Appendix L

Inflow Uncertainty Analysis

INFLOW UNCERTAINTY ANALYSIS

Farad Natural Flow Hindcasts

Impacts on Floodspace Modeling

To: WMOP Technical Team

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2 INTRODUCTION

Hindcasts are re-forecasts of historical events produced using the latest Ensemble Streamflow Prediction (ESP modeling technology). ESP forecasts produce an ensemble of runoff forecasts based on the rainfall-runoff models result with current soil and snow conditions, short term weather forecasts, and climate from an ensemble of historical years for the remainder of the outlook. The runoff forecast based on each year's historical climate pattern called a "trace" and at the time of this report RFC had 41 traces in each ensemble. These traces allow computation of the risk/probability that the forecasted runoff will be within specified ranges such as above flood stage. Hindcasts are useful in that they provide an opportunity to evaluate current ESP technology by comparing its resulting forecasted flows to historical flows.

It is important that the term hindcast not be confused with a forecast. Forecasts apply current modeling technology to predict future flows that have not yet occurred, whereas hindcasts are forecasts produced with current ESP technology for periods of time that have already occurred. Thus, hindcast results are comparable to historical flows, whereas forecasts are not. Other additional differences between hindcasts and forecasts exist as well.

For the Water Management Options Pilot (WMOP) study, the California Nevada River Forecast Center (RFC) has produced hindcasts at daily and hourly timesteps for dates ranging from February through March 1986, as well as the entirety of water years 1990 through 2020. Hourly hindcasts contain forecasted Truckee River Basin flows from 12:00 pm on the re-forecast date produced, through 12:00 pm 30 days later. Daily hindcasts contain daily forecasted Truckee River Basin flows ranging from the re-forecast date produced through 365 days later. Hindcast products have the same outlooks as the forecasts produced each day by RFC. One difference between the hindcast and the forecast is that hourly forecasts are produced twice per day during the rainy season and four times per day during flood events.

The concept of a forecast produced date is important to this analysis, too. A forecast produced date is synonymous with the first re-forecast date in each hindcast. For instance, a hindcast with January 1st, 2000, in its title has a forecast produced date of January 1st, 2000.

This forecast produced date is not to be confused with the forecasted date of a given hindcast. A forecasted date refers to a date within a forecast that flows are forecasted for within a given hindcast. For instance, the daily January 1st, 2000, hindcast has forecasted dates ranging from January 1st, 2000, through January 1st, 2001. The January 1st, 2000, hourly hindcast has forecasted dates ranging from 12:00 pm on January 1st, 2000, through 12:00 pm on January 31st, 2000.

Another important term employed often within this report is the concept of an outlook. The length of time between a given forecast produced date and a given forecasted date will hereby be referred to as the outlook. For example, a forecasted date of January 3rd, 2000, within the hindcast produced to re-forecast flows on January 1st, 2000, represents the 3-day outlook of the hindcast produced for January 1st, 2000. The date a given hindcast is produced corresponds with the one-day outlook by this convention.

A third term utilized often within this report is that of skill. Skill can be thought of as the ability of hindcasts to produce predicted flows that accurately and/or precisely characterize historical flows.

These RFC products provide an opportunity to evaluate current ESP forecasting technology's ability to represent observed flows. Specifically, this inflow uncertainty analysis seeks to identify and characterize the flow forecasting skill of hindcasts across time (1990-2020) in terms of both seasonality and outlook. The results of this evaluation may influence the methodology of floodspace modeling within the scope of the WMOP, despite the potential limitations of extrapolating results from a 30-year dataset.

This report is intended to be read while reviewing the Inflow Uncertainty Analysis PowerBI viewer. A link to view the published PowerBI Viewer is available below.

Link to PowerBI Viewer: Inflow Uncertainty Analysis PowerBI Viewer

3 How Hindcasts Will Be Used in WMOP Study

Hindcasts will be analyzed to determine floodspace requirements. The flood space requirements will be run through the TROA Planning and new Truckee Hourly RiverWare Models developed by Precision Water Resources Engineering (PWRE) to evaluate how the flood space scenario meeting the WMOP studies objectives. Specifically, each daily hindcast will be used to calculate the cumulative natural (unregulated) flow volume over a specified Reno flood flow target across various outlooks and percent exceedance forcings. Specific outlooks considered within this study include 1-5, 7, 14, 30, 60, 90, 120, and 180 days. After all the hindcasts' cumulative flow volumes over the flood flow target at each outlook are calculated, a specific percent exceedance value will be used to the cumulative storage value for each outlook (computing the storage requirement exceeded by a specified percentage of the RFC traces). Whichever outlook requires the most floodspace (the controlling outlook) will be used to determine the floodspace that is required. The specific percent exceedance value for each outlook will be calibrated by an MOEA optimization algorithm. In this way the exceedance value for each outlook that best meets the collective objectives for the WMOP project will be determined.

The percent exceedance employed at each outlook is important to flood space requirements informing the Planning and Hourly models. Since we would expect some continuous behavior in the skill of the hindcast as a function of the outlook and to limit the number of decision variables relationship between exceedance and outlook will be defined. Note that Equation 1 is subject to change.

Equation 1: Exceedance Outlook Relationship

$$y = c + ax^b$$

Where y is percent exceedance,

x is the outlook (days), and

a, b, and c are coefficients optimized by the MOEA algorithm

It is important to understand the impacts of this relationship between percent exceedance and outlook on flood space requirements in the Truckee Hourly model and TROA Planning models. The example below demonstrates how the MOEA optimization algorithm produces different exceedance and outlook curves employing Equation 1 above. In Figure 1 below, the two bold lines represent examples of the outlook exceedance relationship optimized for two different objectives. The bold grey line represents the preliminary optimized relationship for the "average annual days missing the Floriston rate" objective. The bold yellow line represents the preliminary optimized relationship for the "100-year flood flow objective".

Both objectives are ideally minimized as much as possible. The "average annual days missing the Floriston rate" objective can be thought of as a proxy for water supply, whereas the "100-year flood flow objective" can be thought of as a tangible example of flood risk mitigation. Intuition would suggest that the water supply objective would seek to minimize flood space requirement on a given day. It is also anticipated that the flood mitigation objective would seek to maximize flood space requirements on a given day. In other words, these objectives are conflicting, thus their optimal percent exceedance-outlook relationships are expected to differ at some or all outlooks.

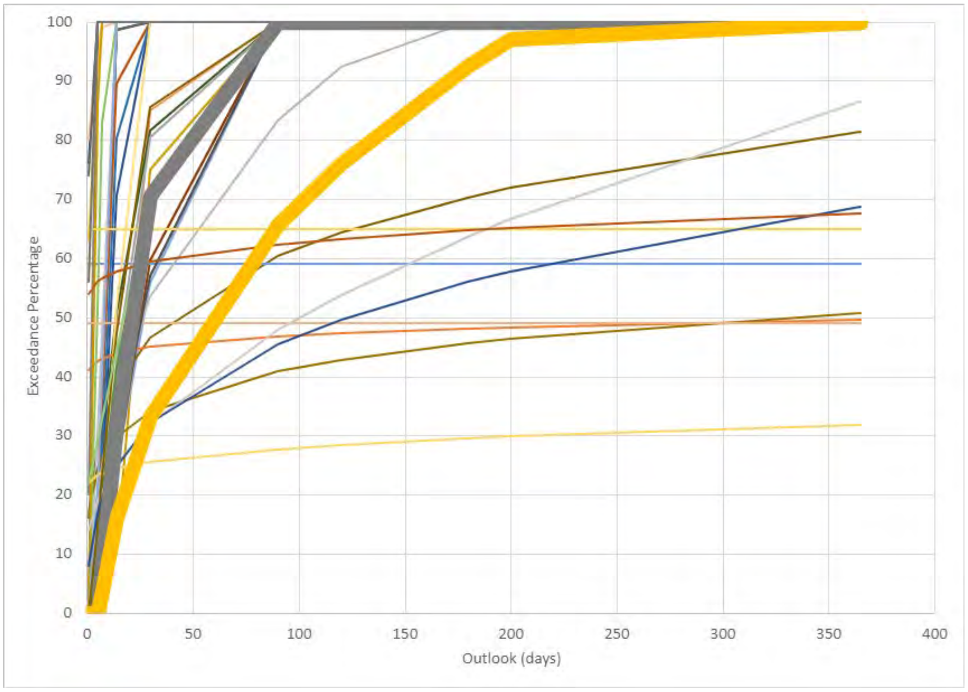


Figure 1: MOEA Preliminary Optimized Percent Exceedance vs Outlook Relationship for Two Conflicting Objectives

Figure 1 realizes these anticipated results. Between outlooks of about 5 days through 300 days, the bold, grey, average annual days missing FR objective exhibits a higher percent exceedance at each of these outlooks than that of the bold, yellow, 100-year flood flow objective. This means that the yellow, 100-year flood flow objective's optimized exceedance outlook relationship requires more flood space at these outlooks than that of the grey, average annual days missing FR objective. At outlooks less than about 5 days, and greater than about 300 days, both bold curves exhibit very similar preliminary optimized exceedance outlook relationships. This means that the optimal relationships for these two objectives will likely require similar floodspace volumes at these outlooks.

Two additional broad objectives of the WMOP study that should be considered for this analysis are that acceptable scenarios must (1) “Must be technically feasible to implement” and (2) “Bring WCM up to date with current technologies and capabilities and allow flexibility for future improvements in data availability and forecasting of future climate conditions”. The first objective should be considered in that whatever processing method to compute a flood space requirement from the RFC ESP forecasts needs to be able to be computed each day in a timely manner after RFC forecasts are produced for the day. The second objective is that an acceptable scenario must “Bring WCM up to date with current technologies and capabilities and allow flexibility for future improvements in data availability and forecasting of future climate conditions”. For the second consideration, use of the RFC ESP forecasts in any capacity will update the WCM to the current technologies which is an improvement over the statistical runoff forecasts based on manual snow measurement that were available when the 1985 WCM was written. The RFC ESP forecast will evolve as new forecasting skill and technologies become available, so using these forecasts will meet the objective of allowing flexibility for future improvements in forecasting. One question that this report seeks to consider is how the well the computed runoff forecasts (based on an optimized MOEA result) will evolve, as the MOEA calibration would adjust for any bias and/or the current skill of the current RFC forecast which may not persist into the future. Discussion of any systematic bias that exists and potential corrections will be discussed later in the report.

4 HINDCAST UNCERTAINTY ANALYSIS OBJECTIVES

To best inform the WMOP’s RiverWare models flood space requirements, the hindcasts’ Farad Natural Flow skill in terms of outlook as well as seasonality must be characterized and accounted for. Hindcast skill in both contexts is characterized by comparing hindcasted cumulative volumes to observed historical cumulative volumes. Within this comparison of hindcasted to historical data, there are a few objective questions that need to be answered.

The first of these questions is, "Does hindcast skill vary seasonally?" To answer this question, analysts must determine what time or times of year that hindcasts predict historical volumes with the smallest amount of error or bias.

The second major question to be answered is, "Do hindcasts vary by outlook?" A more specific question pertaining to this concept includes, "How far in advance of an event can hindcasts accurately predict historical flow volumes?"

The third major inquiry is, "Are hindcasts biased?" To determine if this is true, the frequency and magnitude by which hindcasts' cumulative volumes overshoot or undershoot historical cumulative volumes must be determined.

The fourth and final major topic for investigation is, "Are hindcasts a good representation of real probabilities?" A more targeted inquiry serving to answer this question is, "What percent of the time is the observed volume greater than the 90% exceedance forecast? What percent of time is it greater than the 10% exceedance forecast?" To evaluate this question, the observed volumes can be compared to the hindcast volume statistics to determine how frequently the observed volume was within the various hindcast volume ranges.

All these questions may have impacts on the approach to modeling floodspace within the WMOP's RiverWare models. Generally, the form of the exceedance outlook equation(s) ultimately used in used in the WMOP study should be able to represent the expected variability in hindcast skill as a function of season and outlook. For example, if the hindcasts are shown to have different performance in the summer months than the fall months, then the equations used for the exceedance outlook relationship should be parameterized in a way that could be considered via MOEA optimization.

5 Potential Impacts of Analyses on Flood Space Modeling

Depending on the results of the inflow uncertainty analysis, one or more of the following adaptations may be applied to the exceedance outlook equation and its application to floodspace modeling. A short summary of the means and outcomes of each potential modeling impact is summarized below. Any or all these potential modifications to floodspace requirement calculations may be employed within the WMOP's RiverWare model flood space requirement inputs. The formulation of the flood space calculation ultimately used for the MOEA analysis will depend on what is agreed upon amongst the WMOP technical team.

5.1 Adjusting Hindcast Range

Should the hindcasts' representation of probabilities deviate from expected probabilities, it may be justified to adjust the range of hindcasts. This change to the modeling process would include expanding the range of RFC traces so the observed volumes fall within the hindcast ranges at the expected frequency of occurrence. In other words, this would allow corrected RFC hindcast flows to the variability and value of observed flows.

5.2 Incorporating Hindcast Skill Seasonality

This potential modification to floodspace modeling would be justified if (1) flow volumes of hindcast produced dates in a given season--associated with several outlooks--demonstrate consistent skill and (2) hindcast produced dates in differing seasons demonstrate different skill. Should this modification be modified, this would result in implementing two different exceedance outlook equations for different times of the year when modeling floodspace. For example, if hindcasts have similar skill at several outlooks during the fall months, and consistently different skill during the Spring, a second exceedance outlook relationship in addition to Equation 1 may be implemented to determine fall and Spring floodspace requirements.

5.3 Bias Correcting

If the hindcasts unveil predicted flows systematically larger or smaller than historical flows across outlooks and forecast produced dates, then it may be valid to systematically scale the floodspace requirements up or down, depending on their magnitude of bias, when completing the floodspace calculations. This bias correction could be recomputed for future hindcast efforts and adjusted within the revised WCM to allow for potential future improvements in the RFC forecast skill.

6 Methods

Several visuals were compiled to assess the skill of hindcasts. This section details each analysis metric employed within them and their overall significance in determining hindcast skill.

6.1 Data Sources

Historical and hindcasted data at a daily timestep throughout the study's period or record needed to be obtained for comparison within the Inflow Uncertainty Analysis PowerBI viewer. All hindcast data was computed by RFC specifically for the WMOP project. Historical data for the WMOP study was developed by both PWRE and Stetson Engineering. Data prior to the year 2000 daily data was prepared by Stetson engineering, and post-2000 daily data was prepared by PWRE. A diagram of data employed in these analyses and their sources is available in Table 1. Note that since hindcast data was not available between 1987-1989, only historical and hindcasted data from 1990-2020 was analyzed during this effort.

Table 1: Inflow Uncertainty Analysis Data Sources

Data Type	Time Period Applicable	Data Developers
Hindcasts	Feb-March 1986-2020	RFC
Historical	1985-2000	Stetson Engineering
Historical	2001-2020	PWRE

6.2 Metrics

This section defines and describes statistical metrics utilized to quantify hindcast skill.

6.2.1 Ratio of Hindcasted to Historical Cumulative Volumes

A metric used throughout these analyses is the average ratio between hindcasted and historical cumulative volumes. This metric characterizes hindcasts bias. The numerator to this ratio is the hindcasted cumulative volume (Acre-ft) at the selected outlook and 50% exceedance, averaged over all the forecast produced dates selected. The denominator to the ratio is the historical cumulative volume (Acre-ft) at the same selected outlook and percent exceedance, averaged over all forecast produced dates selected.

$$Ratio = \frac{Avg(Median\ Hindcasted\ Cum.Vol.)}{Avg(Historical\ Cum.Vol.)}$$

6.2.2 R-Squared

This metric is a linear regression correlation coefficient which describes how much variability within the historical cumulative volumes is explained by the median hindcasted cumulative volumes.

$$r^2 = \left(\frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} \right)^2$$

where

x = historical cumulative volume,

and

y= hindcasted cumulative volume

6.2.3 Average Difference

Average difference is defined as the difference between (1) the average historical cumulative volume at the selected outlook and forecast produced dates, and (2) the average hindcasted cumulative volume at the selected outlook, percent exceedance, and forecast produced dates.

$$Average\ Difference = Average(Historical\ Cum.Vol.) - Avg(Hindcasted\ Cum.Vol.)$$

6.2.4 Mean Absolute Error (MAE)

Mean absolute error is defined in this study as the absolute value of the difference between historical cumulative volumes and hindcasted cumulative volumes at the selected outlook, percent exceedance, and forecast produced dates selected.

$$MAE = Absolute\ Value(Historical\ Cum.Vol. - Hindcasted\ Cum.Vol.)$$

6.2.5 Average Percent Error

Average percent error denotes the difference between average historical and hindcasted cumulative volumes divided by the average historical cumulative volume at the selected outlook, percent exceedance, and forecast produced dates selected.

$$Avg\ Percent\ Error = \frac{Avg(Historical\ Cum.Vol.) - Avg(Hindcasted\ Cum.Vol.)}{Avg(Historical\ Cum.Vol.)}$$

6.3 VISUALS

6.3.1 A Note on PowerBI Filters

PowerBI allows for dynamic data visualization via “Slicers”. These slicers allow the user to specify what data is plotted. There are a few different categories of information corresponding with both historical and hindcast data within the PowerBI viewer has been updated to filter results based upon the forecast produced date. Several data fields within the PowerBI viewer have corresponding slicers for users to experiment with.

The first filter to be applied to a given visual is location. Two locations are available for viewing: Farad Natural Flow and Farad to Reno Local Inflows. However, results of these analyses are limited to Farad Natural Flow.

Secondly, date information specified in the "Year" and "Month" slicers filters both historical and hindcast data by forecast produced date selected. Specifically, these slicers can filter results by forecast produced year and forecast produced month. Results of these analyses incorporate all forecasted months and years. By default, forecast produced date years 1990 through 2020 are selected, since historical data between 1986-1989 are not available within the PowerBI viewer for comparison.

Thirdly, the PowerBI visual's percent exceedance and outlooks selected for plotting can also be controlled by the user on most tabs. Note that most results in this report refer to the median percent exceedance, due to its frequent use in many real-world utilizations of ensemble forecasts.

Although all these slicers are made available to the user, it is recommended that the user set percent exceedance to 50% when viewing results, since these filters apply to most analyses offered in this report and inform the potential modifications to floodspace modeling methods within the WMOP study.

6.3.2 Scatter Plot

Fundamentally, this plot is configured to determine when and by what percentage hindcasts overshoot or undershoot historical flow volumes. The scatter plot view qualitatively and quantitatively compares historical cumulative volumes to hindcasted cumulative volumes. This comparison is achieved by plotting these variables directly against one another and compiling some summary statistics. Specific summary statistics analyzed with this view include the average ratio between hindcasted and historical cumulative volumes, and R-squared.

6.3.3 Histogram

This plot is intended to help answer the question of how reliable hindcasts are at predicting flow volumes within certain percent exceedance ranges. Plotted on the x-axis is the confidence interval, or percent exceedance range, being analyzed. On the y-axis is the frequency by which hindcasted flow volumes fall within a given percent exceedance range relative to historical data, depending on the outlook, confidence interval, and forecast produced dates selected.

6.3.4 Correlation Plot

This view investigates to what extent the variability of historical volumes is explained by the hindcasted volumes. This view also illustrates how consistently this variability is explained by hindcasted volumes over time. The x-axis of this plot features the forecast produced date by month, and the y-axis displays the correlation coefficient, which is the R-squared metric. Summary statistics on this view include the R-squared aggregated by month across all hindcast produced dates selected. The result of this statistic is dependent on the percent exceedance, outlook, and forecast produced dates selected.

6.3.5 Bias

This view describes the difference in magnitude of differences between hindcasted and historical volumes. Plotted on the x-axis is the forecast produced date, aggregated by month. This view features dynamic y-axis, in which the user can select between average difference, MAE, or mean percent error statistics.

6.3.6 Correlation vs Outlook

This plot unveils at a high level how correlation, or R-squared, varies with outlook. Specifically, the x-axis displays the outlook in days, and the y-axis shows the correlation coefficient. The series plotted on this view demonstrate the relationship between outlook and R-squared aggregated by hindcast produced date month. Additionally, this view displays this relationship aggregated across all selected hindcast produced dates. Summary statistics tabulated on this view is the correlation coefficient between hindcasted and historical volumes by outlook.

6.3.7 Ratio vs Outlook

This final view allows for comparison of the outlook in days to the average ratio of hindcasted to historical flow volumes aggregated by hindcast produced date month. Additionally, this view displays this relationship across all hindcast produced dates selected. Summary statistics tabulated on this view is the average ratio of hindcasted to historical volumes by outlook.

7 RESULTS

To understand the relationship between skill across outlook and seasons, results were reviewed for several metrics in the PowerBI viewer. This section describes results by PowerBI viewer metric.

7.1 RESULTS: RATIO

The ratio metric allows for comparison of the magnitude of hindcasted cumulative volumes at various outlooks to that of historical data. A few tabs on the PowerBI viewer demonstrate this metric visualized in different ways.

The broadest view of this relationship can be observed on the Ratio vs Outlook tab of the PowerBI viewer. On this tab, two plots and a table are present. The bottommost plot displays the relationship between the ratio of hindcasted to historical and outlook. When all forecast produced dates between 1990-2020 are selected and configured to the 50% exceedance, this plot shows that the average ratio of hindcasted to observed decreases with increasing outlook. Figure 2 demonstrates this relationship below.

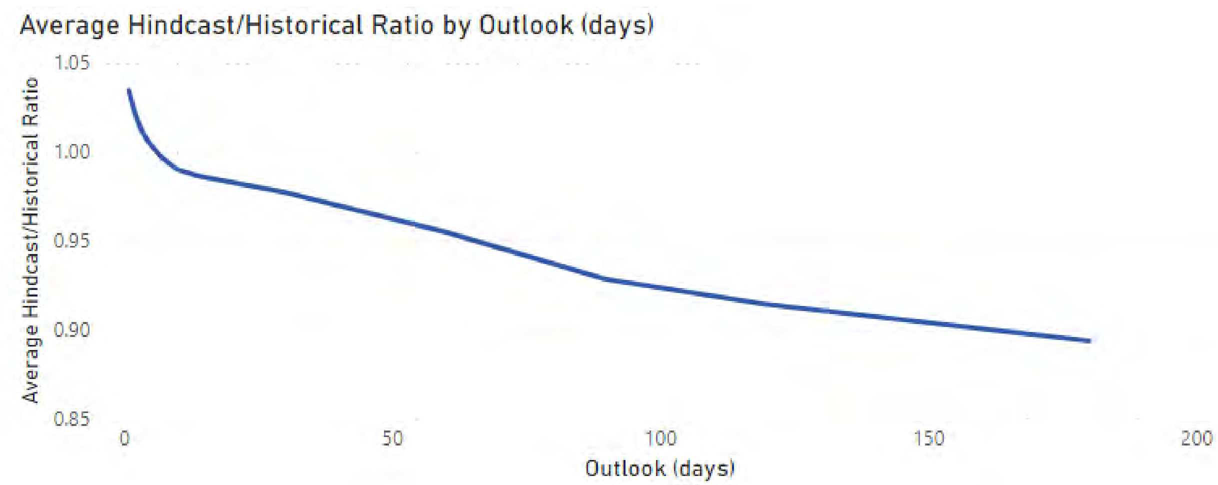


Figure 2: Ratio vs Outlook All Months at 50% Exceedance

A tabular view of these results is summarized in Figure 3 below.

Average Ratio of Hindcasted to Historical By Outlook

Outlook (days)	Average Hindcast/Historical Ratio
1	1.03
2	1.02
3	1.01
4	1.01
5	1.00
7	1.00
10	0.99
14	0.99
30	0.98
60	0.95
90	0.93
120	0.91
180	0.89

Figure 3: Tabular View Ratio vs Outlook at 50% Exceedance

On this same tab of the PowerBI viewer, the uppermost chart displays the relationship between average ratio and outlook. Unlike the previously discussed plot, this plot displays a series for each month. At 50% exceedance, it is observed that July and August forecast produced dates have some of the largest ratios of hindcasted to historical cumulative volumes across outlooks between zero and 90 days. Generally, flows tend to be over forecasted during this season. Flows in the summer months are generally expected to be lower than flows during fall and winter months, so a high ratio could be explained by the observed values' relatively small magnitudes. This phenomenon is displayed in Figure 4.

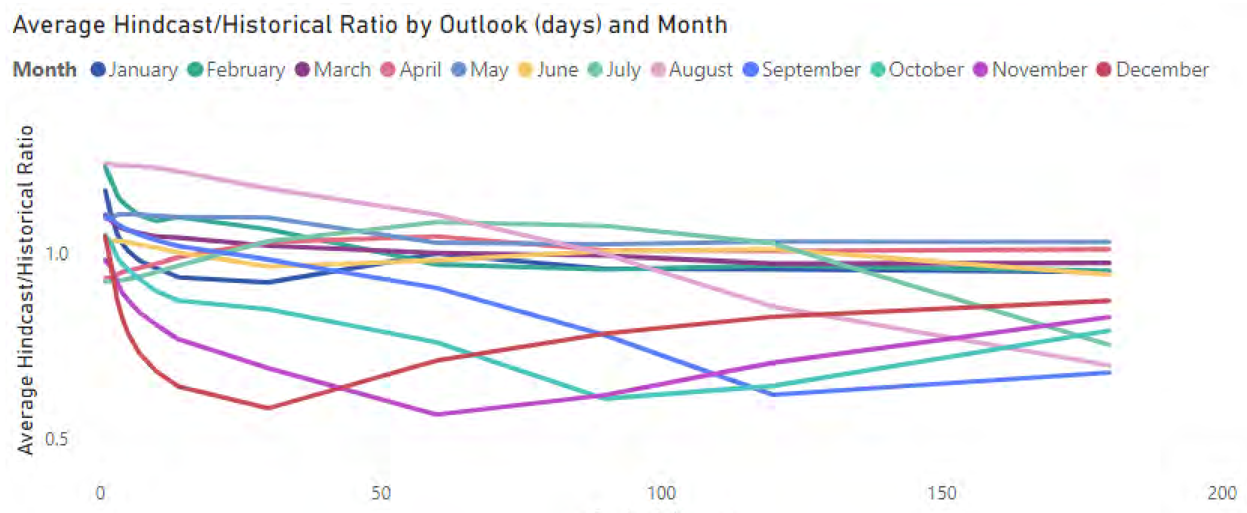
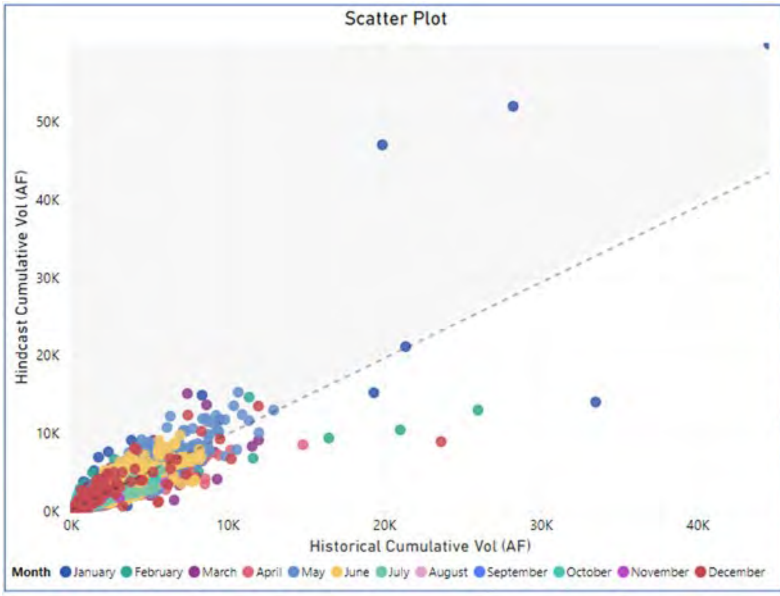


Figure 4: Ratio vs Outlook by Month 50% Exceedance

A more detailed view of the relationship between the ratio metric and outlook is available on the Scatter Plot tab of the PowerBI viewer. This tab directly compares hindcasted to historical cumulative volumes at the user's selected outlook, percent exceedance, and forecast produced dates. Different colors on this plot correspond with different months that the ratio of hindcasted to historical is averaged over.

When all forecast produced dates between 1990-2020, the 1-day outlook, and 50% exceedance are selected, it is observed that the forecasted months with average ratios of hindcasted to historical cumulative volumes closest to 1 are March, November, and June with average ratios of 1.01, 0.97, and 1.03 respectively. This means that these months' average ratios are within 3% of the actual average cumulative volumes during these months. As demonstrated in Figure 3, the overall average ratio of hindcasted to historical across all hindcast produced dates between 1990-2020 is 1.03. This information is pictured in Figure 5 below.



Filtered Results

Month	Outlook	R-Squared	Avg Ratio of Hindcasted to Historical
August	1	0.73	1.24
January	1	0.81	1.17
September	1	0.51	1.10
May	1	0.83	1.09
February	1	0.73	1.07
October	1	0.77	1.04
December	1	0.70	1.04
June	1	0.82	1.03
March	1	0.73	1.01
November	1	0.69	0.97
April	1	0.81	0.93
July	1	0.91	0.92

Overall Results

Outlook	Correlation Coefficient (R2)	Avg Ratio of Hindcasted to Historical
1	0.82	1.03

Figure 5: Ratio at 1-Day Outlook 50% Exceedance

If the percent exceedance is maintained at 50%, and all forecast produced dates between 1990-2020 are still selected, increasing the outlook to 14 days results in slightly different results. With these selections, the months with average ratios closest to 1.00 include February, March, April, and June, with average ratios of 1.01, 0.99, 0.99, and 1.00, respectively. This means that their ratios are within 1% of the historical average ratios for these months. The overall ratio aggregated across all forecast produced dates between 1990-2020 at this outlook is 0.99. This is visualized in Figure 6.

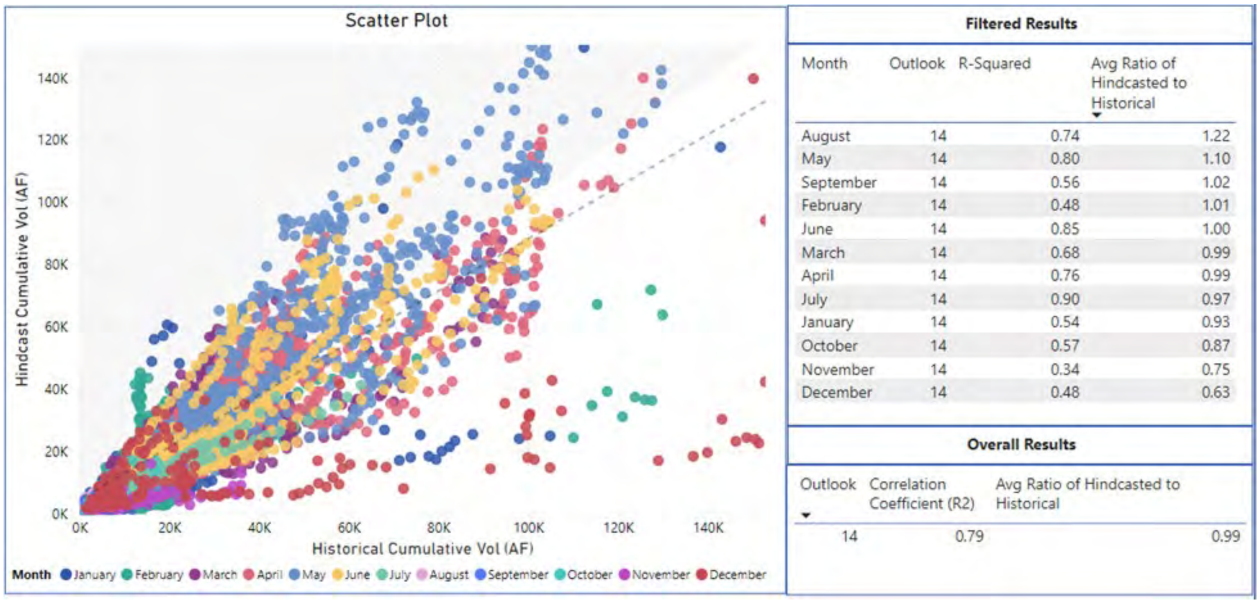


Figure 6: Ratio at 14-Day Outlook 50% Exceedance

If the outlook is held the same, and instead the percent exceedance filtering is modified within the Scatter Plot View, the overall ratio of hindcasted to historical cumulative volumes increases as expected. Table 2 below demonstrates the differences in overall ratio at a 7-day outlook when the percent exceedance is varied.

Table 2: Differences in Overall Ratio with Differing Exceedances

Forecast Produced Dates Selected	Outlook Selected	Percent Exceedance Selected	Overall Ratio
1990-2020	7	50%	1.00
1990-2020	7	30%	1.05
1990-2020	7	10%	1.15

7.2 Results: R-Squared

The first PowerBI tab demonstrating correlation across the outlooks is the Correlation vs Outlook plot. If attention is drawn to the bottommost plot on this page, which compares the correlation coefficient, R-squared, to outlook, at 50% exceedance, with all outlooks and forecast produced dates between 1990-2020 selected, it is observed that the correlation coefficient remains between 0.79 - 0.84 at outlooks less than 90 days. At outlooks greater than 90 days, the correlation coefficient decreases with increasing outlook. A tabular view of this chart is provided below in Table 3.

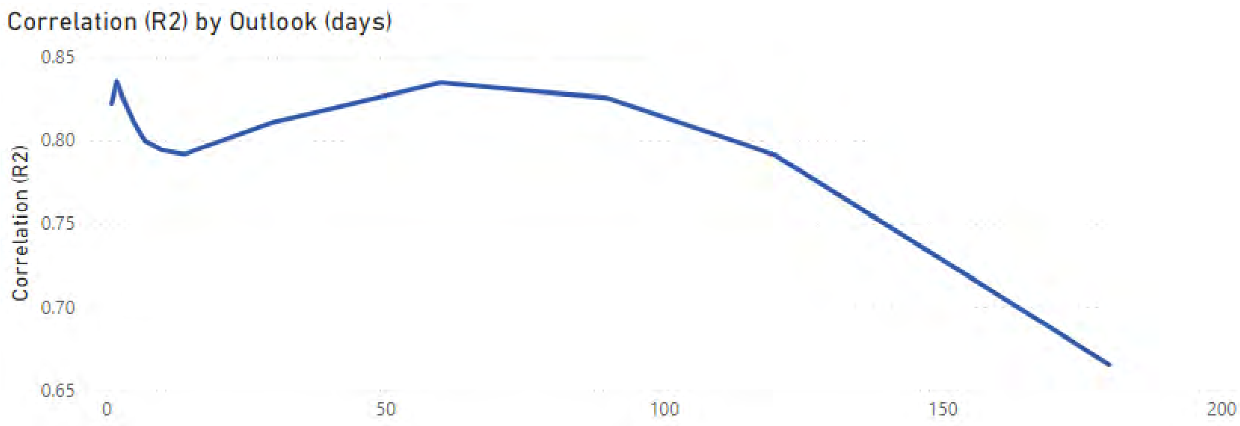


Figure 7: Correlation vs Outlook 50% Exceedance

Table 3: Tabular view of Correlation Across Outlooks 50% Exceedance

Correlation (R2) By Outlook

Outlook (days)	Correlation (R2)
1	0.82
2	0.84
3	0.83
4	0.82
5	0.81
7	0.80
10	0.79
14	0.79
30	0.81
60	0.83
90	0.83
120	0.79
180	0.67

On this same tab of the PowerBI viewer, a plot of correlation compared to outlook specified by forecasted month is available. This plot demonstrates that across most outlooks, correlation coefficients for April through June are closest to 1.00 throughout most outlooks. See Figure 8 and Table 4 for an example of results at the 50% exceedance.

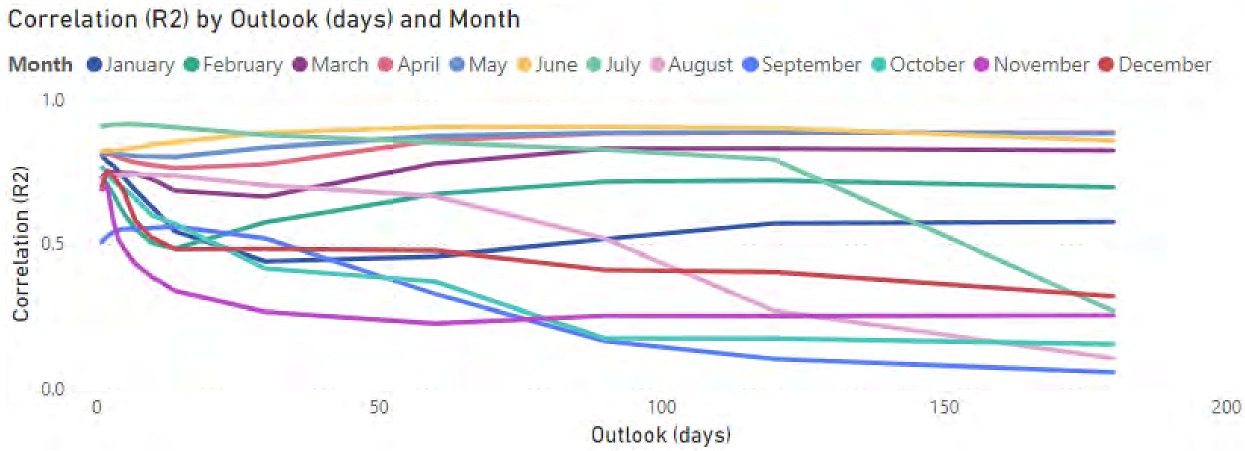


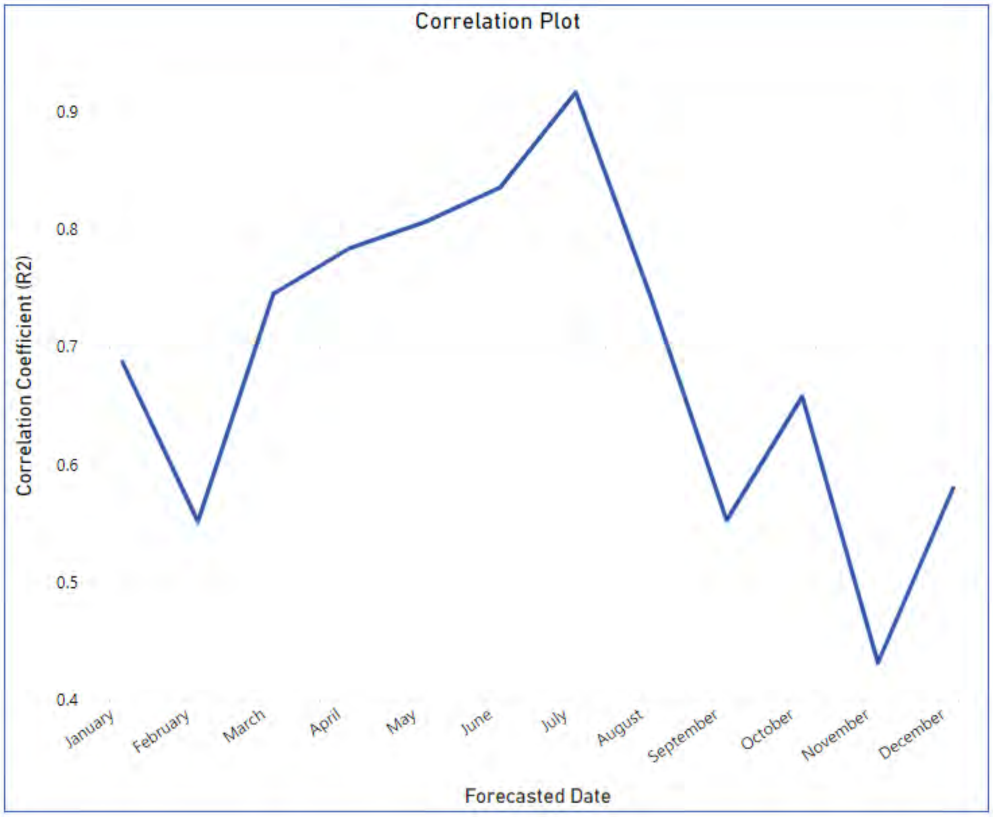
Figure 8: Correlation vs Outlook By Month 50% Exceedance

Table 4: Correlation Coefficients April-August 50% Exceedance

Outlook	April Correlation Coefficient	May Correlation Coefficient	June Correlation Coefficient
1-Day	0.81	0.83	0.82
5-Day	0.79	0.81	0.83
30-Day	0.78	0.84	0.89
60-Day	0.86	0.87	0.91
90-Day	0.88	0.89	0.91
180-Day	0.89	0.88	0.86

A location within the PowerBI viewer demonstrating correlation by forecasted month is on the Correlation tab. In this view, the forecasted month is compared to the correlation coefficient representing the relationship between average hindcasted and historical cumulative volumes.

On this view, when the 50% exceedance and 1-day outlook is selected, the months with highest correlation coefficients (closest to 1) are April through July. As the outlook is increased, and the percent exceedance is kept the same, months with the greatest correlation coefficients remain April through June. Figure 9 below pictures results for the 7-day outlook and 50% exceedance correlation plot.

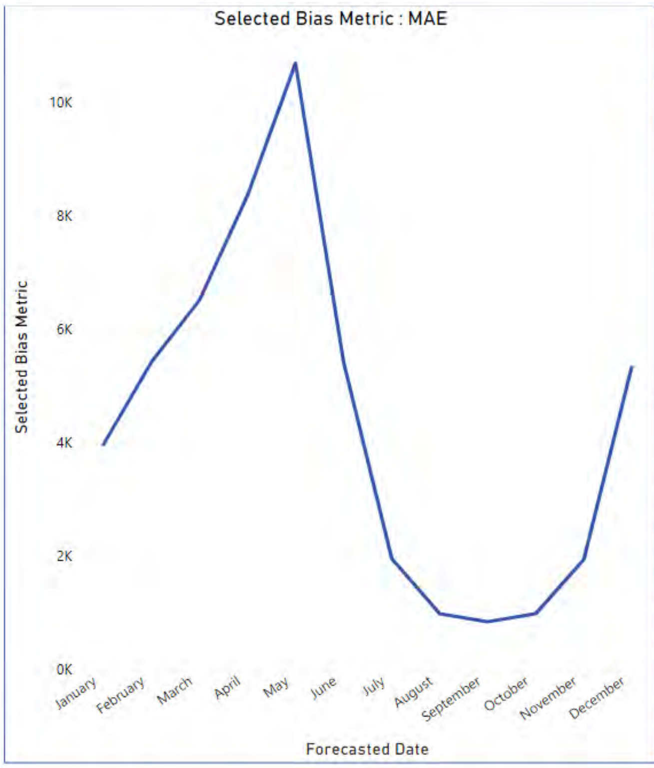


Month	R-Squared
July	0.92
June	0.84
May	0.81
April	0.78
March	0.74
August	0.74
January	0.69
October	0.66
December	0.58
September	0.55
February	0.55
November	0.43

Figure 9: Correlation vs Forecasted Month 7-Day Outlook 50% Exceedance

7.3 Results: Average Difference, Mean Absolute Error, and Percent Error

The bias tab of the PowerBI viewer demonstrates the remaining three metrics of average difference, MAE, and percent error. Across all outlooks less than 90 days, the months with consistently large MAE occur during April and May. Changes in magnitude of average percent error and average difference tend to increase as outlook increases, and as cumulative volume magnitudes increase. Figure 10 below shows the 14-day outlook, 50% exceedance MAE, average percent error, and average difference with all forecast produced dates between 1990-2020 selected.



Averaged Statistics Over Selected Dates Hindcasted Dates and Outlook At Right

The table below demonstrates the following statistics over the date range selected in the filter pane at right:

- Average Difference: The average difference between historical and forecasted cumulative volumes
- Avg % Error: The average percent difference between historical and forecasted cumulative volumes
- MAE: Mean absolute error. Average of absolute difference between forecasted and historical hindcasted cumulative volumes

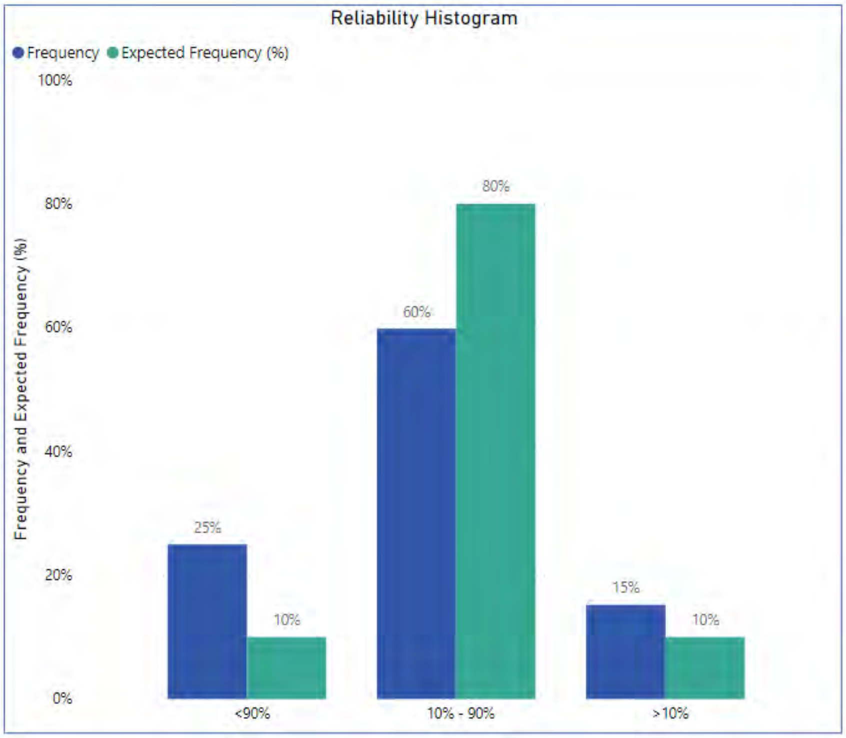
Month	Average Percent Error	Mean Absolute Error (AF)	Average Difference (AF)
May	-10%	10,688	-3,724
April	1%	8,355	423
March	1%	6,505	225
February	-1%	5,416	-75
June	-0%	5,413	-14
December	37%	5,327	3,818
January	7%	3,958	638
July	3%	1,950	222
November	25%	1,933	1,209
August	-22%	979	-579
October	13%	978	430
September	-2%	833	-44

Figure 10: MAE 14-Day Outlook 50% Exceedance

7.4 Results: Reliability Histogram

The histogram tab of the PowerBI viewer seeks to determine how reliable hindcasts are at predicting that flow volumes will occur within certain percent exceedance ranges. On the x-axis of this plot is the confidence interval, which describes the range of percent exceedance values applied to the visual. On the y-axis, the percent of selected hindcasts at the specified outlook within each percent exceedance range is plotted and compared to the expected frequency that hindcasted cumulative volumes would fall in each percent exceedance range.

At the 120-day outlook, 10%-90% confidence interval, with all hindcast produced dates between 1990-2020 selected, the observed frequency at the <90% and >10% exceedance ranges is greater than the expected frequency of 10%, whereas the observed frequency in the 10%-90% exceedance range is less than the expected frequency. This denotes that the observed flows are outside of the range (on both the high and low end) more frequently than explained by the variability in the RFC traces. This is visualized in Figure 11.



Exceedance	Expected Frequency	Observed Frequency
<90%	10%	25%
10% - 90%	80%	60%
>10%	10%	15%

Figure 11: Reliability Histogram 10%-90% Exceedance 120-day Outlook

The results of the 10%-90% confidence interval for various outlooks is summarized in Table 5, which shows that the results are generally further outside of the expected outcomes (both high and low) for the shorter outlooks.

Table 5: Summary of Reliability Histogram 10% -90% Exceedance Results by Outlook

Outlook	**< 90%** (Expected **10%)**	**10% - 90%** (Expected **80%)**	**> 10%** (Expected **10%**)
1 day	51%	0%	49%
3 day	47%	11%	42%
5 day	45%	18%	38%
7 day	43%	21%	35%
10 day	42%	24%	33%
14 day	41%	28%	31%
30 day	35%	40%	25%
60 day	31%	48%	21%
90 day	28%	55%	17%
120 day	25%	60%	15%

At larger outlooks, the frequency of hindcasted cumulative volumes falling within the middle percent exceedance range (i.e., 10%-90%, 20-80%, etc.) is closest to expected. However, at shorter outlooks, the observed frequency is very small relative to the expected frequency at the middle percent exceedance range.

8 POTENTIAL ACTIONS

8.1 SUMMARY OF FINDINGS

Results of the inflow uncertainty analysis demonstrate relationships between hindcast skill in terms of both seasonality and outlook. These overall trends are summarized in Table 6 below.

Table 6: Hindcast Skill Summary

Metric	Hindcast Skill: Seasonality	Hindcast Skill: Outlook
Ratio	Relatively large (>1) during July through August across most outlooks	Forecast closest to 1 at smaller outlooks, but tends to over forecast at shortest outlooks
Correlation (r-squared)	Generally closest to 1 April through June	Aug-December decrease with increasing outlook, January-May increase with increasing outlook, Jun-July generally high
Bias Metrics (MAE)	Generally largest between April and May	Magnitude of MAE increases with increasing outlook
Histogram	Not examined	Middle percent exceedance ranges of confidence interval (i.e., 10%-90%) demonstrate observed frequencies less than expected frequencies at all outlooks, but the difference in expected and observed frequency decreases with increasing outlook

To address these results within the WMOP's floodspace modeling methodologies, three potential alterations to current methodologies have been prepared.

8.2 Seasonal Aspect of Hindcast Skill

To address hindcast skill in terms of seasonality, the first recommendation is to apply a seasonal dependency to the exceedance outlook relationship. Based on the difference in exceedance outlook behavior between months and the overall correlation by month, hindcasts for the summer months tend to behave differently than hindcasts in the other months. This difference in skill is likely explained by the Truckee River runoff is dominated by snowmelt during this period which is generally easier to predict (denoted by the higher R^2 values) than the rain driven events that occur in the other months. Utilizing a separate exceedance outlook relationship for these months should allow the MOEA to customize the exceedance outlook curve for these periods where a different mode or runoff occurs.

8.3 Adjust All Hindcasts Based On Average Bias

The second recommendation, targeting hindcast skill with respect to outlook, is to scale hindcasted cumulative volumes for each outlook based on the average ratio between the 50% exceedance hindcast and the observed volume for that outlook (Figure 2). Since this result indicates that the 50% exceedance RFC trace is less than the observed flow for all outlooks if no adjustment were made the MOEA would adjust for this bias in its calibration and should the forecast skill improve in the future the benefit may not be realized in the Truckee River Flood operations. These bias correction numbers could be re-derived based on a future hindcast error allowing the Water Control Manual to adapt to future changes in forecast skill (which is one of the objectives of the WMOP project). Should this adaptation to floodspace modeling be accepted, a table of updated hindcast outlook versus average ratio would be provided and periodically revised within the updated Water Control Manual (WCM). This would prevent the necessity of running multiple MOEA analyses in future updates to the WCM.

8.4 Adjust the Range of the Hindcasts

As shown in Table 5, the observed flows are outside of the forecasted RFC range more frequently than expected and this is more apparent in the shorter outlooks. To correct for this the forecasted volumes for each outlook could be corrected to expand the range of the RFC traces so that the observed volumes fall within the hindcast ranges at the expected frequency of occurrence. PWRE has utilized a similar trace scaling process operationally for several years to adjust the RFC seasonal runoff traces to match the Natural Resource Conservation Service (NRCS) runoff volume forecasts for use with the TROA Ensemble Forecasting for the Truckee and Carson Basins. This method would allow correcting the RFC hindcasts so that they match the variability and value of the observed flows. This correction would be a more significant adjustment to the RFC forecasts than the correction discussed in section 8.3, however, it would help ensure that the MOEA is not adjusting bias in the current forecasting methodology that may not persist into the future. As in section 8.3, this analysis could be recomputed in the future and adjusted based on future improvements to forecast skill. The processing for this methodology would be somewhat involved where for each day's ensemble the volume distribution computed for each outlook would need to be adjusted to expand the range. Given the complexity of these calculations, there may be a concern that is feasible to compute these calculations in real-time and add undue complications to the WCM.

9 CONCLUSION

Inflow uncertainty analyses of these hindcasts provide insight into how accurately and precisely current ESP forecasting technology can represent historical, unregulated natural flows at Farad. Throughout these analyses, questions of the accuracy and precision of hindcasted cumulative flow volumes in terms of seasonality, outlook, and expected probabilities have been addressed for this 30-year dataset.

Recommended modifications to floodspace requirement methods include creating two exceedance-outlook equations: one for hindcast produced dates during summer months and the other for the other months. The second recommendation would be to Adjust All Hindcasts Based On Average Bias. This method is recommended because it is significantly simpler and requires less processing than the Adjust the Range of the Hindcasts potential action, and it will allow the WCM procedures to adapt to changes in future forecasting skill.

These recommended alterations to floodspace requirement methodologies, if agreed upon by the WMOP technical team, will help to bolster the application of these hindcasts to foster appropriate flood space requirements applied to the WMOP project's RiverWare models and MOEA algorithm at large.