the largest floods for these basins were used. EM 1110-2-1415 cautions against scaling much above 3 times the volume of the actual event. We scaled using standard deviations as suggested by the TRG and was within that. [from Ilya: If this is in reference to the polynomial, it was used as essentially a guide for a graphical curve; this is also true for KC.] |
| 95 | 5.3 | 5-9 | Table 5-1 needs to be introduced. | Jery Stedinger | Concur | Done |

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| 96 | 5.3.1 | 5-9 | Suggest adding a few sentences on the HEC-RAS routing vs. ResSim presented in Figure 5-10 and ultimately which was used for the final transformation. This could be included in section 5.3 since it would apply to all KC transforms. | Michael Crouch | Concur. | I added some text to Rulo and St. Joseph with a bit more discussion as those seemed to capture the range of differences, then added some statements to the other gages as well. Overall, looking at the numbers, if we used the same routing method for both 17C and the transform, the regulated flow frequencies from this method would agree closely. Ultimately we used HEC-ResSIM as we could do a lot more with extreme floods than we could w/ RAS. |
| 97 | 5.3 | 5-11 | Fig 5-8 what is the year for the largest flood in the record, and why is it not labeled. | Jery Stedinger | For information | In the figure, we only labeled the actual events that are the same-year flows. A couple of those (1993 and 2011) plot in the same location as a rank-ordered point, which is the likely confusion. For the rank ordered, the largest event was 2019 for the regulated paired with 1952 for the unregulated. If any questions on these labels, this is why in the previous Figure 5-7 we did not also plot the rank-ordered so that the reader can refer back to verify. |
| 98 | 5.3 | 5-11 | The year in the figure must be for the unregulated flood, because the assumed development for the regulated case may not correspond to the year the flood occurred. | Jery Stedinger | For information | Please see the response to comment #99, hopefully that addresses the question. We built these figure series to add data to it as we go to help reduce confusion. First figure is PoR only. Second is PoR plus rank ordered PoR. Then we add RAS. Then the next section we add the scaled flood information. |

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| 99 | 5.3.2 | 5-13 | I am confused, why are all the scaled floods not multiples of each other. There are several scaled floods, or about the same size, but generated different regulated results. | Jery Stedinger | Dissent | They are multiples of each other, but it's hard to see because there are so many. Please refer to the enhanced text (which also references Appendix E, which we unfortunately didn't provide originally). |
| 100 | 6 | 6-1 | If my Monte Carlo means HEC-WAT , then put HEC-WAT in parenthesis to make clearer. | Jery Stedinger | Concur | Clarified for this study the Monte Carlo utilized the WAT. |
| 101 | 6.2.2 | 6-15 | Table 6-11. Is "160" a typo? Should it be 1.6? | Michael Crouch | Concur | This was a typo. Report has been updated. |
| 102 | 6 | 6-1 | What is ManPlan EIS? Year published? | Jery Stedinger | Concur | ManPlan EIS is the Management Plan Environmental Impact Statement. The Record of Decision was published in December 2018 and the actual EIS was published in August 2018. Both can be found at this link: https://www.nwo.usace.army.mil/mrrp/mgmt-plan/. More detail in the report is provided in Source Model Section 4.1. |
| 103 | 6 | 6-1 | POR or PoR (chapter 5) | Jery Stedinger | Concur | Updated report to be consistent with abbreviation |
| 104 | 6 | 6-1 | The intro section to the MC sampling is confusing--in particular, paragraph 2 and 3 bounce between what was done previously and what was done for this study--suggest reorganizing. | Shaun Carney | Dissent | We feel it is important to keep the descriptions of what was done previously because the previous studies went through rigorous review. Previous MR planning studies such as UMRSFFS and Man Plan helped inform the scope of this study. If the underlying methodology is based on similar procedures for those studies, we bolster the recommendations that using this approach is sound. We are taking it a step farther and improving the procedures. |

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| 105 | 6 | 6-1 | The section also introduces "events", "lifecycles" and "realizations" without really defining these. A figure would be helpful for clarity as this is a critical concept for the reader to understand. I see the terms are defined in 6.1--copy defs into the intro section. | Shaun Carney | Concur | Events and lifecycles are defined in the intro to Chapter 6. Realizations are defined in section 6.2.2. Definitions for events, lifecycles, and realizations for this study were added to the Glossary. |
| 106 | 6 | 6-1 | Instead of "The Missouri River POR has a variety ", say -- The Missouri River POR INCLUDES a variety | Jery Stedinger | Concur | Updated report |
| 107 | 6 | 6-1 | "I do not think you have a "synthetic POR". You develop a synthetic flow record. | Jery Stedinger | Concur | Updated to synthetic flow record and also added definitions to front of report |
| 108 | 6.1 | 6-2 | This is a very innovative way to try to better understand the risk of extreme floods. Some editing should be able to make it easier to understand. | Jery Stedinger | Concur | Minor edits made to clarify |
| 109 | 6.1 | 6-2 | Agree with Jery's comment--the description as it stands is difficult to understand. Some generalized figures and process flow diagrams would be helpful for understandability. | Shaun Carney | Concur | Minor edits made to clarify |

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| 110 | 6.1 | 6-2 | Rather than referring to events (years) and then using "events", recommend using "year"/"synthetic year" throughout this and subsequent sections rather than changing between year and event. I would recommend using "events" to exclusively refer to individual storms or drought periods--this would bring greater clarity. | Shaun Carney | Concur | Updating to reference events when referring to sampling within the WAT. Still referencing years when referring to specific years within the observed POR. |
| 111 | 6 | 6-2 | "POR were verified to closely resemble the historical POR." POR is like 1910 to 2020, or might say the POR is 110 years. Synthetic POR really makes so sense. You generate synthetic flows, synthetic sequences. And what is this lifecycle talk about? | Jery Stedinger | Concur | Confirm with Beth on proper terminology: synthetic POR vs synthetic flow dataset.<br>Lifecycles are a WAT term that defines a period of flows sampled from the larger synthetic flow dataset. For this analysis, lifecycles were 50 years of data simulated through ResSim in a continuous compute. Definitions were added to the glossary section. Changed synthetic POR to synthetic flow datasets |
| 112 | 6 | 6-2 | "When a year is sampled, the hydrology of that year is used “whole,” for the entire year and for all locations in the watershed. " => Say traditionally when .. Because you do not do that here. So let us know this is not what you will do. | Jery Stedinger | Dissent | The WAT/FRA Hydrologic Sampler is still sampling an event "whole" for the entire year and for the entire watershed. The synthetic record we developed for this study is computed externally of the WAT so the Hydrologic Sampler is still sampling an entire event, but the event has been created by mixing different regions and seasons. |
| 113 | 6 | 6-4 | The map shows sub-regions, but these are not referred to in the text. Consider removing, or if needed for this section, discuss what they mean. | Shaun Carney | Dissent | The regions are first mentioned in the preceding paragraph. |

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| 192 | 6.1 | page 6-3 | "The 591-year Big Bucket is used within WAT/FRA with full-year random sampling that maintains the annual serial, correlation, defining a year as starting on March 1 and continuing......" COMMENT: How is the system storage determined for each simulated March 1? The sentence on Page 6-8, "This allowed the model to forecast long term reservoir releases and ensure that all stored flood waters were evacuated prior to the start of the next runoff season." makes me think each March 1 started at the top of system conservation storage. My question then becomes, "why force the start of each year's simulation to be at conservation, if one of the goals is to test the system in 50-year (continuous) lifecycles?" | Kevin Low | Concur | The first sentenced referred to in the comment is referring to the period used for serial correlation. The volume from March 1 - September 30 is used to determine what volume of the next year in the 50-year record used in the lifecycle. Later in the document when the ResSim model is discussed, the continuous simulation is described. The first year of the 50-year simulation begins with the reservoirs at the base of flood control but ResSim then simulates a continuous simulation. The pool elevations at the end of the first year are the beginning pool elevations for the second year. The pool elevations at the end of the second year are the beginning pool elevations at the end of the third year, etc. |

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| 114 | 6.1 | 6-5 | You really mislead the reader by writing as if you are going to use the traditional bootstrapping approach, then switch and say you are doing something different. Please be clear and say, the traditional approach is to, or WAT doers the following …. Then as on page 177 be clear as to how you are getting around the WAT limitation. But what you is much more important than how to get around WAT limitations to do it. The latter is an implementation issue. The former is the innovation in your sampling approach. | Jery Stedinger | Concur | Updated report to make it clearer that a typical WAT Monte Carlo analysis is used. We supplemented the historical sample with the Big Bucket and performed a post-processing on the output. |
| 115 | 6.1 | 6-5 | Not a single paragraph break. - Be kinder to the reader. | Jery Stedinger | Concur | Added some paragraph breaks |

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| 116 | | 6-6 | Formatting >> In addition to keeping the watershed spatially whole, the TRADITIONAL "historical/synthetic bootstrap" sampling method keeps the event temporally whole, meaning that when chosen, the event would be used from beginning to end. However, in addition to combining flows from different years for different regions, the Missouri River Monte Carlo bolstered the available hydrology by using three seasons: early spring, late spring, and remainder, and allowing the seasons from one year to be matched with seasons from a different year.<br><br>For example, the early spring flows from 1976 could be followed by the late spring flows of 1992 and the remainder flows from 1930. Combining seasons from different years in a given region also requires that the random sampling maintain correlation, in this case serial or auto-correlation capturing the relationship of one season to the next.<br><br>Because the "historical/synthetic bootstrap" method does not currently allow for randomly selecting different years of hydrology for each region of the watershed, or for each season of the year, a synthetic dataset was created externally. That dataset randomized four separate regions of the watershed, see Figure 6 1 and Table 6 1, over 3 different seasons, see Table 6 2. The four regions | Jery Stedinger | Concur | Added some paragraph breaks |

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| | | | were separated at gages along the Missouri River and split based on runoff drivers or geographic area. The mountainous region is the drainage area above Garrison Dam, where runoff is driven by the mountain snowpack. The northern plains region is comprised of the drainage area between Garrison Dam and Sioux City, IA, where runoff from the plains snowpack occurs. The southern plains and Missouri hills regions are the drainage areas from Sioux City, IA to Rulo, NE and Rulo, NE to Hermann, MO, respectively.<br>Each season is also split based on runoff drivers where the early spring season (01Mar to 30Apr) is typically when runoff from the plains snowpack runoff occurs. The late spring season (01May to 31Jul) is typically when runoff from the mountain snowpack occurs. These two seasons represent the bulk of the runoff that occurs in the Missouri River Basin so the remainder season (01Aug to 28Feb) captures the remainder of the annual runoff. The synthetic dataset, called the "Big Bucket," is 500 years of synthetic data generated externally along with the 91 years of historical record. It maintains the spatial correlation between the four regions in each season and maintains the serial correlation of each season to the previous season in each region. The 591-year Big Bucket is used within WAT/FRA with full-year random sampling that maintains the annual | | | |

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| | | | serial correlation, defining a year as starting on March 1 and continuing through the end of September. In the Missouri River Basin, this period represents when most of the runoff occurs. | | | |
| 117 | 6.1.2 | 6-8 | Very nice. It is common to describe how you do it first, and then show the results. The results for the marginal distributions are excellent, as they should be (you are resampling). To get the total right is a nice validation of the method, showing a very reasonable extrapolation of frequencies above and below the historical values. NICE JOB. | Jery Stedinger | Concur | |

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| 118 | 6.1.2 | 6-6 | This section discusses the resampling approach and the figure makes it clear that the highest values per region are simple repetitions of the most extreme. Alternatively, you could have sampled from distributions for each season. Consider adding some discussion of why this approach was not taken. The fact that the total fits nicely and seems to be a good extrapolation of frequencies seems to be good validation that the more simplified approach (i.e., resampling rather than distribution-fitting per region) is adequate for the purposes of the study. | Shaun Carney | Concur | Detail from Beth's report was added to the main report to address this comment |
| 119 | 6.1.2 | 6-9 | There are a large number of papers on exactly this topic, and chapters in books. I think a citation would be appropriate, and equation or two. | Jery Stedinger | | Beth: The paragraphs that describe the fact that the season and regions are sampled separately were not included. They are the intro of my chapter on this topic. Only the second section was used. Also doesn't include the later section on the empirical sampling, which answers a later comment. Otherwise, bootstrap sampling is generic, and correlated sampling by gaussian copula is kind of generic. The rest, I developed, and so I don't think it exists anywhere.<br><br>Ryan: Additional details from Beth's report was added to the main report. |

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| 120 | 6.1.2 | 6-9 | SEE, for example >> Stedinger, J.R., and R. Vogel, Disaggregation Procedures for the Generation of Serially Correlated Flow Vectors, Water Resources Research, 20(1), 47-56, 1984. | Jery Stedinger | | See response to comment 121 |
| 121 | 6.1.2 | 6-9 | HOW is this done>> "• Step 4 is using those U[0,1] random values to re-sample the appropriate season from the historical record." There is a tricky step going from uniform, or a "forecast" in normal space, to selecting a discrete value from the historical record. The description of how this was done is INADEQUATE. Maybe you need a note in an appendix. | Jery Stedinger | Concur | It doesn't look like my description of sampling from an empirical dataset was used. It's in my ""big bucket"" chapter. Part of that chapter was pasted in, but the 2nd half wasn't. Text has been updated. |
| 122 | 6.1.2 | 6-9 | What is going on in Table 6-5 escapes me. | Jery Stedinger | | The report seems to have omitted the sentence that should be before the table, and after step 4. "The pattern of random sampling to generate 500 years with 3 seasons in each year, with 4 watershed regions, is as follows." |

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| 123 | 6.1.2 | 6-9 | If you really want to see how this would be done nicely, look at the multivariate version (in Fabers PhD thesis) of Faber, B.A., and J.R. Stedinger, Reservoir optimization using sampling SDP with ensemble streamflow prediction (ESP) forecasts, J. of Hydrology 249(1-4), 113-133, 2001. (Multivariate also in > Stedinger, J.R., and B.A. Faber, Stochastic Dynamic Programming for Hydropower Operations with Ensemble Streamflow Prediction (ESP) Forecasts, IX Symposium Of Specialists in Electric Operational And Expansion Planning, IX SEPOPE, RIO de JANEIRO - BRASIL May 23, 2004.) | Jery Stedinger | Concur | Noted |
| 124 | 6.1.2 | 6-7 | Consider providing the AR model parameters | Shaun Carney | | It's the correlations, along with Normally-distributed N(0,1). This is described in the following sentence, and the correlations are in the previous section. |

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| 125 | 6.2.1 | 6-8 | Discusses using historical runoff forecasts (side: historic vs historical--used incorrectly). What was the source of these historical forecasts used to generate the synthetic forecasts? Was anything done to check the sensitivity of simulations to the forecasts? Please comment (even qualitatively) on the importance of the assumption regarding forecasts. | Shaun Carney | Concur | Changed historic to historical. Historical forecasts were provided by Missouri River Basin Water Management, which creates the monthly, calendar year forecasts. A sensitivity to the forecasts was not completed for this study, but based on previous studies, releases can moderately sensitive to the forecasts when evacuating stored flood waters. During droughts, releases from the most downstream project is driven by storage checks and not forecasts. During flood events starting at normal pools, what comes into the reservoirs, must go out. This means a forecast that misses low in the spring can result in higher releases during the fall. Conversely, a forecast that misses high can result in lower releases in the fall because more water was evacuated during the spring. The ResSim model's goal is to release the lowest amount possible for the longest amount of time possible. |

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| 126 | 6.2.1 | 6-8 | Note I wrote the above comment reading straight through the document--I now realize this is discussed in Section 6.2.2.2. The document could benefit from "roadmapping" where you refer to the following section for details. There are various sections where you present a pseudo-summary of what's coming, but it's unclear that it's not the full description. I recommend changing to a very brief intro of subjects with pointers to where the detail is. | Shaun Carney | Concur | Report revisions throughout are intended to provide more summaries at the beginning of sections and roadmapping. |
| 193 | 6.2.1 | Page 6-8, 9 | The last paragraph of Section 6.2.1 loses me. I do not understand why the WAT needs to have a "known" forecast in order to be able to compute flows. | Kevin Low | Concur | The WAT needs to have a starting value that it can vary around. Since the error statistics are based on the forecast vs actual, the actual or known volume is used as that starting point. |
| 127 | 6.2.2.1 | 6-11 | This sentence contradicts itself - "Lifecycles are generally treated as individual events for each year in the lifecycle" | Jery Stedinger | Concur | This was a confusing sentence. Changed sentence to be: For this study, each realization contained 50 analysis periods or lifecycles. Each lifecycle was a 50-year continuous simulation that allowed the simulation to capture the effects of varied reservoir levels. The maximums and minimums of various parameters were extracted for each event in the lifecycle to create the frequency curves |
| 128 | 6.2.1 | 6-11 | Then -- "so each lifecycle was a 50-year continuous simulation " | Jery Stedinger | Concur | |
| 129 | 6.2.2.1 | 6-12 | I do not know what you did. | Jery Stedinger | Concur | Detail from Beth's report was added to the main report to address this comment |

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| 130 | 6.2.2.2 | 6-10 | Here are some thoughts on the issue> Lamontagne, J.R., and J.R. Stedinger, Generating synthetic streamflow forecasts with a specified precision J. Water Resources Planning and Management, DOI: 10.1061/(ASCE)WR.1943-5452.0000915, 144(4), April 2018. | Jery Stedinger | | Beth: We need to include reference to the forecast sampling theory. Included in the CRT reports but they are not public. Beth wrote the method up in a document on Confluence. Reference that document to describe the forecast method.<br><br>Ryan: I think this comment has been addressed by adding detail from Beth's report. |
| 131 | Table6-6 | 6-12 | I really do not understand what is in this table. Need equations to define variables. | Jery Stedinger | | Beth: We need to include reference to the forecast sampling theory. Included in the CRT reports but they are not public. Beth wrote the method up in a document on Confluence. Reference that document to describe the forecast method.<br><br>Ryan: I think this comment has been addressed by adding detail from Beth's report. |
| 132 | | | When modelling correlations among flows and building multivariate AR(1) models, if often works better to work with the logarithms of the flows, resulting in lognormal marginals. Did you model the raw flows or their logarithms for the purpose of building a multivariate AR(1)? | Jery Stedinger | Concur | Added additional information from Beth's report to the flow frequency report. Did empirical sampling, so didn't' use flow or log-flow. Used N(0,1) values transformed to U(0,1) values, which where used to sample years from the record. |
| 133 | 6.2.2.2 | 6-10 | "Big Bend inflows are included in the Fort Randall forecast." -- unclear what this is/why commented. | Shaun Carney | | There are six reservoir reaches but only error statistics for five reaches. Big Bend's drainage area is small so reach forecasts this reach are combined with Fort Randall's reach forecast. A sentence was added for clarity. |

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| 134 | 6.2.2.2 | 6-12 | Are these standard deviations for the flows, or for the logarithms? | Jery Stedinger | Concur | Statistics are based on volumes not log of volumes. |
| 135 | 6.2.2.3 | 6-14 | "To ensure the Monte Carlo analysis converged and gave accurate results for the tails of the frequency curves…"--we can't ensure it gives accurate results at these tails, but we can ensure volumes are consistent with the Bulletin 17C flow frequency results. This was the real purpose--which is stated later, but should be clarified here. | Shaun Carney | Concur | Clarified sentence |
| 136 | 6.2.2.3 | 6.14 | "Previous studies used one scaling factor for the entire basin…"--recommend adding more detail on how the approach ensures matches 17C before getting into details about scaling and differences with what was done before. | Shaun Carney | Concur | Added some clarifying details in first paragraph. |
| 137 | 6.2.2.3 | 6-15 | "Undeveloped flows represent no regulation and no surface water withdrawals. In the Flow Frequency Study, they are referred to as unregulated flows."--why not call them "unregulated flows" in this section then as well since it's the same study? | Shaun Carney | Concur | Section taken from a different report that refers to flows as undeveloped flows. References to undeveloped flows removed from this report. Glossary has been updated to only show unregulated. |

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| 138 | 6.2.2.3 | 6-15 | "When synthetic events are added to the WAT with assigned AEPs, the WAT creates bins between each synthetic event"--I didn't follow this paragraph. The use of the example years is confusing--why are we talking about 1967, 1995, and 1978? I realize this is from a specific sequence of synthetic years in a realization (or something like that), but it's not clear from the writing.<br>Overall, I can't follow exactly how the synthetic events are used to adjust the original WAT results. The graphics look better with the change, but unclear the justification for the changes or how they are applied as the doc stands. | Shaun Carney | Concur | Paragraph was confusing. Removed. More detail was added in previous paragraphs as to why the synthetic events are needed and how the WAT uses them. |
| 139 | Fig 6-6 | 6-18 | Fig 6-6 is better than 6-5, but it would still be nicer to match better around AEP 0.0003. Wish we had another point in there. It is an important range. | Jery Stedinger | Concur | Figures were trimmed back to 0.002 AEP. This particular WAT simulation was only designed to be confident out to the 0.002 AEP. |
| 140 | 6.2.3 | 6-19 | What here is a "realization" Is that like a lifecycle or big/small bucket? | Jery Stedinger | Concur | Realizations are groups of lifecycles. At the beginning of a new realization, a 90-year Small Bucket is sampled from the 590-year Big Bucket plus synthetic events. Each 50-year lifecycle will then sample from the Small Bucket. |

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| 141 | 6.2.3 | 6-21 | Really? > "There is uncertainty in how many events are needed in each realization to achieve convergence at the desired AEPs. " | Jery Stedinger | Concur | Since knowledge uncertainty is used, which creates the 90-year Small Bucket for each realization, the estimate of flow magnitudes at various quantiles will change depending on how many total events have been simulated. For example, if the first realization sampled several extreme events from the Big Bucket, the estimated 0.01 AEP flow will be high. As more realizations with different sampled events are completed, the estimate of the 0.01 AEP will change. At some point, the estimate of the 0.01 AEP flow will stop changing or have little change even as more events are added. The amount of events needed to achieve this convergence can vary depending on the basin. |
| 142 | 6.2.3 | 6-20 | Where does that rule of thumb come from, or why is it justified? | Jery Stedinger | Concur | The rule of thumb came from a recommendation from the Hydrologic Engineering Committee members that had prior experience in other Monte Carlo studies and noted that was generally when they observed convergence. This was verified for the Missouri River study and displayed in the plots. |
| 143 | 6.2.3 | 6-20 | A half order of magnitude is a factor of 3, so 300 not 500. | Jery Stedinger | Dissent | Unsure on this comment. The order of magnitude example described is based on the 100-yr return interval (0.01 AEP). A full order of magnitude above 100 is 1000 and half an order of magnitude is 500? |

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| 144 | | 6-20 | But asking for a full order of magnitude (factor of 10) is safer. | Jery Stedinger | Concur | We started with half an order of magnitude. If convergence was not observed, more simulations would have been needed. We would have likely incrementally increased the number of events until convergence was observed. |
| 145 | 6.2.3 | 6-20 | What is an event and what is a realization? | Jery Stedinger | Concur | An event is 1 year of data simulated through ResSim. Events are grouped into lifecycles (50-year continuous simulation of ResSim). Lifecycles are grouped into realizations (50 lifecycles per realization for this study). |
| 146 | 6.2.3 | 6-20 | Id=f POR is 100+ years, and you want Confidence Bounds, do you not want to generate MANY 100 year records? | Jery Stedinger | Concur | In a manner of speaking, yes. We are using the realizations to determine confidence bounds. We have 100 realizations so a frequency curve is created for each realization and those frequency curves are used to determine the confidence bounds. For example, there are 100 estimates of the 0.01 AEP flow. If we want the 90/10 confidence bounds, we select the 10th highest and 10th lowest values out of those 100. This process is repeated for each quantile. Since there is 2500 events per realization, we can technically produce confidence bounds out to the 0.0004 AEP. Although we don't show that because we are only confident in the results out to 0.002 AEP. |

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| 147 | Fig 6-7 to 6-10 | 6-21 | Okay, what did you do? | Jery Stedinger | Concur | These plots are showing the estimate of the 0.002 and 0.01 AEP flows based on the mean frequency curve, which is based on the total number of events (all realizations). The discrete points shown in the plots are based on 50000 event increments. As more events are added to the total, the estimate of the 0.002 and 0.01 AEP flows change. At some number of total events, the estimate of flow stops changing. Even if we continue to simulate more events, the estimate will remain constant. If there wasn't an exact discrete point estimate of the 0.01 or 0.002 AEP flow, the value would have been interpolated. |
| 148 | Fig 6-7 to 6-10 | 6-21 | I think the number of discrete points you have was fixed, so as you got more and more years (events?), soon it hung on the best discrete point. What happen to realizations? Now imagine that instead of taking the closest discrete value with and AEP of 0.1%, you interpolated between the discrete points. That would be more reasonable - right? Then what would this look like? And can we use realizations to define a CI or a standard error? | Jery Stedinger | Concur | See response to comment 149. Realizations were used to create the confidence bounds. |

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| 149 | Fig 6-7 to 6-10 | 6-21 | Figures are nice, but I do not know what an event is. Earkuer discussion seems to indicate you were concerned with accuracy of estimated probability associated with a give flow. And that would be easy to compute. But now you seem to be pursuing the accuracy of the flow associated with a given probability - statistically that is a little harder to do, but can be done. What do you want? Then instead of just a nice graph, we might be able to generate a statistical measure of uncertainty. | Jery Stedinger | Concur | Event has been clarified in the report to refer to 1 year. Lifecycles are 50 events simulated as 1 50-year continuous simulation. These graphics are not displaying the official estimate of the 0.01 and 0.002 AEP flows. Rather they are confirming that the Monte Carlo analysis will converge on an estimate of flow at each quantile. |
| 150 | Fig 6-7 to 6-10 | 6-21 | How does the original POR length effect these results? | Jery Stedinger | Concur | Yes, which is why convergence needed to be verified. We are capturing knowledge uncertainty by sampling a Small Bucket, which is based on the original POR length, for each realization. If large events are sampled in the Small Bucket, this will skew the estimates of the flows. However, with enough events, the estimates of flows stop changing even when more realizations/Small Buckets are used in the total number of events. |
| 151 | 6.3.1 | 6-25 | I lost the thread of what was done. When this was presented in power point, it was a lot clearer. The entire Section 6 could really use some flow charts at the start and a high-level overview of the process, with pointers to specific sections providing the details. | Shaun Carney | Concur | Added graphic to show general Monte Carlo process as well as the general steps discussed in Chapter 6. |

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| 152 | 6.3.1 | 6-25 | This section discusses adjusting AEPs to match 17C results. The basic assumption is 17C unregulated frequency is correct, therefore we want WAT to match that. State this clearly. As it stands, this section discusses overriding default probabilities to be correct--it could easily be misread to say that USACE didn't like the outcomes so they went in and changed probabilities to be what they wanted.<br>Again, a figure would help show the distinction. | Shaun Carney | Concur | Report has been updated to specifically state the post processing was done because Bulletin 17C is the official unregulated estimates and the WAT methodology should reproduce it. |
| 153 | 6.3.1 | 6-25 | "The AEP of years in the Big Bucket containing the 1951 and 1986 events could be accurately estimated based on one location because those events were mostly localized to a tributary watershed" -- unclear why this would be the case. | Shaun Carney | Concur | The events that caused the 1951 and 1986 events were intense rain events that we localized over a relatively small area on 1 tributary. Coupled with the lower flows on the Missouri River, estimating the frequency of these events based on locations on the Missouri River resulted in too frequent of AEPs. Estimating the AEPs based on a tributary gage resulted in a more realistic estimate of those events' AEPs. The report has been updated to clarify this. |
| 154 | 6.3.1 | 6-25 | Consider changing "events" to "years" in this section | Shaun Carney | Dissent | Based on other comments, the report was updated to use event when referring a year of flows. |

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| 194 | 6.3.1 | page 6-27 | "To mitigate the limitation of assigning AEPs based on one location, a probability weighting method was applied to the data as a post-processing step." COMMENT: Are there examples cited in the literature where this approach has been successfully taken in order to compensate for WAT's limitation of assigning one probability to each event? (Evidently not, as Section 7.3 implies this study is the first such use.) Alternatively, did HEC document the development of this approach, which can appear as a reference in Section 9? This project hinges on defending/answering the well-made statement in Section 7.3, "Because of the novel approach used in the WAT analysis, and the lack of external review, there is uncertainty that the WAT methodology is acceptable...." | Kevin Low | | A Monte Carlo approach is not new. It is referenced in Chapter 12 of EM 1415, but it hasn't been applied widely for regulated flow frequency because of lack of computing power. Monte Carlo is being used more now with improved computing power and the development of the WAT. The WAT version of a Monte Carlo approach has been used in other studies such as the Columbia River Treaty. The approach completed for the Missouri River Study is the addition of the Big Bucket synthetic record and the post-processing method. The Big Bucket is seen as an improvement because of more variety in flows compared to the observed POR. The post-processing method is a novel idea but has been reviewed. The CRT team is considering revising their output using the same post-processing method.<br><br>Added paragraph to the report in Section 7.3 and the Executive Summary |
| 155 | 6.3.1 | 6-28 | With 250,000 years simulated and convergence verified, the last step to verify that the WAT was sampling and producing hydrology that closely matched the historical record was to compare the 1-day volume frequency curves to the curves created from the historical record. | Jery Stedinger | | I think this is part of comment 158. Responding to both in Comment 159 |

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| 156 | 6.3.1 | 6-28 | Wait> What was verified? Your analysis gets stuck on one of the discrete points. I do not think you have demonstrated accuracy. | Jery Stedinger | Dissent | I think "Your analysis gets stuck on one of the discrete points." is referring to the convergence plots. Those are not frequency curves. They are showing that the estimate of the 0.01 and 0.002 AEP flows are not changing by adding more events. We want to make sure that we are simulating enough total events so the estimate of flows at various AEPs doesn't change just because we simulate more events. Convergence is one form of verification that the methodology is producing quality results. The other part is comparing the WAT output to the Bulletin 17C curves, which is discussed in this section. |

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| 157 | fig 6-11 to 6-12 | 6-26 | I think these two figures show that WAT FAILS at this locations. Particularly Gavin's point. I would conclude we cannot trust the WAT analysis above Nebraska City. Somehow the simple mixing algorithm failed to capture the joint arrival of large flow volumes that Bulletin 17C saw with a mixed population model. | Jery Stedinger | Dissent | These 2 figures show that the raw WAT output underestimates the accepted Bulletin 17C estimates, but that does not mean we cannot trust the WAT output. There is 1 main reason the raw WAT output differs from the Bulletin 17C estimates. Each event is only given 1 AEP, which can be vastly different depending on the selected location. The WAT could be calibrated to match the Bulletin 17C curve at 1 location by setting the incremental probabilities of each event in the Big Bucket and the synthetic events to the Bulletin 17C estimates at that location. Calibrating the WAT would make 1 of these plots match the Bulletin 17C curve. This process is essentially changing how often each event is sampled during the Monte Carlo simulation. However, all other locations wouldn't match their respective Bulletin 17C curves. The post-processing portion of the methodology, which produces the final estimates, is doing the same thing as calibrating the WAT but allows each location's WAT output to match its respective Bulletin 17C curve. |
| 158 | fig 6-13 | 6-27 | Kansas city is great. Two methods support each other. | Jery Stedinger | Concur | |

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| 159 | 6.3.1 | 6-28 | What is the theory that justifies this 0.5 adjustments. Need an equation. Are we trying to go from a set of points with probabilities pi, to a cumulative distribution function, where need to split the pi for that value? This section is written as if this is magic that people should automatically understand. It is not magic, and it needs a little explanation. | Jery Stedinger | Concur | Added clarification to report |
| 160 | 6.3.1 | 6-28 | Put the paragraph starting with, "Probability weights were assigned to individual undeveloped events in order to match the Bulletin 17C flow frequency curves at each gage." into bullets (or short paragraphs) and show the equations. I followed the previous paragraph, but then lose it in reading this paragraph--I get bogged down by all the examples numbers, forgetting what goes with what. | Shaun Carney | Concur | Broke up paragraph into several shorter paragraphs. |
| 161 | 6.3.1 | 6-28 | Paragraph starting with "Each year sampled by the Hydrologic Sampler is simulated through the ResSim model, producing regulated flows…" is a nice introduction to *why* we should use the WAT/ResSim approach--use this as an introduction paragraph to Section 6. Lost buried here. | Shaun Carney | Concur | Report edited |

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| 162 | 6.3.1 | 6-29 | "Post-processing mean frequency curves based on all 250,000 events alters the uncertainty around the mean frequency curve. " + ADD because the probability assigned to some of the largest flood values were increased. | Jery Stedinger | Concur | Report edited |
| 163 | Fig 6-14 | 6-30 | Tell us prob. curve for what: "An Example Probability Distribution Curve is Shown as a Blue Curve" | Jery Stedinger | Concur | Updated caption to state Nebraska City |
| 164 | Fig 6-14 | 6-30 | WHAT SITE? | Jery Stedinger | Concur | Updated caption to state Nebraska City |
| 165 | fig 6-15 | 6-30 | I do not believe that the WAR Adjusted should almost equal the upper CI for the WAT Adjusted at the upper end (0.2%). I read the page 182 discussion of the desire to avoid releases at Oahe, but at some point they must. I fear that the operations is codes so it cannot happen, which appears not to be correct. | Jery Stedinger | Dissent | Figure 6-16 shows the final output for Gavins Point. The plateau at 164 kcfs does occur because the ResSim model does try to limit the amount of times that the Oahe spillway is utilized. However, operations are not coded so that it cannot happen. Releases exceed 164 kcfs around 0.04 AEP. At this point, events are too large to not use Oahe's spillway so releases exceed 164 kcfs. |

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| 166 | Figure 6-15 | 6-30 | If I'm reading this correctly, the "adjusted" WAT is 465k vs 360k for the "unadjusted" WAT -- about a 30% increase at 0.2% exceedance probability. This suggests the adjustment is a key driver of the outcomes; it also suggests if the adjustment is correct, the WAT/ResSim modeling didn't do a particularly good job of representing reality. Was any sensitivity done for the adjustment procedure? Any commentary on why? | Shaun Carney | Concur | The unadjusted output or the raw WAT output underestimates the accepted Bulletin 17C estimates, but that does not mean the WAT cannot do a good job of estimating reality. There is 1 main reason the raw WAT output differs from the Bulletin 17C estimates. Each event is only given 1 AEP, which can be vastly different depending on the selected location. The WAT could be calibrated to match the Bulletin 17C curve at 1 location by setting the incremental probabilities of each event in the Big Bucket and the synthetic events to the Bulletin 17C estimates at that location. Calibrating the WAT would make 1 of these plots match the Bulletin 17C curve. This process is essentially changing how often each event is sampled during the Monte Carlo simulation. However, all other locations wouldn't match their respective Bulletin 17C curves. The post-processing portion of the methodology, which produces the final estimates, is doing the same thing as calibrating the WAT but allows each location's WAT output to match its respective Bulletin 17C curve. There was a sensitivity completed on the post-processing. It found that the post-processing was moderately sensitive to certain events in the Big Bucket. Mostly the large events that occurred over unregulated drainage areas because those events tended to have a smaller spread of regulated peaks. Care was taken not to adjust the weights of those events. |

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| 167 | Table 7-1 | 7-1 | I would need help with a discussion of these points before I agree. There is a tremendous amount packed in here. | Jery Stedinger | Concur | Chapter 7 tables revised significant and discussion added to lead the reader through |
| 168 | 7.2.1 | 7-3 | Is this a glossary - then should be at end. If there are basic definitions, should go in the beginning. If this is a review of the basic methodology, then it should do that -= not just provide unconnected definitions. | Jery Stedinger | Concur | move to glossary |
| 169 | 7.2.1 | 7-3 | Agree re: glossary -- there is already a glossary section. Is section 7 intended as a standalone document? Looks like this was just dropped in without trying to merge with the other earlier sections. | Shaun Carney | Concur | It was dropped in. Was merged to a single glossary. |

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| 170 | 7.2.1 | 7-3 | I was unable to understand the WAT method before. The Big Bucket included all of the mixing of regional areas (4) for different seasons (3)? This then allowed you to have a greater or effectively a longer record of flows. Include both more extreme and drier conditions than were in the 100 real record. So now we effectively has 590 years. -- Did you then sample whole years from this 590 years Bucket??? And if so, to estimate the AEP for any quantile, why not just simulate the 590 years - each and every year once? I think the answer is (1) because of over-year storage it depends on the sequence of the years, and (2) by redrawing POR sequences you can capture the uncertainty in the whole computation (if data processed correctly). Please confirm. | Jery Stedinger | | Correct. The 6 mainstem reservoirs are extremely large and can produce vastly different regulated flows downstream of the system depending on how much storage is available to capture runoff. Different runoff forecasts can also have an impact on regulated flows. Therefore, multiple combinations of pool elevations, forecasts, and events are needed. |
| 195 | 7.2.2 | Page 7-3,4 | "If WAT Monte Carlo unregulated flow frequency curves track closely to the undeveloped Bulletin 17C flow frequency curves, we conclude that the WAT Monte Carlo method is producing the hydrology that accurately represents the historical POR." COMMENT: I concur. | Kevin Low | Concur | Acknowledged |

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| 196 | 7.2.2 | Page 7-4 | "It is known from previous studies and reviews of the underlying MR ResSim Model being used in the WAT that the MR ResSim model is accurate with respect to Missouri River Mainstem Dams operations and regulated flows." COMMENT: "accurate" or should we way "adequately simulates". We too use this (or very similar ResSim), but ResSim does not "accurately" (I would argue) capture the day-to-day operational flexibility built-in to the regulating rules. | Kevin Low | Concur | Updated reported to state "adequately simulates". The ResSim model simulates all the criteria within the Master Manual, but it is still a model and all models have limitations. In this case, there is limitations in how accurate tributary flows are forecasted within the model vs actual operations, deviations in releases due to river ice, etc. |

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| 171 | 7.2.2 | 7-4 | WEIGHTS -- What was done appears to be valid and entirely appropriate. However, the justification is included along with chatter that detracts from the validity of what was done. You note that two watersheds have unusually large floods, to which you wish to assign more appropriate probabilities. And because you added "scaled" events, they are not equally likely realizations as WAT assumes (when redrawing "equally likely" sample values. To assign reasonable probabilities to these two sets of unusual events , the frequency distribution developed using Bulletin 17C was used as guidance. {Please avoid saying weights. You may have achieved your end by using weights to draw some values more frequently, BUT the issues is how to assign PROBABILITIES to these two sets of special values.} The description of weighting sounded like you were just adjusting WAT probabilities to match 17C, and thus WAT was no longer an independent analysis. | Jery Stedinger | Concur | The last sentence is correct, except that the WAT is not trying to be an independent analysis. It's trying to be consistent with the 17C curves. |

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| 172 | 7.2.2 | 7-4 | YES> The Transform method uses the unregulated Bulletin 17C curves directly, so that method does not need to reproduce them through sampling like the WAT Monte Carlo method. | Jery Stedinger | Concur | Yes the unregulated to regulated transform relationships are applied directly to the Bulletin 17C flows to estimate regulated flows in the "transform method". |
| 173 | 7.2.4 | 7-5 | NOW you tell me > "The WAT samples 90 years (length of the historical POR) from the Big Bucket " | Jery Stedinger | Concur | Order of discussion revised in report |
| 174 | 7.2.5 | 7-6 | QUOTE > "Historic floods and perception thresholds help reduce knowledge uncertainty for the undeveloped flows, but this does not reduce the knowledge uncertainty for regulated flows." Wrong. Hist. Info improves the unregulated flood distribution, upon which the regulated distribution is based. So hist. info does reduce knowledge uncertainty. | Jery Stedinger | Concur | Changed text to " Historic floods and perception thresholds help reduce knowledge uncertainty for the unregulated flow frequency which indirectly improves the regulated flow frequency." |
| 175 | 7.2.5 | 7-6 | For the B17C analysis you smoothed the mean, st. dec. and skew. Did you do the same with WA T when it generated quantile estimates that went into the uncertainty analysis. IF not, you are not mimicking how the analysis was done. | Jery Stedinger | tentative | From Ryan: "We weighted the WAT unregulated flow frequency curves to match the final B17C curves, which I'm assuming used the smoothed statistics. What does he mean by quantile estimates for the uncertainty analysis? If he means did we apply the same weighting to the confidence limits, then yes. I applied the same weights that were used to match the final B17C curves when I calculated the confidence limits. " |

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| 176 | 7.2.5 | 7-7 | YES> "No matter how carefully the scaled floods are chosen or how many are chosen, they will not capture the relative frequency of runoff throughout the basin at the extremes that determine the shape of the transform curve for extreme events." Thus one must use extreme care in extrapolating the transformation function. | Jery Stedinger | Concur | Acknowledged |
| 177 | 7.2.5 | 7-7 | Quote> "The transform must be thought of as a probability transform. In other words, how does the magnitude of flow at a given probability change between basin conditions? Or how does the probability of a flow of a given magnitude change between basin conditions?" I think this is backwards. You have a quantile transformation function. The undeveloped flow associated with some probability is transformed into the developed flow associated with that same probability. Look at how the transformation function was derived when you pair ranked flows (thus finding how to transform one set of quantiles to another. | Jery Stedinger | Concur sort of? | "How does the magnitude of flow at a given probability change between basin conditions" = "The unregulated flow associated with some probability is transformed into the regulated flow associated with that same probability." I think the previous two sentences are equivalent. What I'm trying to say is that, rather than thinking of a transform function as taking you from one unregulated flow to another regulated flow (this is a shotgun blast because of initial conditions and runoff distributions, etc.), the transform function is only useful for converting an unregulated flow frequency curve into a regulated one by accounting for the probabilities of various flows and the differences between them across different basin conditions. I would really like to find a clear way to communicate this as I feel there is a lot of misunderstanding about this method, especially when adding scaled floods because their probability is not known. |

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| 178 | 7.2.6 | 7-7 | I find this hard to believe > "Out of the 250,000 simulated events, there are only 618 unique flow events used in the WAT simulation. " And what is an event anyway? { 100 years of data times 4 regions suggests 10^8 scenarios for each season are possible. If we consider 3 seasons that is 10^24. Certainly bigger than 618.} | Jery Stedinger | Dissent | We created a 500-year synthetic record through the sampling of flows from 4 regions and 3 seasons. We then added the observed record to that for a total of 590 unique events. An event was defined as 1 year of flow. We also added several synthetic scaled events to ensure we had large enough events to define the upper end of the frequency curve for a total of 618 events defined in the WAT. The hydrologic sampler samples events or years of flow from those 618 events and simulates them through the ResSim model. Although there are 618 unique events, each time run through ResSim, the simulation can have different starting conditions (e.g., pool elevations) and/or runoff forecasts that will provide different regulated results for each simulation. |

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| 179 | 7.26 | 7-8 | NOW YOU SAY > "There is also a threshold when releases from Gavin's Point will exceed 164,000 cfs. This is based on when Oahe's spillway will be utilized." YES. Something is wrong with HecSim which appears to not allow this reality. AND that reality may be a true disaster if Oahe were to fail. And it is the likelihood of that catastrophe that should be pointed out by this study. HOWEVER, here we are only going to an AEP of 0.002, or one in 500. And you are not modeling flows above Gavin's point. So if the argument that the probability of inflows to Gavin's Point exceeding 164,000 is less than 10^(-5), and thus is outside the range of this study ??? | Jery Stedinger | Dissent | We are not reporting flows above Gavins Point but we are modeling the entire Missouri River Mainstem System from Fort Peck Dam to Hermann, MO. The regulated flow frequency curve at Gavins Point reflects System operations and does show the point when Oahe's spillway is utilized. Figure 6-16 shows 164 kcfs release until ~0.04 AEP. At that point, releases exceed 164 kcfs which means Oahe's spillway is being utilized. |
| 180 | 7.3 | 7-8 | If this were so, it would be a big concern >> "post processing the WAT results to align the sampling with computed Bulletin 17 unregulated peak flow results. " However, I understood that there were a few special values that one could anticipate had problems and it was the probability of those values that were adjusted with the reality provided by the B17C analysis. | Jery Stedinger | | See response to #179 above. |

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| 181 | 7.4 | 7-8 | If you say that WAT results were adjusted to match Bulletin 17C, then you should NOT SAY in the conclusions >>"Confidence in the results of this method is increased because the unregulated output matches Bulletin 17C unregulated peak flow frequency curves" | Jery Stedinger | Concur | The WAT output is adjusted to match the unregulated flow frequency but that is not the goal. The confidence in the regulated flow frequency curves is higher because the unregulated WAT output is matching the Bulletin 17C curves. |
| 182 | 7.5 | 7-9 | Please be a little more humble. The Archilles Heel of WAT is that the mixing frequencies may not be correct. There is a lot that could go wrong in the specification of the joint distribution of flows in the 4 regions. Did you use a multivariate distribution for the flows, OR the LOG of the flows, or some other transformation. That would be worth looking as a sensitivity analysis exercise. | Jery Stedinger | Concur | Agreed that sampling is critical. More detail was added to describe how the sampling of regions and seasons was completed. Several different 500-year synthetic records were developed and compared. Each record was assessed and the team selected the best record based on shape of the curves and spatial and serial correlation values (compared to the historical record). After the synthetic record was completed, the WAT sampling during the Monte Carlo simulation was also assessed. To ensure the sampled years during the Monte Carlo simulation was representative of the historical record, a post-processing step was completed by adjusting the weights of each event so the unregulated flow frequency curve from the WAT matched the Bulletin 17C frequency curve. Those weights were then translated to their resulting regulated flows to provide an adjusted regulated flow frequency curve. |
| 183 | 7.6 | 7-9 | Why is there more after the final two sections? | Jery Stedinger | | Formatting revisions made to address |

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| 184 | 7.6 | 7-9 | Need text for fig 7-2 through 7-27. | Jery Stedinger | Concur | Added clarification to report |