Russian River Watershed

Final Viability Assessment of the Forecast Informed Reservoir Operations at Lake Mendocino

Varied Guide Curve Alternative (Alternative 6)

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Forecast-Informed Reservoir Operation (FIRO) study within Full Viability Assessment FVA

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I. Overview

This report describes Alternative 6 of the Final Viability Assessment (FVA) of the Forecast Informed Reservoir Operations (FIRO) research and development project at Lake Mendocino in the Russian River watershed in the State of California. Alternative 6 includes selected adjustments to the Baseline operations that make use of deterministic forecast products, although its concepts could instead be applied using ensemble forecasts if desired. Baseline operations are prescribed by a Water Control Manual (WCM) that was originally compiled in 1959 and later updated in 1986. The Baseline alternative in this study represents both these current reservoir operation and boundary condition assumptions, such as extra-basin diversions and evaporation losses.

The goal of Alternative 6 was to determine if some very simple forecast-informed adjustments could be successful in improving operation of Lake Mendocino. The adjustments to Baseline operations are of two types: (1) changes to the Lake Mendocino guide curve based on the 5-day inflow forecast, and (2) reservoir release maximums based on West Fork flow and forecasted local flow above Hopland.

A reservoir's guide curve is the target storage level for each day of the year, which effectively separates the Flood pool (kept empty except during flood events) from the Conservation Pool (kept as full as feasible). Variation from the Standard Guide Curve (as defined in Baseline operation) forms the basis of the Alternative 6 strategy, allowing more conservation storage in the absence of high forecasts but returning to the Standard Guide Curve and even drafting more volume from the Conservation pool when larger forecasts suggest a significant flood event is imminent.

The FVA study was performed on a period of record (1985 – 2017) as well a series of scaled historical events (1986, 1997, 2006, March 1995 and a synthetic event referred to as "Extended 2006") for which a hindcast of the ensemble forecast products of the Russian River basin are available. However, a hindcast of deterministic forecasts was not available, and so evaluation of Alternative 6 required development of artificial deterministic forecast values based on the ensemble forecasts. The decision metrics used in the alternative, based on the deterministic forecasts, are described in Section II (Forecast Inputs), and the analysis leading to the development of the artificial deterministic forecasts is described in Appendix A (Development of Artificial Deterministic Forecasts).

HEC-ResSim version 3.4 Build 106, which is an unreleased development version, was used to model the reservoir operations for this alternative.

II. Forecast Inputs

Two deterministic forecast products are used as inputs to Alternative 6 decisions: the forecast of 5-day inflow volume at Lake Mendocino, and the forecast of Hopland local flow at 8 hours and 14 hours lead time. Simulation of POR and scaled events used artificial deterministic forecasts approximated from ensemble hindcast for the FVA study because a hindcast of deterministic forecasts was not available. The ensemble hindcast consists of an ensemble forecast with 61 traces extending 14 days, produced for each day of the record, at 12 pm GMT (Greenwich Mean Time) or 4 am PST (Pacific Standard Time).

The comparison of ensemble to deterministic forecasts can be found in Appendix A (Development of Artificial Deterministic Forecasts). To summarize, it was found that for Lake Mendocino inflow forecasts of 5-day volume, the deterministic forecasts (for the period available) seem less downwardly biased for large flood events than the ensemble forecasts. Thus, when actual 5-day volume is less than 10 kilo acre feet (KAF), the ensemble mean is a good surrogate for the deterministic volume, but when actual volume is greater than 10 KAF, the 75th percentile of the ensemble volumes is the better surrogate.

Note, “actual 5-day inflow volume” noted above was the California Nevada River Forecast Center (CNRFC) simulated inflow. A statement of the artificial deterministic forecast is as follows:

deterministic 5-day inflow volume =	ensemble <u>mean</u> 5-day vol, for actual 5-day inflow < 10 KAF
	ensemble <u>75th pcntl</u> 5-day vol, for actual 5-day inflow > 10 KAF

Use of the Hopland local flow forecast was introduced later in the development of Alternative 6 (for consistency between alternatives and in lieu of using a downstream control rule in ResSim) and did not have same level of analysis as the Lake Mendocino inflow forecast due to project timeline constraints. A brief review found that use of the 75th percentile of each hour of the ensemble forecast would be a reasonable surrogate when the ensemble was spread enough to produce any difference between mean and 75th percentile.

deterministic Hopland forecast = ensemble 75th percentile flow for each day

III. Guide Curve Specification

The primary forecast-informed aspect of the Alternative 6 operation is allowing the Lake Mendocino guide curve to vary from the Standard Guide Curve (Standard GC) of Baseline operations, depending on the deterministic 5-day reservoir inflow volume forecast. The general operation of the reservoir is described here, and specific forecast triggers for adjusting the guide curve are discussed in Section II.A.

The operational concept is that while the inflow volume forecast is low, operation follows an Encroached Guide Curve (Encroached GC), which allows storage of 11,000 acre feet (AF) additional water volume in winter, and begins spring refill on 16 February rather than 1 March. When the inflow volume forecast gets larger, the guide curve returns to the Standard GC specified in the existing WCM. And when the inflow volume forecast is larger yet, suggesting that additional flood storage volume might be needed, the guide curve is lowered to 10,000 AF below the Standard GC to allow limited extra draft of conservation storage. This lower guide curve is referred to as the Draft Guide Curve (Draft GC).

Figure 1 shows these three guide curves, with Encroached in green, Standard in blue and Draft in red. The winter levels of the Encroached, Standard and Draft guide curves are pool elevations 744 feet, 737.5 feet, and 731.35 feet, respectively. The Encroached GC follows the same fall draft trajectory as the Standard GC, and therefore reaches its lowest level by 23 October, rather than 1 November. The Draft GC only exists during the period the Standard GC is at its full flood pool level, between 1 November and 1 March, and so extra draft is not available at other times.

Note, these three guide curves are distinct, and used as they are shown, with no intermediate levels between them. For example, when the forecast is large enough to prompt return to the Standard GC, operations attempt to bring the reservoir storage all the way down to that storage level.

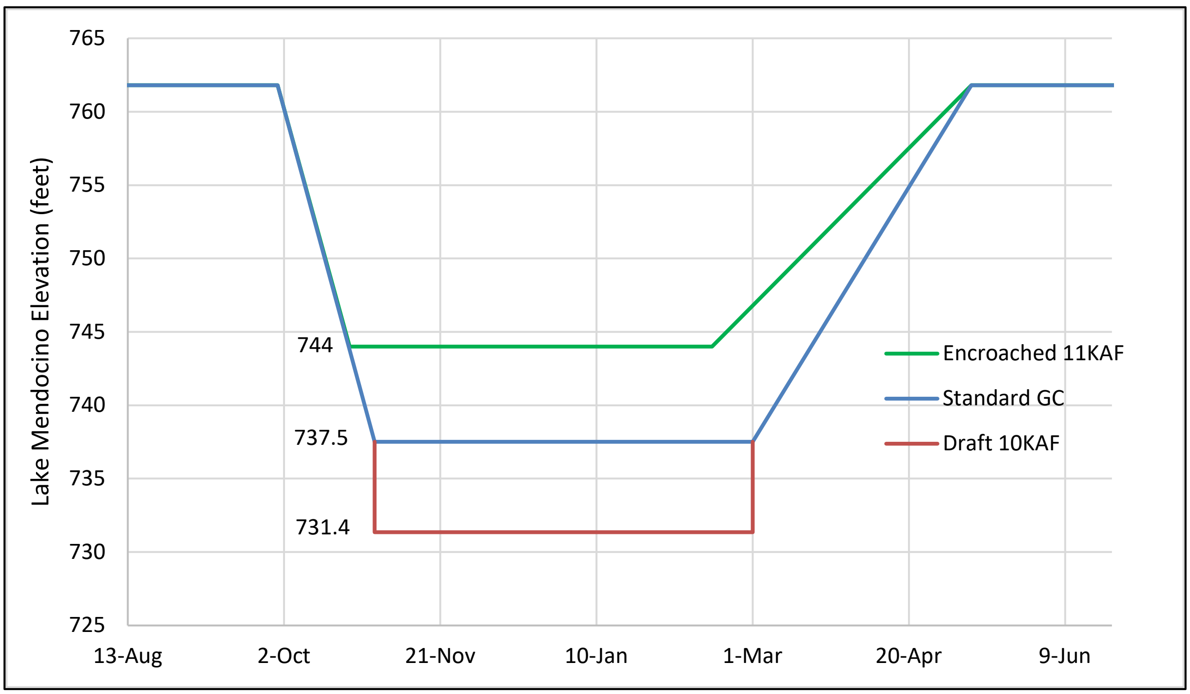

Figure 1. Alternative 6 Guide Curve levels: Encroached, Standard, Draft

Within the HEC-ResSim simulation decision code, the three potential guide curve levels are defined as states, with the Standard GC being state 0, the Encroached GC being state 1, and the Draft GC being state -1.

A. Guide Curve Forecast Winter Triggers

During the flood season, movement between the three possible guide curves is based on the forecast of the 5-day inflow volume to Lake Mendocino, and is triggered by specific levels of forecast. Trigger 1 defines the level needed to drop from the Encroached GC (state 1) to the Standard GC (state 0). Trigger 2 defines the level needed to drop to the Draft GC (state -1). The guide curve returns to a higher level as the forecast of 5-day inflow decreases. However, making that change when the forecast simply falls below the trigger can lead to oscillation of the guide curve, and so while the guide curve drop occurs at the trigger, the guide curve rise includes a buffer, and occurs when the forecast falls below the trigger minus the buffer, or the "untrigger."

The trigger levels and the buffer are parameters in the Alternative 6 operation strategy. The values presented here are the result of some study, but can be adjusted. The choice of triggers is a balance or trade-off of objectives across the Period of Record and scaled events. Lower triggers lead to earlier and more frequent evacuation of encroachment (for flood space), which can be helpful for large events but will respond to more "false alarms," when forecasts are overestimates and draft is unnecessary. Higher triggers lead to fewer "false alarms," but can lead to inadequate evacuation and storage space when the forecasts are smaller than the eventual outcome. The levels that were found in the FVA study to produce a reasonable trade-off are as follows:

Trigger 1 = **15000** AF forecasted 5-day inflow volume

Trigger 2 = **20000** AF forecasted 5-day inflow volume

Buffer = **3000** AF

Thus, a drop from state 1 (Encroached GC) to state 0 (Standard GC) is triggered when the volume of the 5-day inflow forecast is greater than 15,000 AF, but a return from state 0 to state 1 will only occur when the forecast volume is less than 12,000 AF (15,000 – 3,000). Similarly, a drop from state 1 (Encroached GC) or state 0 (Standard GC) to state -1 (Draft GC) is triggered when the volume of the 5-day inflow forecast is greater than 20,000 AF, but a return from state -1 to state 0 will only occur when the forecast volume is less than 17,000 AF.

When no forecast-based change has yet been made (current state = 1):

Triggers:

5dayVol < **15000**,	Encroached GC: state 1
15000 < 5dayVol < **20000**,	Standard GC: state 0
5dayVol > **20000**,	Draft GC: state -1

When already in a triggered forecast-based drop of the guide curve, use "untriggers" = trigger – buffer to return to higher guide curve level.

Untriggers: *when already at Standard GC or Draft GC*, state 0 or -1

5dayVol < **12000**,	Encroached GC: state 1	**12000** = **15000** – **3000**
12000 < 5dayVol < **17000**,	Standard GC: state 0	**17000** = **20000** – **3000**
5dayVol > **17000**,	Draft GC: state -1	

In fact, there is a more complex structure for the trigger–buffer thresholds than shown above, depending on whether currently at state 0 or state -1. The complete structure is shown in the listing of the Guide_Curve state variable in Section VI (HEC-ResSim State Variables).

Figure 2 shows the December 2005 (WY 2006) flood event from the POR as an example of the forecast-based guide curve specification. The top viewport shows the guide curve zone and reservoir elevation; the second viewport shows Lake Mendocino inflow and outflow; the third viewport shows the Russian River flow at Hopland and the cumulative local flows to that point without reservoir release (i.e., lowest possible flow); finally, the bottom viewport shows the 5-day inflow volume forecast for each day as well as the trigger and "untrigger" levels.

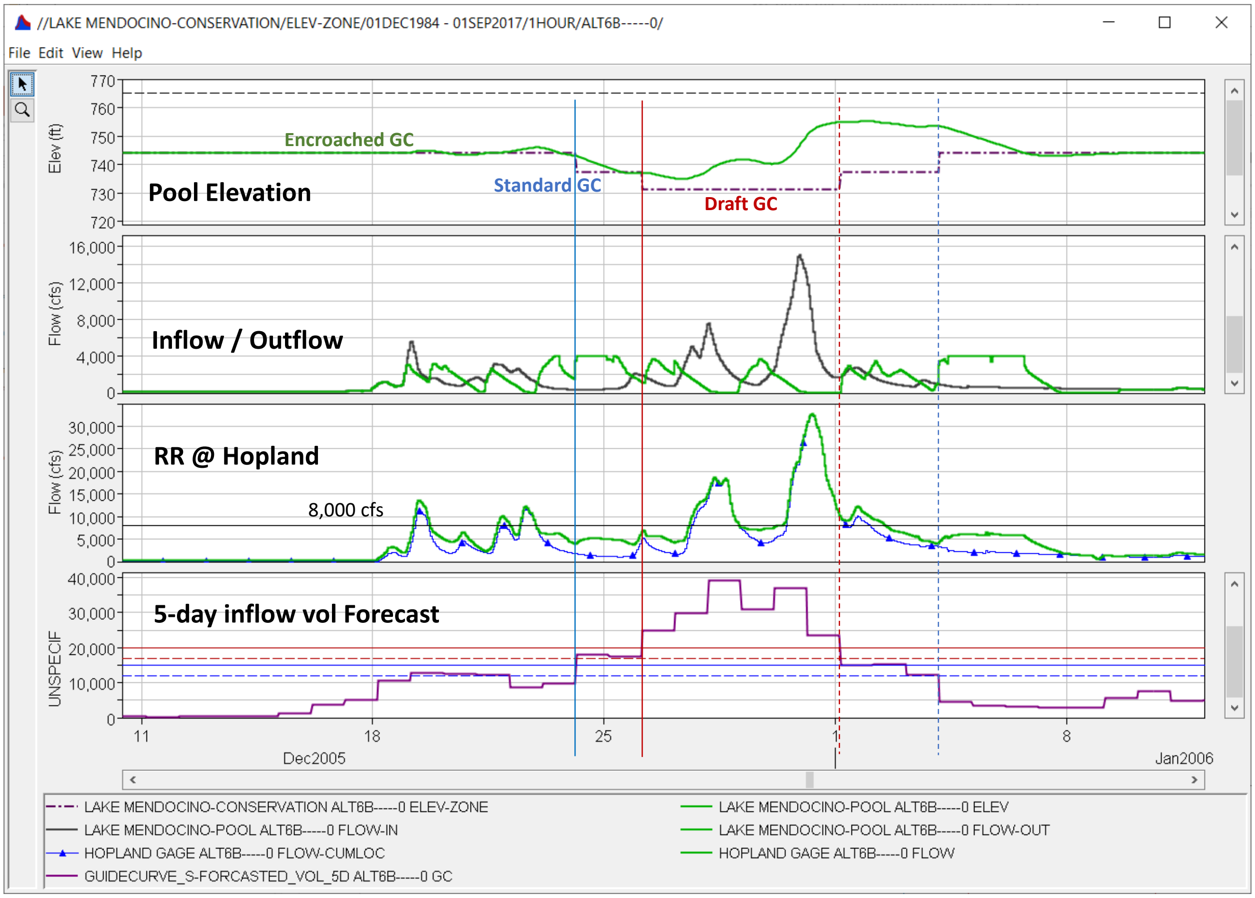

Figure 2. December 2005 flood event as example of Alternative 6 guide curve specification

The event begins with the Encroached GC specified, and the reservoir at that level. On 23 December, the 5-day volume of the inflow forecast is 9,754 AF, but on 24 December, the inflow forecast rises to 18,128 AF, exceeding Trigger 1 (15,000 AF) and so triggering a drop from the Encroached GC to the Standard GC. The reservoir release increases to bring the reservoir storage toward the new guide curve level because there is "space" available in the river downstream at Hopland to accommodate the reservoir release. On 26 December, the inflow forecast volume is 23,362 AF, exceeding Trigger 2 (20,000 AF) and triggering a drop to the Draft GC. The guide curve remains the Draft GC (though the reservoir level does not reach it) until 1 January, when the forecast volume falls to 15,046 AF. Since this volume is below 17,000 AF (Trigger2–buffer), the guide curve rises to the Standard GC. On 4 January, the inflow forecast drops to 5,506 AF, which is below the 12,000 AF (Trigger1–buffer), and the guide curve rises to the Encroached GC. (Note, the 3 January inflow forecast was just slightly above 12,000 AF.)

The inflow forecast level usually drops below the triggers by the end of a flood event, though in some cases in the period of record, more inflow volume is expected that does not arrive, leaving forecasts high. The buffer to delay return to a higher guide curve was chosen in an effort to be large enough to prevent most oscillation of the guide curve when forecasts vary, but small enough to allow return to the Encroached GC by the end of a flood event, retaining some of the flood volume. However, volume not stored because high forecasts cause a delay in return to the Encroached GC level, missing the end of the event, is generally recovered during the remainder of the flood season. This recovery is less likely in spring, and so a more conservative buffer is used in spring, as described below.

Summary of Variable Parameters:

Trigger1 and Trigger2, currently 15,000 AF and 20,000 AF forecasted 5-day inflow volume.

Buffer to prevent GC oscillation, currently 3,000 AF for both triggers.

B. Guide Curve Forecast Triggers in Spring

The forecast triggers noted above for adjustment between the Encroached, Standard and Draft Guide Curves are for use during the winter flood season, specifically starting when the Encroached and Standard GCs diverge on 23 October. However, the Encroached GC continues into spring refill (after 1 March on the Standard GC and 16 February on the Encroached GC). As the size of the flood space decreases, triggers to prompt the drop of the guide curve to the Standard GC level in response to forecasted 5-day inflow volume must therefore be smaller. Note, Alternative 6 had several options for implementation, and in the FVA study it was decided there would be no extra draft below the Standard GC in spring. Thus, while both Trigger 1 and Trigger 2 are discussed, only Trigger 1 was used.

One method to define the spring triggers is to maintain the same ratio of forecast trigger level to available flood storage space as was used for the winter triggers. Available flood storage space is defined here as the volume between the lip of the spillway and the guide curve, which changes daily in spring. The volume of space between the spillway (at pool elevation 764.8 feet and storage of 116,470 AF) and the Encroached GC in winter (at pool elevation 744 feet and storage of 79,409 AF) is 37,061 AF, and the space above the Standard GC in winter (at pool elevation 737.5 feet and storage of 68,409 AF) is 48,061 AF. Comparing the winter Trigger 1 of 15,000 AF to the Encroached GC flood space, and winter Trigger 2 of 20,000 AF to the Standard GC space, shows the triggers to be about 42% of those volumes.

Using this comparison, as the flood space between the spillway and the rising guide curve decreases in spring, the forecast triggers specified for each day are defined as 42% of that day’s flood space below the spillway, with flood space above the Encroached GC defining Trigger 1 and above the Standard GC defining Trigger 2. Triggers are recomputed each day, and decrease to their lowest level on 10 May when the summer reservoir level is reached.

The spring buffer was set similarly, based on the changing guide curve and resulting flood storage space, but chosen to be more conservative than in winter. The buffer is used to delay triggering a rise in the guide curve, in order to prevent oscillation when the forecast volume varies, but with the intention of allowing return to the Encroached GC level by the end of a flood event (if the forecast is low enough). Ending an event at the Encroached GC level allows storage of some of the flood event volume. However, in cases for which the forecast remains high enough to prevent return to the Encroached GC by the end of the event, the recovery of that volume with future inflow becomes less and less likely as the spring proceeds. Often, a spring flood event is the last inflow of the season. To account for this decreased probability of inflow after the event, the initial spring buffer is defined to be half the winter value of 3,000 AF, to allow trigger the guide curve rise more easily. Therefore, the buffer is set to 4.2% of the daily Encroached GC flood space, which provides about 1,500 AF at the beginning of spring refill.

Within the simulation decision code, the spring triggers are defined each day as follows:

Encr FloodPool = Full pool volume (116,470 AF) – Encroached GC volume that day
Spring Trigger1 = 42% * Encr FloodPool

Standard FloodPool = Full pool volume (116,470 AF) – Standard GC volume that day
Spring Trigger2 = 42% * Standard FloodPool **NOTE, THIS TRIGGER IS NOT USED**

Spring Buffer = Encr FloodPool *4.2%

Figure 3 shows an example of the spring guide curve specification in the historical March 1995 flood event. The reservoir followed the Encroached GC as it began spring refill until 6 March, when the 5-day inflow volume forecast reached 19,520 AF, exceeding Spring Trigger1 of 12,527 AF on that day. The guide curve dropped to the Standard GC, prompting a release to reach that level.

On 15 March, the inflow forecast fell to 6,304 AF, below the trigger minus buffer, and so allowing return to the Encroached GC. In this case, the Encroached GC was in place before the end of the event, allowing some of the event volume to be stored. However, on 18 March the forecast again rose above Spring Trigger1 (10,621 AF on that day), calling for a drop to the Standard GC. For this "event," though the forecast fell below Trigger1 on 21 and 22 March, it did not fall below the trigger minus buffer for those days and so the reservoir stayed at the Standard GC until March, not rising to the Encroached GC level until after the event.

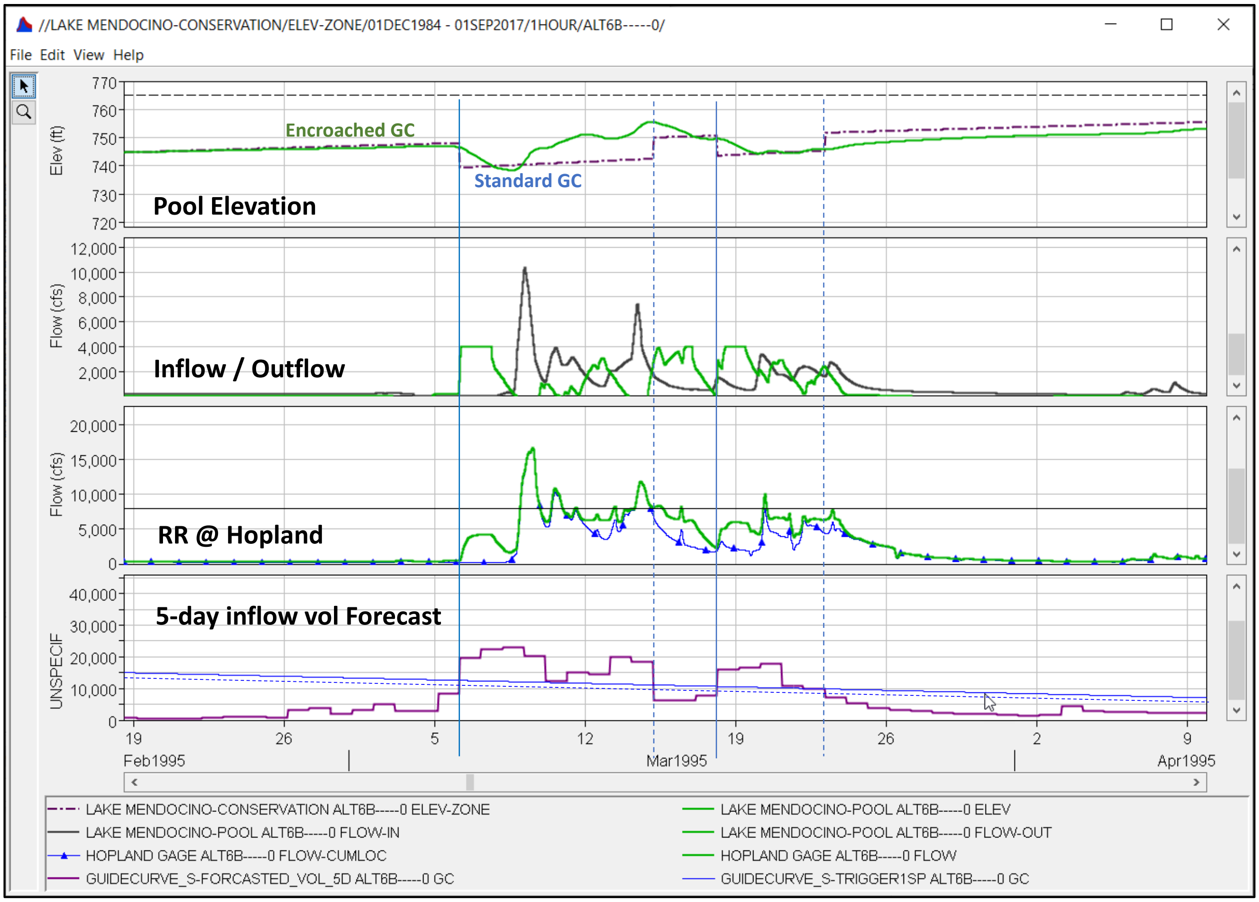

Figure 3. March 1995 flood event as example of Alternative 6 Guide Curve specification in spring

Summary of Variable Parameters:

Spring Trigger1, currently 42% of volume between Encroached Guide Curve and spillway each day.

Buffer to prevent GC oscillation, currently 4.2% of volume between Encroached GC and spillway.

C. Computation of the Guide Curve in HEC-ResSim

The guide curve as used within HEC-ResSim is computed in a state variable called "GuideCurve_S," which references simple state variables "Encroached_GC" and "Original_GC." Because it only exists part of the year, the Draft GC is not defined using a similar state variable, but rather produced as a subtraction. The state variable text can be found in Section VI (HEC-ResSim State Variables).

IV. Maximum Release for Hopland Threshold

The second forecast-informed aspect of Alternative 6 is defining a maximum release from Lake Mendocino that respects the channel capacity in the Russian River at Hopland, the first location below the reservoir with a defined flow threshold. Initially, an HEC-ResSim downstream control rule was used for this purpose, but in the second phase of the study it was determined that the rule's use of local flow in future time-steps was not appropriate when studying the impact of using forecast information. In its place, a rule was added to the alternative that explicitly uses the deterministic 5-day forecast of Hopland local flow. An overview of the rule is provided here, with specific parameters provided below in Section IV.A.

It is estimated that the Russian River at Hopland has a bank full capacity of approximately 8,000 cfs. Flow from the West Fork (WF) of the Russian River and local flow entering the river below Lake Mendocino but above Hopland both contribute flow to that location, along with the Lake Mendocino release. Baseline operations prescribed by the existing WCM require reservoir releases to take into account the capacity at this location, and in order to keep flow at Hopland below 8,000 cfs as well as possible, the release from Lake Mendocino must take both of those contributing flows into account. Travel time to Hopland at high flow was found to be about 4 to 6 hours for both the Lake Mendocino release and flow passing the WF at Ukiah gage.

Forecasts are provided by the CNRFC for Lake Mendocino inflow (LAMC1), WF flow at Ukiah (UKAC1) and Hopland local flow (HOPC1). For the purpose of considering when flow reaches Hopland, the WF flow at Ukiah is nearly "level" with the reservoir release with regard to the travel time, and so the current time-step value of WF flow was considered in the Alternative 6 Hopland release rule. A forecast was used only for the Hopland local flow, in order to consider future values when setting current release.

If flows were perfectly known, a satisfactory release could be computed as

Hopland-Release(t) = Hopland-threshold – WF-flow(t) – Hopland-local-flow(t+K)

where: t is the current time-step, and
t+K is some number of time-steps in the future.
Hopland-threshold = 8000 cfs

Or, more correctly, the release is the higher of this value and zero. The choice of K time-steps into the future of the Hopland local flow must consider both travel time from the reservoir to Hopland and the additional time required to decrease the reservoir release from the current level to the desired level, respecting the defined Decreasing Rate of Change in flow (DROC) constraints. The time to reduce from 4,000 cfs to zero can extend a full day.

The equation above is defined for flows that are perfectly known. Instead, forecasts are consulted for Hopland local flow in future time steps.

Hopland-Release(t) = Hopland-threshold – WF-flow(t) – Hopland-local-flow-forecast(t+K)

where: Hopland-local-flow-forecast(t+K) is the Hopland local forecast K steps ahead

Even with forecast estimates, the future Hopland local flow is still uncertain, and so two hedges against this uncertainty are used in computing the Hopland-Release. The first hedge is a reduction in the 8,000 cfs threshold in the release equation (above), and the second hedge is in defining the applied release as a reduced percentage of the computed release. Different levels of these hedging reductions are used depending on same conditions defined in the Baseline Alternative for the Hopland release: (1) whether WF flow is rising or falling (compared to a 3 hour average), and when falling, (2) whether Lake Mendocino elevation is above or below 755 feet. These two conditions form three cases: WF rising, WF falling with elev < 755 ft, and WF falling with elev > 755 ft. In this third case, in place of the Hopland-Release rule described here, Alternative 6 uses the WF proxy rule for that case used in the Baseline alternative.

In addition to those two conditions from the Baseline alternative, the two Alternative 6 Hopland release rule hedges are also adjusted when the Lake Mendocino inflow forecast is very large. When the 5-day inflow volume forecast is greater than 25,000 AF, parameters are set to produce a more aggressive (higher) release to help achieve reservoir draft prior to the event that will serve to lower Hopland flow later. The hedges against uncertainty are reduced to make the release higher (and Hopland flow closer to 8,000 cfs) and evacuate more flood space in the reservoir.

A third adjustment when the inflow forecast is large is that the look-ahead value (K) is reduced by 6 hours, which will yield a lower flow value as flow rises. This lower value subtracted from the Hopland threshold will produce a higher release.

Finally, as protection against missed forecasts, when the current Hopland local flow is greater than the forecasted flow, the current Hopland-local-flow is used in place of the forecast in the release equation.

A. Hopland Release Rule parameters

The Hopland Release equation that includes the forecast of Hopland local flow is noted as:

Hopland-Release(t) = Hopland-threshold – WF-flow(t) – Hopland-local-flow-fcast(t+K)

The Hopland release rules applied in HEC-ResSim are defined as a function of the Hopland-Release state variable computed using this equation. The description below specifies the values of all parameters of the Hopland release rule and state variable as they vary based on the three conditions (modeled as IF-Blocks) described above. Two of these parameters are defined in the state variable that computes the rule, and the last is varied in the rule tables.

The three conditions used to define the Hopland-Release rule hedging parameters are:

(1) 5-day inflow volume forecast > or < 25,000 AF
(2) WF flow > or < previous 3 hour average of WF flow (i.e., rising or falling)
(3) Elevation > or < 755

These three conditions are evaluated by an IF-Block, and the hedging parameters for each condition are defined as follows. The same IF-Block structure appears in the HEC-ResSim Operation Set rule stack, and some of it in the Hopland-Release state variable script.

```
LOW INFLOW FORECAST CONDITION
If 5-day inflow volume forecast < 25,000 AF

    Hopland-threshold = 8000 * 85% = 6800 cfs
    WF-flow(t) = current WF flow
    Hopland-local-flow-forecast(t+K) = forecast flow K=14 hours in future

    If WF is rising (compared to 3 hr avg),
        release = 75% of computed Hopland-Release
    Else WF is falling (compared to 3 hr avg),
        If elev < 755
            release = 95% of computed Hopland-Release
        Else elev > 755
            release = Baseline Alternative's WF proxy rule for falling with elev>755
        End If
    End If


HIGH INFLOW FORECAST CONDITION
Else, when 5-day inflow volume forecast > 25,000 AF (current, OR the day before)

    Hopland-threshold = 8000 * 95% = 7600 cfs
    WF-flow(t) = current WF flow
    Hopland-local-flow-forecast(t+K) = forecast flow K=8 hours in future

    If WF is rising (compared to 3 hr avg),
        release = 100% of computed Hopland-Release
    Else WF is falling (compared to 3 hr avg),
        If elev < 755
            release = 100% of computed Hopland-Release
        Else elev > 755
            release = Baseline Alternative's WF proxy rule for falling with elev>755
        End If
    End If
End If
```

Summary of Variable Parameters:

Hopland threshold, defined as percentage of 8000 cfs:

- 85% = 6800 cfs for 5day forecast < 25,000 AF
- 95% = 7600 cfs for 5day forecast > 25,000 AF

K hours ahead in the forecast:

- K=14 hours for 5day forecast < 25,000 AF
- K=8 hours for 5day forecast > 25,000 AF

Multipliers on the computed release in the rule table, based on whether WF rising or falling:

- 75% and 95% for WF rising and WF falling, respectively, when 5day forecast < 25,000 AF
- 100% for both WF rising and WF falling when 5day forecast > 25,000 AF

B. Computation and Application of Hopland-Release

The Lake Mendocino release for the Hopland threshold is computed by HEC-ResSim in two steps. First, a state variable called "Hopland_Release" computes a release based on the current West Fork (WF) flow and the forecasted Hopland local flow at the appropriate look-ahead time, including choices based on the 5-day inflow volume forecast. The state variable code is displayed in Section VI (HEC-ResSim State Variables). Next, rules in the operation set's rule stack reference the state variable, and implement a certain percentage of the state variable release. Figure 4 shows the IF-Block structure for implementing the multiple versions of the rule based on the conditions described above.

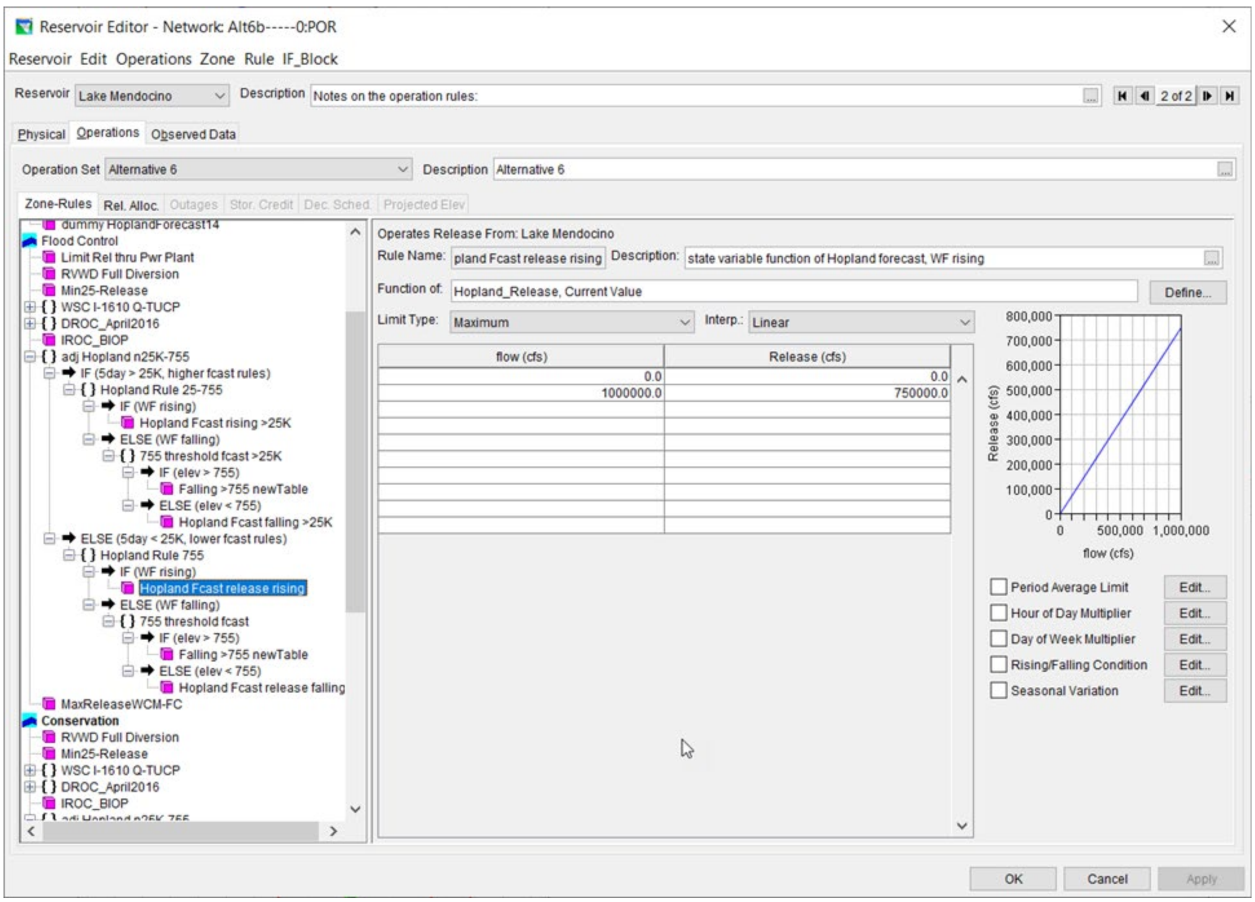

Figure 4. HEC-ResSim Operation Set IF-Block for Hopland Release Rule

For the selected rule in the 5day vol < 25,000 AF and WF-Rising conditions, it can be seen that reservoir release is set to 75% of the "Hopland_Release" state variable by looking at the second row in the rule table. Similar rules in other locations of the IF-Blocks apply a percentage of either 95% or 100%. Note, rule "Falling >755 newTable" is the Baseline WF proxy rule, which is used in Alternative 6 in the condition that reservoir elevation is above 755 feet.

Figure 5 below shows the use of the Hopland-Release rule in February 2004. The second pane shows Lake Mendocino inflow and outflow, and contains a pink line showing the computed Hopland-Release. Subject to the decreasing rate of change (DROC) limits, the reservoir release (in green) is kept below some percentage of this computed release, as described in Section IV above. The fourth pane shows the Hopland local flow in blue, and the forecast of the Hopland local flow, 14 hours ahead, in purple. On February 15, the increasing forecast causes the allowable Hopland-Release to decrease. Because WF flow is rising, reservoir release is limited to 75% of the Hopland-Release, and begins to decrease in response. However, decrease in release is limited by the higher priority DROC limits, and so actual release does not fall as quickly as the Hopland-Release. Note, when the Hopland-local flow (in blue in the fourth pane) is greater than the forecast, it is used in place of the forecast, as described in Section IV above. Thus, it is as the Hopland-local flow decreases, rather than as the forecast decreases, that the Hopland-Release starts to rise on February 18, allowing release to follow at 95% until the guide curve is reached. A similar pattern of decreasing Hopland-Release is seen on February 25, though it does not affect release which is already down at 25 cfs. However, the increasing Hopland-Release on February 26 again allows reservoir release to follow and draft the small amount of flood storage.

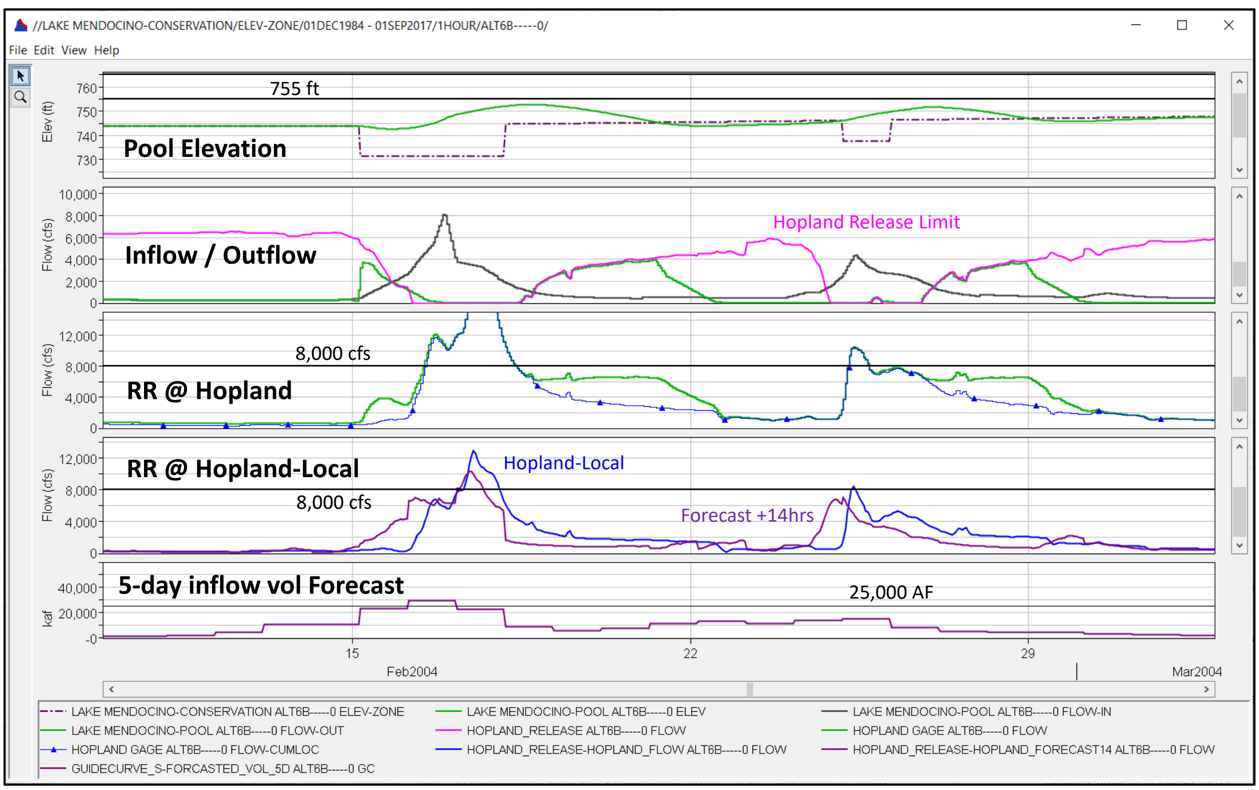

Figure 5. February 2004 Example of Use of Hopland-Release Rules

V. Results

Alternative 6 was simulated for the period of record for which ensemble hindcasts were available, 01Jan1985 – 30Sep2017, and for the 200 year and 500 year level of five scaled flood events: 1986, 1997, 2006, March 1995 and a synthetic event referred to as "Extended 2006." Extended 2006 is a version of the 2006 event that starts earlier, and is scaled up more for the early events, producing a challenging back to back event situation. Results of the defined metrics are presented in another section of the FVA report, but selected results (graphs, as well as May 10 storage and Hopland flow) are also presented here.

A. Period of Record Simulation

Figure 6 shows the guide curves and elevations for Alternative 6 and Baseline, with January 1985 – July 2002 in the top half, and and March 2002 – September 2017 in the bottom half. For Alternative 6, the guide curve is pink and elevation is green. For Baseline, the guide curve is purple and elevation is red. Where they differ, the Alternative 6 guide curve is higher, except during brief periods when inflow forecasts are large enough to prompt a drop to the Standard GC, or Draft GC. Due to the allowed 11,000 AF (11 KAF) of encroachment, as well as spring refill from that encroached level that starts on 16 February rather than 1 March, the Alternative 6 elevation is nearly always higher than Baseline elevation, except during flood events.

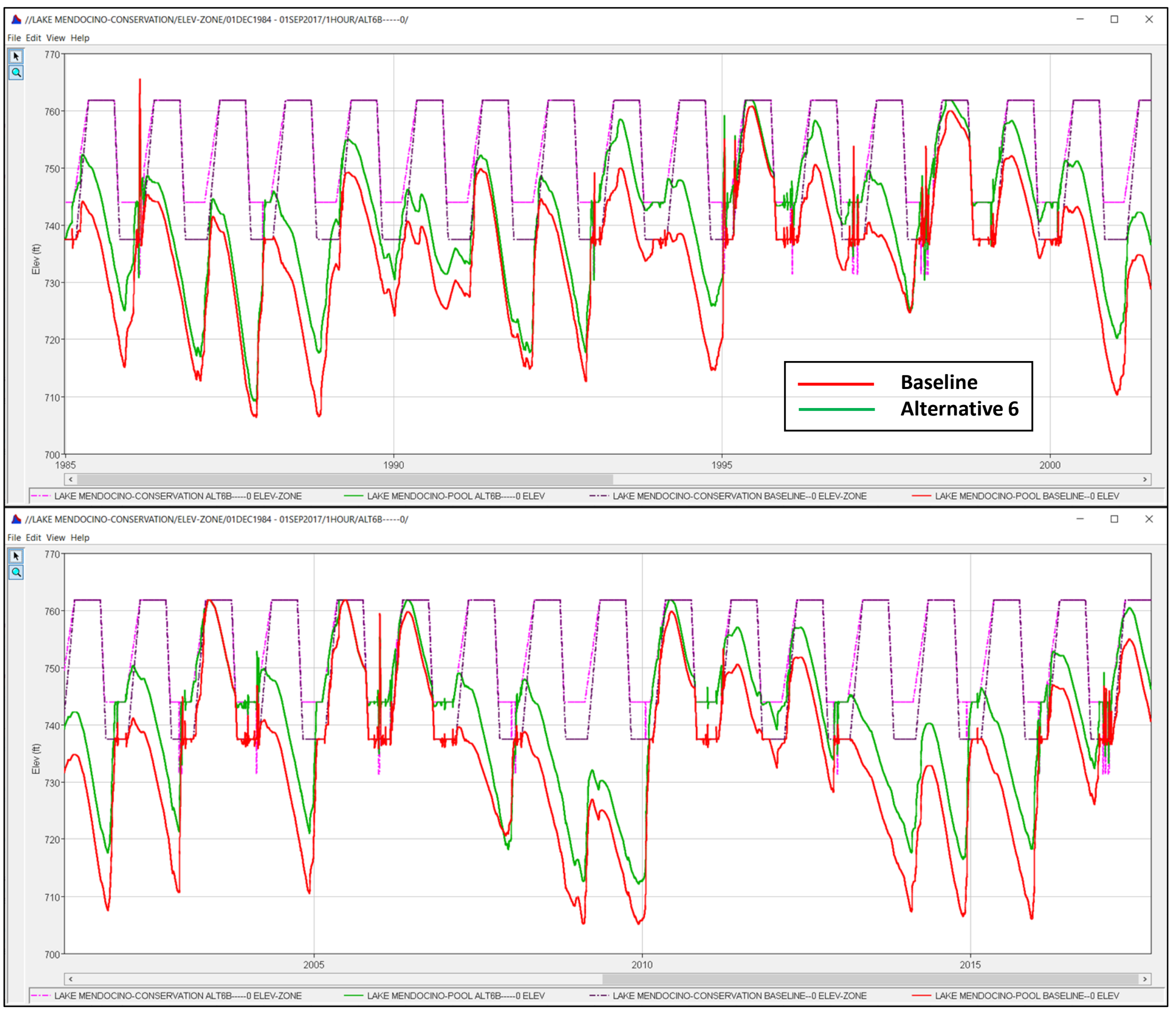

Figure 6. Lake Mendocino Guide Curve and Elevation for Alternative 6 (green) and Baseline (red)

Reservoir storage level on May 10 is a relevant metric to capture impact to water supply. The median May 10 storage for Alternative 6 is 14,000 AF greater than Baseline. Figure 7 shows the May 10 storage for each year of the record, ordered from highest to lowest against percent of years exceeding (with median = 50% exceedance).

An important flood metric is exceedance of the 8,000 cfs threshold for Russian River at Hopland. Figure 6 doesn't show flows, but Figure 8 shows daily duration curves for the Russian River at Hopland computed from the period of record for Baseline and Alternative 6. The two alternatives are nearly the same. Zooming in on 8,000 cfs threshold, Alternative 6 has a slightly lower % of time exceeding, but both round to 0.59% of time exceeding 8,000 cfs. Note, the official FVA metric looks at only how often the annual maximum Hopland flow exceeds 8,000 cfs, while this measure considers all daily flows.

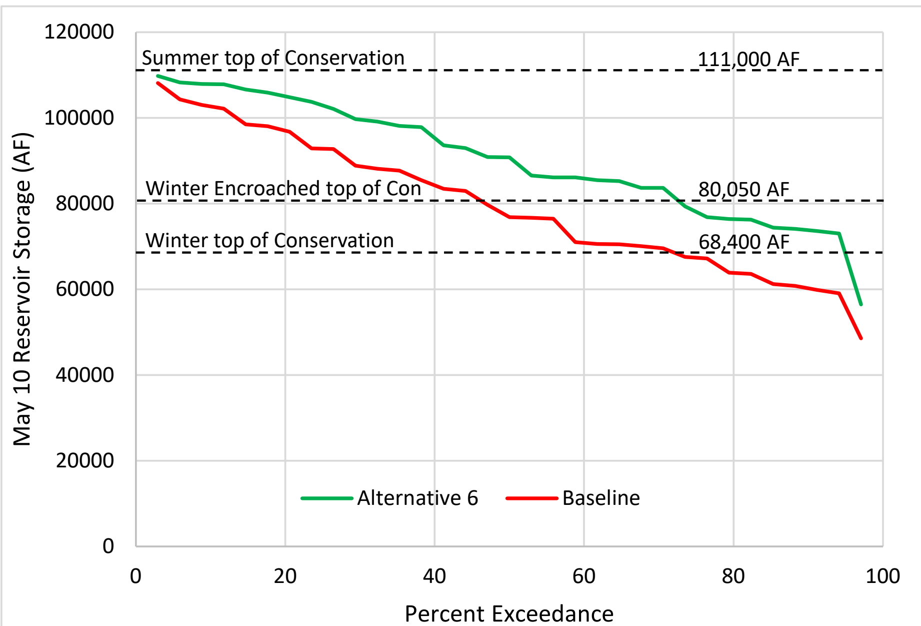

Figure 1. May 10 storage values for Alternative 6 (green) and Baseline (red) vs %-time exceeded

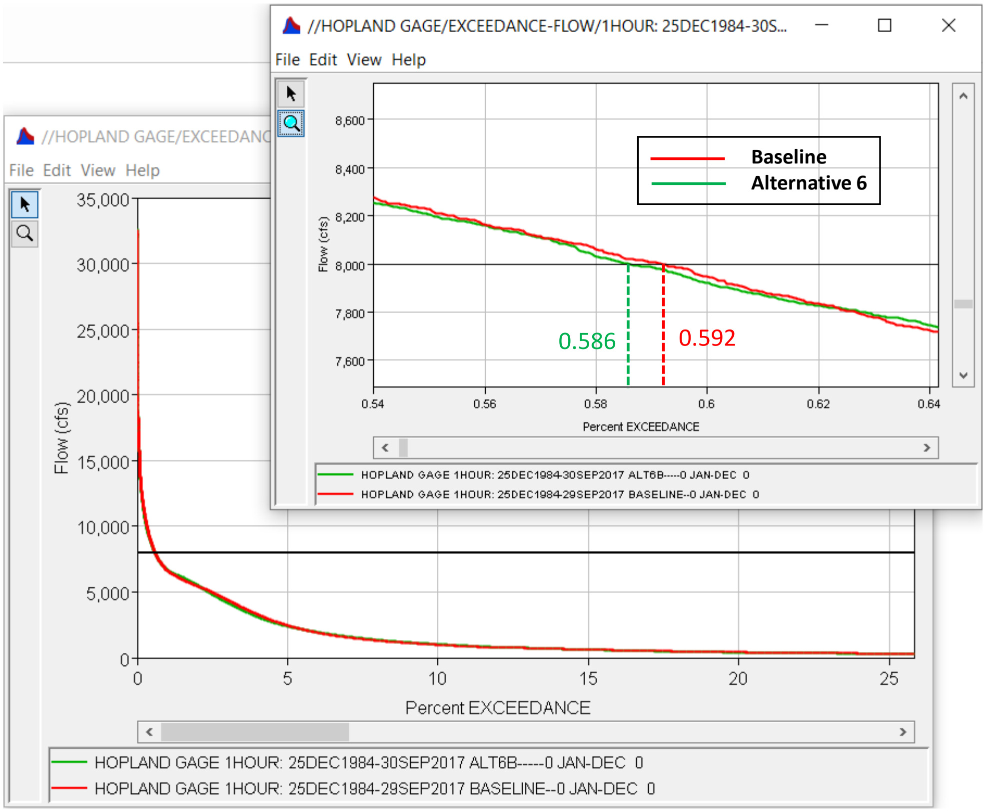

Figure 2. Daily Duration Curves, percent of time exceeding 8,000 cfs at Hopland

Figure 9 below shows the 1998 water year as an example of the features of *Alternative 6* as compared to Baseline. Before mid-January, low forecasts (bottom viewport) allow the guide curve to remain at the Encroached GC level, which is 11,000 AF higher than the Standard GC. Inflow eventually fills the reservoir to that level. Starting in mid-January, forecasts preceding the multiple flood events trigger lowering the guide curve to the Standard and sometimes to the Draft GC, with additional draft of 10 KAF. The reservoir is drafted to those levels as “space” in the river downstream at Hopland allows (to remain below the 8,000 cfs threshold). The guide curve is generally restored to the Encroached GC level before the end of each event, allowing some flood volume to be retained.

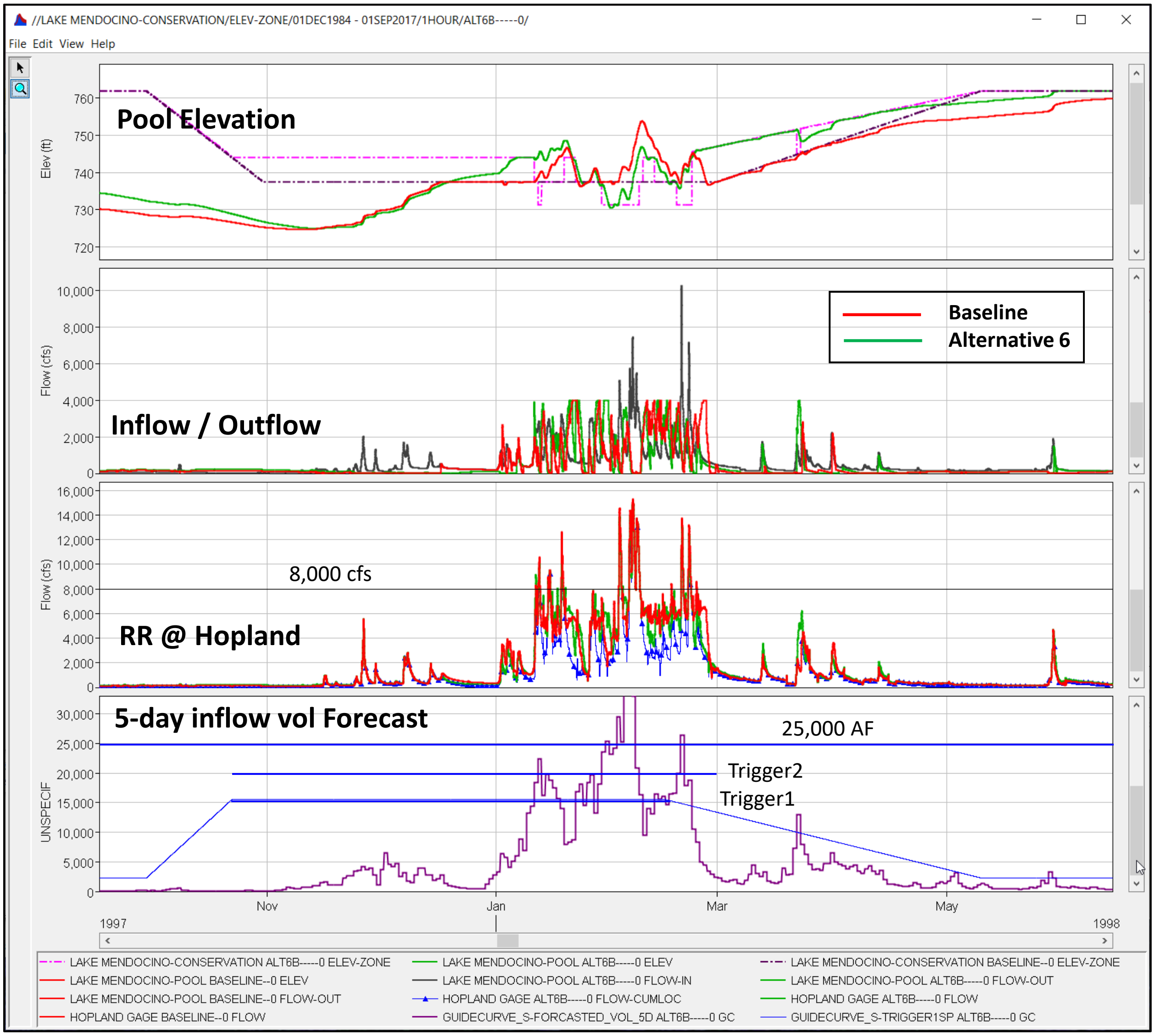

Figure 9. 1998 Water Year from Period of Record Simulation

Operation resulted in a lower peak pool than the Baseline simulation for the largest volume flood event (in February), but also allowed greater storage level into the spring. A single forecast above spring-Trigger 1 in April lowered the guide curve to the Standard GC for one day, prompting some of the encroachment to be evacuated, but it was recovered by the following (forecasted) inflow volume. The 1998 water year yields the positive features of the alternative, including improved flood operation (a lower peak reservoir pool during the flood events due to forecast-based draft before the events) and improved water supply (greater storage by the end of spring) without exceeding the 8000 cfs Hopland flow threshold by more than the Baseline alternative.

Figure 10 shows the 2017 water year. This year also yields the positive features of the alternative, but perhaps makes less use of the flood pool than it could. Figure 11 shows the 2016 water year. Both of these years (2016 and 2017) have some examples of unneeded draft in response to inflow forecasts, but downstream thresholds were well-respected and drafted water was recovered. In both years, as well as 1998 above, Alternative 6 operation has approximately 10,000 AF more storage volume on May 10 than the Baseline alternative. In 2016 and 2017, this difference carries into the following year, while in 1998, the Baseline alternative was also able to fill by July.

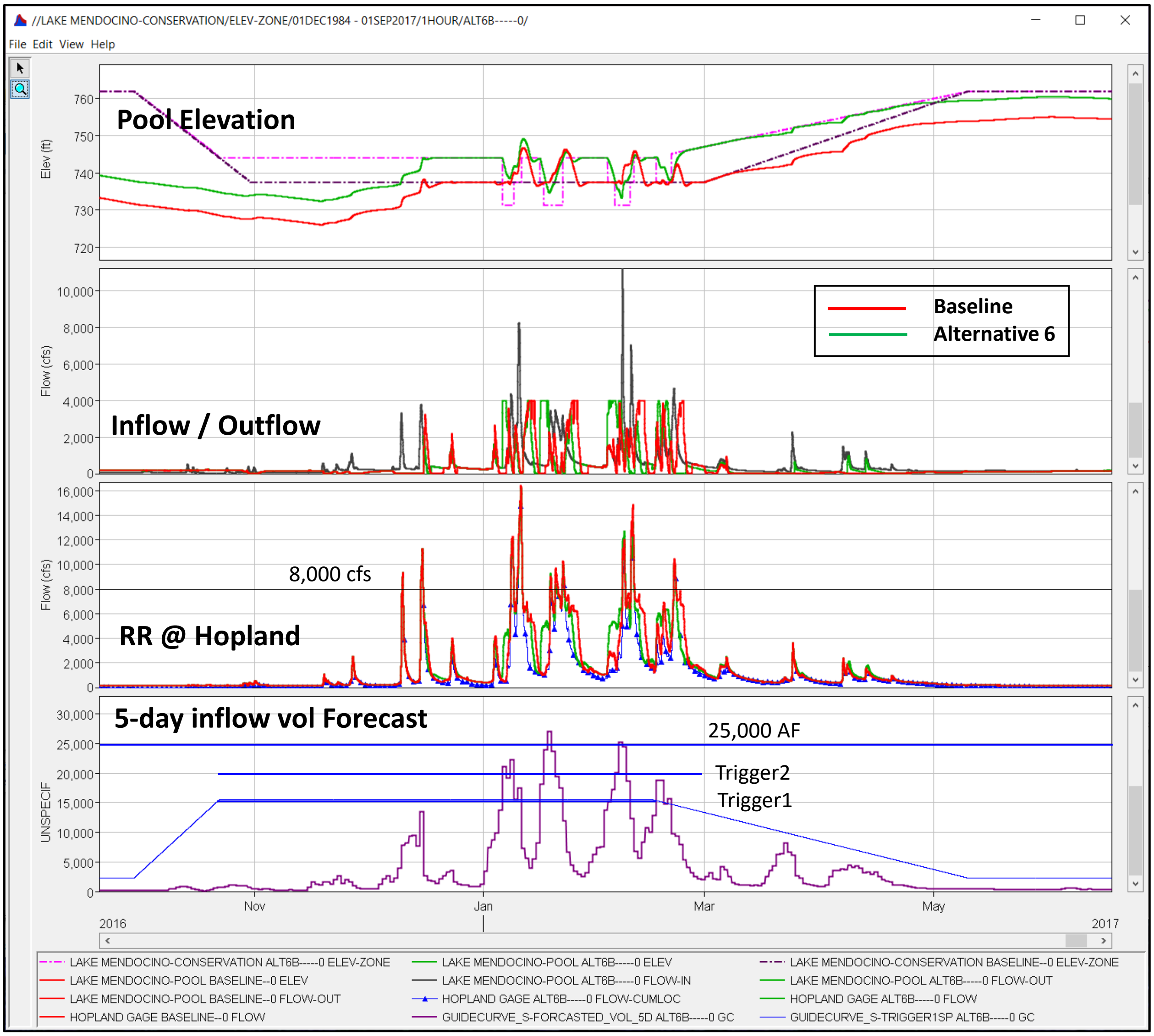

Figure 10. 2017 Water Year from Period of Record Simulation

Figure 11. 2016 Water Year from Period of Record Simulation

B. Scaled Event Simulations

Figure 12 through Figure 21 display plots of the five scaled event sets: 200 year and 500 year for 1986, 1997, 2006, March 1995, Extended 2006 (back to back).

The colors in the plots scaled event plots are as follows:

Green = Alternative 6
Red = Baseline alternative

Viewports in the scaled event plots are (from top to bottom): (1) Lake Mendocino Elevation, (2) Lake Mendocino inflow and release, (3) flow on Russian River at Hopland, and (4) inflow forecast volume.

1986 Event Scalings

In the 1986 scaled events, 200 year in Figure 12 and 500 year in Figure 13, forecasts exceeded trigger levels early enough to allow Alternative 6 to draft Lake Mendocino to the Draft GC, 10 KAF below the Standard GC, before increased flow at Hopland caused release to be curtailed to 25 cfs. Both events reached the spillway with both alternatives, but Alternative 6 produced lower peak elevation, reservoir release and Russian River flow at Hopland than the Baseline alternative. The Alternative 6 Hopland release rules were successful at keeping the Hopland flow below 8,000 cfs when the cumulative local flow (the lowest possible flow, shown in blue) was below 8,000 cfs. The events end with elevation at the Encroached GC, providing greater water supply.

1986 200-year:

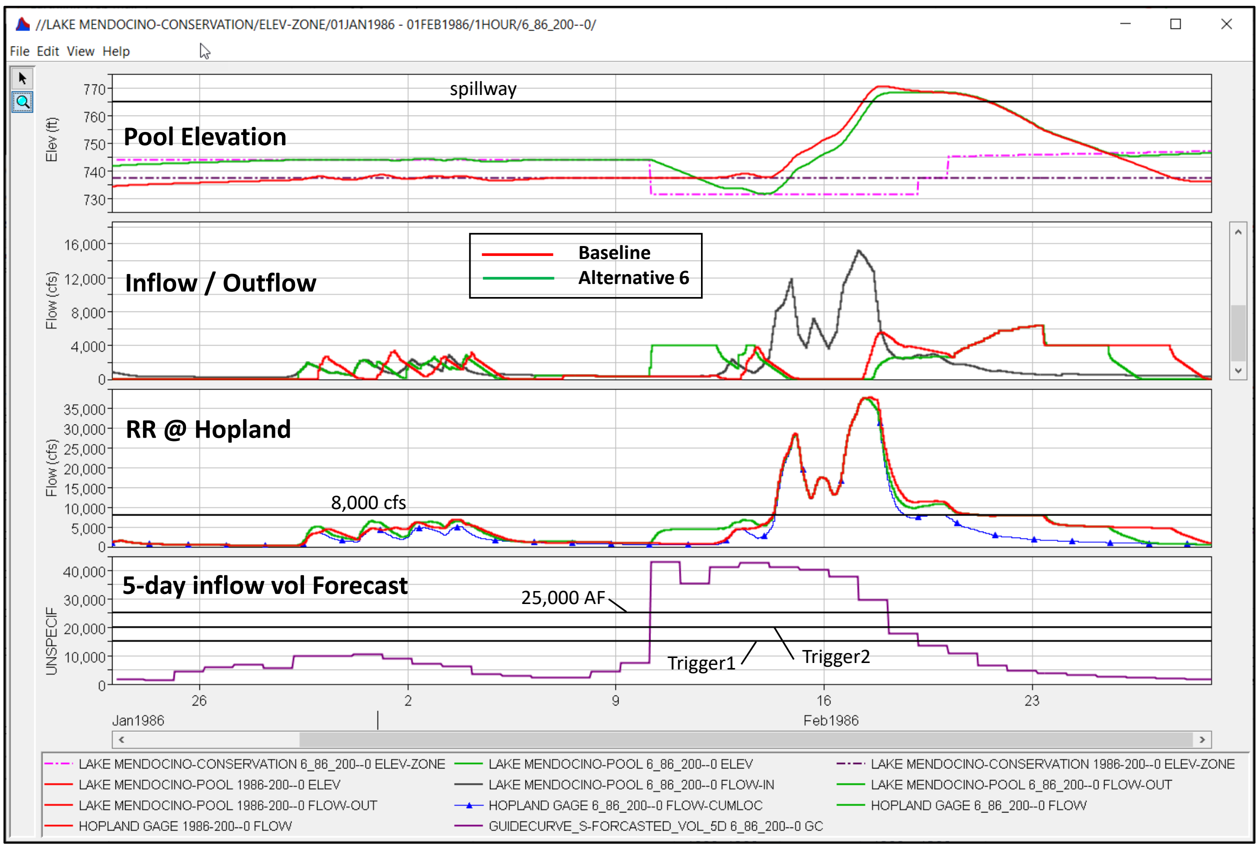

Figure 12. 1986 200-year event, *Alternative 6* (Alt 6) and *Baseline* alternative results

1986 500-year:

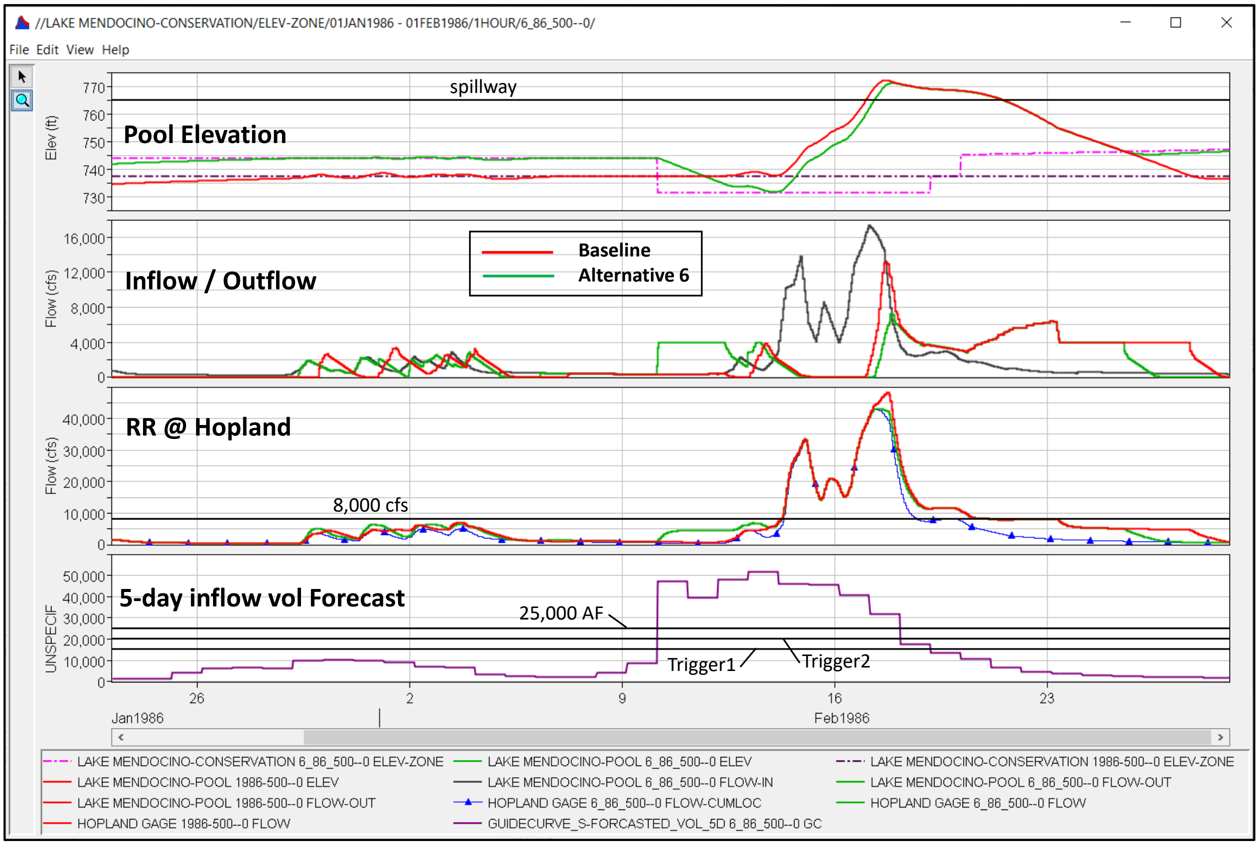

Figure 13. 1986 500-year event, *Alternative 6* (Alt 6) and *Baseline* alternative results

1997 Event Scalings

In the 1997 scaled events, 200 year in Figure 14 and 500 year in Figure 15, forecasts exceeded trigger levels early enough to allow Alternative 6 to draft Lake Mendocino to the Draft GC, 10 KAF below the Standard GC, before increased flow at Hopland caused release to be curtailed. Both events reached the spillway in the Baseline alternative, but Alternative 6 was able to keep the reservoir just below the spillway in the 200 year scaling. Alternative 6 produced lower peak elevation and reservoir release than Baseline in both events. Russian River flow at Hopland was the same as the Baseline alternative for the 200 year scaling, but lower for the 500 year scaling. The Alternative 6 Hopland release rules were successful at keeping the Hopland flow below 8,000 cfs when the cumulative local flow (the lowest possible flow, shown in blue) was below 8,000 cfs. The events end with elevation at the Encroached GC, providing greater water supply.

1997 200-year:

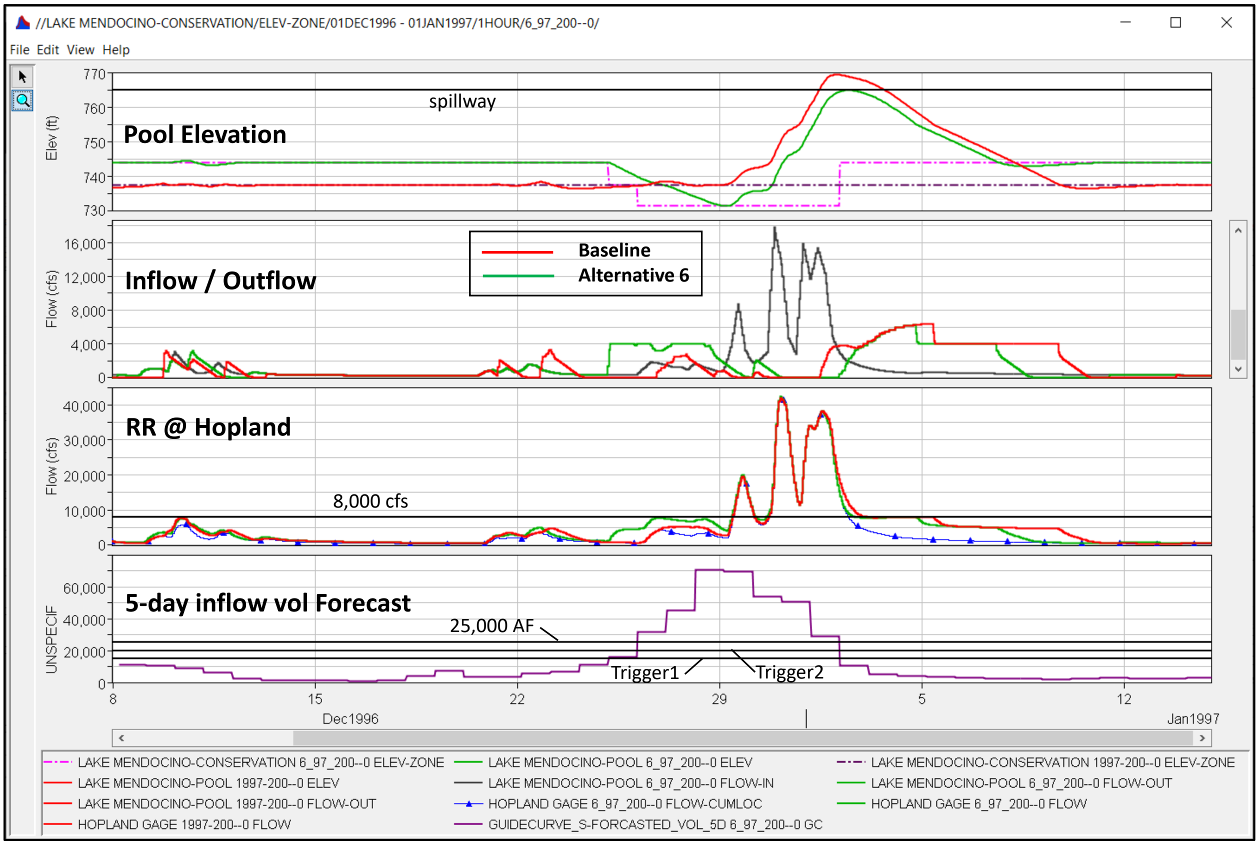

Figure 14. 1997 200-year event, *Alternative 6* (Alt 6) and *Baseline* alternative results

1997 500-year:

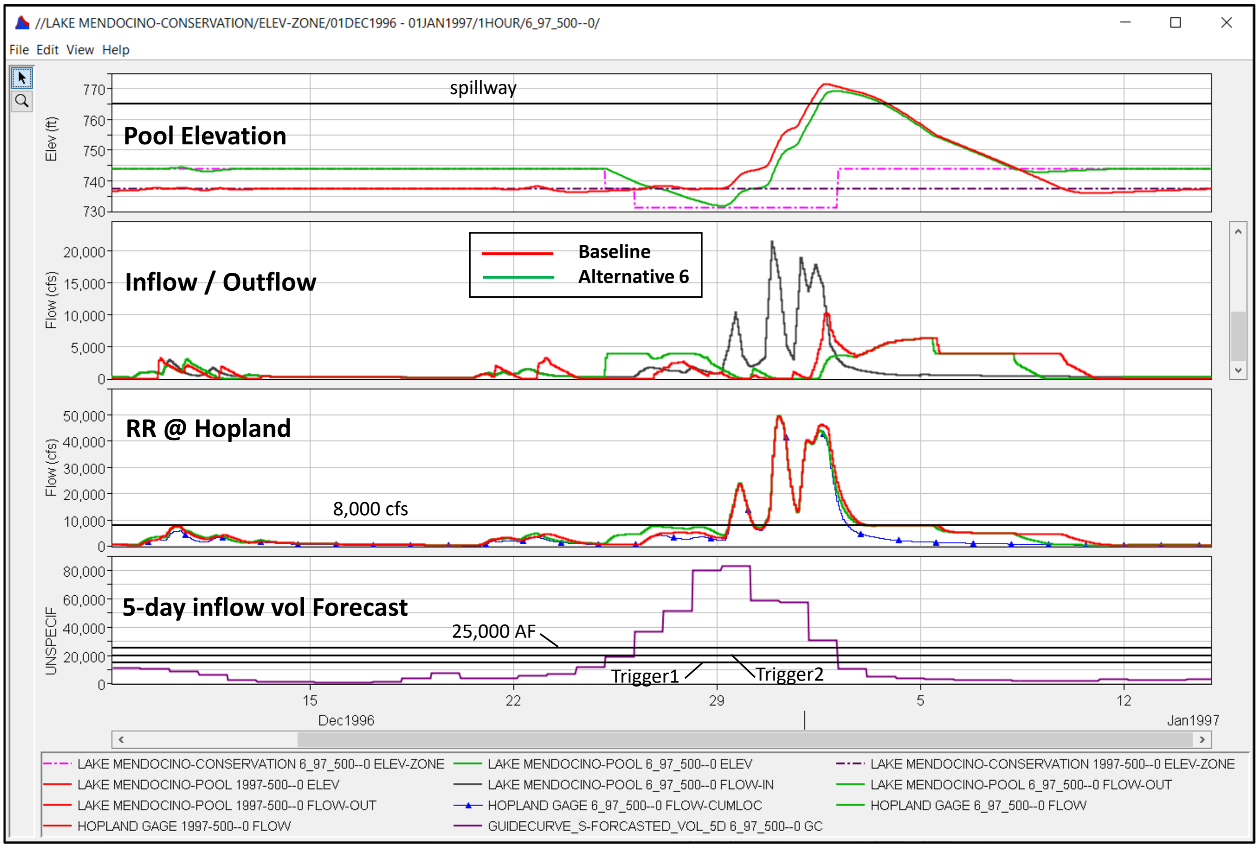

Figure 15. 1997 500-year event, *Alternative 6* (Alt 6) and *Baseline* alternative results

2006 Event Scalings

In the 2006 scaled events, 200 year in Figure 16 and 500 year in Figure 17, forecasts did not exceed trigger levels early enough to allow Alternative 6 to draft Lake Mendocino to the Draft GC, 10 KAF below the Standard GC, before increased flow at Hopland caused release to be curtailed. However, some additional draft below the Standard GC was achieved in each event. Both events reached the spillway in both alternatives, but Alternative 6 produced lower peak elevation and reservoir release than Baseline in both events. Russian River flow at Hopland was somewhat lower for Alternative 6 than the Baseline alternative for the 200 year scaling, and notably lower for the 500 year scaling. The Alternative 6 Hopland release rules were successful at keeping the Hopland flow below 8,000 cfs when the cumulative local flow (the lowest possible flow, shown in blue) was below 8,000 cfs. Both events end with elevation at the Encroached GC, providing greater water supply.

2006 200-year:

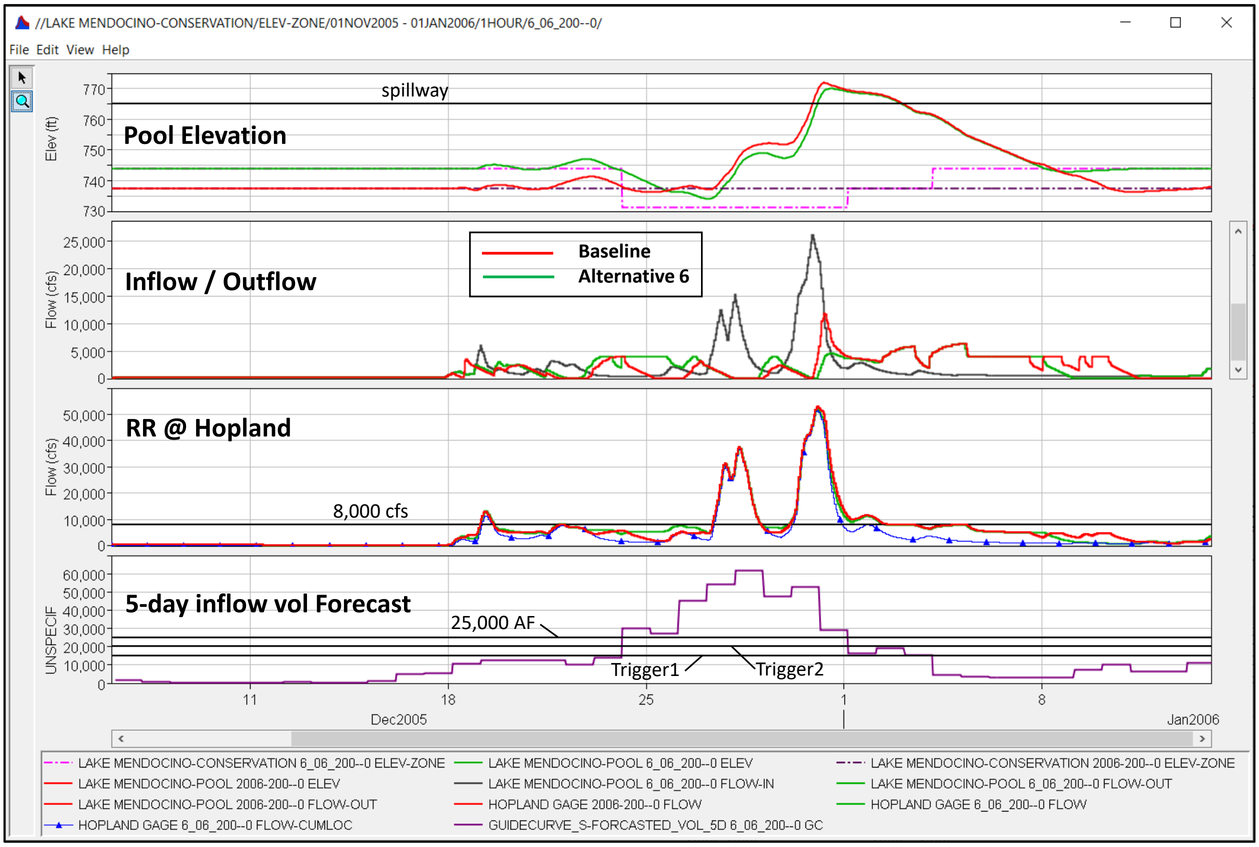

Figure 16. 2006 200-year event, *Alternative 6* (Alt 6) and *Baseline* alternative results

1997 500-year:

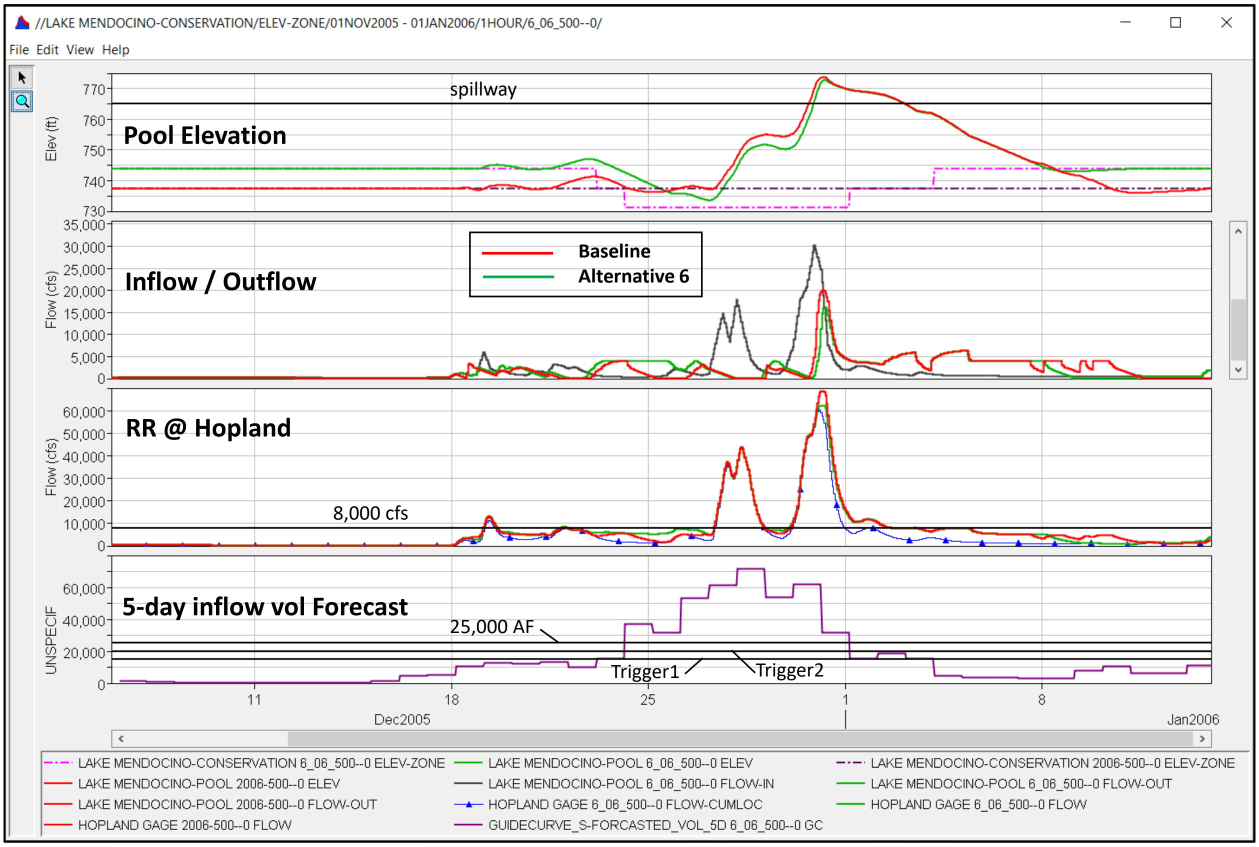

Figure 17. 2006 500-year event, *Alternative 6* (Alt 6) and *Baseline* alternative results

March 1995 Event Scalings

The March 1995 scaled events were included to evaluate a flood event occurring after spring refill has begun. In these events, 200 year in Figure 18 and 500 year in Figure 19, forecasts exceed the trigger level early enough to allow Alternative 6 to draft Lake Mendocino to the Standard GC well before flow increased on the Russian River at Hopland. (The Draft GC does not exist in spring.) Neither alternative reaches the spillway in the 200 year scaling, but both just exceed the spillway in the 500 year scaling, though without a release higher than the rules already allowed due to high elevation. Reservoir release and Russian River flow at Hopland were the same for Alternative 6 as Baseline in both events. The Alternative 6 Hopland release rules were successful at keeping the Hopland flow below 8,000 cfs when the cumulative local flow (the lowest possible flow, shown in blue) was below 8,000 cfs, except on 20 March with both alternatives slightly exceeded.

The Lake Mendocino 5-day inflow volume forecast rose high enough to exceed the trigger and evacuate the encroachment a second time on 18 March in both scalings. The reservoir was able to rise back to the Encroached GC by the end of the defined event in the 500-year scaling, but did not quite reach it by the end of the 200 year scaling.

March 1995 200-year:

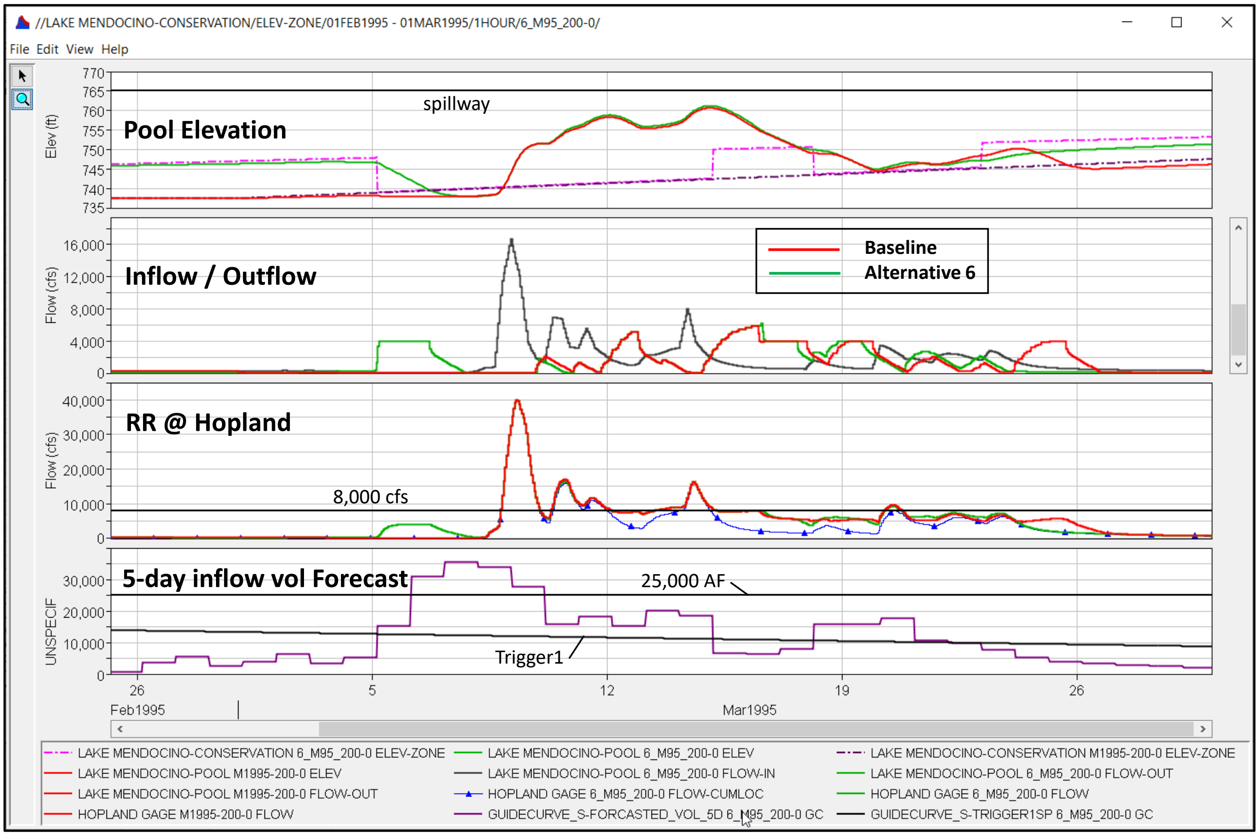

Figure 18. March 1995 200-year event, *Alternative 6* (Alt 6) and *Baseline* alternative results

March 1995 500-year:

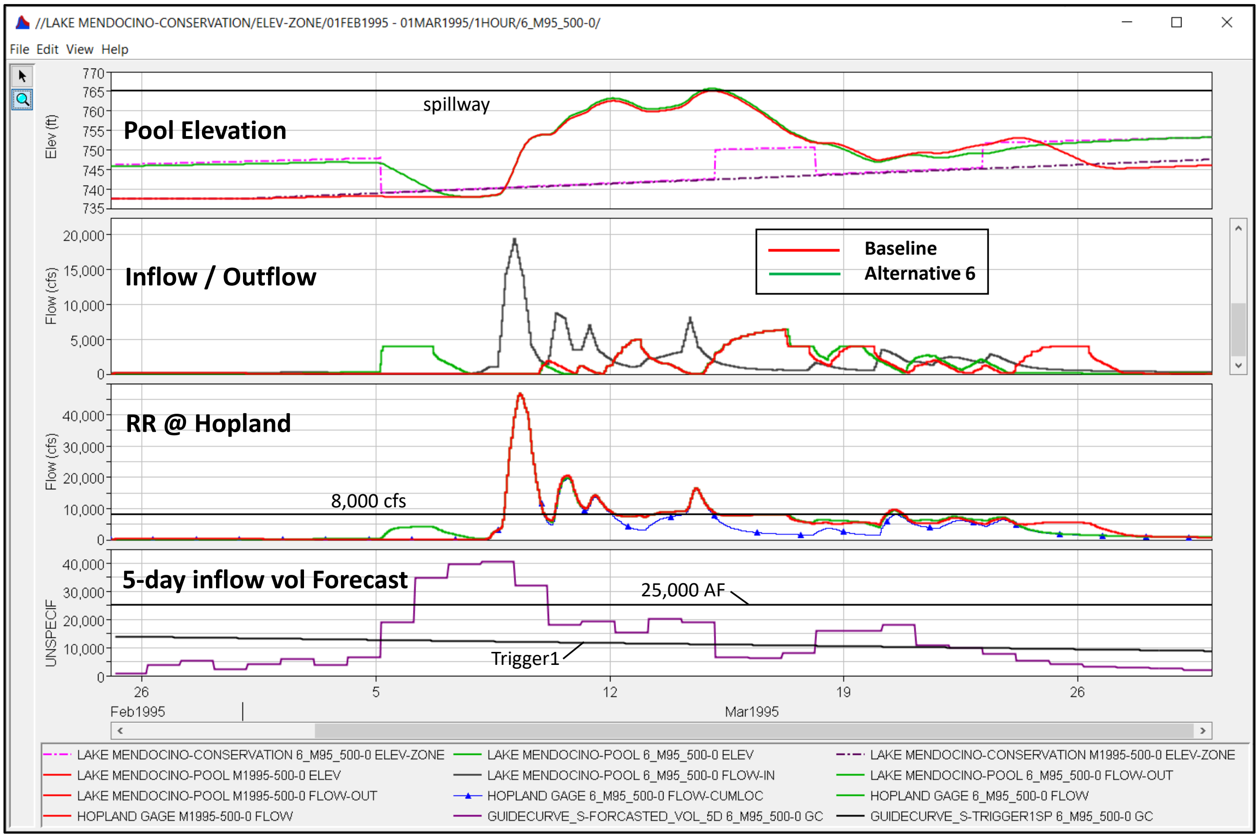

Figure 19. March 1995 500-year event, *Alternative 6* (Alt 6) and *Baseline* alternative results

Extended 2006 Event Scalings

The Extended 2006 event was included to consider the operation of the alternatives during several large flood events occurring in close succession. While the original 2006 event scalings increased the flows in late December, the Extended 2006 event scalings started earlier, with the flows increased to match 200 and 500 year levels of an 18-day average Lake Mendocino inflow frequency curve. (Note, in all scaled events, flows are increased as a result of scaling up precipitation, such that resulting simulated flows match X-day flow frequency curve values.) Unlike the other scaled events which used a constant scaling, in this event the early flood peaks were scaled somewhat more than the later peaks to make those first peaks more significant.

In these events, 200 year in Figure 20 and 500 year in Figure 21, forecasts did not exceed the trigger levels early enough to allow the reservoir to draft below the Encroached GC at all before increased flow at Hopland forced curtailment of release. Thus, in both scalings, in Alternative 6 the reservoir began the first flood event in the encroached state. This fact caused a peak pool higher than Baseline for the first peak, and the same as Baseline for the second peak in both scalings. In the 500 year scaling, the first peak exceeded the spillway in Alternative 6, but not Baseline. Flows at Hopland were the same for Alternative 6 and Baseline throughout all peaks of both scalings. Both events end with elevation at the Encroached GC, providing greater water supply.

Extended 2006 (back-to-back) 200-year:

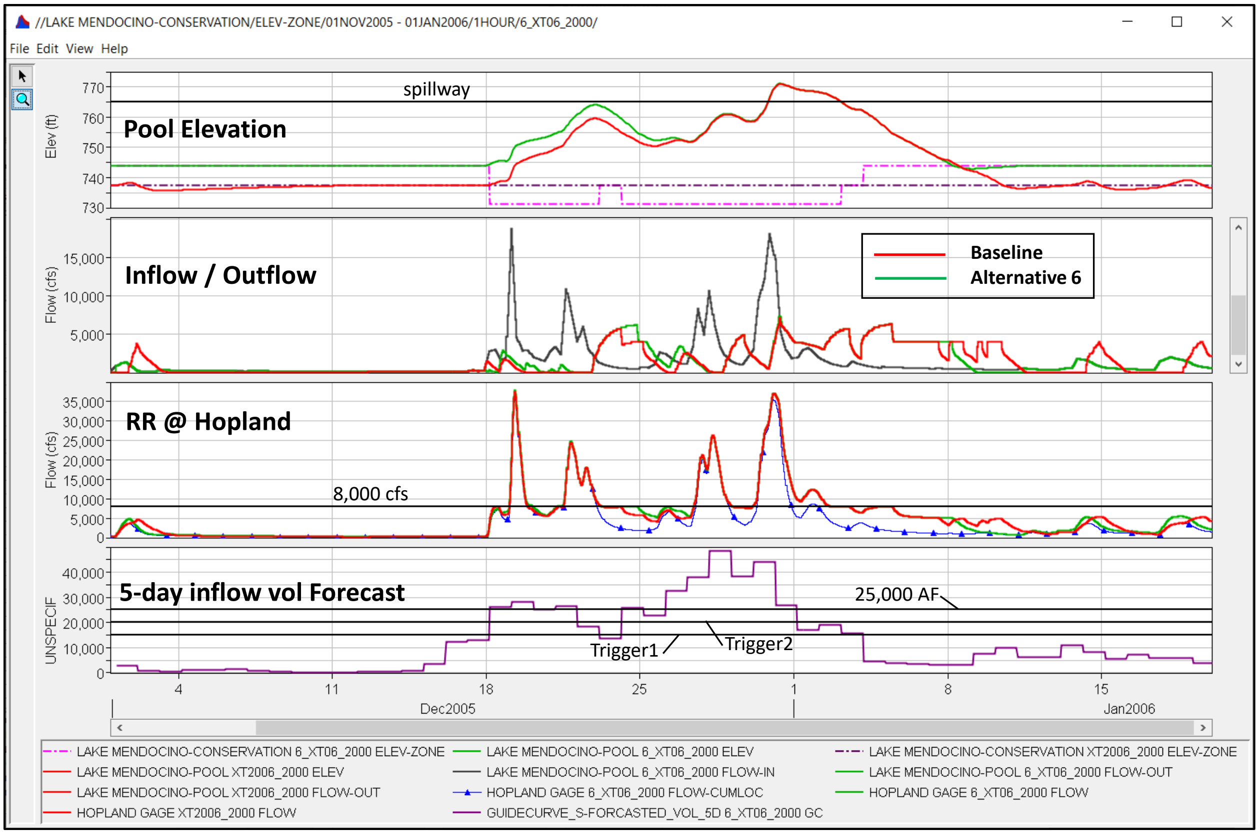

Figure 20. Extended 2006 (back to back) 200 year, *Alternative 6* (Alt 6) and *Baseline* results

Extended 2006 (back-to-back) 500-year:

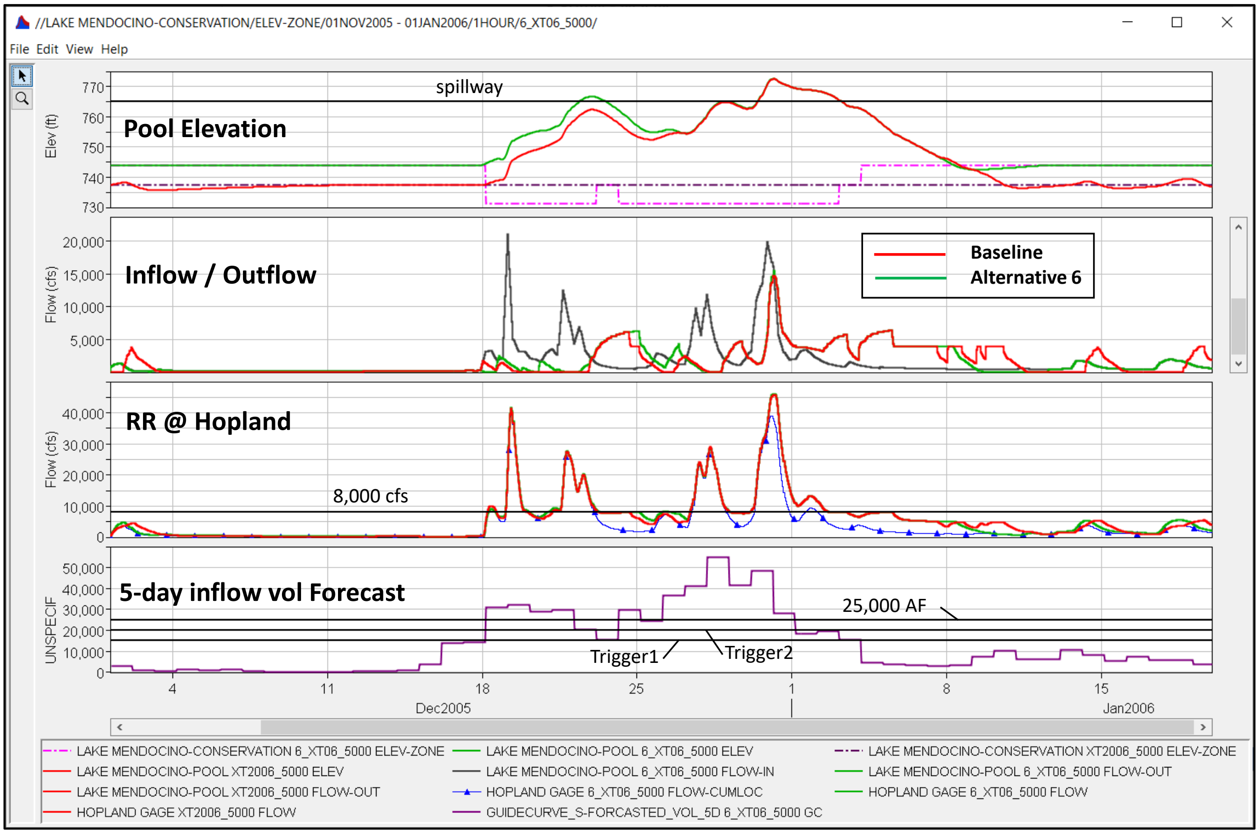

Figure 21. Extended 2006 (back to back) 500 year, *Alternative 6* (Alt 6) and *Baseline* results

VI. HEC-ResSim State Variables

A. Guide Curve State Variable

GuideCurve_S

<u>Initialization:</u>

```
from hec.script import Constants
from hec.hecmath import TimeSeriesMath, DSS, DSSFile
from hec.script import  ClientAppWrapper
from hec.model import  SeasonalRecord

def initStateVariable(currentVariable, network):

        tw=network.getRssRun().getCurrentComputeBlockRunTimeWindow()
        tws = tw.getTimeWindowString()

        currentVariable.localTimeSeriesNew("step")
        currentVariable.localTimeSeriesNew("Mendocino_GC")
        currentVariable.localTimeSeriesNew("Encr_GC")
        currentVariable.localTimeSeriesNew("Forcasted_Vol_5D")
```

```
        currentVariable.localTimeSeriesNew("Vol")
        currentVariable.localTimeSeriesNew("Vol_FR")
        currentVariable.localTimeSeriesNew("Vol_1")
        currentVariable.localTimeSeriesNew("Target_Vol")
        currentVariable.localTimeSeriesNew("Trigger1Sp")
        currentVariable.localTimeSeriesNew("Trigger2Sp")
        currentVariable.localTimeSeriesNew("BufferSp")

        return Constants.TRUE
```

Main:

```
from hec.heclib.util import HecTime

curDOY=currentRuntimestep.getHecTime().dayOfYear()

# convert factor from cfs to ac-ft/day
cfstoacft=1.983471074

Encr_GC=network.getStateVariable("EncroachedGC_S").getValue(currentRuntimestep)
Encr_GC_TS=currentVariable.localTimeSeriesGet("Encr_GC")
Encr_GC_TS.setCurrentValue(currentRuntimestep, Encr_GC)

Mendocino_GC=network.getStateVariable("Original_GC").getValue(currentRuntimestep)
Mendocino_GC_TS=currentVariable.localTimeSeriesGet("Mendocino_GC")
Mendocino_GC_TS.setCurrentValue(currentRuntimestep, Mendocino_GC)

#Pool volume at spillway crest elev 764.8, 116,470 af
Orig_FP=116469 -Mendocino_GC
Encr_FP=116469 -Encr_GC

#Pool Volume at elevation 731.35, 10K below standard GC
Min_Vol=58409.13

Trigger1=15000
Trigger2=20000
Buffer=3000

#based on spillway crest 116,469 af
Trigger1Sp= Encr_FP *0.42                    # 42% equal 15000
Trigger2Sp= Orig_FP *0.42
BufferSp=Encr_FP * 0.042   # 4.2% equals 1500, 1/2 of the winter buffer

Trigger1Sp_TS=currentVariable.localTimeSeriesGet("Trigger1Sp")
Trigger1Sp_TS.setCurrentValue(currentRuntimestep, Trigger1Sp)

Trigger2Sp_TS=currentVariable.localTimeSeriesGet("Trigger2Sp")
Trigger2Sp_TS.setCurrentValue(currentRuntimestep, Trigger2Sp)

BufferSp_TS=currentVariable.localTimeSeriesGet("BufferSp")
BufferSp_TS.setCurrentValue(currentRuntimestep, BufferSp)

Forcasted_Vol_5D = network.getTimeSeries("Reservoir","Lake Mendocino", "Forecast",
                    "",1).getCurrentValue(currentRuntimestep)

# set for previous day
if Forcasted_Vol_5D >=Trigger2:
        Vol=-1   # dropping pool below standard GC
elif Forcasted_Vol_5D >=Trigger1:
        Vol=0    # Moving back to standard GC
else:
```

```
        Vol=1    # Allow encroachment above standard GC

Forcasted_Vol_5D_var=currentVariable.localTimeSeriesGet("Forcasted_Vol_5D")
Forcasted_Vol_5D_var.setCurrentValue(currentRuntimestep, Forcasted_Vol_5D)

Vol_TS=currentVariable.localTimeSeriesGet("Vol")
Vol_TS.setCurrentValue(currentRuntimestep, Vol)
Vol_1=Vol_TS.getPreviousValue(currentRuntimestep)

#First Run of Vol
Vol_FR_TS=currentVariable.localTimeSeriesGet("Vol_FR")
Vol_FR_TS.setCurrentValue(currentRuntimestep, Vol)

Vol_1_TS=currentVariable.localTimeSeriesGet("Vol_1")
Vol_1_TS.setCurrentValue(currentRuntimestep, Vol_1)

#Defining the state, 1, 0 -1, based on triggers

# use the encroached GC between 23 Oct and 19 Mar
# use the Min volume between 01 Nov and 01 Mar
#23 Oct (day 296) , 19 March (day 78) , 01 Nov(day 305) , 01 March (day 60), 10 May (day 131)

if (curDOY>=296 or curDOY<60):              #Oct 23 to Feb 28, winter
        if Vol_1==1:
                if Forcasted_Vol_5D <Trigger1:
                        Vol=1
                elif Forcasted_Vol_5D >Trigger2:
                        Vol=-1
                else:
                        Vol=0
        elif Vol_1==0:
                if Forcasted_Vol_5D < (Trigger1 - Buffer):
                        Vol=1
                elif Forcasted_Vol_5D >Trigger2:
                        Vol=-1
                else:
                        Vol=0
        else:
                if Forcasted_Vol_5D < (Trigger1 - Buffer):
                        Vol=1
                elif Forcasted_Vol_5D > (Trigger2 - Buffer):
                        Vol=-1
                else:
                        Vol=0
elif (curDOY>=60 and curDOY<=131):          # March 1 to May 10, spring
        if Vol_1==1:
                if Forcasted_Vol_5D <Trigger1Sp:
                        Vol=1
                elif Forcasted_Vol_5D >Trigger2Sp:
                        Vol=-1
                else:
                        Vol=0
        elif Vol_1==0:
                if Forcasted_Vol_5D <(Trigger1Sp - BufferSp):
                        Vol=1
                elif Forcasted_Vol_5D >Trigger2Sp:
                        Vol=-1
                else:
                        Vol=0
        else:
                if Forcasted_Vol_5D < (Trigger1Sp- BufferSp):
                        Vol=1
```

```
                elif Forcasted_Vol_5D > (Trigger2Sp-BufferSp):
                        Vol=-1
                else:
                        Vol=0
else:                                           # May 11 to Oct 22, no encroachment or extra draft
        Vol=1

Vol_TS=currentVariable.localTimeSeriesGet("Vol")
Vol_TS.setCurrentValue(currentRuntimestep, Vol)

# Setting the Target Volume, i.e. the Guide Curve

if ((curDOY>=296 and curDOY<=305) or (curDOY>=60 and curDOY<=131)): #Oct 23 to Nov 1 & March 1 to May 10
        if Vol==1:
                Target_Vol=Encr_GC
        else:
                Target_Vol=Mendocino_GC
elif (curDOY>=305 or curDOY<=60):                       #Nov 1 to March 1
        if Vol==1:
                Target_Vol=Encr_GC
        elif Vol==0:
                Target_Vol=Mendocino_GC
        else:
                Target_Vol=Min_Vol
else:                                                   #May 11 to Oct 22
        Target_Vol=Mendocino_GC

Target_Vol_var=currentVariable.localTimeSeriesGet("Target_Vol")
Target_Vol_var.setCurrentValue(currentRuntimestep, Target_Vol)

Res_Name=network.findReservoir("Lake Mendocino")
Storage_Function=Res_Name.getStorageFunction()
Target_Elev= Storage_Function.storageToElevation(Target_Vol)

currentVariable.setValue(currentRuntimestep, Target_Elev)
```

B. Standard Guide Curve State Variable

Original_GC

Initialization:

```
from hec.script import Constants
from hec.model import  SeasonalRecord

# This state variable computes the elev-zone to be used in "Original" state variable.
def initStateVariable(currentVariable, network):


#	t[]=[01 Jan,01 Mar,10 May,30 Sep,31 Oct]
#	t=[1,60,130,273,304,365]   Days
	t=[0,86400, 187200,393120,437760,525600] #Minutes
#	Elev=[737.5, 737.5, 761.8, 761.8, 737.5,737.5]
	Stor=[68409.13, 68409.13, 110967.02, 110967.02, 68409.13,68409.13]
	SR=SeasonalRecord()
	SR.setArrays(t, Stor)
	currentVariable.varPut("GC_Stor", SR)

	return Constants.TRUE
```

Main:

```
Mendocino_GC_Stor=currentVariable.varGet("GC_Stor")
Mendocino_GC=Mendocino_GC_Stor.interpolate(currentRuntimestep)

currentVariable.setValue(currentRuntimestep, Mendocino_GC)
```

C. Encroached Guide Curve State Variable

EncroachedGC_S

Initialization:

```
from hec.script import Constants
from hec.model import  SeasonalRecord

# This state variable computes the elev-zone to be used in "Encroachment" state variable.
def initStateVariable(currentVariable, network):

#   "Encr_Elev" is calculated to find the Encroached GC which has 11,000 acft more than original winter
GC(68,409.13 acft at elevation 737.5)
#           which is 79,409.13 at elevation 743.98
#
#           t[]=[01 Jan,01 Mar,10 May,30 Sep,30sep+ 22.72]
#           t=[1, 60, 130, 273, 273+22.72 , 365]Days

#Mar 1 refill
#           t=[0, 86400, 187200,393120,425838,525600]            #Minutes, removed the decimal values

#early refill:  change Mar 1 to Feb 16, 60 to 46, 86400 to 66240
            t=[0, 66240, 187200,393120,425838,525600]            #Minutes, removed the decimal values

#           Elev=[743.98, 743.98, 761.8, 761.8, 743.98, 743.98]
            Stor=[79409.13, 79409.13, 110967.02, 110967.02, 79409.13, 79409.13]
            SR=SeasonalRecord()
            SR.setArrays(t, Stor)
            currentVariable.varPut("Encr_Stor", SR)

            return Constants.TRUE
```

Main:

```
Encroched_GC_Stor=currentVariable.varGet("Encr_Stor")
Encroched_GC=Encroched_GC_Stor.interpolate(currentRuntimestep)

currentVariable.setValue(currentRuntimestep, Encroched_GC)
```

D. Hopland Release Computation State Variable

Hopland_Release

Initialization:

```
from hec.script import Constants

def initStateVariable(currentVariable, network):

        currentVariable.localTimeSeriesNew("step")
        currentVariable.localTimeSeriesNew("Hopland_Flow")
        currentVariable.localTimeSeriesNew("WF_Flow")
        currentVariable.localTimeSeriesNew("Hopland_Forecast")
        currentVariable.localTimeSeriesNew("Hopland_Forecast14")
        currentVariable.localTimeSeriesNew("Forecast_Vol_5D")

        return Constants.TRUE
```

Main:

```
from hec.heclib.util import HecTime

step=currentRuntimestep.getStep()
step_TS=currentVariable.localTimeSeriesGet("step")
step_TS.setCurrentValue(currentRuntimestep, step)

# Hopland forecast 75th percentile, 8 hours ahead and 14 hours ahead
Hopland_Forecast = network.getTimeSeries("Reservoir","Lake Mendocino", "Hopland 8hr forecast", "",1)
Hopland_Forecast14 = network.getTimeSeries("Reservoir","Lake Mendocino", "Hopland 14hr forecast", "",1)

# Save Time series to Quality Control
Hopland_Forecast_8hr= Hopland_Forecast.getCurrentValue(currentRuntimestep)
Hopland_Forecast_TS=currentVariable.localTimeSeriesGet("Hopland_Forecast")
Hopland_Forecast_TS.setCurrentValue(currentRuntimestep, Hopland_Forecast_8hr)

Hopland_Forecast_14hr= Hopland_Forecast14.getCurrentValue(currentRuntimestep)
Hopland_Forecast14_TS=currentVariable.localTimeSeriesGet("Hopland_Forecast14")
Hopland_Forecast14_TS.setCurrentValue(currentRuntimestep, Hopland_Forecast_14hr)

# get values of "actual" West Fork and Hopland flow
WF_Flow=network.getTimeSeries("Junction","Russian River NR Ukiah Gage", "", "Flow-
            Local").getCurrentValue(currentRuntimestep)
Hopland_Flow=network.getTimeSeries("Junction","Hopland Gage", "", "Flow-
            Local").getCurrentValue(currentRuntimestep)

# bring in the 5-day inflow volume forecast
Forecast_Vol_5D = network.getTimeSeries("Reservoir","Lake Mendocino", "Forecast", "",1)
Forecast_Vol_5D_var = Forecast_Vol_5D.getCurrentValue(currentRuntimestep)

# Save Time series to Quality Control
WF_Flow_TS=currentVariable.localTimeSeriesGet("WF_Flow")
WF_Flow_TS.setCurrentValue(currentRuntimestep, WF_Flow)
Hopland_Flow_TS=currentVariable.localTimeSeriesGet("Hopland_Flow")
Hopland_Flow_TS.setCurrentValue(currentRuntimestep, Hopland_Flow)

# when 5-day inflow forecast < 25,000 AF, use 14 hour forecast, otherwise use 8 hour
if Forecast_Vol_5D_var < 25000:   #5day inflow forecast > 25,000 AF so use 14 hour ahead, and start 85% of 8000
```

```
# this block is to combat missed forecasts, and also a look-ahead that starts to recede when flow hasn't arrived yet
#           when forecast is higher than actual, use it
            if Hopland_Forecast_14hr >= Hopland_Flow:
                        Rel= 8000*.85- Hopland_Forecast_14hr - WF_Flow
#           when forecast is lower than actual, use actual Hopland flow
            else:
                        Rel= 8000*.85- Hopland_Flow - WF_Flow

else:   #here, 5day inflow forecast > 25,000 AF so use 8 hour look-ahead, and start closer to 8000 (95%)

# this block is to combat missed forecasts, and also a look-ahead that starts to recede when flow hasn't arrived yet
#           when forecast is higher than actual, use it
            if Hopland_Forecast_8hr     >= Hopland_Flow:
                        Rel= 8000*.95- Hopland_Forecast_8hr - WF_Flow
#           when forecast is lower than actual, use actual Hopland flow
            else:
                        Rel= 8000*.95- Hopland_Flow - WF_Flow

if Rel <= 0:
            Rel=0

currentVariable.setValue(currentRuntimestep, Rel)
```

Appendix A Development of Artificial Deterministic Forecasts

Early discussions of Alternative 6 centered on deterministic forecasts, specifically the forecasted 3-day or 5-day inflow volume to Lake Mendocino. But while a hindcast record exists for ensemble forecasts throughout the Russian River basin dating from 01Jan1985 through 30Sep2017, a similar record does not exist for deterministic forecasts. Therefore, to evaluate Alternative 6 across the same period of record and scaled events as the other alternatives that are based either on ensemble forecasts or no forecasts (in the case of Baseline), an artificial deterministic forecast record was needed.

Deterministic forecasts were available, as archived, for the October through May period of each year from 01Dec2005 through 31May2018, with one forecast each day. The forecasts are 6-hourly values extending five days into the future. These archived forecasts were used to determine whether the cumulative volumes are similar enough to a summary of the hindcast ensemble volumes for them to be approximated from those ensembles.

After examining the relationship between cumulative volumes of the deterministic and ensemble forecasts for Lake Mendocino Inflow, it seemed feasible to generate artificial deterministic forecasts from the hindcasted ensemble forecasts. The following sections contain images and discussion of the relationship between deterministic and ensemble forecast volumes at Lake Mendocino for the two flood events in the archived deterministic forecast record, as well as for each day of the record.

i. December 2005 event

The flood event in December 2005 was considered first. In Figure 22, the top row of figures show the 1-day volumes, 3-day volumes and 5-day volumes of the deterministic forecasts on the horizontal axis and the CNRFC simulated flows on the vertical axis (note floating axis labels). The deterministic forecast volumes are simply an accumulation of volume in the single forecast time series over the first day, first 3 days and all 5 days, and are plotted against the same duration volumes of the CNRFC simulated hourly record as an estimate of the true values. It can be seen that the first day of the forecasts (top row, far left) were a good match to simulated values, with all values close to the equal-volume diagonal line. The 3-day volumes (middle) show more scatter, but are unbiased across the entire range. The 5-day volume continue the same trend of more scatter around the "correct" value, but no bias upward or downward. It is especially notable that there is no downward bias evident in the forecasts of the largest values.

The deterministic forecast volumes were then compared to ensemble forecast volumes, both an ensemble mean and 75th percentile of each of the duration volumes. To compute an ensemble mean of the first day's volume, the 1-day volume was computed for each ensemble member to produce 61 values of 1-day volume, and then those volume values were averaged. The 75th percentile of the 1-day volume was simply the 75th percentile value (or as near as possible) of those 61 values of 1-day volume. (This computation is depicted below in Figure 26.)

The second row of Figure 22 shows the deterministic forecast volumes on the horizontal compared to the ensemble mean volumes on the vertical, and the third row shows the comparison of deterministic volumes to the ensemble 75th percentile volumes. In this case, points falling close to the equal-volume diagonal are an indication that a value computed from the ensemble forecast provides a reasonable replica of the deterministic forecast value. The second row shows that as the forecast volumes get larger, the ensemble means tends to be less than the deterministic values for the same day. The third rows shows that the 75th percentile volumes seem to be a closer match to the deterministic values when the forecasts are large, and still a good match for the smaller values (with less ensemble spread).

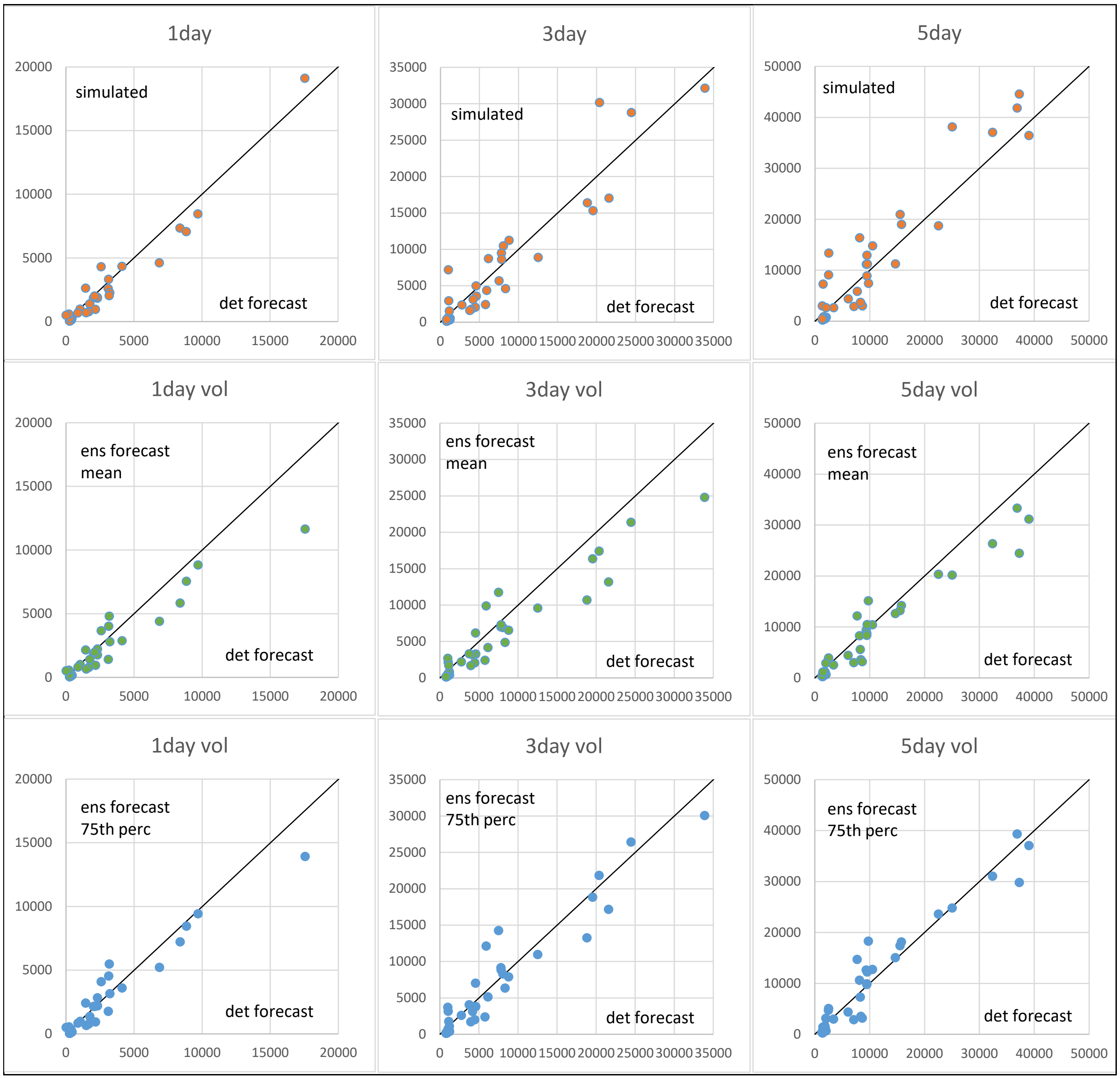

Figure 22. Deterministic and Ensemble Forecast Volumes for December 2005 Flood Event

ii. January – February 2017 events

Figure 23 shows plots similar to Figure 22 for the smaller flood events in January and February of 2017. The first row shows the deterministic forecast volumes for 1-day, 3-day and 5-day to be mostly unbiased compared to the simulated hourly flows used as the representation of actual flow. The second and third rows containing comparisons to the ensemble mean and 75th percentile of these volumes show the mean to be the closer approximation to the deterministic forecasts for the lower values, and the 75th percentile to be closer for the higher values. This observation suggested that use of the mean or the 75th percentile might be varied depending on the actual volume being forecasted, using the mean for lower volumes for which the ensembles are not expected to be biased, and the 75th percentile for larger volumes for which downward ensemble bias is more common.

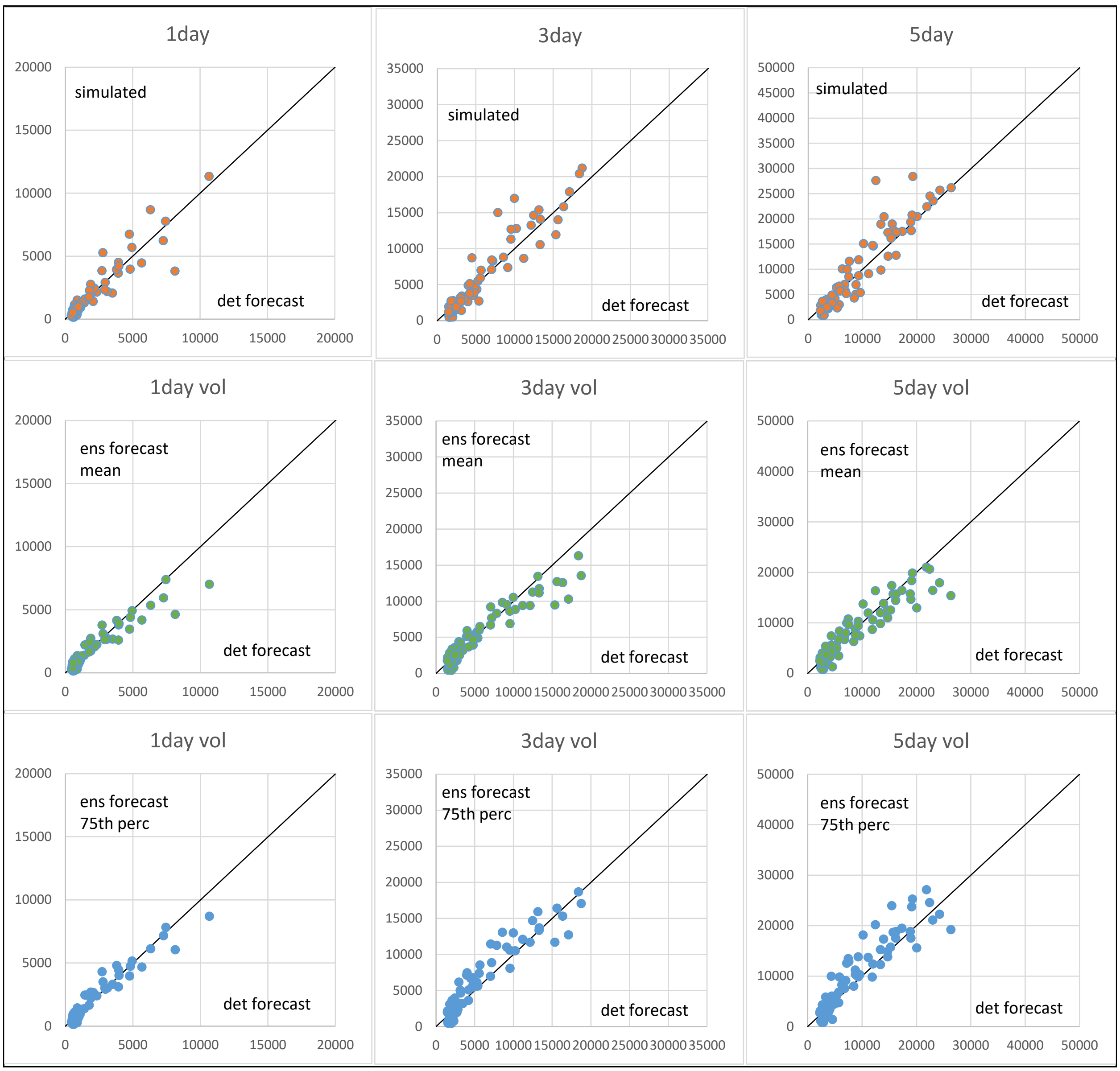

Figure 23. Deterministic and Ensemble Forecast Volumes for January and February 2017 Flood Events

iii. Full Overlapping Period, 01Dec2005 – 31May2018

Figure 24 shows the forecast comparison figures including each day of the period of overlap between deterministic and ensemble forecasts of Lake Mendocino Inflow. The highest values are those already seen in the plots of the December 2005 event, but here we see occurrence of more smaller flood events and lower flows, as well as some forecasts that expected smaller flood events or lower flows. There is more spread around the equal-volume diagonals than when looking specifically at larger flood events, but there is still an overall lack of upward or downward bias in the deterministic forecasts as compared to simulated flow record, shown in the first row. The second and third rows, with comparison to ensemble mean and to 75th percentile volumes, again show that the ensemble mean is a better match for the deterministic volume for smaller values, and the 75th percentile is a better match for larger values.

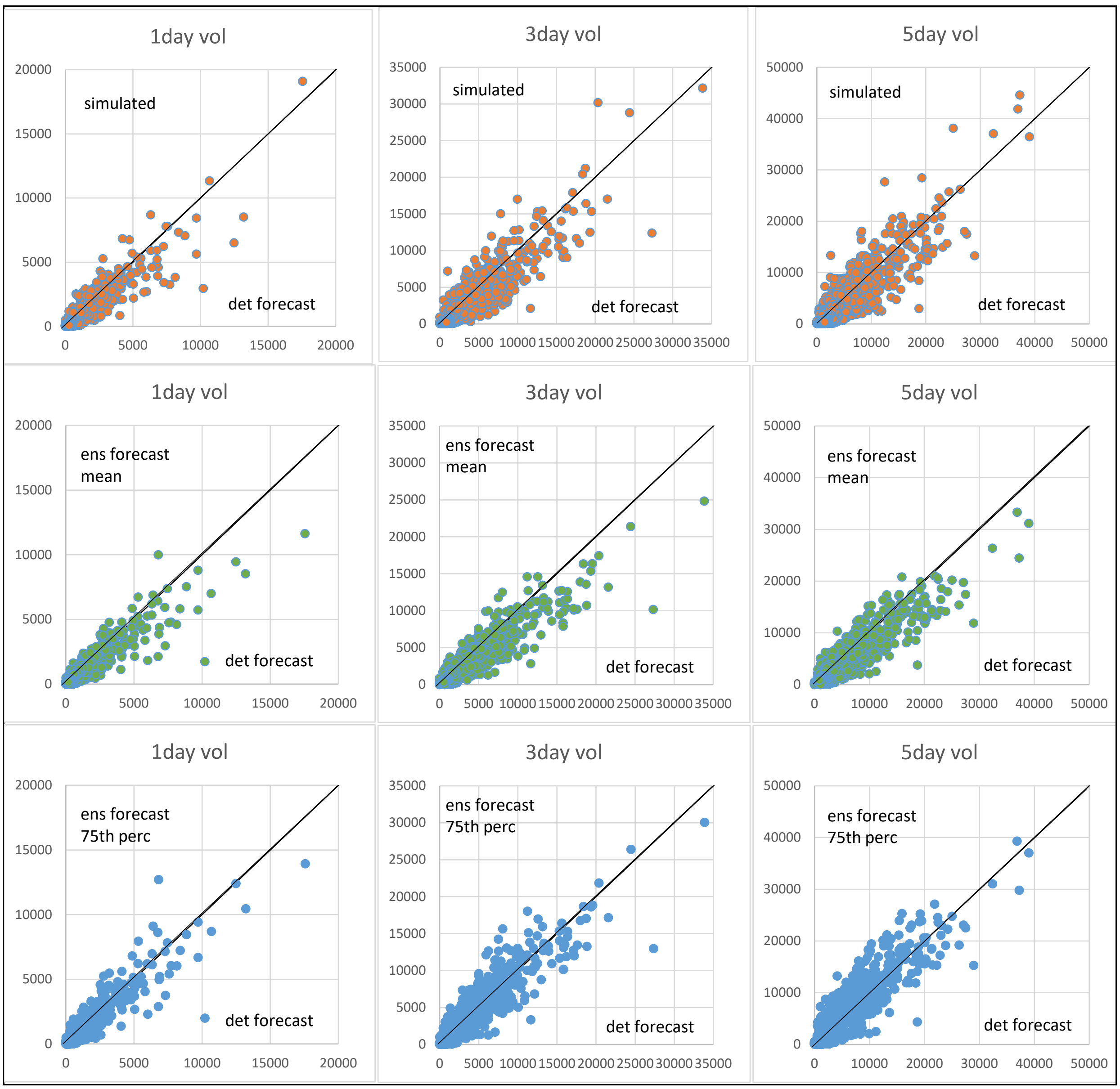

Figure 24. Deterministic and Ensemble Forecast Volumes for Overlap, 01Dec2005—31May2018

Figure 25 shows the forecasted 5-day volumes only, with a selection between ensemble mean and 75th percentile based on the simulated 5-day volume for each day. On the left is deterministic versus ensemble mean, in the middle is deterministic versus ensemble 75th percentile, and on the right is deterministic versus either the ensemble mean when the simulated (actual) volume is less than 10,000 AF or the 75th percentile when the simulated (actual) volume is greater than 10,000 AF. This figure represents the choice made to generate the artificial deterministic 5-day volume forecast record from the ensemble hindcast of the POR and scaled events. This artificial record was used for the simulations in this report.

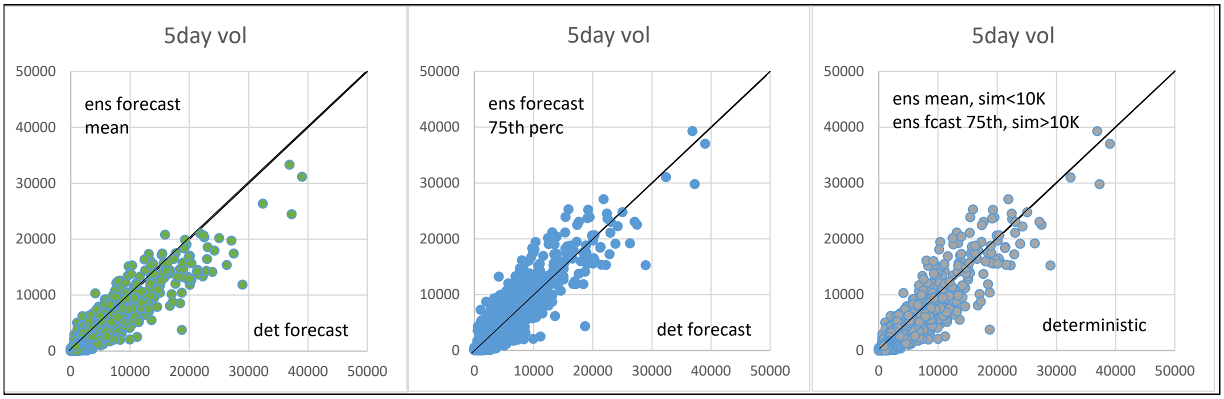

Figure 25. Deterministic and Ensemble 5-day Forecast Volumes, with Ensemble Mean, 75th Percentile, and Final Selection (mean when actual < 10KAF, 75th per when actual > 10KAF)

iv. Estimation of Deterministic Forecast Volumes from Hindcast Ensemble Forecasts

a. Lake Mendocino Inflow

The analysis described above led to the relationship:

deterministic 5-day inflow vol = ensemble <u>mean</u> 5-day vol, when actual 5-day inflow < 10 KAF
ensemble <u>75th pcntl</u> 5-day vol, when actual 5-day inflow > 10 KAF

The values in the relationship were computed from the ensemble forecast (hindcast) available for each day of the period of record, and each of the scaled events. To compute an ensemble mean of the X-day volume, the X-day volume was computed for each ensemble member to produce 61 X-day volumes, and those volumes were averaged. The 75th percentile of the X-day volume was simply the 75th percentile value (or as near as possible) of those 61 X-day volumes. Figure 26 shows the computation of the 1 through 5 day cumulative volumes from a single ensemble forecast for 2/13/1986. In Alternative 6, only the 5-day volume was utilized.

For use in HEC-ResSim state variable scripts, an hourly time series was required, though only one forecast per day is available for the simulation periods. This hourly time series was created using the value computed from each forecast, starting at the forecast date/time and repeated for each of the next 24 hours. The time series changed to a new value with the next forecast, using its computed value starting at its date/time and for the next 24 hours. Figure 27 shows the hourly time series with the value repeated, as well as a daily time-series with the volume value placed only at the time of the forecast. Note, the hindcasts were each generated at noon GMT, Greenwich Mean Time, which was later translated to 4 AM Pacific Standard Time (PST) for the simulations.

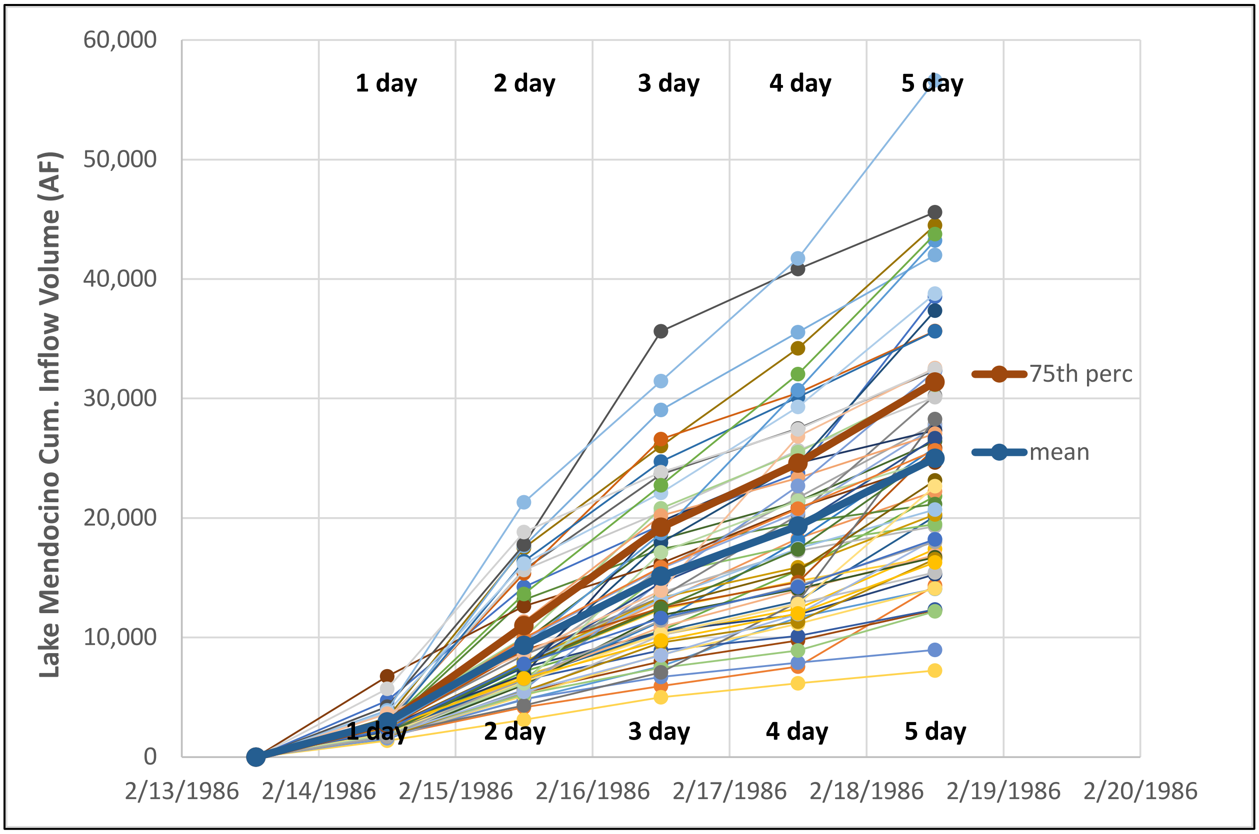

Figure 26. Computation of Ensemble Mean and 75th Percentile of 1-day through 5-day Volumes

/DETERMINISTIC FORECAST FROM ENS 10KSPLIT/LAKE MEND...

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Ordinate	Date / Time	LAKE MENDOCINO INFL... VOLUME 5-DAY VOLUME	LAKE MENDOCINO INF... VOLUME 5-DAY VOLUME
9790	12 Feb 86, 21:00	32,201	
9791	12 Feb 86, 22:00	32,201	
9792	12 Feb 86, 23:00	32,201	
9793	12 Feb 86, 24:00	32,201	
9794	13 Feb 86, 01:00	32,201	
9795	13 Feb 86, 02:00	32,201	
9796	13 Feb 86, 03:00	32,201	
9797	13 Feb 86, 04:00	30,489	30,489
9798	13 Feb 86, 05:00	30,489	
9799	13 Feb 86, 06:00	30,489	
9800	13 Feb 86, 07:00	30,489	
9801	13 Feb 86, 08:00	30,489	
9802	13 Feb 86, 09:00	30,489	
9803	13 Feb 86, 10:00	30,489	
9804	13 Feb 86, 11:00	30,489	
9805	13 Feb 86, 12:00	30,489	
9806	13 Feb 86, 13:00	30,489	
9807	13 Feb 86, 14:00	30,489	
9808	13 Feb 86, 15:00	30,489	
9809	13 Feb 86, 16:00	30,489	
9810	13 Feb 86, 17:00	30,489	
9811	13 Feb 86, 18:00	30,489	
9812	13 Feb 86, 19:00	30,489	
9813	13 Feb 86, 20:00	30,489	
9814	13 Feb 86, 21:00	30,489	
9815	13 Feb 86, 22:00	30,489	
9816	13 Feb 86, 23:00	30,489	
9817	13 Feb 86, 24:00	30,489	
9818	14 Feb 86, 01:00	30,489	
9819	14 Feb 86, 02:00	30,489	
9820	14 Feb 86, 03:00	30,489	
9821	14 Feb 86, 04:00	28,100	28,100
9822	14 Feb 86, 05:00	28,100	
9823	14 Feb 86, 06:00	28,100	
9824	14 Feb 86, 07:00	28,100	
9825	14 Feb 86, 08:00	28,100	
9826	14 Feb 86, 09:00	28,100	
9827	14 Feb 86, 10:00	28,100	
9828	14 Feb 86, 11:00	28,100	
9829	14 Feb 86, 12:00	28,100	
9830	14 Feb 86, 13:00	28,100	
9831	14 Feb 86, 14:00	28,100	
9832	14 Feb 86, 15:00	28,100	
9833	14 Feb 86, 16:00	28,100	

Figure 27. Hourly and Daily Time-Series of Forecast Volumes for Use in ResSim State Variable Scripts

b. Hopland Local Flow

For use in determining a reservoir release that maintained flow on the Russian River at Hopland below its threshold of 8,000 cfs, values from the ensemble forecast of Hopland local flow were used to approximate a deterministic forecast. In this study, the hindcast record of the Hopland local flow did not receive the level of analysis as the Lake Mendocino inflow forecast, described above, as use of the forecast was introduced much later in the process. Instead, the 75th percentile of the ensemble, computed each hour, was chosen to represent a deterministic forecast. On dates that were not during flood events, the ensemble members are so close together that the mean and 75th percentile are nearly the same. But during flood events, the slight downward bias seen in the Lake Mendocino inflow forecasts was assumed to also occur in the Hopland local flow forecasts, while the lack of bias seen in the deterministic forecast was also assumed. Thus, the 75th percentile was chosen for use each day, to be a better match for high flow while not notably different from the mean for lower flow.

deterministic Hopland forecast = ensemble 75th percentile hourly flow for each day

From each hindcast ensemble, summary values were computed for each hour as depicted in Figure 28. The figure shows the 61 ensemble members, and the ensemble mean and ensemble 75th percentile as computed each hour. Two 24-hour time windows are noted in green, with one starting 8 hours after the forecast date, and the other starting 14 hours after the forecast date. Because only one ensemble forecast is available for each day in the simulation periods, a 24-hour window is taken from each forecast, before switching to the next forecast on the next day.

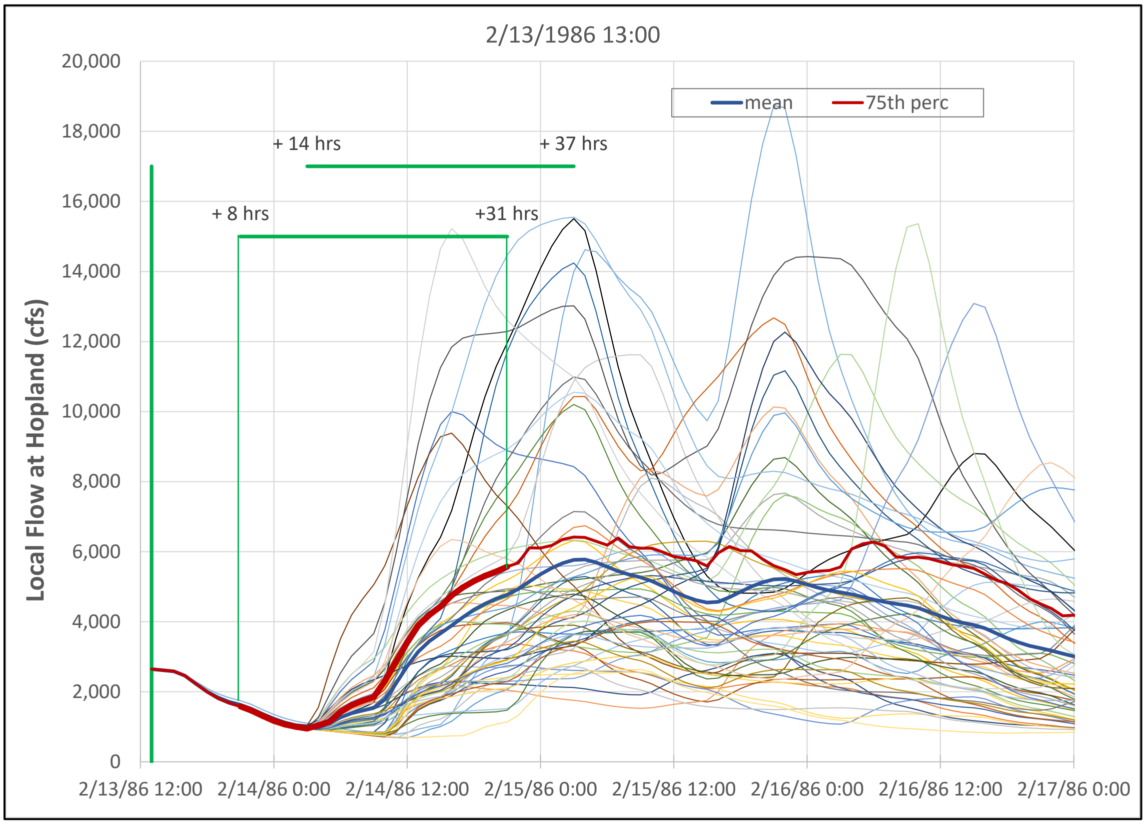

Figure 28. Computation of Hourly Mean and 75th Percentile of Ensemble Traces for 24-hour Windows Beginning at +8 hours and + 14 hours

For use in HEC-ResSim state variable scripts, a time series was created for the 8-hour-ahead forecast values, and another for the 14-hour-ahead forecast values, because both values were used in Alternative 6. For the 8-hour-ahead time series, each of the 24 hours in the first window noted above, from +8 hours to + 31 hours, was placed into the 24 hours of the day that the forecast applied, starting at the forecast date/time. Thus, when the script accessed the time series on the first hour the forecast was in use, it would get hour 9 of the forecast, and when the script accessed the times series on the tenth hour the forecast was in use, it would get hour 18 of the forecast. Note, the hindcasts were generated for each day at noon GMT, Greenwich Mean Time, which was later translated to 4 AM PST for the simulations.