Utilization of the Sonoma Water Ensemble Forecast Operations Model for Lake Mendocino to Evaluate Expected Outcomes of Reservoir Operations during Extreme Runoff Events

David Reynolds

CIRES

Boulder, CO 80303

1.0 Introduction

A series of tests have been conducted using the Sonoma Water Ensemble Forecast Operations Model (hereafter called EFO) developed to test the feasibility of Forecast Informed Reservoir Operations for Lake Mendocino. This model is fully described in Delaney and Mendoza (2016) and Delaney (2018). These tests were designed to determine how the reservoir might operate under FIRO during extreme runoff events utilizing scaled event simulations. These scaled events were based on the maximum storm of record (1964) and the 200 and 500-year return period 3-day inflow volumes as provided by the US Army Corp of Engineers (Faber, 2018), Figure 1.

The EFO model was originally evaluated for the period of record 1985-2010 utilizing a 61 member ensemble hindcast made available through the California Nevada River Forecast Center (CNRFC) - developed Hydrologic Ensemble Forecast System or HEFS. During this period there was only one major flood event simulated; February, 1986. Although a major event, it was only estimated as a 25 year return period event based on an average 3-day inflow of 6300 cfs. Therefore it was decided to scale the three largest observed events in the available 1985-2010 hindcast period, February 1986, New Year's 1997, and New Year's 2006, to the December 1964 event, and to a 200 and 500 yr return period event derived from Figure 1.

The methodology used by the CNRFC was to scale the maximum 5-day Mean Areal Precipitation (MAP) for each event until the average 3-day inflows matched that observed for the December 1964 event and the 200 and 500 year return period values. These 5-day scaled MAP values along with the observed values are shown in Figure 2 along with the observed 5-day rainfall for the record December 1964 event and the observed 5-day MAPs for the three cases being simulated. Of note is the 2006 scaled values for the three simulations all scale above the 64 observed 5-day MAP. Only the 500-yr scaling for the 86 and 97 events scale above the 64 observed value.

The number of days used in the simulations varied from 37 to 39 with ~26 days before and ~12 days after the main runoff event (Table 1). Both the Meteorological Ensemble Forecast Processor ensemble output and the observed unimpaired flows were scaled. The multiplication factors applied to the maximum 5-day precipitation to arrive at the appropriate 3-day inflows are shown in (Table 1). This scaling factor was also applied to the 1-day and 5 or 7-day inflows for each of the cases. The results are shown in Figure 3.

Figure 3 shows that the 3-day average inflow volumes match exactly to the 3-day observed 1964 event, and the 200 and 500-year return period events. Overall the 1986 event seems to scale best of the three scenarios for the 1, 3, 5-day inflows. The 2006 event appears to scale the 1-day inflows for both the 200 and 500-yr events higher by a considerable amount to the desired return period values. This most likely relates back to how the 5-day MAPs scaled. Remember from Figure 2 that the MAPs for 2006 all scaled higher than the other two cases for all three scenarios. The impacts of these larger 1-day scaled flows will be further emphasized in the results section below.

The simulations performed used hourly time steps instead of daily time steps used in the Preliminary Viability Assessment (PVA, 2017) simulations. The CNRFC hindcasts are hourly so it was possible to modify the original EFO model to accommodate hourly forecast inflows and hourly unimpaired observed flows. The current EFO model running for the Water Year 2018-19 as part of the FIRO demonstration utilizes this hourly capability. For these simulations both the EFO model utilizing the full 111,000 ac-ft as the top of the conservation pool and the Hybrid (HYB) operations, which utilizes the modified rule curve as described in Delaney and Mendoza(2016) (80,050 ac-ft instead of 68,400 ac-ft) and current existing operations (EXO) following the 68,400 ac-ft rule curve are run. In addition, two sets of risk curves were used. One using the risk curve as used in the PVA which will be referred to as the “Fixed” risk curve and a “Variable” risk curve which was developed as part of another simulation study utilizing the EFO model to improve end of season water storage without impacting downstream flooding. This will be briefly described below. The reservoir storage levels at the beginning of each scenario were based on the average storage the EFO model determined on that date for the given virtual operations (full EFO, HYB and EXO) using the 1985-2010 period used for the PVA.

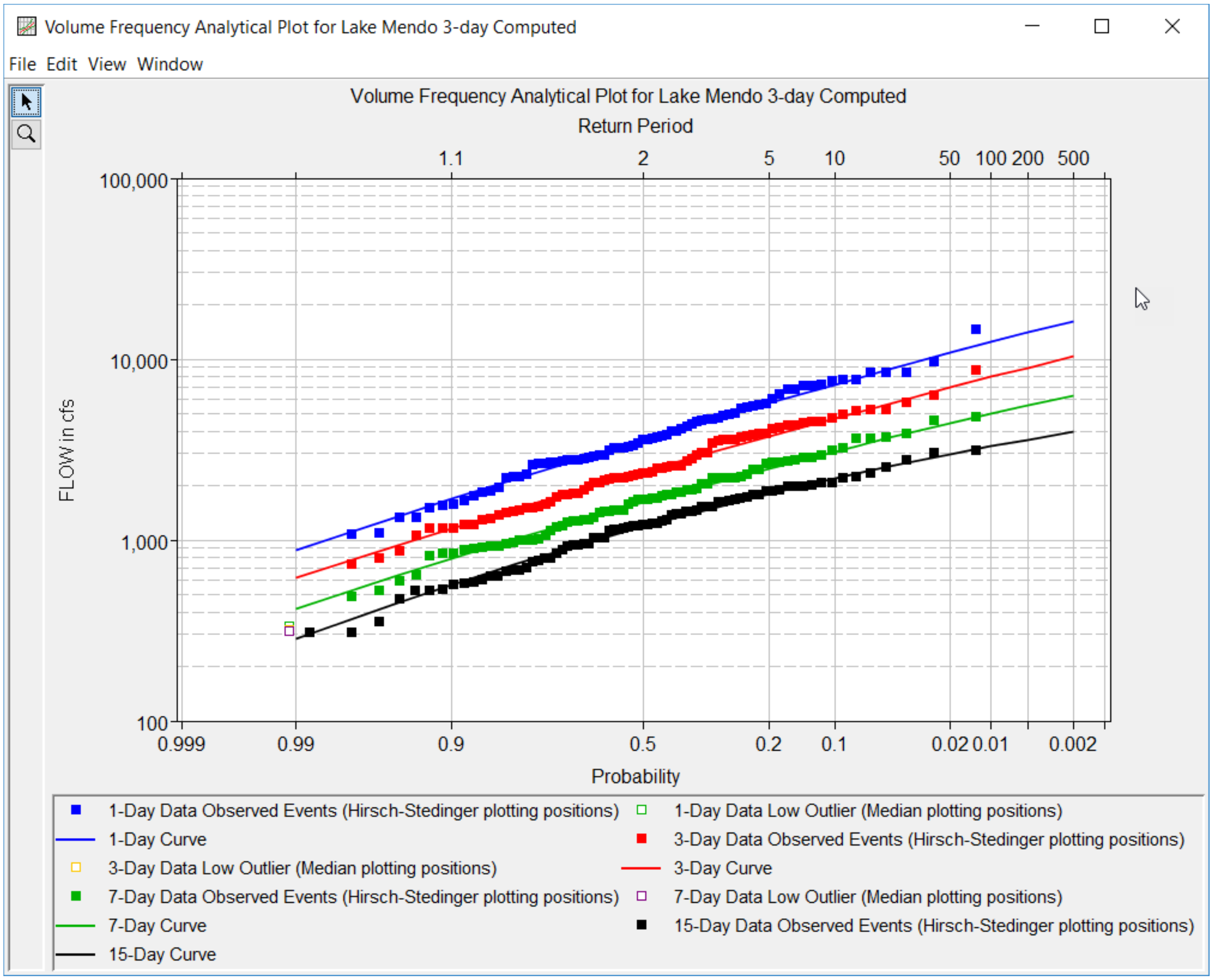

Figure 1 Return periods of average daily flows into Lake Mendocino for 1, 3, 7 and 15 days. (Faber, 2018)

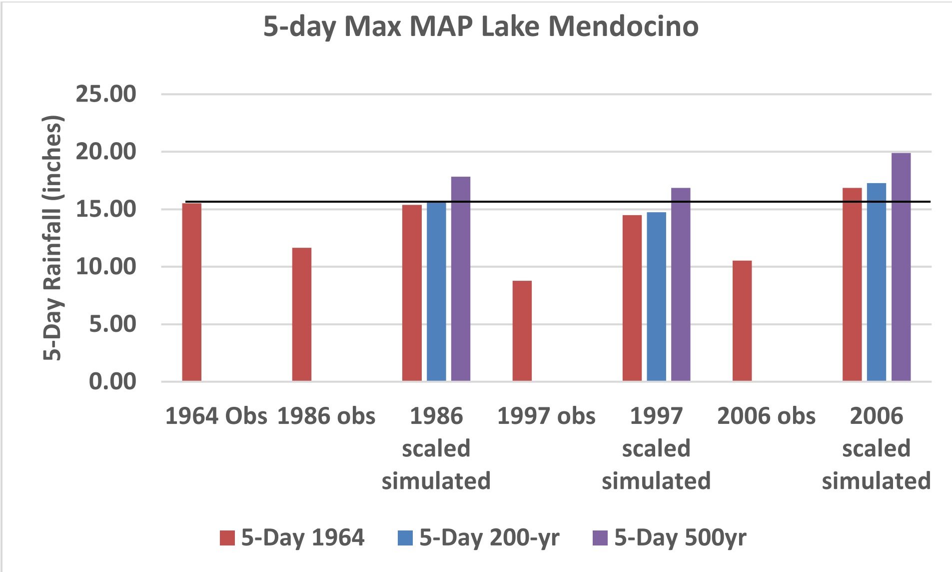

Figure 2 5-day MAP for Lake Mendocino Watershed observed in the Dec. 1964 and for each of the three cases along with the results of scaling up to the 5-day 64, 97 and 06 events.

Table 1 Dates of Events scaled and scaling factors to reach 3-day volumes

Simulated Events Dates and Scaling Factors			
Scenario	1986 scaled simulated	1997 scaled simulated	2006 scaled simulated
Dates Utilized	01/23/1986 02/28/1986	12/08/1996 01/14/1997	12/06/2005 01/13/2006
1964 obs scale factor	1.32	1.65	1.6
200yr USACE scale factor	1.35	1.68	1.64
500yr USACE scale factor	1.53	1.92	1.89

Figure 3 Daily average inflows for 1, 3 and 5 day periods for 1964 scaled event (upper left), and for 1,3, 7 day average inflows for a 200-yr (upper right) and 500-yr (lower left) event for each of the three scenarios along with the peak inflows to Lake Mendocino (lower right) using the scaling factors from Table 1.

2.0 Results of Scaling Exercise

Three model outputs were used in assessing the impacts of these very large simulated events on reservoir operations and downstream flood flows. These included average spill volume per simulation, peak flows at Hopland and comparison of these values to virtual existing operations. To help put these results in perspective as relates to each scenario the scaled peak inflows to Lake Mendocino and peak flows at Hopland were compared to historical flows at Calpella and Hopland. Figure 4 shows the peak scaled inflows and peak Hopland flows along with the historical flows for the major forecast points along the Russian from the Water Control Manual for Lake Mendocino. One can see that for the 1986 set of simulations, the peak inflows to Coyote Reservoir and the peak flows at HOP are below the inflow of record in December 64 at Calpella and the December 1955 flood for HOP. These results reference the EFO simulations using the current “fixed” risk curve. The 64 and 200yr 97 simulation also have peak flows below the records. All of the 2006 scaled simulations exceed the record 64 event at COY and the 55 event at HOP and by significant margins. As noted earlier, the 06 event did not scale well to the 1-day flows and this can be seen by the very large peak flows for both COY and HOP. One does see however that the peak flows for all simulations using the EFO model produce flows at HOP below those for the virtual EXO. Even in these extremely large events there is a slight mitigation in downstream flooding from FIRO operations.

Fixed Risk EFO	COY Peak Inflows (cfs)	HOP Peak Flow (cfs)	HOP Peak Flows Exist
86 Scaled 64	14887	36998.6	37080.88
86 Scaled 200yr	15248	37893.8	38474.50
86 Scaled 500yr	17406	43444.31	50604.53
97 Scaled 64	17310	42816.3	43252.21
97 Scaled 200yr	17775	43705.17	44325.56
97 Scaled 500yr	21480	52221.09	52581.78
06 Scaled 64	24835	49741.5	50028.51
06 Scaled[1] 200yr	26044	53249.28	54584.37
06 Scaled 500yr	30214	66301.27	72669.18

HISTORICAL FLOODFLOWS

	Peak Flow cfs				
Flood	East Fork Russian River Near Calpella	East Fork Russian River Near Ukiah	Russian River Near Hopland	Russian River Near Healdsburg	Russian River Near Guerneville
February - March 1940	(a)	(a)	34,100	67,000	88,400
January 1943	11,200	(a)	34,000	53,300	69,200
December 1945	10,200	(a)	30,100	41,800	56,800
November - December 1950	10,700	(a)	31,200	42,800	53,600
January 1954	10,500	10,300	27,400	53,700	59,900
December 1955	13,300	13,600	45,000	65,400	90,100
February 1958	11,600	4,300	32,300	50,900	68,700
February 1960	(b) 9,160	(a)	22,500	36,100	63,100
January - February 1963	7,940	(a)	21,200	41,800	71,800
December 1964	18,700	6,780	41,500	71,300	93,400
January 1966	9,890	3,200	27,100	49,400	77,000
January 1970	12,400	7,350	27,800	53,500	72,900
January 1974	12,200	6,320	39,700	64,700	74,000
January 1980	10,900	4,740	23,500	39,400	59,700

Figure 4 Simulated peak flows into COY and at HOP for all events along with historical observed flows. In addition peak flows at HOP using virtual existing operations are provided indicating slight mitigation of downstream flooding from FIRO.

We will take a closer look at two of the simulated scenarios, 1986 which scaled the best of the three, and 2006 which had much higher peak inflows, uncontrolled spills and flows at HOP. Figure 5 shows the 1986 event scaled to 1964, 200yr and 500yr return periods with spills and inflows at the top, storage the middle diagram and HOP flows in the bottom diagram. Spills were produced for each virtual scenario with existing operations having the largest and longest duration spills. There were only minor increases in spill volume and HOP flows between the 64 and 200 yr return period simulations. More substantial increases were noted for the 500 yr return period simulation. The EFO virtual operations produced larger spills than the HYB virtual operations. The virtual EFO and HYB operations reduce flows downstream compared to EXO. There also is no increase in the duration of flood stage or nuisance flooding at HOP from either pre-releases, spills or post-flood releases produced by the EFO or HYB virtual operations for all three simulations.

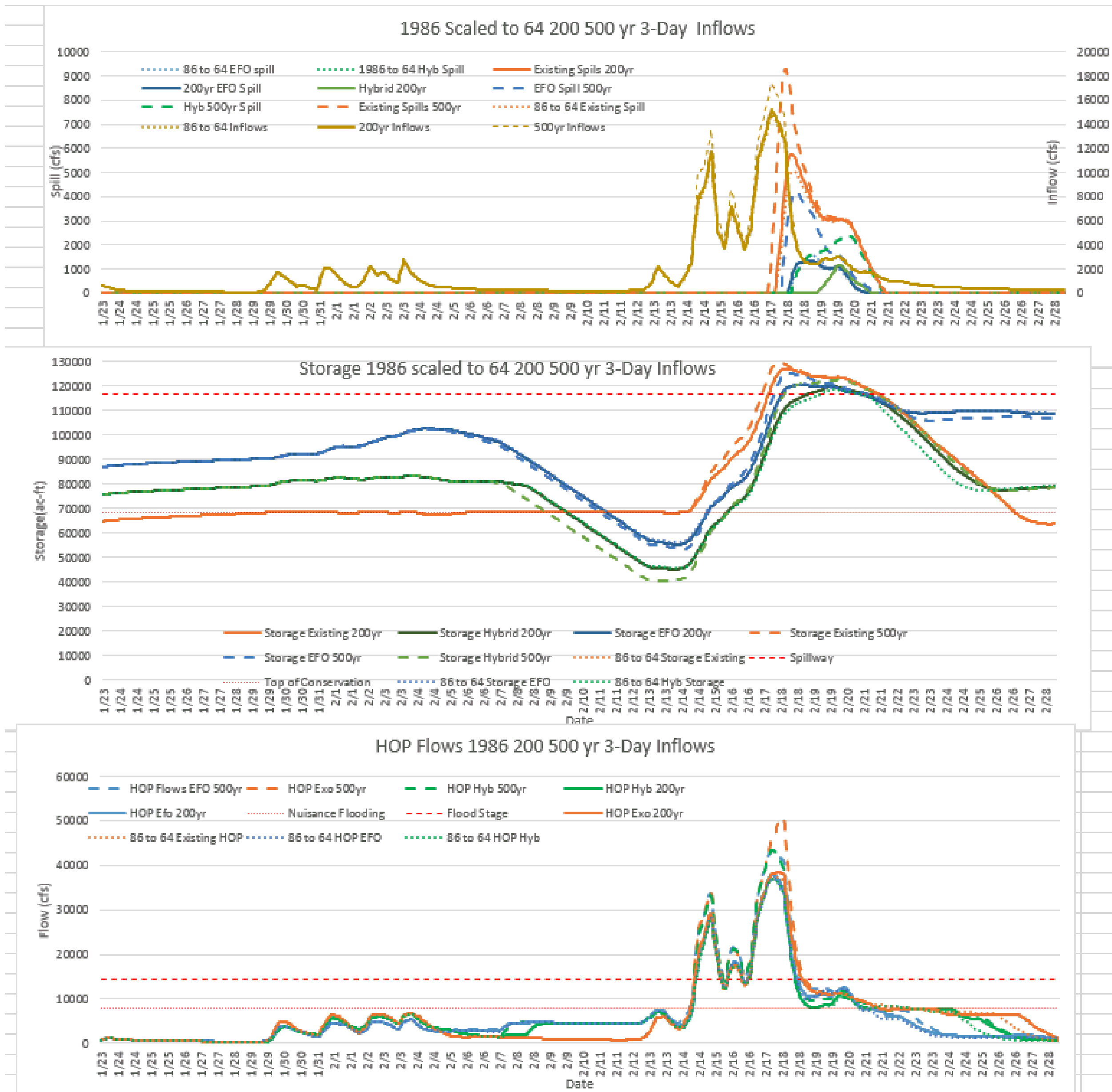

Figure 5 Simulated inflows and spills (top) storage (middle) and HOP flows (bottom) for the EFO, HYB, and EXO virtual operations for the 1964 scaled event and the 200 and 500 yr return period events. Color key is noted in each diagram. Nuisance flooding and flood stage at HOP are also noted.

Figure 1 are the results for the 2006 simulations. These results show higher inflows, larger spills, higher downstream flows at HOP due to the higher simulated large 1-day average flows and peak flows produced. In all three simulations for the 2006 event, the HYB and EFO scenarios reduce spills, and reduce flows downstream at HOP and do not extend the duration of flood stage via pre-releases or spills. However there are at least three periods during pre-releases or post-flood releases, Dec. 22nd, Dec 26h and Jan 4th, that nuisance flooding occurs at HOP from EFO and or HYB virtual operations when EXO virtual operations do not indicate flows above 8,000 cfs. The increased nuisance flooding occur for all three scaled 2006 simulations and average an additional 36 hours for the EFO scenario and 48 hours for HYB scenario in each simulation with maximum flows approaching 11,000 cfs on Dec. 22nd for the EFO scenario.

The 500 yr return period simulation indicates that the first runoff peak on Dec 28 at HOP matches the historical record peak flows set in December 1955 (45,000 cfs). The second higher peak on Dec. 31 at HOP exceed 70,000 cfs. This simulation constitutes the worst case scenario of the three simulations performed. Again it is noted that the 2006 scaling of 1-day flows was much higher than the 200 and 500 yr 1 day return period flows provided by USACE, thus it might be expected this simulation would produce extreme results. Again it is noted that both of the peaks in flows at HOP are reduced in the EFO and HYB virtual operations. This maybe offset slightly by the increased number of hours of nuisance flooding due to the pre-releases.

It should be pointed out that for the 2006-1964 scaled simulations, the HYB spills are slightly larger than the EFO spills. One can see this by noting the green and blue dotted lines in the top plot in Figure 6. This appears to be caused by slightly higher releases made by the EFO virtual operations versus HYB virtual operations when forecasted HOP flows were to fall below nuisance levels on Dec 29-30. Figure 7 shows just the results for the 2006 event scaled to 64 but adding a fourth panel showing flood releases for the EFO, HYB and EXO virtual operations. The bottom panel shows that there were slightly higher flood releases for the EFO virtual operations compared to the HYB during the minimum in inflows to the reservoir allowing the storage levels for the EFO virtual operations to be slightly below the HYB storage going into the main Dec 31-Jan 1 peak in inflows. This did not occur in any of the other simulations.

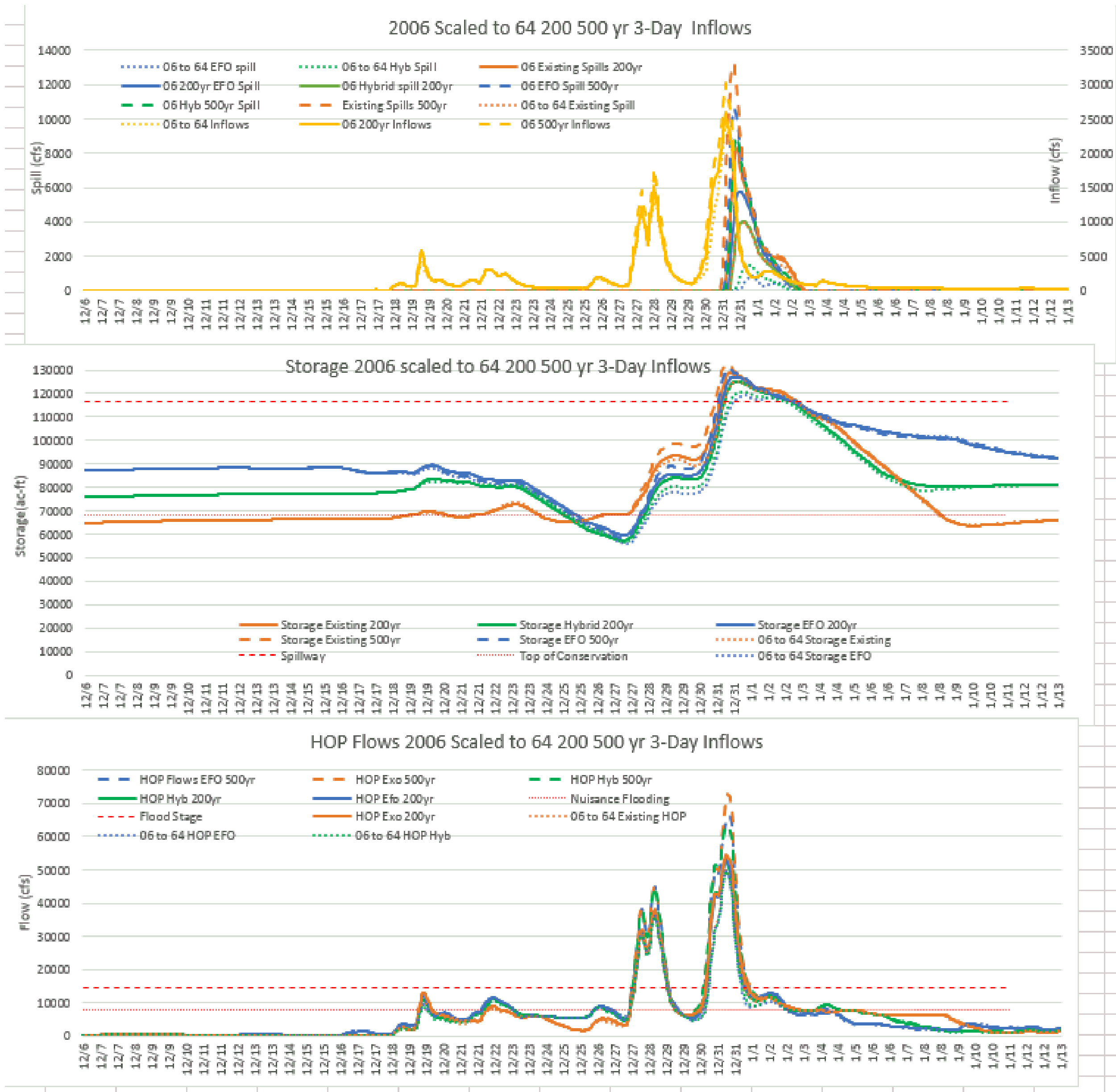

Figure 6 Same as Figure 6 but for the 2006 scaled event.

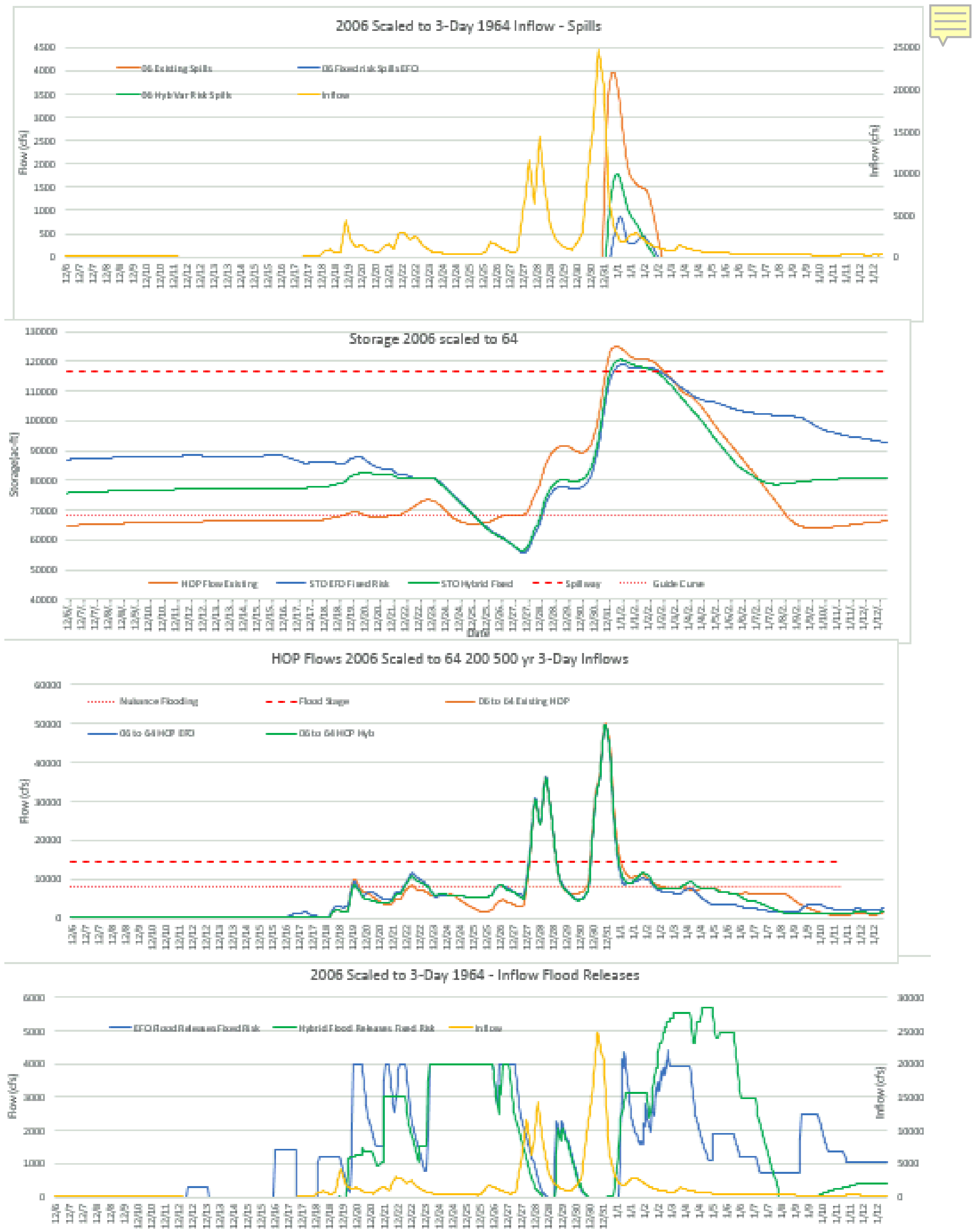

Figure 7 Same as Figure 6 but only for the 64 scaling with the bottom panel showing flood releases for the virtual EFO and HYB operations along with simulated inflows. Solid lines are used instead of dotted to better display results.

3.0 Comparison of Scaling Exercise Results Using Variable Risk Curve

As an external exercise, the fixed risk curve used in current FIRO major deviation operations was modified in an attempt to remove false alarms produced by the HEFS inflow forecasts, especially for forecast lead-times beyond day 8. It was shown in the PVA that the GEFS mean precipitation had a high false alarm rate for the watershed beyond day 8 and especially beyond day 10. The EFO model was modified to allow monthly risk curves to be used. A series of tests were performed to modify the risk curves to increase the end of season (May 10) water storage but not allow spills or increase flooding downstream. These series of tests produced two different risk curves. One for the primary flood season of Dec-Feb and another for Mar-Nov. These two risk curves are shown in Figure 8 along with the current operational risk curve. Figure 9 shows the exceedance probability of the May 10 water storage in Lake Mendocino comparing EFO model scenario using the fixed risk and variable risk curves, the HYB scenario using the fixed and variable risk curves, the EXO scenario, and the EFO model using observations or a perfect forecast. The EFO model using the variable risk curve provides 97% of the perfect forecast water storage on May 10th.

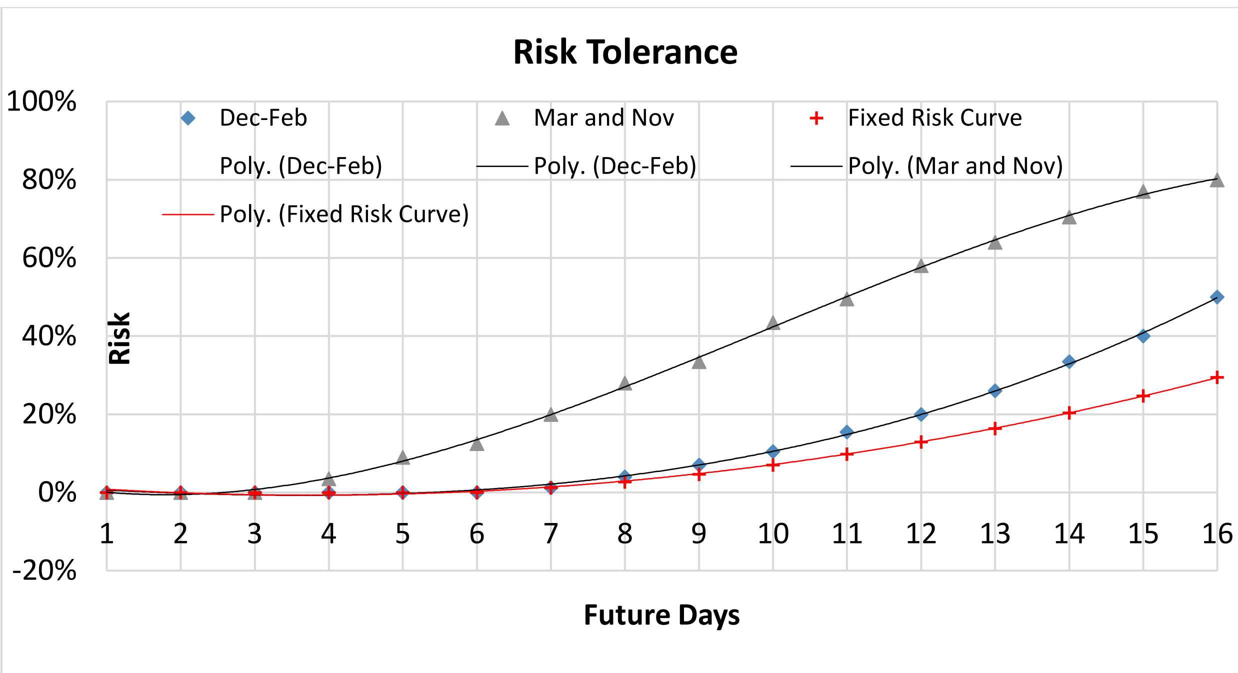

Figure 8 Existing and modified seasonal risk curves noted as "variable" in the text. For these simulations on the blue risk curve (variable) and red risk curve (fixed) are used since all three scenarios were in the Dec-Feb time frame.

The results of running the scenarios with the two different risk curves are shown in Figure 10. The main conclusion from this comparison is that; 1) both risk curves reduce or eliminate spill volume when compared to the EXO scenario; 2) the variable risk curve does show slight increases in average spill volume for the EFO and for some HYB scenarios compared to the fixed curve, 3) in most of the scenarios both risk curves reduce or not increase HOP flows compared to the EXO scenario. Only in the 500yr 2006 EFO scenario was there a slight increase in HOP flows using the variable risk curve compared scenario to the fixed risk curve scenario (upper right plot of Figure 10). It is also noted that for the 2006 scaled events, the variable risk curve results for the EFO and HYB scenarios indicated flows above nuisance flooding when EXO flows were below 8000 cfs for the same dates using the fixed risk curves. Flows were nearly the same for these periods regardless of the risk curve used.

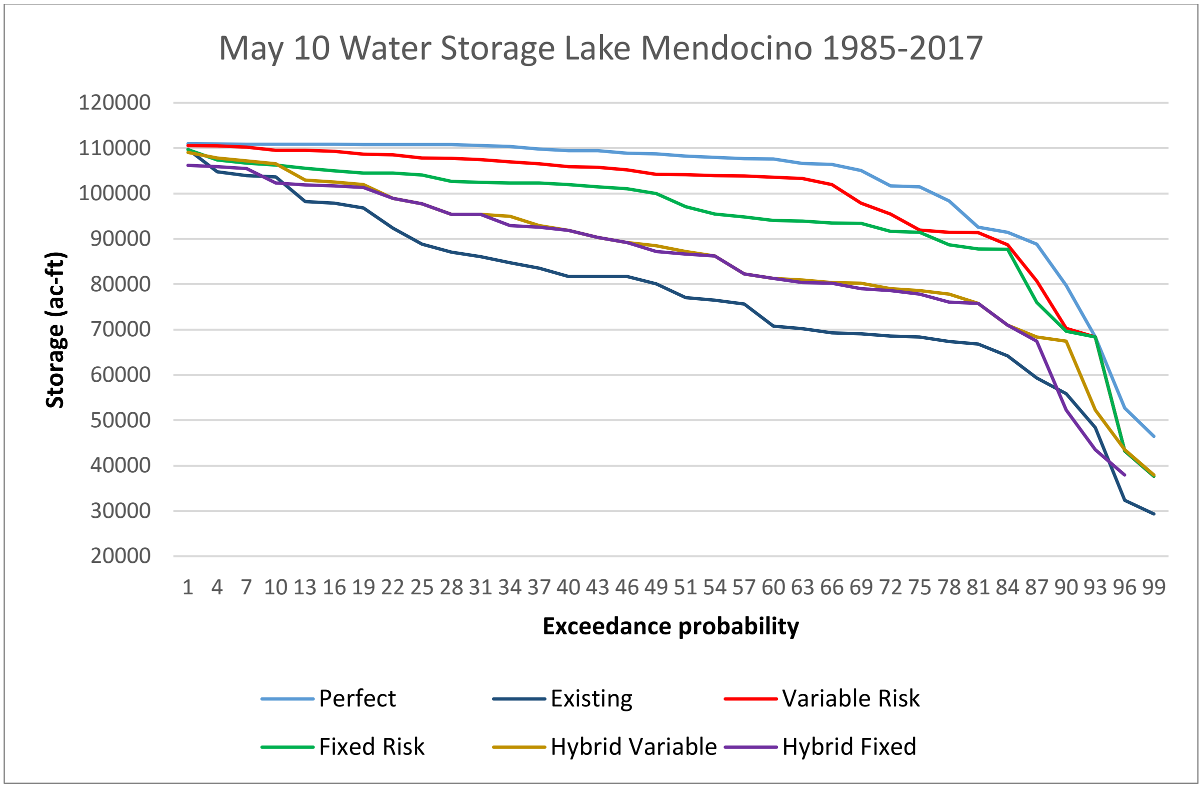

Figure 9 Exceedance probability for May 10 storage for Lake Mendocino utilizing both fixed and variable risk curves for the EFO and HYB scenarios compared to a perfect forecast and existing operations.

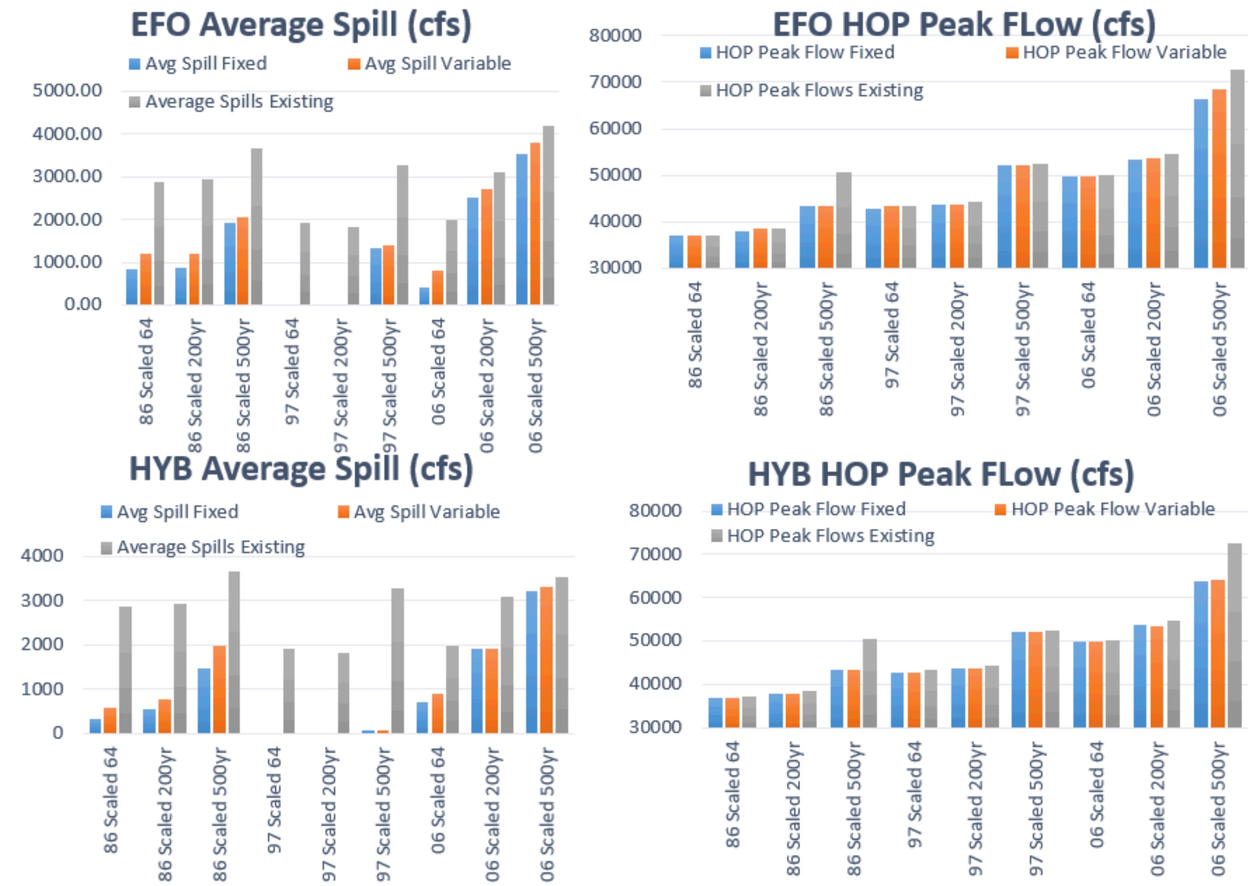

Figure 10 Comparison of Average spill volume and HOP peak flows utilizing the fixed and variable risk curves for both the EFO and HYB virtual operations.

4.0 General Conclusions

The most significant results drawn from this scaling exercise are:

1) 1986 scaled to 1964 and 200 and 500 yr return periods scales best to 1 3 and 7 day inflows
   a) All 86 scaled events have peak inflows less than the observed record peak flows in Dec 1964
   b) All 06 scaled events have peak inflows greater than observed in Dec. 1964
   c) Peak inflows have large influence on magnitude of spills and flows downstream at HOP – 06 scaled 500 yr event demonstrates this
2) All EFO and HYB simulations for all scaled events show a reduction or even elimination of spills (97 scaled to 64 and 200 yr event) versus EXO.
3) There are no increases in flood flows at HOP for any scenario simulated using EFO or HYB virtual operations but a reduction in most scenarios to EXO.

4) For all three 2006 scaled events there are 3 days (between 36-48 hours total) in which nuisance flooding occurs for the EFO and HYB scenarios when the EXO scenario is below this level regardless of risk curve used.
5) There are some slight increases in flood flows at HOP using variable Dec- Feb risk curve vs current fixed annual risk curve for EFO virtual scenario. This was only observed for the 2006 500 yr simulation. HYB shows little difference. All are still below the EXO virtual scenario.
   a) Variable risk curve provides 96% of the Perfect Forecast water storage on May 10 using EFO model for years 1985-2017.

These results indicate that even for the most extreme events, which the 2006 scaled event represents, FIRO virtual operations, whether EFO or HYB scenarios, reduce reservoir spills and reduce or at least do not exacerbate downstream flooding at HOP. There were however 36-48 hours of increased nuisance flooding for all three 2006 scaled events due to pre-releases, or post-flood releases.

5.0 References

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