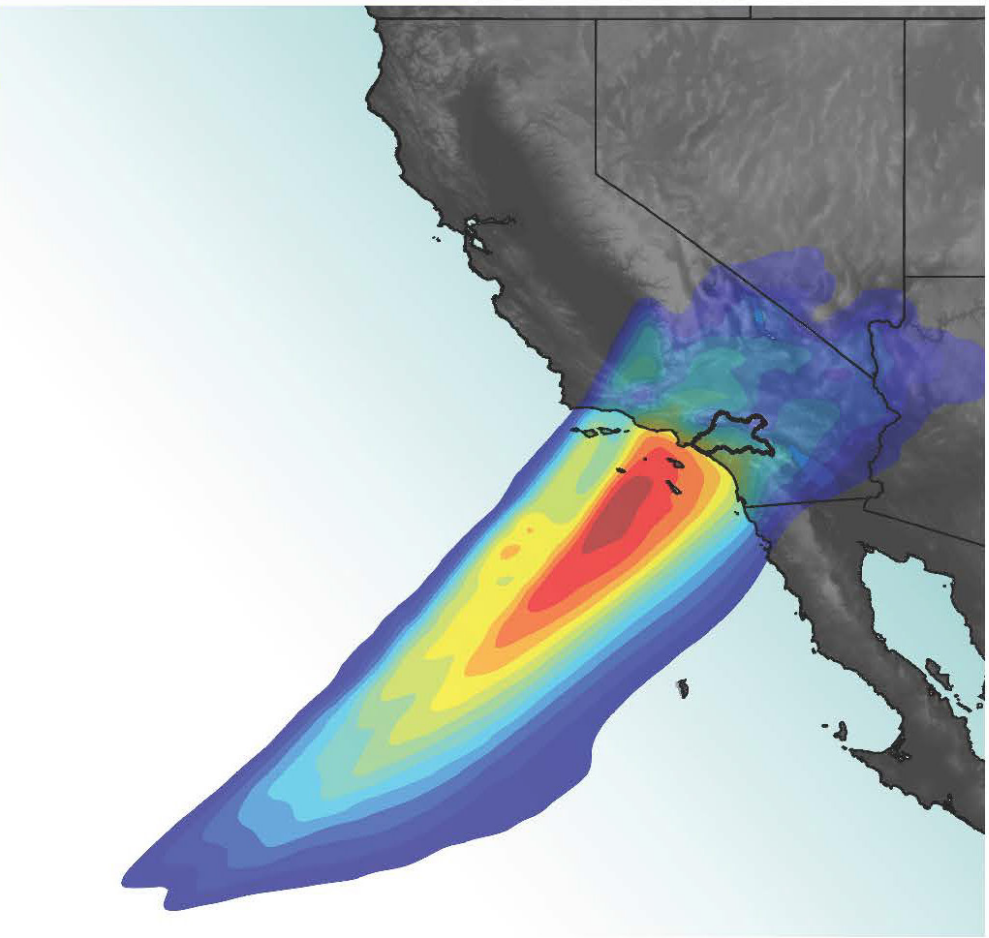
Prado Dam

FORECAST INFORMED RESERVOIR OPERATIONS

Final Viability Assessment

Appendices

November 2023



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Appendix A—Forecast Skill Assessment (Section 3)

A.1 Relative Forecast Error of MAP

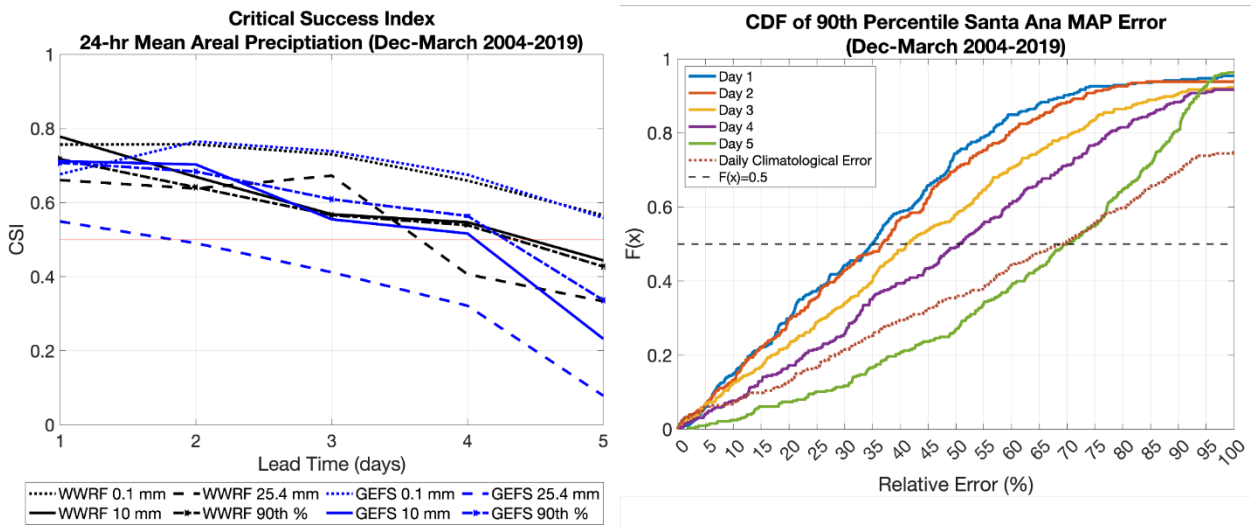
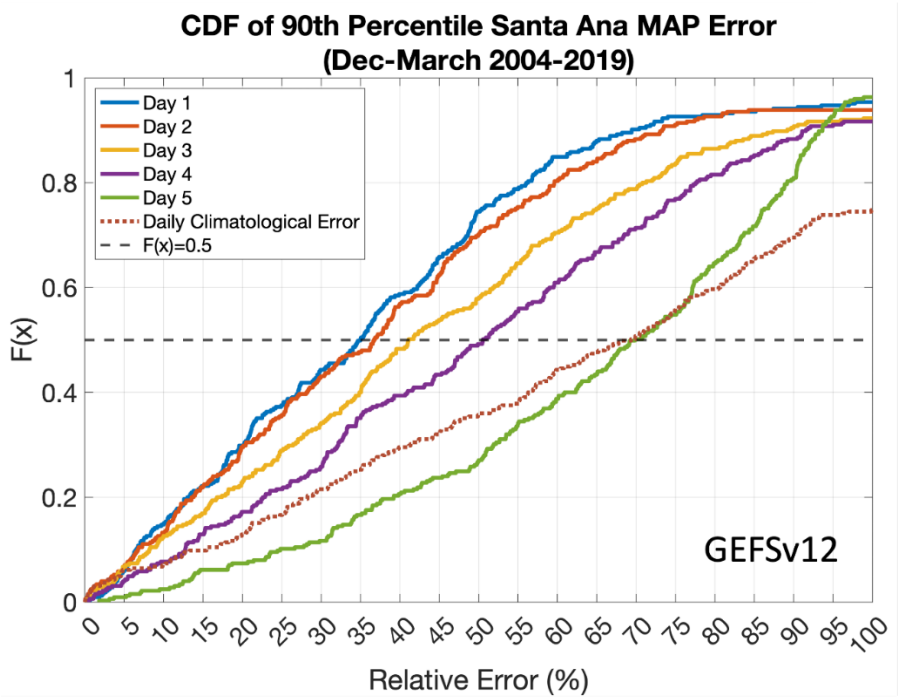


Figure A-1. *(Left) Critical Success Index (CSI) of 24-hr MAP using data from the West-WRF Reforecast (black) and GEFSv12 (blue) between December through March of water years 2005-2019. The different line styles indicate different thresholds used to calculate the skill of different magnitudes of precipitation; dotted for MAP>0.1 mm, solid for MAP>10 mm, dashed lines without symbol for MAP>25.4 mm, and dashed lines with x for MAP>90th percentile of the forecast distribution. (Right) Probability Cumulative Distribution Function (CDF) of the relative forecast errors of MAP for 1-day (blue), 2-day (red), 3-day (yellow), 4-day (purple), and 5-day (green) GEFSv12 forecasts. The error calculated using daily climatology is given in the dotted red line. The 50% probability threshold (P(x)=0.5) is denoted by the dashed black line.*

The full distribution of GEFS MAP errors for MAP < 90th percentile is shown in the left panel of Figure A-1 and expressed as the cumulative distribution. The cumulative distribution represents the probability of a variable having values less than or equal to the x-axis. The cumulative distributions for each lead time (1 through 5-day) errors are shown as individual solid-colored lines. The black dashed line represents the 50th percentile value of the forecast error distribution; in other words, 50% of the time the forecast errors are equal to or less than the value on the x-axis where the dashed line is intersecting the cumulative distribution of each lead time. As lead time increases, the relative forecast error on the x-axis increases. Additionally, the lead time relative forecast errors can be compared against daily climatology to determine when forecasts have added value over "typical" conditions during certain periods of time in the year. For example, the daily climatology for October 1st is calculated as the 80th percentile value of all MAP occurring on October 1-15 of each year across all the available years of observations. Because we are evaluating extreme precipitation forecasts errors, we use the 80th percentile observed value to capture the extreme observed events; using the mean value would almost certainly yield a value of 0 mm, given the highly skewed distribution of precipitation. The relative forecast errors using the climatology (red dotted line) is less than the errors using a forecast 5 days in advance, meaning there is added value in the 1 through 4-day forecasts over climatology. At a 4-day lead time, precipitation errors are equal to or less than

50% of the observed value. Both of these metrics show that GEFSv12 has skill of predicting extreme events up to a 4-day lead time in the Santa Ana basin using different baselines to define skill. Additionally, the relative forecast errors also highlight the total possible range at which forecasts could be off from their observed value.



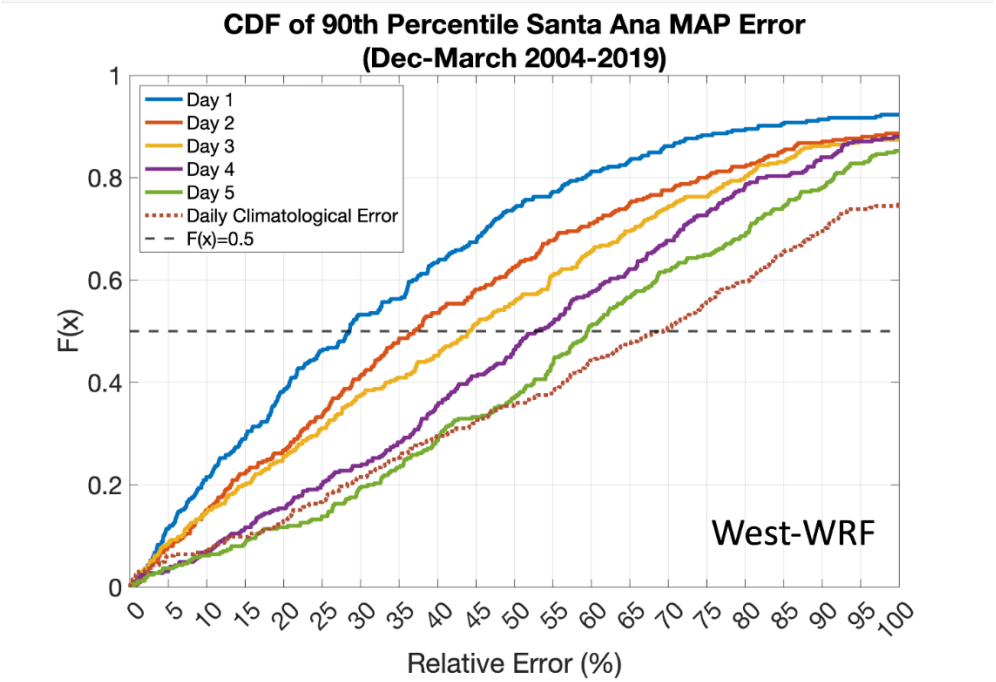


Figure A-2. *Same as Figure A-1 (right) for GEFSv12 (top) and West-WRF (bottom).*

A.2 Inflow forecast errors at Prado

The aim of this subtask is the evaluation of 3-day (72-hour) total inflow forecasts for Prado Reservoir, with potential science goals of 1) providing baseline meteorological/hydrological forecast skill to assess future model improvements, 2) understanding the priority forecast skills for Forecast-Informed Reservoir Operations (FIRO) needs, and 3) determining relationships between atmospheric river (AR) events and model skill. To accomplish this objective, California-Nevada River Forecast Center's (CNRFC's) probabilistic/ensemble hindcasts and period-of-record historical simulation based on NOAA's Community Hydrologic Prediction System (CHPS POR) are chosen, given their utilities in the operational forecast.

Both ensemble hindcasts and CHPS POR are available hourly from October 1989 to December 2019 and assume full natural flow, so no upstream regulations are accounted for in their simulations. The verification focuses on the period of record (1989-2019) as a benchmark evaluation. Observed inflow to Prado Reservoir is not available, so a synthetic inflow dataset composed of synthetic baseflow and historical stormflow is used as the observation. This synthetic observation is available daily from October 1989 to September 2019 and has been used for model calibration by the CNRFC.

The ensemble hindcasts (hereby forecasts) were generated using the National Weather Service's Hydrologic Ensemble Forecast System (HEFS). By design, HEFS translates an ensemble of meteorological inputs through hydrologic models, which in this case is a coupled snow (SNOW-17)-soil (SAC-SMA) model, to produce an ensemble of streamflow outputs. The ensemble meteorological inputs are produced as meteorological forecast uncertainties using a statistical model called the Meteorological Ensemble Forecast Processor (MEFP). MEFP is based on the Global Ensemble Forecast System version 12 (GEFSv12) precipitation and temperature reforecast datasets that are available from 1989 to 2019.

The ensemble 3-day total inflow is derived from aggregating the hourly data at rolling lead times 1-3 days (1-72 hours), 4-6 days (73-144 hours), and 7-9 days (145-216 hours). We evaluate 4 scenarios: 1) all time, including both clear-sky/baseflow and precipitation periods, 2) all non-AR events, 3) all AR events, and 4) top 5% AR-related flows during the wet season (November-April). AR periods are identified using Rutz's AR catalog (Rutz et al., 2014) at the nearest point to Prado Dam, which is available from 1980 onward (ftp://sioftp.ucsd.edu/CW3E_DataShare/Rutz_AR_Catalog). Non-AR precipitation periods are determined by aligning non-AR periods on Rutz's AR catalog with the basin mean-areal precipitation derived from the Parameter-Elevation Regressions on Independent Slopes Model (PRISM) dataset (Daly et al., 1994, 2008), which is available daily from 1981 onward (PRISM Climate Group: http://prism.oregonstate.edu).

The ensemble forecast 3-day inflow verification metrics, including 10%, 25% and 50% non-exceedances, spread-skill plot, reliability diagram and Brier score (Brier, 1950), are evaluated for every lead-time aggregate and scenario. The all time (Nov-Apr of 1989-2019) forecast 80% exceedance value is used to evaluate the reliability diagram and Brier score at all lead time aggregates and in all scenarios. A threshold based on the observation instead of forecast was considered, but it yielded similar results and conclusions. The same all-time threshold is used to maintain a consistent benchmark across different data subsets. The CHPS POR simulation error, RMSE and Nash-Sutcliffe Efficiency (NSE: Nash & Sutcliffe, 1970) are also computed. However, due to the relatively limited independent sample size, the statistics associated with the CHPS POR are computed at a daily scale.

Figure A-3 illustrates how biased the ensemble 3-day 10%, 25%, and 50% non-exceedances forecasts are compared to the observation at different lead time aggregates and scenarios. Errors are generally larger at longer lead times, with higher non-exceedance forecasts and all ARs and non-ARs are underforecasted (negative error). Larger events, typically those resulting in 3-day inflows >40 thousand acre-ft (TAF) and most notably those associated with the top 5% AR-related flows, exhibit larger errors (diverging from the 1:1 line) against the observation. These results demonstrate that forecast errors increase with longer lead times as well as when flows associated with AR events are exceptionally high.

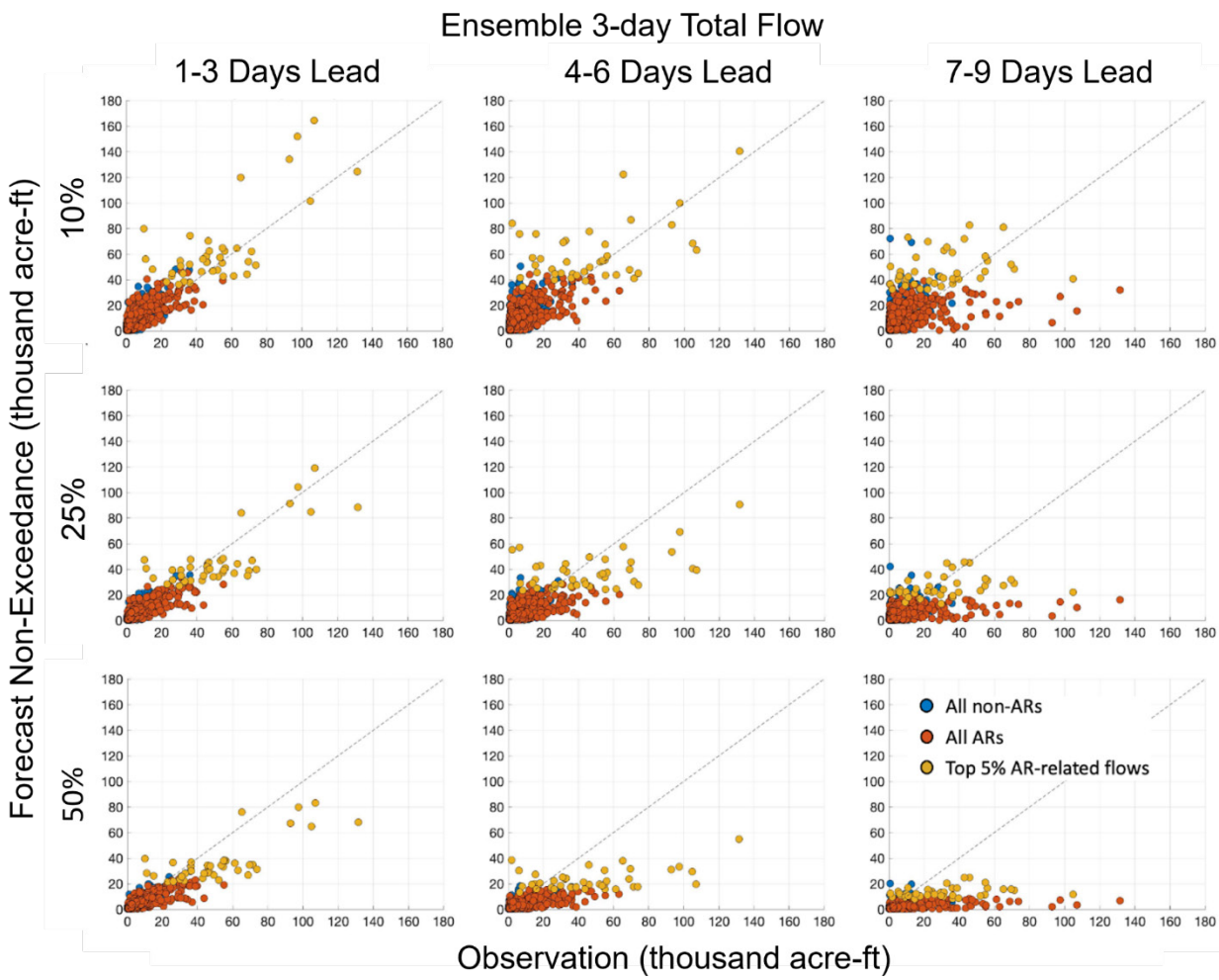


Figure A-3. *10% (top), 25% (middle), and 50% (bottom) non-exceedance scatter plots of ensemble forecast's 3-day ensemble inflow to Prado Reservoir against observation at lead-time aggregates 1-3 days (left), 4-6 days (center), and 7-9 days (right), for all non-ARs (blue), all ARs (red), and top 5% flows during AR periods (yellow) periods spanning Nov-Apr of 1989-2019.*

The spread-skill plots in Figure A-4 demonstrates whether the ensemble spread is proportional to the ensemble-mean error at different lead times and different scenarios. The prediction is considered reliable when the spread is approximately equal to the error. This regime occurs mostly when the spread is small (<5 TAF), which is evident in the all non-AR and all AR subsets shown in Figure 2, regardless of the lead time. There is a tendency in both all non-AR and all

AR subsets of flows for the forecasts to be overdispersive at the shortest lead time (3-day) when the standard deviation is >5 TAF. The all ARs subset, however, exhibits underdispersion at longer lead times. This shift in the ensemble tendency is accentuated in the top 5% AR-related flows subset, with an underdispersion when the spread is relatively small (<10 TAF) and an overdispersion when the spread is relatively large (>15 TAF) (Figure A-6). This subset also shows notably large 10th-90th percentile ranges of the errors with magnitudes of >20 TAF in most cases. Overall, the ensemble spread is representative of the forecast error when the spread is relatively small. When the spread is larger, the ensemble appears overdispersive during non-AR events and underdispersive during AR events.

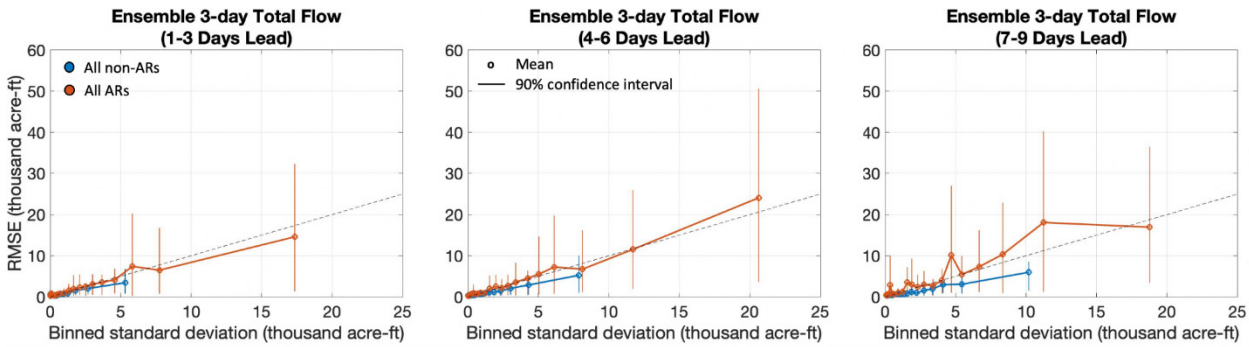


Figure A-4. *Binned spread-skill plots of ensemble forecast's 3-day total inflow to Prado Reservoir at lead-time aggregates 1-3 days (left), 4-6 days (center), and 7-9 days (right), for all non-AR events (blue) and all AR events (red) spanning Nov-Apr of 1989-2019. The black dashed lines denote the 1:1 relationship.*

The reliability diagrams displayed on the top panels in Figure A-5 show relatively reliable forecasts in all time and all non-ARs subsets when the issued forecast probability/observed frequency is low (<0.25), regardless of the lead time. The forecast probabilities become higher than the observed frequencies at higher forecast probability bins, especially at those >0.5. This behavior suggests an underdispersion/overconfidence in the ensemble forecasts. On the other hand, the all ARs subset exhibits large fluctuations around the 1:1 line at lead time aggregates 1-3 days and 4-6 days, which reflect the undersamplings at middle forecast probability bins (bottom panels in Figure 3). The 7-9 days lead time aggregate shows that the higher observed frequencies are consistently higher than the forecast probabilities, indicating an under-forecast tendency under AR conditions.

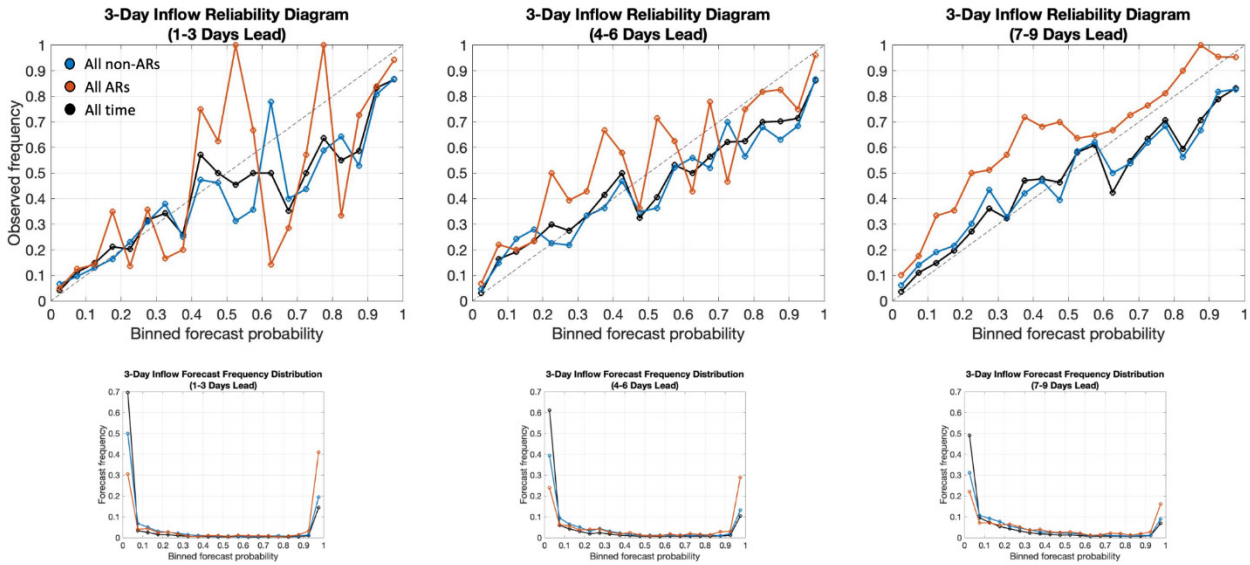


Figure A-5. *<u>Top panel</u>: Reliability diagrams of ensemble forecast's 3-day inflow to Prado Reservoir at 1-3 days (left), 4-6 days (center), and 7-9 days (right), for all non-AR events (blue), all AR events (red), and all time (black) spanning Nov-Apr of 1989-2019. The threshold is 80% exceedance based on the ensemble forecasts. The black dashed lines denote the 1:1 relationship. <u>Bottom panel</u>: frequency distribution associated with the forecast probability bins.*

Table A-1 shows that the ensemble has a reasonable 3-day inflow forecast skill with Brier scores <0.55. However, the forecast accuracy tends to deteriorate with longer lead times, except in the all non-ARs subset, which improves with longer lead times. Brier scores are generally best in the all time subset and worst in the all ARs subset, indicating the lower forecast accuracy under AR conditions. The Brier skill scores exhibit the same pattern with all values >0 (Table A-2), which confirms that the ensemble forecasts are still more skillful than the reference forecast based on climatology.

Table A-1. *Brier scores of ensemble forecast's 3-day total inflow to Prado Reservoir at lead-time aggregates 1-3 days, 4-6 days, and 7-9 days, for all time, all non-AR events, and all AR events spanning Nov-Apr of 1989-2019. The threshold is 80% exceedance based on the ensemble forecasts.*

Lead Time Aggregate	Brier Score		
	All time	**All non-ARs**	**All ARs**
1-3 days	0.40	0.42	0.50
4-6 days	0.40	0.40	0.52
7-9 days	0.41	0.38	0.52

The CHPS POR simulation daily inflow mean errors, RMSEs and NSEs are shown in Table A-2. For reference, the ensemble forecast bias and RMSE distributions are shown in Figure A-6. Both the mean errors and the RMSEs show that the simulation errors are larger in the all ARs subset than in the all non-ARs subset, particularly in the top 5% scenario. This difference is related to the fact that ARs are responsible for larger precipitation events in California (Dettinger et al.,

2011). However, the mean errors are negative in the all ARs subset and positive in the other subsets, indicating under-forecasting tendency in the former and over-forecasting tendency in the latter. The NSEs indicate reasonably skillful simulation with values >0.5 in all subsets. The NSE is highest in the all ARs subset (0.86) and lowest in the top 5% AR-related flows subset (0.53). Aside from the simulation error, NSEs also account for the correlation between the simulation and the observation. The latter suggests a particularly strong correlation in the all ARs subset.

Table A-2. *CHPS POR daily-total inflow simulation errors (acre-ft), RMSEs (acre-ft), and NSEs at Prado Reservoir, for all non-AR events, all AR events, and top 5% flow during AR periods spanning Nov-Apr of 1989-2019.*

Metric	All non-ARs	All ARs	Top 5% AR Flows
Error (acre-ft)	168	-194	4486
RMSE (acre-ft)	1151	2818	7555
NSE	0.72	0.86	0.53

In conclusion, CNRFC ensemble forecasts largely capture the forecast uncertainty with a 90% confidence level, especially with shorter lead times where the forecasts tend to be less biased. However, it becomes more underdispersive when the spread grows larger, typically during larger AR events. Overall, the ensemble has skill at forecasting the 3-day inflow volume, but it is also shown to potentially benefit most from improvement during AR events. The result from CHPS POR simulation supports the fact that the 3-day inflow prediction, though reasonably skillful, exhibits larger errors during AR events.

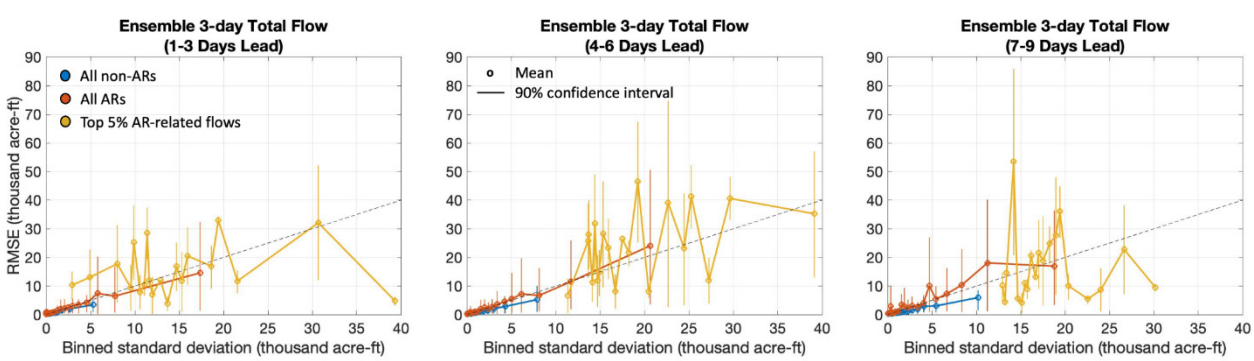


Figure A-6. *Same as Figure A-4, but with the top 5% AR-related flows subset added (yellow).*

Table A-3. The Brier skill scores alternative to Table A-1. The reference Brier score is based on the observed climatology.

Lead Time Aggregate	Brier Skill Score		
	All time	All non-ARs	All ARs
1-3 days	0.30	0.26	0.12
4-6 days	0.30	0.29	0.09
7-9 days	0.28	0.32	0.09

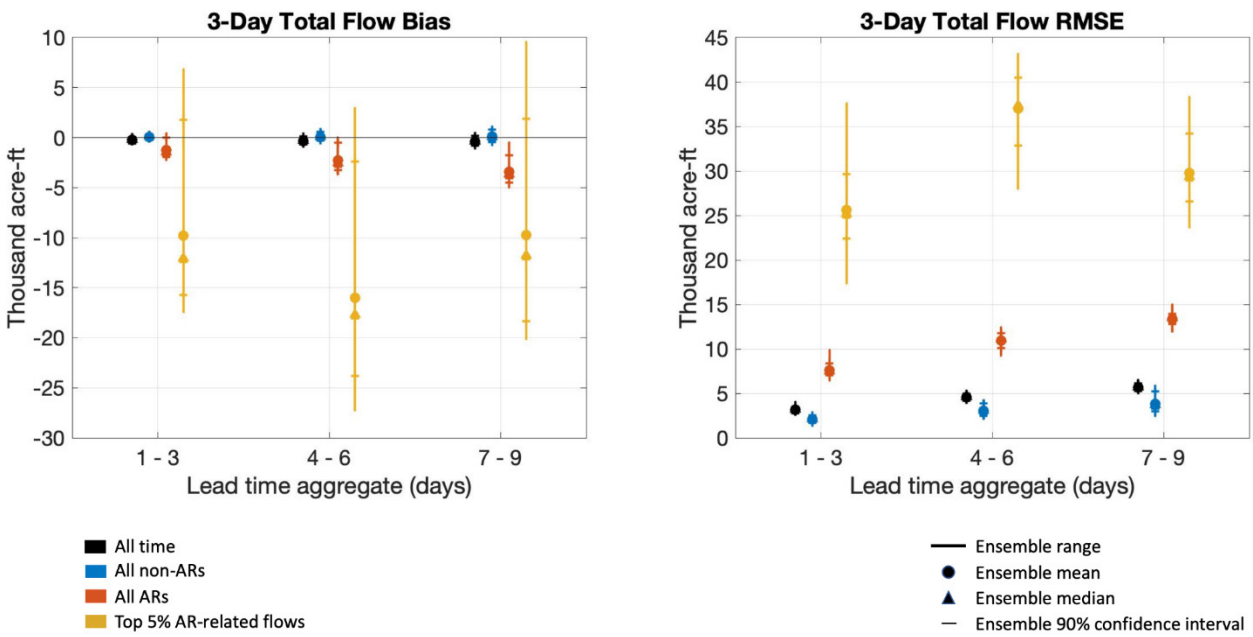


Figure A-7. The biases and RMSEs of ensemble forecast's 3-day total inflow to Prado Reservoir in thousand acre-ft (TAF) at lead-time aggregates 1-3 days, 4-6 days, and 7-9 days, for all time, all non-AR events, all AR events, and top 5% flow during AR periods spanning Nov-Apr of 1989-2019.

A.2.1 References

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Nash, J. E., & Sutcliffe, J. V. (1970). River flow forecasting through conceptual models part I—A discussion of principles. *Journal of hydrology*, *10*(3), 282-290.

Rutz, J. J., Steenburgh, W. J., & Ralph, F. M. (2014). Climatological characteristics of atmospheric rivers and their inland penetration over the western United States. *Monthly Weather Review*, *142*(2), 905-921.

Model (threshold)	1-day	2-day	3-day	4-day	5-day	6-day	7-day
GEFS (250)	79.13	69.48	154.99	226.00	214.04	353.75	453.91
GEFS (500)	4.27	13.87	5.55	83.25	150.64	186.32	263.62
GEFS (500) pairs	13	14	10	10	7	7	6
GEFS (250) pairs	148	135	123	125	122	107	98
West-WRF (250)	103.20	99.50	133.94	219.88	287.08	320.55	410.58
West-WRF (250) pairs	153	140	127	118	113	107	93
West-WRF (500)	55.5	49.6	59.5	115.6	38.2	277.5	261.6
West-WRF (500) pairs	13	14	14	12	8	9	7

A.3 Inflow forecast errors at Prado

Attached PDF following this page.

A case study of precipitation forecasts and simultaneous operations at Prado Dam in the Santa Ana Basin; Forecast-Informed Reservoir Operations (FIRO-Prado)

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1. Introduction

The Prado Dam is a U.S Army Corps of Engineers (USACE) structure built in 1941 at the southwestern edge of the Santa Ana River basin in Southern California. It is used for regulating underground water recharge and flood prevention in highly urbanized areas of Orange County. The sources for runoff generation within the Santa Ana basin often result from meteorological phenomena such as atmospheric rivers (ARs) and cutoff lows, the combination of which usually occurs over a handful of days a year. Forecasting these extreme events accurately in advance provides an opportunity to better mitigate potential flooding risks and optimize water retention. This concept is the foundation of a multi-agency water management study called Forecast-Informed Reservoir Operations (FIRO), a flexible water management approach that uses data from watershed monitoring and improved weather and hydrologic forecasting to help water managers selectively retain or release water from reservoirs in a manner that can adapt to weather extremes and that leverages advancements in the science of meteorological and hydrologic forecasting. Developing FIRO for a specific reservoir or system is an exploratory process involving key partner interaction and understanding. Experience and understanding gained through "interim operations" where FIRO concepts are experienced through operational deviations has proven quite valuable. In addition, careful examination of recent events through "case studies" has also proven enlightening and can help inform the application of FIRO.

In late December 2021, a unique sequence of precipitation events occurred where major forecast changes and subsequent operational decisions provided a good opportunity to learn about the role of weather and water forecasts and their applications in reservoir operations decisions for Prado Dam. This paper will describe the sequence of the meteorological phenomena, the weather forecast evolution using global and regional numerical weather models, and alignment of the operational decisions. An analysis of this event and the associated reservoir release decisions should provide insight into the sensitivity of weather and water forecast errors (uncertainty) as well as the release decision process used by the LA District of the USACE (LAD).

2. Sources of forecasts, observations, and operational decision markers

2.1. Numerical weather prediction models

Several sources of weather forecasts were analyzed to study the prediction of precipitation and the responsible meteorological mechanisms to understand the implications of resolution and uncertainty of the forecasts. The Center for Western Weather and Water Extremes (CW3E) produces daily near-real

time forecasts over the Western U.S. using a customized version of the Weather Research and Forecasting (WRF) model (Skamarock et al., herein West-WRF). West-WRF has been established as a skillful predictive tool for extreme precipitation over California (Martin et al. 2018, Cannon et al. 2020, Cobb et al. *submitted to Weather and Forecasting)* and integrated water vapor associated with Atmospheric Rivers (ARs) (DeHaan et al. 2021). West-WRF consists of two regional domains, a parent 9-km domain extending over the northeast Pacific Ocean and U.S. West Coast and a 3-km one-way nested domain extending over California and extreme southern Oregon (Figure 1). The forecast horizon is 5 and 7 days, respectively. Data over the Santa Ana and nearby basins are used for this study. The initial and boundary conditions of the model are driven from the National Center for Environmental Prediction (NCEP)'s Global Forecast System (GFS). As such, the 25-km native GFS forecasts are also compared to understand the implications of the dynamical downscaling within the high-resolution model.

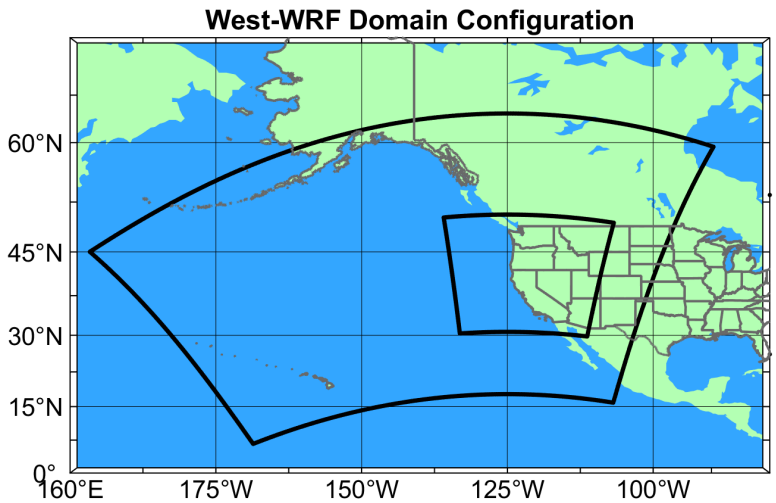


Figure 1. West-WRF domain during WY2022.

2.2. Quantitative Precipitation Estimates

To verify the precipitation forecasts within and surrounding the Santa Ana basin, the forecasts were compared to the 4-km gridded quantitative precipitation estimate (QPE) from the California-Nevada River Forecast Center (CNRFC). This operational product consists of 24-hr total QPE on an HRAP projection and is composed of gauge data that is distributed using elevation-based information along the complex topography of California and eastern Nevada. Both time series data at 117.63 W, 33.89 N and the full gridded fields over Southern California are extracted between 24th December 2021 and 1st January 2022.

2.3. Analysis of integrated vapor transport

The sequence of precipitation falling in the Santa Ana basin between 23 December and 1 January were generated by a mixture of atmospheric phenomena. To contextualize the presence or lack thereof of AR activity, the integrated water vapor time series was extracted from the European Reanalysis version 5 (ERA-5). Periods of time in which IVT > 250 kg m s at 117.75° W, 34° N indicate AR conditions at Prado.

2.4. Reservoir Elevation at Prado Dam

Hourly reservoir elevations at Prado Dam (PRA) are obtained from the California Data Exchange (CDEC) and available at an hourly time step through the period of study.

2.5 Timeline of release decisions and available postings of inflow and precipitation forecasts

Beginning in August 2022, a series of workshops were held between CW3E and members of the USACE LAD to focus on a timeline of events surrounding the releases in preparation for the anticipated precipitation event. During these workshops, a timeline event summary was created, listing dates and times of forecast postings and actions made in response to coordinate releases and notifications to the relevant authorities and stakeholders. These event points were aligned with the forecast evolution to determine how the variability in the forecast could have played a role in the decision-making process.

3. Discussion of meteorological systems impacting Prado during December 2021

Several pulses of precipitation occurred over the Santa Ana Basin during the period between 23 December 2021 and 1 January 2022 and resulted in the activation of the LAD to make water management decisions at Prado Dam. Figure 2 shows the time series of 6-hr precipitation and hourly IVT over Prado through the study period. Between 24-25 December, an AR3 scale storm generated 58.61 mm of precipitation nearest Prado. The subsequent pulses of precipitation were characterized by enhanced water vapor flux but classified as a weak AR (26 December) or non-AR as it did not exceed the 250 kg m^{-1} s^{-1} threshold (28 December). These two pulses also increased the water pool at Prado leading up to the final precipitation event on 30-31 December. Following the series of precipitation events between 24-28, the reservoir elevation was 503.42 feet. Any subsequent forecasted rainfall would likely require release decisions at Prado as to avoid further encroachment.

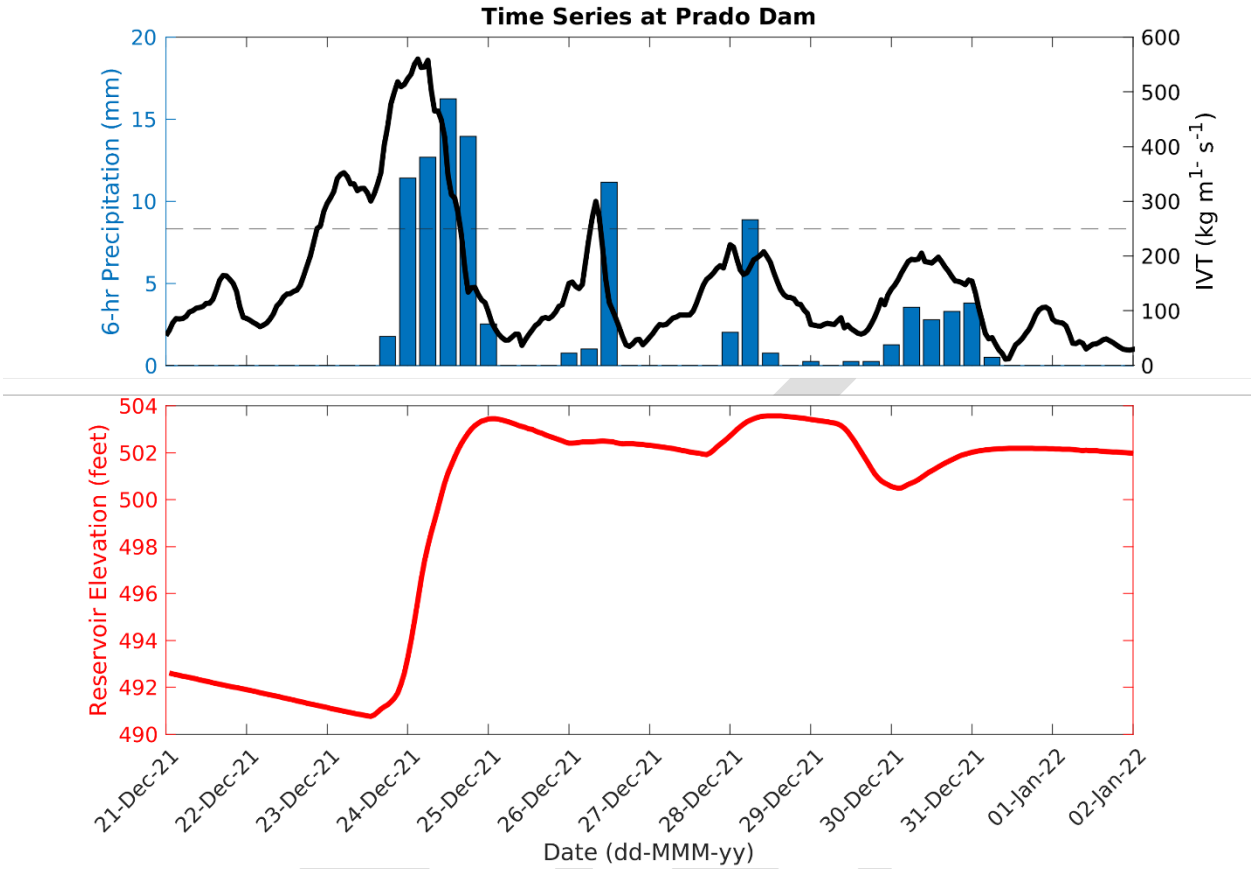


Figure 2. Time series of (top) 6-hr precipitation totals (mm, blue bars) and IVT (kg m^{-1} s^{-1}, black line) at Prado Dam and (bottom) Prado reservoir elevation (red, feet) between 21 December 2021 and 2 January 2022. An IVT threshold of 250 kg m^{-1} s^{-1} is denoted by the black dashed line in the top panel.

Beginning on December 27th, the 00Z GFS forecasts signaled another potential weather system approaching Southern California around 00Z 30 December and additional precipitation over the Santa Ana Basin. Figure 3 shows the observed weather pattern, dominated by a hybrid cutoff low centered at 123 W, 35N, onshore southwesterly flow in the vicinity of the Santa Ana basin, and precipitation across much of Orange, Los Angeles, and Ventura Counties. The IVT in this case is weak during the period of maximum precipitation accumulation and indicates that there is additional dynamical forcing to generate precipitation in association with the cutoff low.

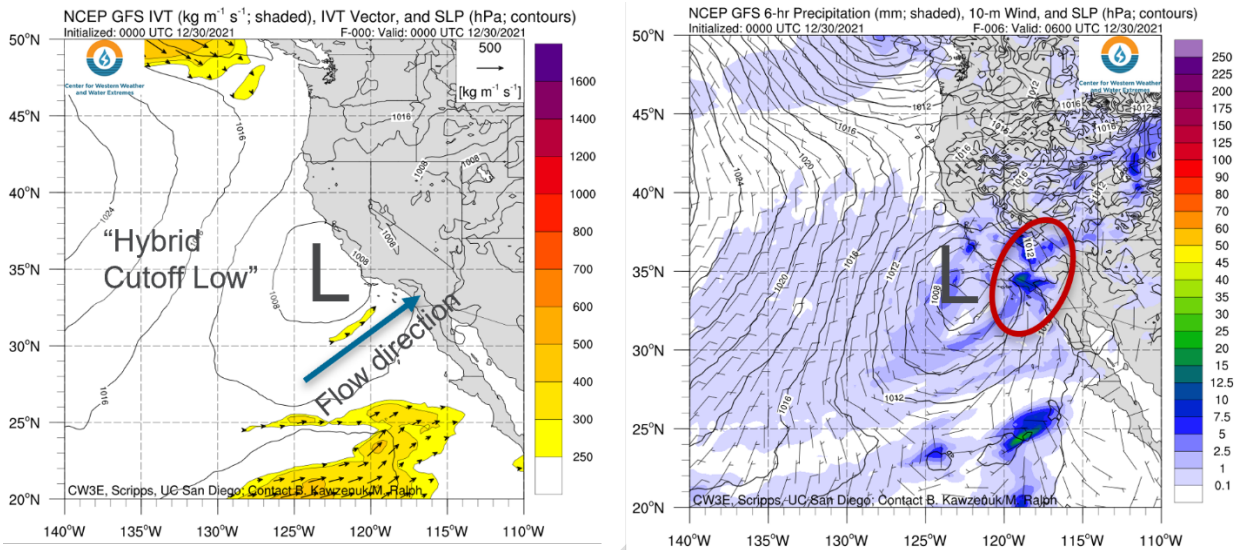


Figure 3. GFS analysis of IVT (left) and forecasted 6-hr precipitation accumulation (right) valid at 00Z 30 December 2021 and 06Z 30 December 2021, respectively. Sea level pressure (hPa) contours are plotted in both panels and the center of the low pressure system is marked by an "L". The arrows within the IVT shaded regions represent the IVT vector (kg m^{-1} s^{-1}), and the barbs overlaid on the precipitation field represent the 10-m wind speed (m/s). The low-level wind speed and water vapor flow direction is denoted by the blue arrow and the focus area of precipitation accumulation is denoted by the red oval.

4. Forecast skill assessment at Prado

Precipitation forecasts from the West-WRF 3km and GFS 25-km runs at 1 and 2-days lead time, as well as the QPE from the CNRFC, are shown in Figure 4. The QPE field shows a local maxima of ~150 mm over the San Gabriel mountains and much smaller accumulations throughout the lower elevations of the basin. Notably, the total precipitation during this period over the San Bernardino mountains was generally less than 25 mm. Thus, much of the basin received less accumulations than areas to the West of the basin, particularly in Ventura and Los Angeles counties. The 1-day forecasts from West-WRF and GFS reasonably capture this precipitation gradient across Southern California and the increased resolution of the West-WRF model is able to resolve the intra-basin spatial distribution of precipitation maxima and minima during this time. However, the 2-day forecasts from West-WRF and GFS predicted much more widespread precipitation within the Santa Ana basin, with higher accumulation over the San Bernardino mountains and the lower elevations upstream of Prado. The GFS 2-day forecasts predicted precipitation accumulations in excess of 60 mm over much of the central and western portions of the basin, while the West-WRF dynamical downscaling reduces the overall signal over lower elevations and primarily generated precipitation over the higher mountains of the northern watershed border. West-WRF reduced the GFS forecast error by ~38 mm (1.5 inches) near the center of the basin. Overall, both models predicted too much precipitation at 2 days lead time, while the 1-day lead time forecasts better at simulating the observed precipitation distribution.

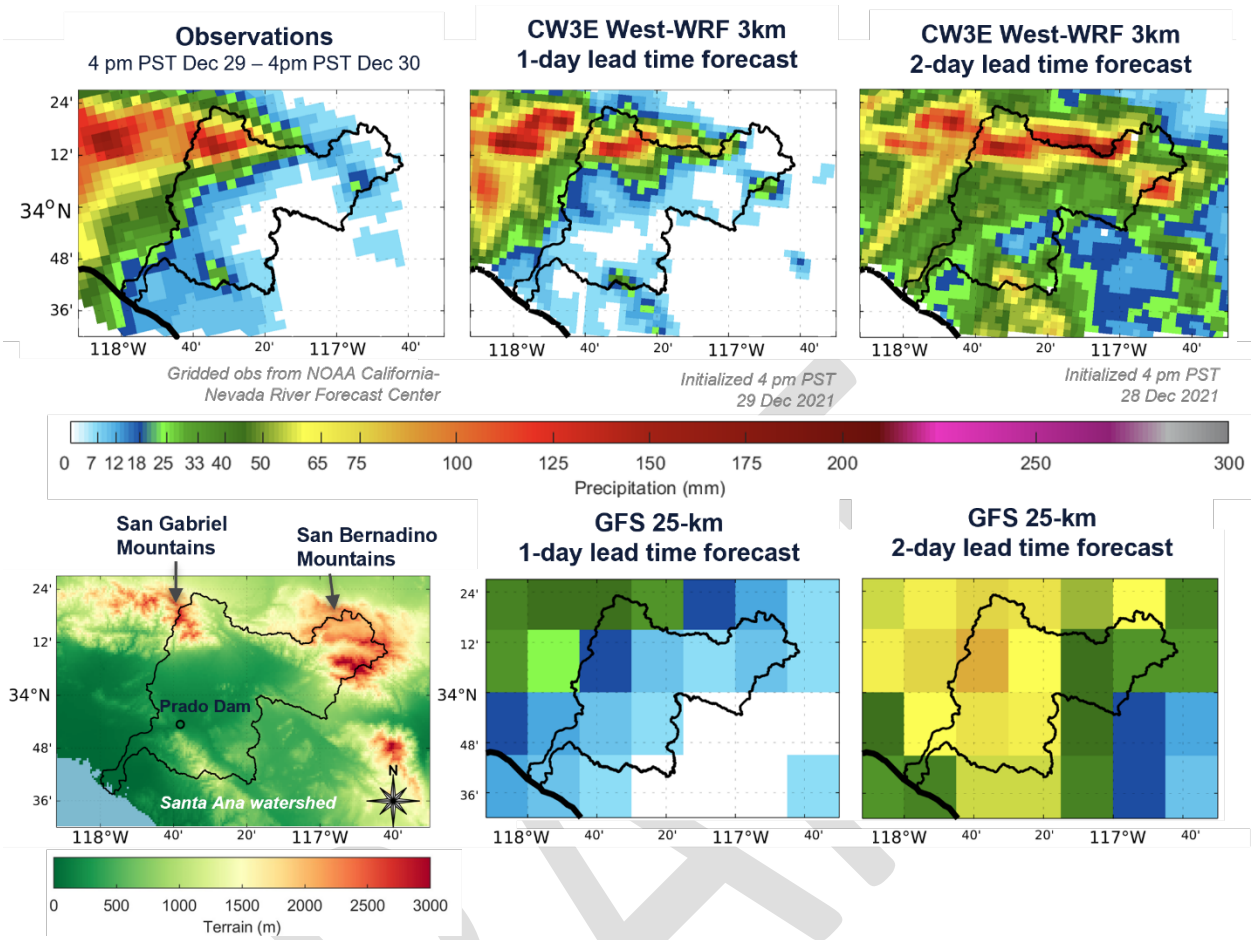


Figure 4. 24-hr precipitation totals from a) Gridded CNRFC QPE, b) 1-day lead time West-WRF forecast, c) 2-day lead time West-WRF forecast, e) GFS 1-day forecast, and f) GFS 2-day forecast over the Santa Ana basin (black contour). Panel d shows the terrain relief within the Santa Ana basin with the San Gabriel and San Bernardino mountains marked by the black arrows, and the location of Prado dam with a black circle. Forecasts are valid at 00Z 31 December 2021 (4 pm PST 29-30 December).

Figure 5 shows the radar reflectivity of the precipitation occurring on 30 December, when the rainfall was occurring to the west of the Santa Ana basin. Throughout the day, the higher reflectivity values are persistently occurring to the north and west of Santa Ana until about 21Z. This supports the theory that the precipitation stalled on its southward progression and aligns with the overforecast errors from the models.

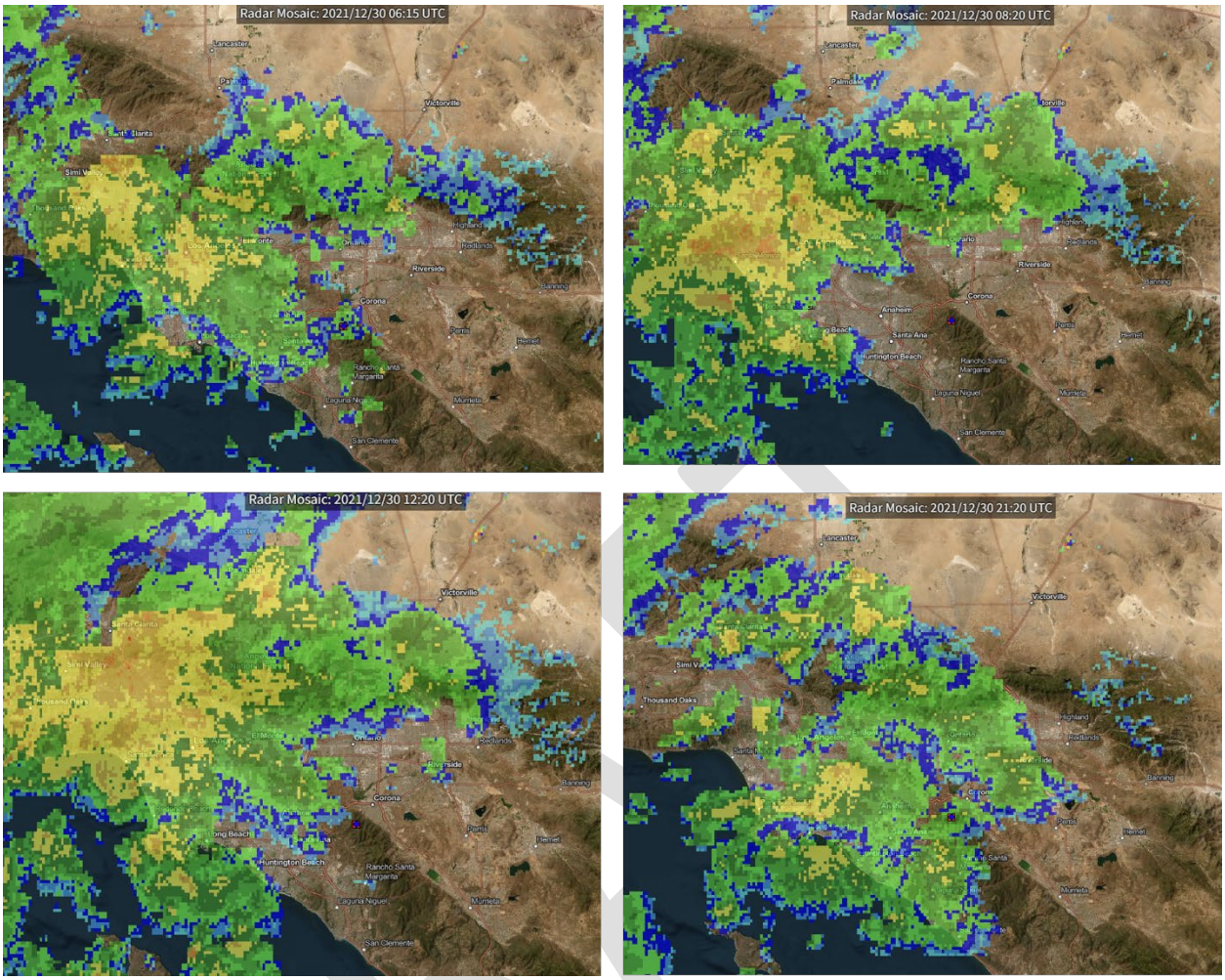


Figure 5. Radar reflectivity over Southern California on 30 December 2021 at (top left) 6:15Z, (top right) 8:20Z, (bottom left) 12:20Z, and (bottom right) 21:20Z.

5. Alignment of forecast availability and variability

As shown in section 4, 24-hr total precipitation forecasts between 1 and 2-day lead times were quite different in terms of their magnitude and distribution, ultimately leading to a large forecast overestimation at the 2-day lead time. Water operations at Prado require advance notifications and ramping rates for release out of the dam. The longer lead forecasts provide some basis for decisions made in advance of the precipitation and release from the reservoir. Figure 6 shows the alignment of the 24-hr mean areal precipitation over the Santa Ana watershed, as well as the timing of available forecasts of precipitation and inflows for the Prado drainage area as reported by the LAD. The important forecast issuances for the rapidly changing precipitation prediction are noted by the blue and red boxes. Between 9Z and 14Z on the 29th, the precipitation forecasts issued from NWS San Diego decreased by half (not shown). Releases during this time were ramped up to X and notifications would have been made to local authorities, etc. The decisions of the release rates align with the expectation of forecasts made at these critical times and support decreased water capacity in order to make space for incoming runoff and streamflow. This analysis highlights the challenges associated with large forecast

variability during a short window of lead times and warrants further investigation into the uncertainty characteristics of the forecast such that they might be leveraged in future decision-making processes.

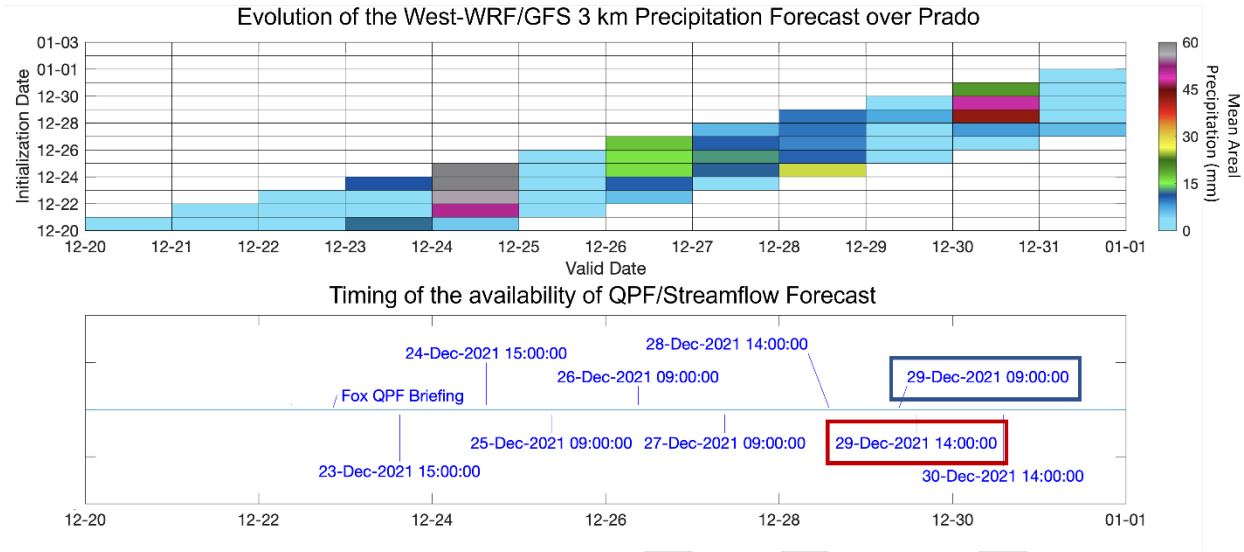


Figure 6. (Top) 24-hr mean areal precipitation (MAP) over Prado as a function of valid time and forecast lead time and (bottom) timing of the availability of the QPF/streamflow forecasts between 20 December 2021 and 1 January 2022. The red and blue boxes highlight the times in which CNRFC streamflow forecasts were available but the precipitation forecasts within Prado decreased by half.

Appendix B—Water Resources Studies and Research (Sections 4 and 5)

B.1 Process Documents

1. Hydrologic Engineering Management Plan (HEMP) for the evaluation of Prado Dam Water Control Plan Alternatives.
2. Adjustments to Santa Ana River Baseflow
3. HEC Simpler Forecast Operations Model (SFO)
4. Adjusted Scaled Hindcasts
    a. February 1998
    b. December 2005
    c. December 2010

B.2 Evaluation Graphics

1. Frequency of Maximum Annual Pool Elevation
    a. By Alternative
    b. By Buffer Pool elevation
        i. All Alternatives
        ii. All Alternatives (zoomed on 5-50%)
        iii. Perfect Alternatives omitted
        iv. Perfect Alternatives omitted (zoomed on 5-50%)
        v. Perfect and No Forecast Alternatives omitted
        vi. Perfect and No Forecast Alternatives omitted (zoomed on 5-50-%)

B.3 Frequency of Maximum Annual Reservoir Release

a. By Alternative
b. By Buffer Pool elevation
    i. All Alternatives
    ii. All Alternatives (zoomed on 5-50%)
    iii. Perfect Alternatives omitted
    iv. Perfect Alternatives omitted (zoomed on 5-50%)
    v. Perfect and No Forecast Alternatives omitted
    vi. Perfect and No Forecast Alternatives omitted (zoomed on 5-50-%)

B.4 HEMP Metrics – Frequency Charts

a. All Alternatives
b. 520′ Buffer Pool omitted
c. Perfect and No Forecast Alternatives omitted

B.5 HEMP Metrics – Bar Charts

a. All Alternatives
b. 520′ Buffer Pool omitted
c. Perfect and No Forecast Alternatives omitted

B.6 HEMP Metrics – Box and Whisker Plots

a. All Alternatives
b. 520′ Buffer Pool omitted
c. Perfect and No Forecast Alternatives omitted

B.7 Scaled Hindcast Plots

a. By Alternative
b. By Buffer Pool elevation
    i. All Alternatives
    ii. Perfect Forecast Alternatives omitted
    iii. Perfect and No Forecast Alternatives omitted

Hydrologic engineering management plan (HEMP) for Prado Dam Forecast-informed Reservoir Operation (FIRO) evaluation of water control plan alternatives within the Final Viability Assessment (FVA)

Draft Version 2.0, July 2022

Summary

Organized efforts to evaluate the potential application of FIRO for Prado Dam began in the Fall of 2017. An inter-agency inter-disciplinary steering committee (SC) was formed and a workplan for evaluation was completed in the Fall of 2019. The objective of the Preliminary Viability Assessment (PVA) was to identify, through appropriate detailed technical analyses and other considerations, candidate FIRO strategies for Prado Dam, and along with the way they might be implemented in real-time operation USACE and OCWD. That assessment was completed in 2021 and efforts have shifted to the FVA where a more thorough investigation of potential FIRO strategies (WCP alternatives) will be performed as informed by the PVA process.

The FVA is managed by the Prado Dam FIRO steering committee (To be consistent with USACE guidance for conduct of similar technical studies the SC prepared this hydrologic engineering management plan (HEMP) as *…a technical outline of the hydrologic engineering studies necessary to formulate a solution to a water resources problem* (*Engineering Pamphlet 1110-2-9*).

This HEMP includes the following:

1. Statement of objective and overview of technical study process to provide information needed for the FVA.
2. Specification of requirements for FIRO alternatives that will be considered. These are presented in **Table 1**, **Table 2**, & **Table 3**.
3. Identification of tasks to be completed for the technical analysis. These are presented in **Table 4**.
4. Identification of analysis tools and methods to be used for the study.
5. Identification of the project team members and their roles and responsibilities for conduct, review, and approval of the hydrologic engineering study. These are presented in **Table 7** and **Table 8**.
6. Analysis schedule. This is presented in **Figure 1**.

Objective of technical analysis, overview of process, and tasks to be completed

The objective of the hydrologic engineering study described herein is to identify and evaluate Prado Dam FIRO alternatives in a systematic, defendable, repeatable manner, thus providing information to the SC so it may identify the best FIRO strategy for consideration by the USACE when the WCM for Prado Dam is updated following the SARM spillway raise to 563'. The approach taken leverages the experience and recommendations from the PVA.

The process used to meet the hydrologic engineering study objective is a "nominate-simulate-evaluate-iterate" process, consistent with the process used commonly by USACE for water resources planning studies. Tasks in this process, as applied for technical analyses to support the Prado Dam FIRO PVA, include the following:

1. A set of feasibility criteria and performance metrics is developed for assessing and comparing FIRO alternatives. This set will be applied to all alternatives, thereby permitting the project delivery team (PDT) to compare and rank alternatives and the SC to identify the best FIRO strategy.
2. A set of alternative FIRO strategies is nominated by the PDT. The strategies are screened to ensure they meet specified requirements, which are described below.
3. Performance of the river-reservoir system with each FIRO strategy is simulated using a common set of meteorological and hydrological conditions.
4. Simulation results are used to evaluate the viability and performance of each strategy. The evaluation uses metrics identified in Task 1, comparing each alternative to performance for the *without-project* condition, which is operation following the WCP included in the current water control manual (WCM). If results of the evaluation inform refinements to FIRO strategies, the simulation and evaluation tasks are repeated with enhanced strategies
5. The PDT uses the technical analysis results to rank the alternatives and submits the rankings to the SC. The SC identifies the best strategy for potential implementation by USACE.

These tasks are described in more detail in Table 4. Major tasks are listed in column 1, and subtasks in column 3.

FIRO alternatives to be evaluated

Selection of specific FIRO alternatives is a task to be completed as a component of the hydrologic engineering study (see below). Requirements of all candidate FIRO strategies are shown in **Table 1**. **Table 2** and **Table 3** show additional constraints and objectives that should be met by proposed alternatives. While selection of FIRO alternatives to be evaluated is a task of the technical studies (see below), a tentative set evolved as an outcome of the PVA; that list is shown in **Table 6**.

Table 1. Requirements of all alternative FIRO strategies

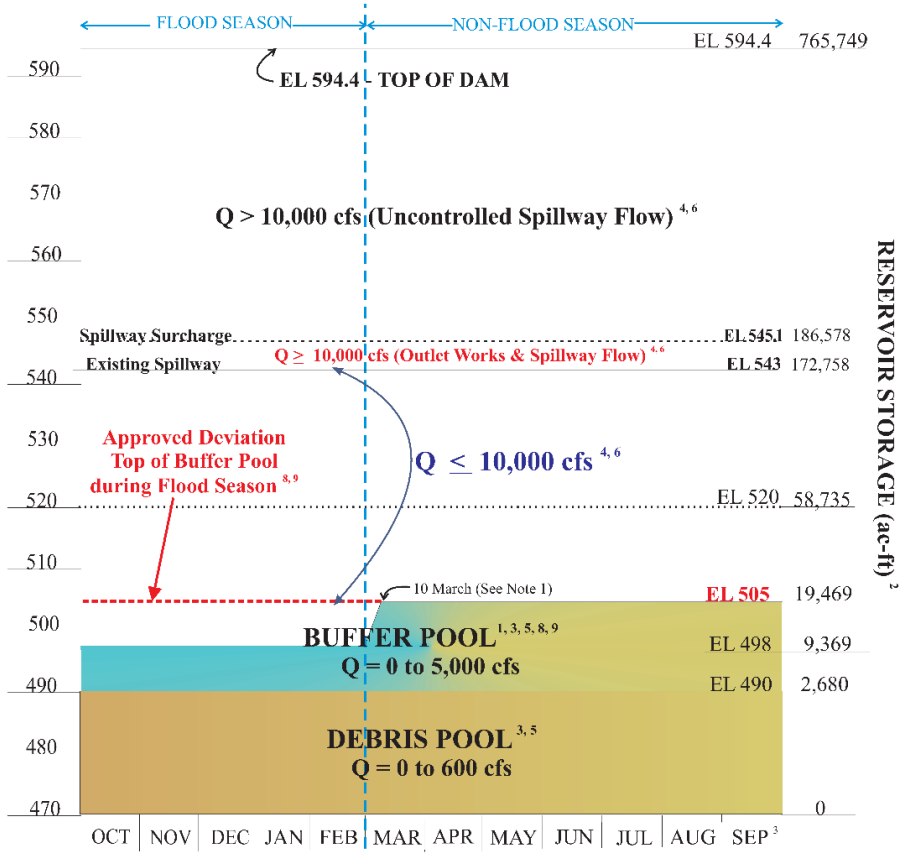
ID (1)	Description (2)
1	The candidate FIRO strategy must satisfy all relevant USACE engineering regulations (ERs), including but not limited to the following: • ER 1105-2-100 *Planning Guidance Notebook* • ER 1105-2-101 *Risk Assessment for Flood Risk Management Studies* • ER 1110-2-240 *Water Control Management* • ER 1110-2-1156 *Safety of Dams Policy and Procedures* • ER 1110-2-1941 *Drought Contingency Plans* • EM 1110-2-3600 *Management of Water Control Systems* • ER 1110-2-8156 *Engineering and Design Preparation of Water Control Manuals* • EM 1110-2-1420 Hydrologic *Engineering Requirements for Reservoirs*
2	The analytical tools required for implementation of the candidate FIRO strategy must be compatible with the USACE's Corps Water Management System (CWMS) software. In addition, results of any analyses completed with software not currently certified for use by USACE must be demonstrated to produce results consistent with results of USACE software.
3	Streamflow forecasts used by the candidate FIRO strategy must be those provided by the California-Nevada River Forecast Center (CNRFC) of the National Weather Service. Simulated streamflow forecasts must be consistent with the skill characteristics of those issued by the CNRFC. As appropriate for the alternative, the forecast used can be ensemble and/or deterministic (single-value).
4	The FIRO strategy must satisfy the hard (inviolable) operation constraints shown in Table 2.
5	The FIRO strategy should represent, and to the extent possible, meet the operation objectives shown in Table 3.
6	Software development needed to implement the FIRO alternative must be limited for the FVA, as the objective is to select from amongst a set of readily available (or nearly so) strategies.
7	Simulations during periods when release rate of change may become a factor should be completed at an hourly time step. When release rate of change is not a factor, the simulation time step can be daily.

Table 2. Hard (inviolable) operational constraints that must be satisfied by all FIRO strategies

ID (1)	Limiting condition (2)	Description (3)
1	Must satisfy limits on release rate of change	Release rate of change is governed by the potential impacts on downstream evacuation of the channel, movement of construction equipment, and bank erosion and stability. ROC limits (up and down) will be defined prior to evaluation. Limits are defined for flows up to 5000 cfs. Limits will be established for flows between 5,000 cfs and 30,000 cfs by LA District staff.
2	Maximum release capacity associated with WCM Update #1	One downstream limit of 30,000 cfs will be evaluated. Construction of Reach 9 and the BNSF Railroad bridge is assumed to be completed for the purposes of this study.
3	Must accommodate maximum release schedule	The maximum release schedule is defined by LAD staff and is shown in Figure 1. The logic for using the chart will be clarified by the PDT.
4	Must meet instream minimum flow requirements	Minimum discharge set at 50 cfs.
5	Other	24 hour lead time notifications

Table 3. Operational considerations that should be evaluated in the hydrologic engineering study

ID (1)	Operational consideration (2)	Description (3)
1	Corona Airport	Flooding/closure of the Corona Airport @ 515’
2	Euclid Avenue	Euclid Avenue closed @ 515’ (Normally closed earlier due to Chino Creek floodwaters)
3	Least Bells vireo nests	Increases in the pool elevation of 1m or greater between March 21 (vireo arrival) and May 1 may flood vireo nests
4	Potential harm or benefit to riparian habitat above 505’	Prolonged inundation of riparian vegetation has the potential to harm or benefit the vireo habitat
5	Spillway flow	Spillway flow in excess of downstream channel capacity has serious flood impacts. Any uncontrolled spillway flow has negative implications for the Corps.
6	Other	
7	Others?	
8	Others?	



Prado Dam Release Ranges - Using New Outlet Works

Pertinent Pool Elevations (ft, NGVD29)	Recommended Plan of Discharge Description
DEBRIS POOL 470 - 490	At the start of a runoff event, a debris pool is built to settle out floating debris to limit their being drawn into the outlet works. Discharge from within this pool range varies (0-600 cfs), but generally accommodates the OCWD's downstream spreading capacity without waste to the Pacific Ocean. Flow may also be shut off temporarily to facilitate construction.
BUFFER POOL Flood Season * EL 490-498 /505; Non-Flood Season ** EL 490-505	Discharge range (0 - 5000 cfs). The buffer pool range is borrowed flood risk management space to temporarily store water for water conservation. The top of buffer pool elevation during flood season is normally up to EL 498; however during the approved Deviation period, this elevation can be maximized up to 505. Upon completion of the Prado Basin Feasibility Study and approval of water conservation alternative, the top of buffer pool will remain at EL 505 during both flood and non-flood seasons.
FLOOD RISK MANAGEMENT POOL Flood Season EL 498/505-520; Non-Flood Season EL 505-520	Discharge (≤ 10,000 cfs). The resulting maximum reservoir release will depend on anticipated inflow and downstream conditions. Maximum discharge is maintained until the pool elevation recedes back down to/below the top of buffer pool elevation.
FLOOD RISK MANAGEMENT POOL 520 - 543 ***	Discharge (≤ 10,000 cfs). The resulting maximum reservoir release will depend on anticipated inflow and downstream conditions. Maximum discharge is maintained until the pool elevation recedes back down to/below the top of buffer pool elevation. If hydrologic conditions warrant, or if dam safety is a concern, discharge through the outlet works may exceed 10,000 cfs.
SPILLWAY SURCHARGE POOL 543 - 545.10 ***	Discharge (> 10,000 cfs) Combined controlled discharge through outlet works and uncontrolled discharge over the spillway. Existing dam safety concern with the unmodified spillway. Controlled outlet discharge may be maximized (>10,000 cfs) to minimize the duration of spillway flow.
UNCONTROLLED SPILLWAY DISCHARGE 545.10 - 594.4 ***	Discharge (> 10,000 cfs) Combined controlled discharge through outlet works and uncontrolled discharge over the spillway. Existing dam safety concern with the unmodified spillway. Controlled outlet discharge may be maximized (>10,000 cfs) to minimize the duration of spillway flow.

Footnotes:

* Flood season is defined 1 OCT through 29 FEB. Within this time period, if flood risk management discharge is not warranted, then water conservation releases are made, coordinated with OCWD, while the pool elevation does not exceed top of approved buffer pool elevation. The entire buffer pool is under Corps control and can be evacuated any time for any reason. Discharge for water conservation will vary depending on OCWD diversion capacity. Discharge may also be shut off temporarily to accommodate downstream maintenance or channel inspections, as needed.

** Non-flood season is defined 1 MAR through 30 SEP. Within this time period, if flood risk management discharge is not warranted, then water conservation releases are made, coordinated with OCWD, while the pool elevation does not exceed top of approved buffer pool elevation, and outside of the month of SEP (see Note 3). The entire buffer pool is under Corps control and can be evacuated any time for any reason. Below EL 505, discharge from the dam will also be maintained at an average of 350 cfs, providing that there is sufficient reservoir pool to support this release. Discharge may also be shut off temporarily to accommodate downstream maintenance or channel inspections, as needed.

*** The decision of release magnitude will depend on storm and runoff conditions, as well as conditions of the reservoir and channels in the Santa Ana River watershed and how flood risk management objectives can best be met. Releases could exceed 10,000 cfs to either prevent/minimize the occurrence of spillway flow, or if there are dam safety concerns. Coordination with District Chain of Command and SPD will be made prior to implementing a discharge exceeding 10,000 cfs.

NOTES:
1. The top of buffer pool in during flood season is normally up to elevation 498 ft and at 505 ft during non-flood season. Beginning 1 March, the reservoir pool is gradually increased to transition from EL 498 ft to EL 505 ft by March 10. Discharge from Prado to accommodate OCWD's spreading capacity varies, maximizing up to 600 cfs during both flood and non-flood seasons.
2. Storage Data based on Reservoir Survey completed in 2008 and 2015. Refer to Area and Storage Tables in Exhibit B for more detail.
3. September is designated as maintenance period (i.e., reservoir to be empty by then, if possible).
4. Maximum outlet discharge capability is up to 30,000 cfs. Above elevation 520 ft, releases may be increased to the maximum possible discharge to prevent/minimize spillway flow, or due to dam safety concerns.
5. During non-flood season, discharge is subject to minimum release requirements (average 350 cfs).
6. If discharge will exceed 10,000 cfs, a dam safety team must be on site to evaluate impacts to the dam and outlet works. Discharge greater than 10,000 cfs will be also be coordinated with SPD.
7. All elevations cited are in feet, NGVD 1929.
8. **The Multi-Year Deviation Request will change ONLY the top of buffer pool elevation from 498 to 505 during flood seasons. All other conditions specified for the IWCP will remain the same.**
9. **Upon completion of the Prado Basin Feasibility Study and approval of the water conservation alternative, the approved deviation plan will be permanently implemented as part of this IWCP. Should the deviation period expire prior to completing the Feasibility Study, then the maximum top of flood season buffer pool will remain at elevation 498.**

PRADO DAM
SANTA ANA RIVER BASIN, CALIFORNIA
INTERIM WATER CONTROL MANUAL

INTERIM
WATER CONTROL PLAN
(IWCP - July 2020)

U.S. ARMY CORPS OF ENGINEERS
LOS ANGELES DISTRICT

This Diagram Supersedes the 2003 IWCP Diagram (Plan A) Plate 7-01

Figure 1. Prado Dam maximum release schedule (LAD July 2020).

[to be updated by LAD when available]

Table 4. Tasks and subtasks to be completed for hydrologic engineering study of FIRO strategies

Major task (1)	**Description (2)**	**Subtasks (3)**
Task 1. Select performance metrics	Both quantitative and qualitative measures of performance will be identified. Methods of computation of quantitative measures will be described. A tentative list is shown in Table 5.	**Task 1.1.** With appropriate input from subject matter experts, formulate a candidate set of quantitative and qualitative measures of performance. (A tentative list is shown in Table 5.) Define methods for assessing these for typical FIRO strategies. Screen set to select feasible metrics for ALL likely alternatives to permit objective comparison of strategies. Prepare a technical memo. Submit to SC for review. **Task 1.2.** Receive comments from SC. Revise selected set of performance metrics as required. **Task 1.3**. If necessary, design, develop, test software applications (scripts, spreadsheets, etc.) to apply selected metrics.
Task 2. Nominate/formulate alternative FIRO strategies that will be considered	Each alternative FIRO strategy to be considered will be identified and described, along with the method by which performance with the strategy will be evaluated. A tentative set is shown in Table 6.	**Task 2.1**. With appropriate input from subject matter experts, formulate a candidate set of FIRO strategies to be considered. Describe each strategy in memo, submit proposed list/memo to SC for approval. **Task 2.2.** Receive comments from SC and revise list as appropriate. Get SC agreement to proceed with comparison. **Task 2.3**. Identify software applications that will be used to model FIRO strategies (tentatively, these are HEC-ResSim and Ensemble Forecast Operations [EFO]).
Task 3. Side studies	Identify, conduct, document, and incorporate outcomes of "side studies" that affect the simulation and evaluation of alternatives.	**Task 3.1.** Identify any additional "side studies" that must be completed to provide information required for simulation. Details of side studies will be identified in this subtask, with scope of work and schedule submitted to SC for approval. **Task 3.2.** Undertake and complete side studies, as approved by SC. Document findings. Incorporate findings in selected FIRO strategy models or procedures

Major task (1)	Description (2)	Subtasks (3)
Task 4. Simulate performance with each alternative	Each alternative FIRO strategy will be simulated with the HEC-ResSim model with a consistent set of hydrologic boundary conditions and system constraints (identified in Table 2).	**Task 4.1.** Considering all FIRO strategies to be evaluated, identify boundary conditions and initial states of the system to be considered in simulation for comparison. Document. **Task 4.2.** Simulate performance of Prado Dam with candidate strategies. [For EFO model, validate release schedule, simulated storage, and computed downstream flows with HEC-ResSim model.] Prepare a technical memo describing application of each strategy. Prepare a database of results (for use in Task 5).
Task 5. Using results of simulation, evaluate each alternative in terms of identified performance metrics	Each alternative FIRO strategy will be analyzed and the appropriate performance metric statistics computed.	**Task 5.1.** Using a database of results from the HEC-ResSim simulation of each FIRO strategy (from subtask Task 4.2) apply software applications (scripts, spreadsheets, etc.) from Task 1.3 to compute performance metrics for each strategy. **Task 5.2.** Revise FIRO strategies and performance metrics as necessary to ensure fair, repeatable comparisons. This subtask acknowledges initial uncertainty about compatibility of strategies and metrics. **Task 5.3.** Document results of evaluation in technical memo.
Task 6. Compare the alternatives by comparing the metrics	Each alternative FIRO strategy evaluation will be compared against the baseline and against each other.	**Task 6.1.** Using results from Task 5, prepare charts, tables, etc. to compare performance of strategies. Prepare a technical memo with this information and submit it to SC for information. **Task 6.2.** Refine strategies if evaluation and comparison expose opportunities for "quick gains" through minor adjustments to strategies. Repeat subtasks Task 4.2— Task 5.1 with revised results. **Task 6.3.** Prepare a final technical memo on simulation, evaluation, and comparison. Submit for SC review. Receive SC comments and revise technical memo as needed.
Task 7. Brief SC on findings and facilitate the selection of a preferred alternative.	Each alternative FIRO strategy comparison will be scrutinized, and all findings will be documented and presented to the SC.	**Task 7.1.** Using results of comparison from Task 6, rank alternatives considering individual metrics from Task 1. Document findings. **Task 7.2.** Provide comparisons and ranking to SC.

Metrics for evaluating viability and efficiency of alternatives

The efficiency of FIRO will be evaluated with a set of measurable statistics. These will be used in the same manner (to the maximum extent possible) to assess each alternative objectively. Selection of the specific metrics and stipulation of the manner of computing or calculating those is a task to be completed as a component of this study.

An initial tentative list of metrics is shown in **Table 5**.

Table 5. Tentative list of metrics for evaluation of FIRO alternatives (listed in Table 6)

ID (1)	Metric description (2)	Category (3)	Likely method of computation: (4)
M1	Annual maximum discharge frequency from Prado Dam	Flood risk management	Frequency curve. Simulate 32-year hindcast and extend with scaled 100-, 200-, and 500-year events. Consider the use of synthetic ensemble forecasts.
M2	Annual max. pool elevation frequency function of PRDO	FRM and Environmental	Frequency curve. Simulate 32-year hindcast and extend with scaled 100-, 200-, and 500-year events. Consider the use of synthetic ensemble forecasts.
M3	Vireo nest inundation between 3/21 and 5/1	Environmental	Simulate 32-year hindcast period. Frequency of pool elevation changes between March 21 and May 1.
M4	Average annual number of days of pool above 505′	Environmental	Frequency curve. Simulate 32-year hindcast.
M5	Average annual number of days of pool above 508′	Environmental	Frequency curve. Simulate 32-year hindcast.
M6	Average annual number of days of pool above 510′	Environmental	Frequency curve. Simulate 32-year hindcast.
M7	Average annual number of days of pool above 512′	Environmental	Frequency curve. Simulate 32-year hindcast.
M8	Average annual number of days of pool above 514′	Enviro & Corona Airport impacts	Frequency curve. Simulate 32-year hindcast.
M9	Average annual number of days of pool above 515′	Enviro & Corona Airport impacts	Frequency curve. Simulate 32-year hindcast.
M10	Average annual number of days of pool above 520′	Enviro & Euclid Ave. closure	Frequency curve. Simulate 32-year hindcast.
M11	Average annual total recharge below Prado Dam	Water Supply	Frequency curve. Simulate 32-year hindcast.
M12	Ave. annual release above recharge capacity (volume)	Water supply	Frequency curve. Simulate 32-year hindcast.
M13	Potential impacts on San Antonio and Seven Oaks operations	FRM and Water supply	TBD

Notes:

(1). Hindcast of the Hydrologic Ensemble Forecasts System (HEFS) for forecast points in the Santa Ana was developed by the CNRFC, which includes daily forecasts of hourly flows out to 15 days for 41 ensemble members based on GEFSv12. The Hindcast covers water years 1990 through 2021. References and resources for HEFS include:

https://journals.ametsoc.org/doi/full/10.1175/BAMS-D-12-00081.1

https://cepsym.org/Sympro2016/Hartman.pdf

(2). Scaled events from the hindcast dataset have been developed to simulate 100-, 200-, and 500-year flood events for Prado Dam. Observed hydrology and hindcasts from (spec. years here) historical flood events have been scaled to match the estimated 100-, 200-, and 500-year return frequency inflow volume into Prado Dam. This effort requires a side study to (1) define the 100, 200, and 500-year 3-day inflow volume, (2) the identification of 2 to 4 large events within the 1990-2020 period, and (3) the scaling the HEFS ensemble forecasts associated with these events by the CNRFC. Recent work to develop synthetic ensemble hydrologic forecasts may be leveraged to increase the robustness testing of the FIRO strategies.

Table 6. *Candidate FIRO alternatives to be evaluated*

ID (1)	**Alternative strategy (2)**	**Description (3)**
1	Unrestricted 505′ (Baseline)	Buffer pool allowed to extend up to 505′ without a seasonal restriction. Releases when pool is <= 505′ at maximum recharge rate. Releases above 505′ are at the maximum scheduled rate. No forecasts are used.
2	EFO-508	Buffer pool allowed to extend up to 508′ provided risk of exceeding 508′ is acceptable. Releases when risk is acceptable = maximum recharge rate. Determines release required to mitigate risk of exceeding 508′. Uses ensemble inflow forecast.
3	508-NF	Same as baseline but Buffer pool allowed to extend up to 508′.
4	EFO-510	Buffer pool allowed to extend up to 510′ provided risk of exceeding 510′ is acceptable. Releases when risk is acceptable = maximum recharge rate. Determines release required to mitigate risk of exceeding 510′. Uses ensemble inflow forecast.
5	510-NF	Same as baseline but Buffer pool allowed to extend up to 510′.

ID (1)	Alternative strategy (2)	Description (3)
6	EFO-512	Buffer pool allowed to extend up to 512′ provided risk of exceeding 512′ is acceptable. Releases when risk is acceptable = maximum recharge rate. Determines release required to mitigate risk of exceeding 512′. Uses ensemble inflow forecast.
7	512-NF	Same as baseline but Buffer pool allowed to extend up to 512′.
8	EFO-514	Buffer pool allowed to extend up to 514′ provided risk of exceeding 514′ is acceptable. Releases when risk is acceptable = maximum recharge rate. Determines release required to mitigate risk of exceeding 514′. Uses ensemble inflow forecast.
9	514-NF	Same as baseline but Buffer pool allowed to extend up to 514′.
10	EFO-515	Buffer pool allowed to extend up to 515′ provided risk of exceeding 515′ is acceptable. Releases when risk is acceptable = maximum recharge rate. Determines release required to mitigate risk of exceeding 515′. Uses ensemble inflow forecast.
11	EFO-520	Buffer pool allowed to extend up to 520′ provided risk of exceeding 520′ is acceptable. Releases when risk is acceptable = maximum recharge rate. Determines release required to mitigate risk of exceeding 520′. Uses ensemble inflow forecast.
12	USACE-F1	Buffer pool allowed to extend up to 505′ without a seasonal restriction. Release is computed as the portion of the forecasted inflow volume that would exceed 505′. The forecast metrics used in the computation are the ensemble median of 1-day volume, 2-day volume, 3-day volume. Release = excess volume / duration, for 1-day, 2-day, 3-day, with larger release implemented.
13	USACE-F2	Same as USACE-F1, with buffer pool allowed to extend up to 512′.
14	USACE-F3	Variations on USACE-F1 or F2 with alternative parameter choices. For example, considering ensemble summary metrics for higher percentile volume, rather than mean or median, depending on magnitude, and/or limiting look-ahead in release computation to 2 days rather than 3 days with buffer = 505′.

Bookend Analysis

To better understand the maximum benefit of forecasts, Alternatives 2-14 will be configured and run with full foresight of future streamflow conditions in the next 15-days (perfect forecasts).

The "bookends" will be established by Alternative 1 and the results of the perfect forecast simulations (Alternatives 2-14). Our current position between the two "bookends" will be provided by the assessment of Alternatives 2-14 using currently available forecasts.

Project delivery team members and their roles

The PDT for evaluation of FIRO alternatives includes subject matter experts (SMEs) who will complete the analyses described herein, report on the findings and understandings, and recommend a single approach to be taken by CW3E, and managers who will oversee the work effort. PDT members are identified in **Table 7**.

Table 7. *Prado Dam FIRO FVA technical analysis PDT members*

- Prado Dam FIRO steering committee
- OCWD technical staff
- USACE Headquarters staff (HQ)
- USACE, South Pacific Division (SPD) staff
- USACE, Los Angeles District (SPL) staff
- USACE, Hydrologic Engineering Center staff
- Center for Western Weather and Water Extremes, Scripps Institution of Oceanography at University of California, San Diego (CW3E). Includes RKHCS and Sonoma Water staff under contract to support FIRO efforts.

The PDT members have 1 of 4 roles, consistent with established project management planning, as shown in **Table 8.** These roles vary by hydrologic engineering task. **Table 9** shows roles assigned to PDT members for the analysis described herein.

Table 8. Project roles

ID (1)	Role (2)	Description of duties (3)
R	Responsible	Responsible for completing the analyses described herein.
A	Accountable	Answerable for correct and thorough completion of task; ensures requirements are met; delegates work to those responsible.
C	Consulted	As SMEs, offer opinions through two-way communication with those responsible and accountable, about conduct of analyses.
I	Informed	Kept up to date on progress through 2-way communication.

Table 9. PDT roles by task

	Major Task	Steering Committee	OCWD Tech Staff	USACE HQ	USACE HEC	USACE SPD	USACE SPL	CW3E
1	Select performance metrics	I	R	I	R	C	R	R
2	Nominate/formulate alternative FIRO strategies that will be considered	C	R	I	R	C	R	R
3	Side studies	C	R	I	R	C	R	R
4	Simulate performance with each alternative	I	C	I	R	I	C	R
5	Using results of simulation, evaluate each alternative in terms of identified performance metrics	I	R	I	R	I	R	R
6	Compare the alternatives by comparing the metrics	I	R	I	R	C	R	R
7	Brief SC on findings and facilitate the selection of a preferred alternative.	I	R	I	R	C	R	R

Schedule for completion of technical analyses

Technical analysis to be completed by 1/1/2023.

Risks to success of study

Risks to the success of this study and mitigation actions are shown in **Table 10**.

Table 10. Project risks

Potential failure mode (1)	Actions PDT can take to mitigate (2)
Simulation or evaluation software does not function as expected.	Limit analysis to use of software that is readily available and has been stress tested.
Necessary data—including hydrological, meteorological, water use, vulnerability—are not readily available.	Limit analysis to use of best-available data.
Key personnel are not available to complete tasks.	Ensure back up staff for all critical tasks.
Critical path tasks fall behind schedule due to unforeseeable distractions and disruptions.	Limit project activities to those that are necessary to satisfy objectives.
PDT disagrees about technical analysis procedures.	Defer to PDT project assignments (see above).
Nature of alternative FIRO strategy prevents evaluation with selected metrics.	Disqualify alternatives from further consideration unless metrics can be adjusted and applied in uniform manner for all alternatives.

TECHNICAL MEMORANDUM

DATE: July 20, 2022
TO: Robert Hartman, Robert K. Hartman Consulting Services
FROM: Adam S. Hutchinson, Recharge Planning Manager

SUBJECT: ADJUSTED SANTA ANA RIVER BASEFLOW FOR FINAL VIABILITY ASSESSMENT OF FORECAST INFORMED RESERVOIR OPERATIONS AT PRADO DAM

This memorandum documents the work done to develop inflow to the Prado Basin from the Santa Ana River (SAR) as part of the Final Viability Assessment (FVA) of Forecast Informed Reservoir Operations (FIRO) at Prado Dam. This work was performed by the Water Resources Engineering Team and falls within Task 2 of the team's charter.

Task 2 is described as follows: **Ensure modeling and observations are consistent with the currently reduced levels of baseflow in the Santa Ana River above Prado Dam.** Subtasks include:

> 2a. Create an adjusted record of historical inflows to Prado Dam based on current levels of reduced baseflow. Period to be 1990 through 2021 at daily time step.
>
> 2b. Review CNRFC hydrologic model calibration to ensure the parameterization reflects current baseflow conditions. Run 1990-current simulation and compare with adjusted historical observations generated in 2a. Make model parameter adjustments as required.
>
> 2c. Memorandum for the Record (MFR) describing the process used to adjust the historical observations and the assessment of the CNRFC forecasting model showing consistency with current baseflow conditions
>
> *Deliverables:* Adjusted record of historical inflows to Prado Dam. MFR describing the process used to adjust the historical observations and the assessment of the CNRFC forecasting model showing consistency with current baseflow conditions.

This memorandum (MFR) is the deliverable for Task 2a and part of 2c.

Santa Ana River Flows

Each year the Santa Ana River Watermaster determines the split of base flow and storm flow arriving at Prado Dam and publishes this information in a report submitted to the Superior Court of Orange County. This is a requirement of Case No. 117628,

OCWD vs City of Chino, et al. These data were used by OCWD staff to generate daily inflow of base flow and storm flow to Prado Dam for the period Oct. 1, 1989 to September 30, 2021, as shown on Figure 1.

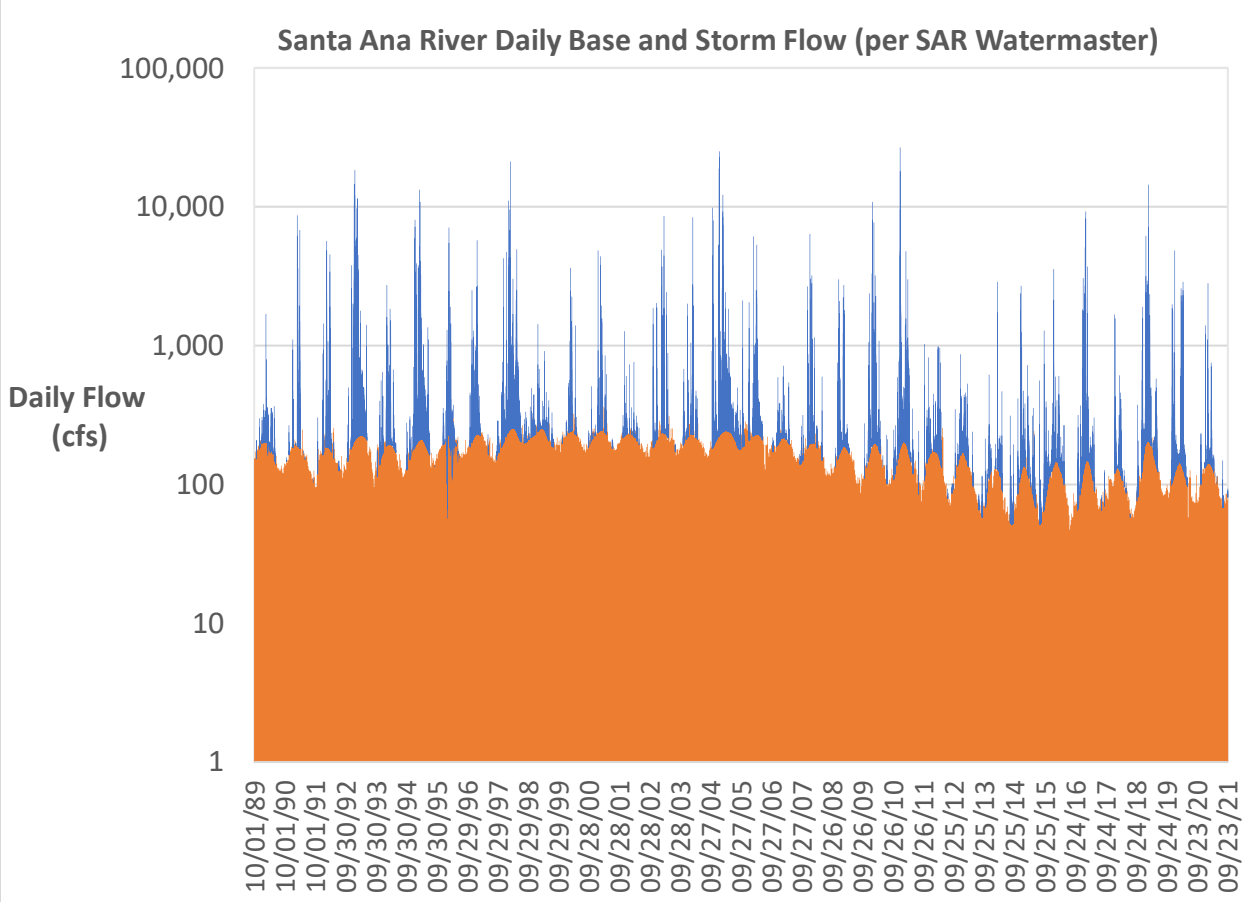


Figure 1. Daily Base Flow (Orange) and Storm Flow (Blue) Arriving at Prado Dam Per SAR Watermaster, Oct. 1989 to Sept. 2021

The reason this analysis was conducted is that base flows have declined significantly since the early 2000s by as much as 50 percent or more. This is important because the time to drain storm water temporarily retained behind Prado Dam will be affected by the estimated base flow arriving at the dam. If historical data is used in the modeling work, this could overestimate the time to drain storm water, which could affect management of the water conservation pool and potential environmental impacts.

Adjusting SAR Base Flow

SAR base flow arriving at Prado Dam is primarily comprised of upstream discharges from Wastewater Treatment Plants (WWTP) to the SAR and a minor amount of rising groundwater. There is a strong correlation between WWTP discharges to the SAR and the amount of base flow arriving at Prado Dam, as shown in Figure 2.

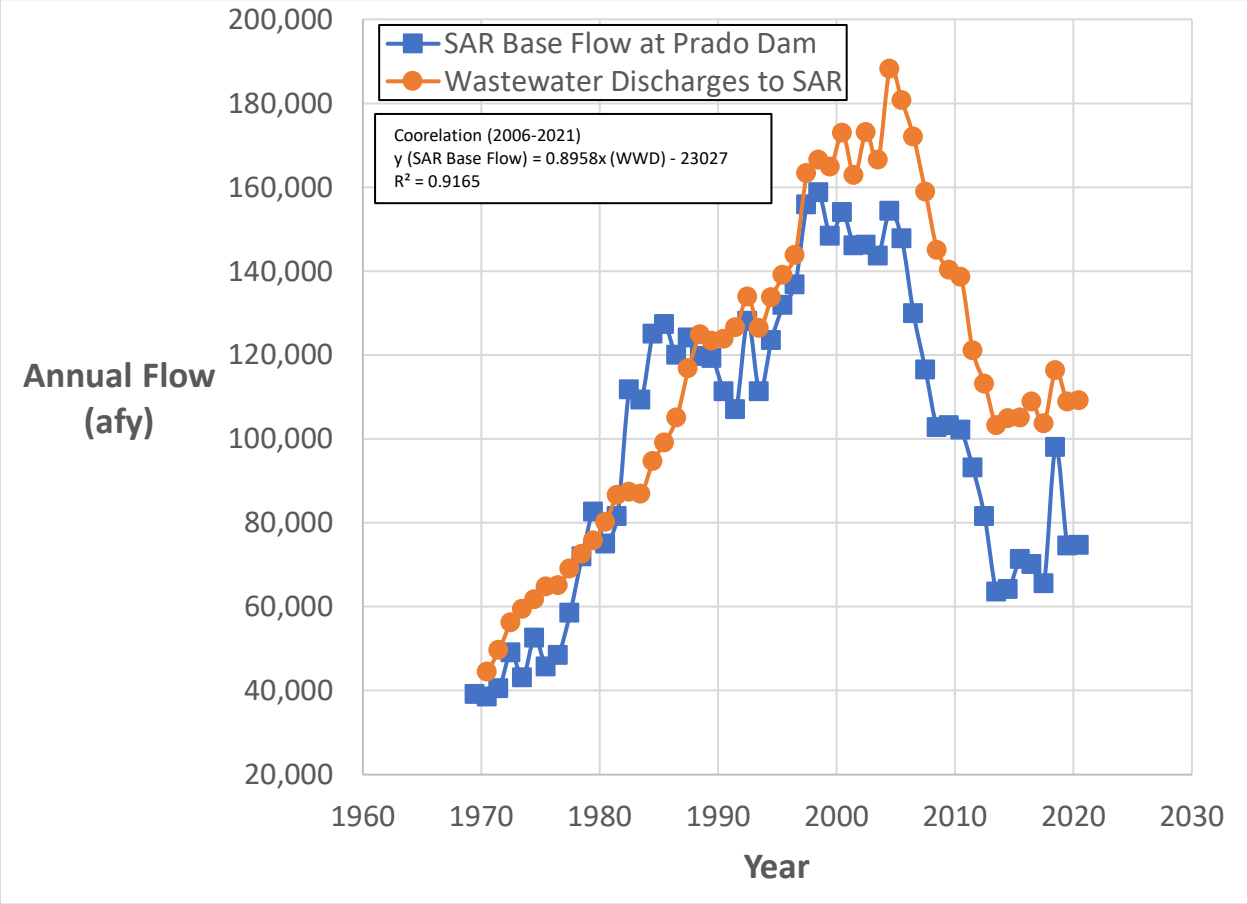


Figure 2. Annual Wastewater Discharges to SAR and Base Flow Arriving at Prado Dam (1969-2021)

Further decreases in WWTP discharges are planned in the future as water supplies become scarcer and more expensive. To evaluate the potential impacts of reduced WWTP discharges, storm water capture projects, and other activities that affect flows in the SAR, an integrated surface/groundwater model (aka ISARM) was developed (*Geoscience, 2020. Upper Santa Ana River Integrated Model – Summary Report. Prepared for San Bernardino Valley Municipal Water District, dated September 2020*). This model contained various scenarios with different project combinations. As shown in Table 1, the average annual WWTP discharge for three scenarios are listed. The estimated SAR base flow arriving at Prado Dam was calculated based on the correlation shown in Figure 2 for data from 2006-2021. This period was selected because it represents the more current declining trend in base flows.

Table 1. WWTP Discharges and Estimated SAR Base Flow for Three Scenarios

	No Projects	Most Likely	All Projects (Scen 2b.1)
Average Annual WWTP Discharge (afy)	104,850	63,100	73,000
Estimated Average Annual SAR Base Flow (afy) (Using 2006-21 correl)	70,900	33,500	42,300

For this evaluation, the All Projects (Scen 2b.1) Scenario is used to create a future daily synthetic SAR base flow projection.

Daily flow arriving at Prado Dam for the All Projects Scenario from the ISARM was adjusted to mimic the typical cycle of increasing base flows in the winter months and declining base flows in the non-winter months until the annual total reached approximately 42,000 af. The two most recent years of SAR Watermaster data were used to guide the annual base flow pattern. Figure 3 shows the total daily inflow and "synthetic" base flow for the All Projects Scenario (Scen 2b.1) and SAR Watermaster flows for Water Years 19-20 and 20-21. Note that the spikes in total inflow for the All Projects Scenario typically occurs during the winter months and includes storm flow.

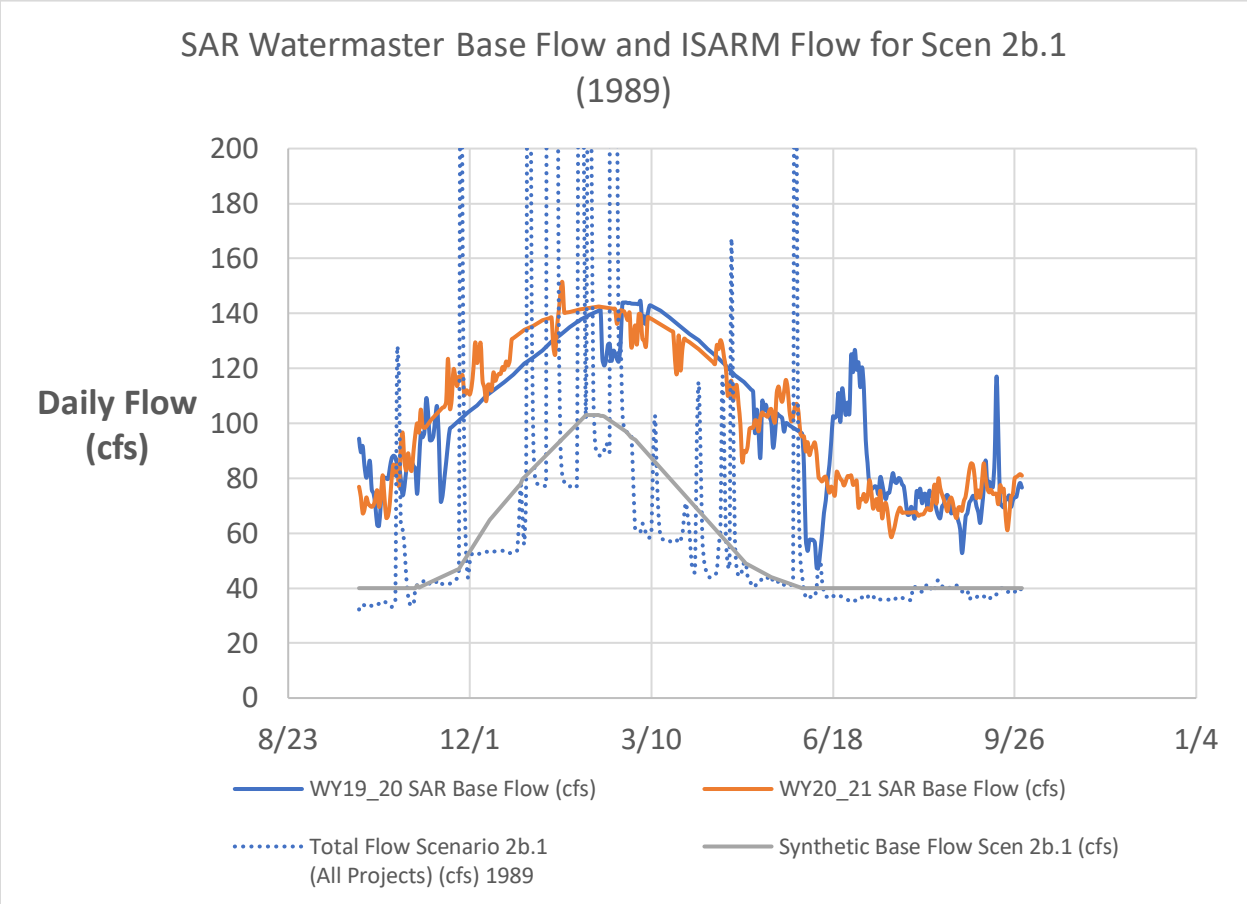


Figure 3. Total Inflow to Prado for All Projects Scenario (Scen 2b.1) and Synthetic Base Flow. Also shown is the SAR Watermaster Base Flow for WY19-20 and WY20-21.

This synthetic annual base flow was then combined with observed SAR Watermaster storm flow (also shown on Figure 1) to generate a new total inflow condition. This is shown on Figure 4.

The daily flow data shown on Figure 4 was provided to staff at the California-Nevada River Forecast Center (CNRFC) for Task 2b.

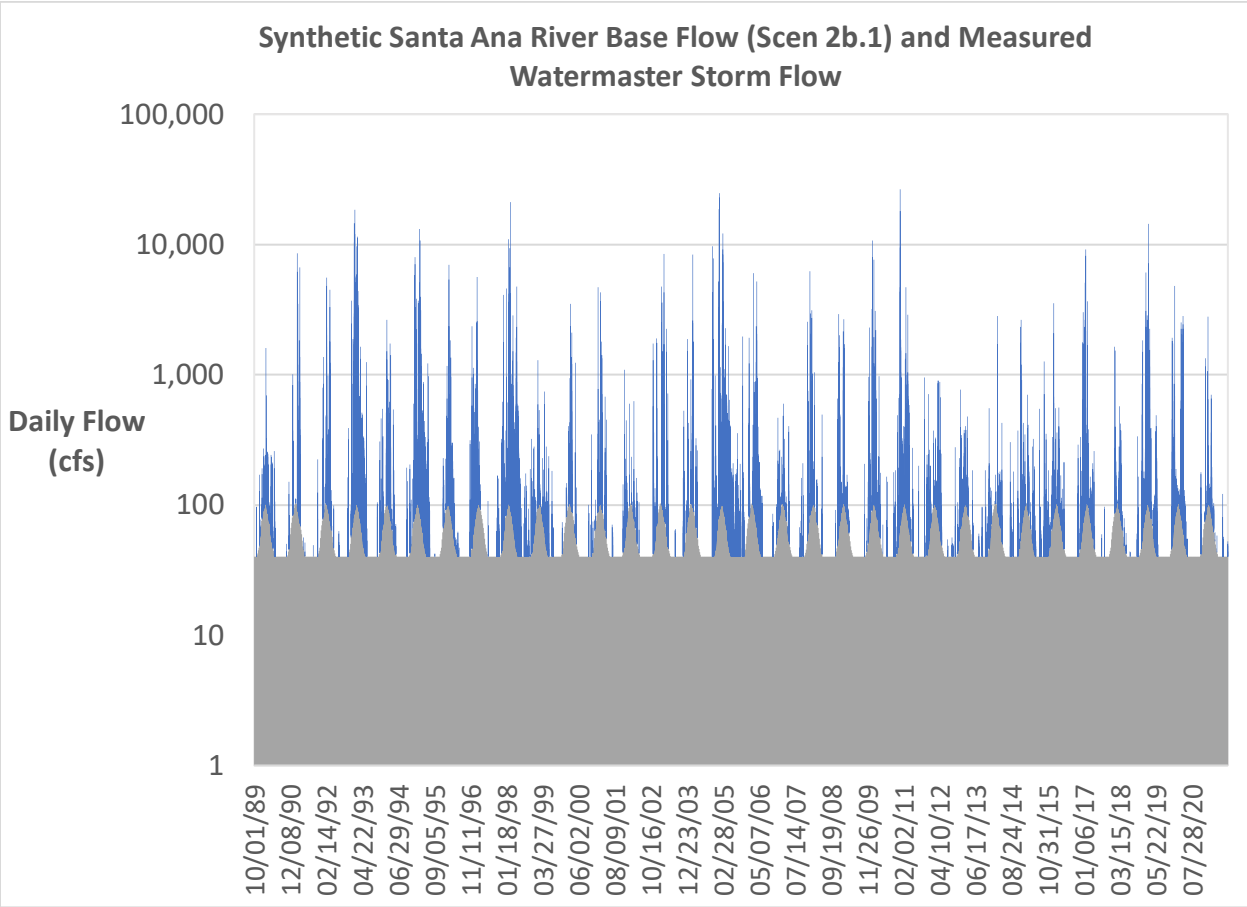


Figure 4. Synthetic SAR Base Flow for Scenario 2b.1 (Gray) and Measured Watermaster Storm Flow (Blue).

HEC Simpler Forecast Operation Model (SFO)

This document is under preparation by HEC staff and will be placed into this location when complete.

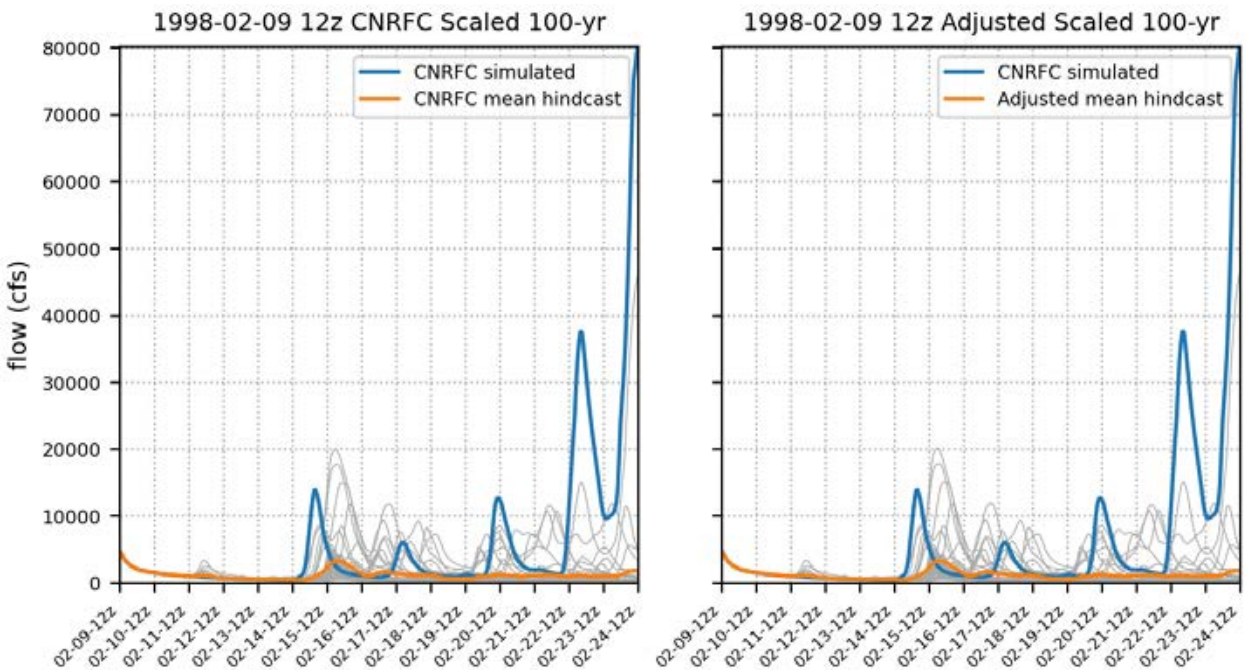
Adjusted Scaled Hindcasts

- February 1998
  - 2/9/1998 through 3/3/1998
- 100-yr – slides 2-25
- 200-yr – slides 26-49
- 500-yr – slides 50-73

Adjusted Scaled Hindcast 1998 100-yr

2023-03-25

100-yr 2/9/1998



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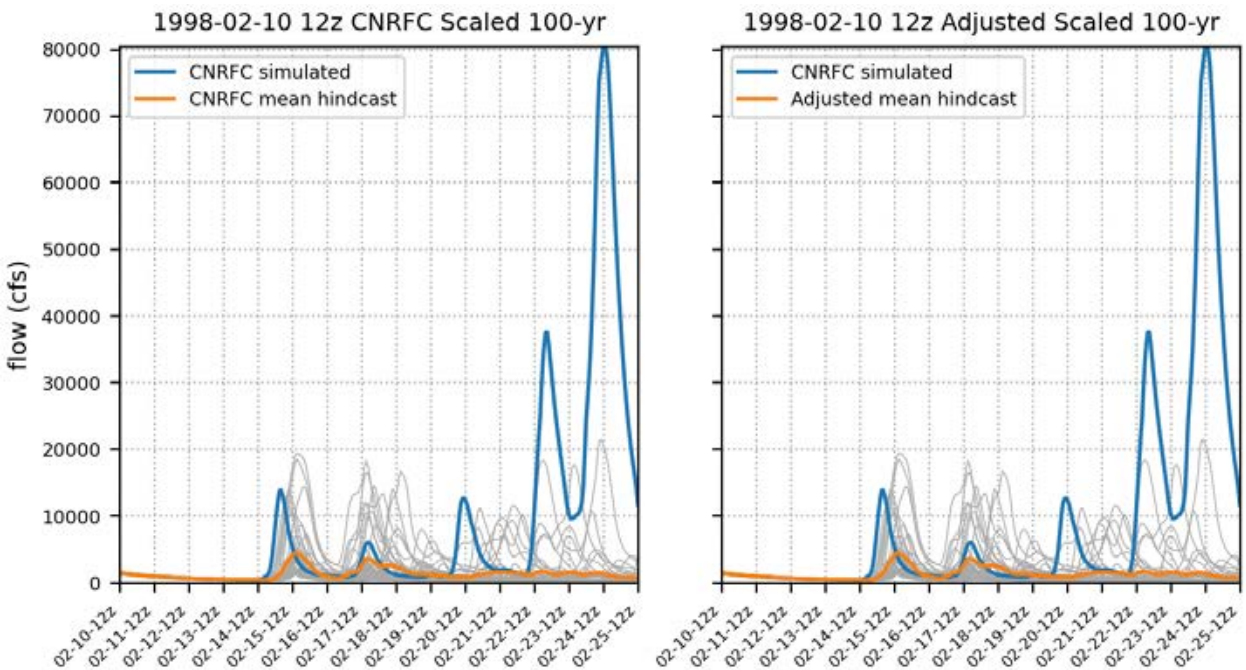

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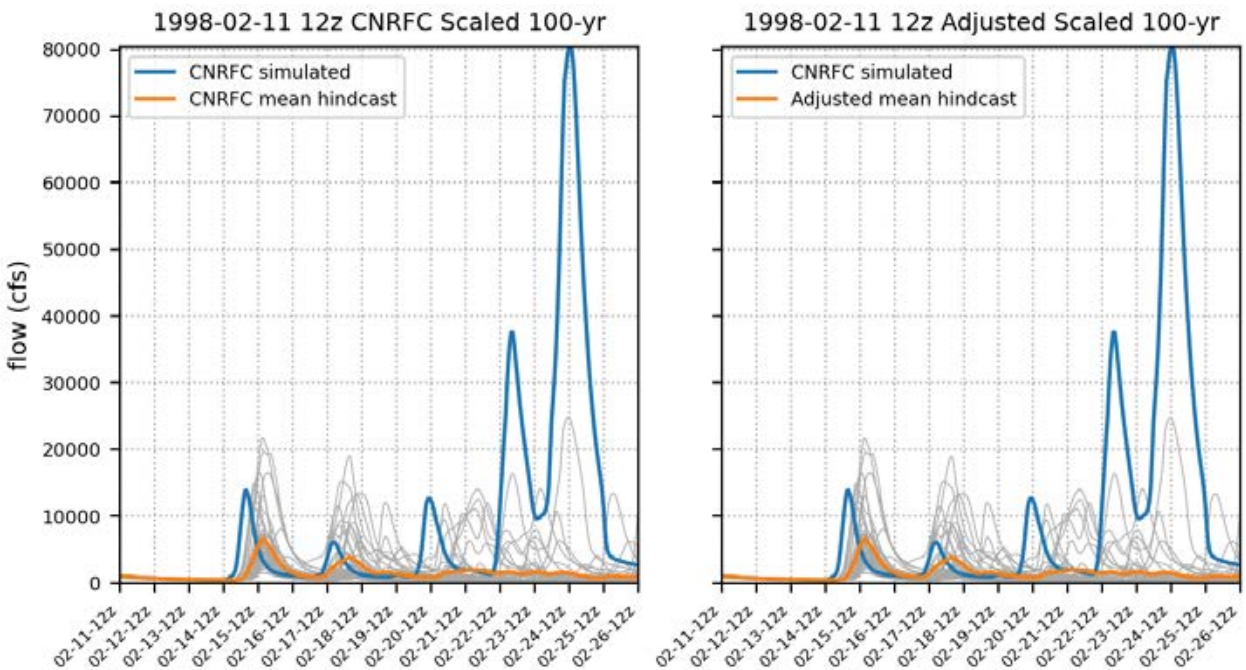

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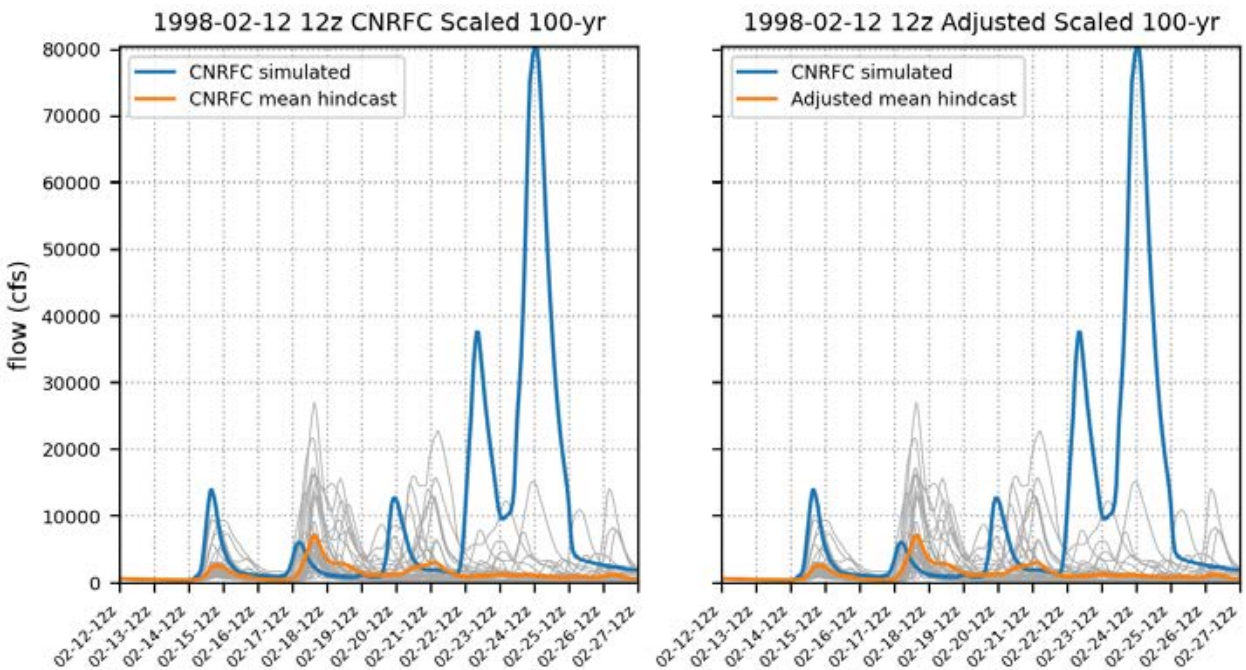

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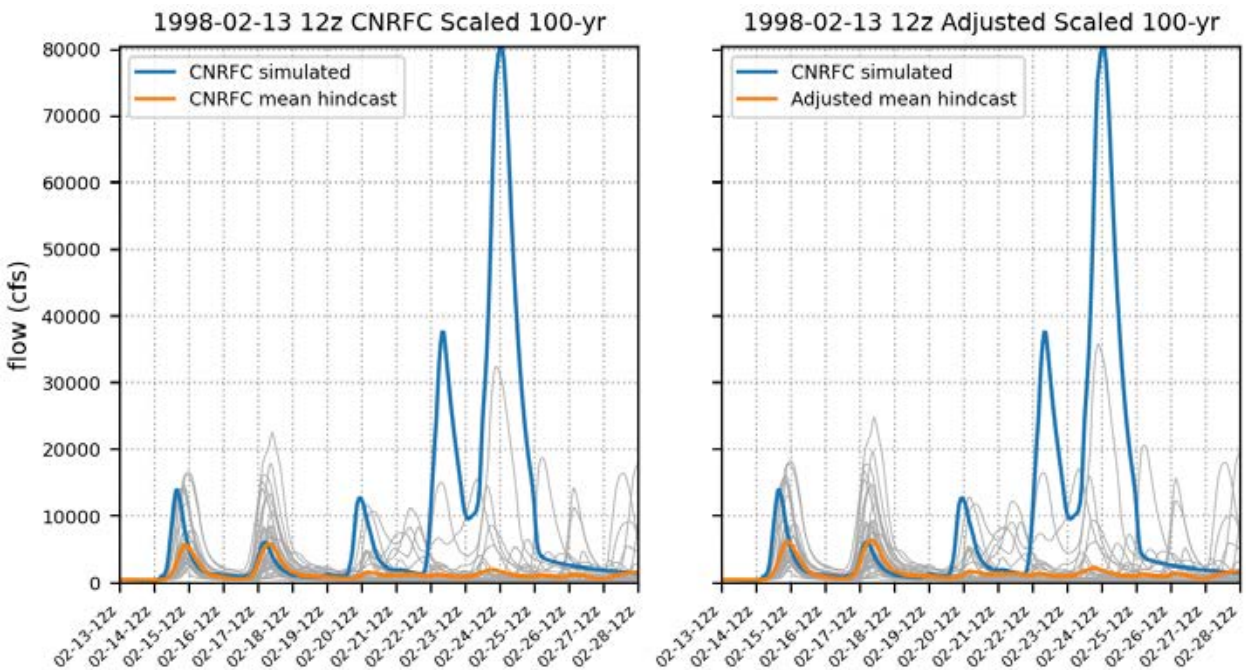

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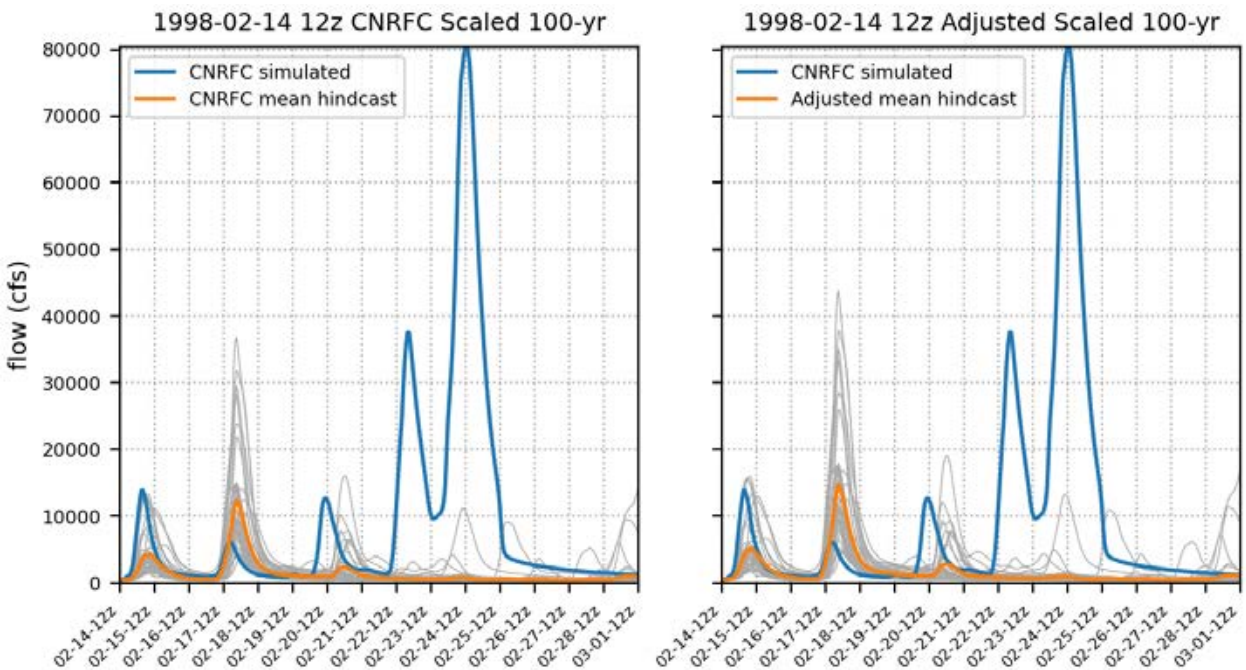

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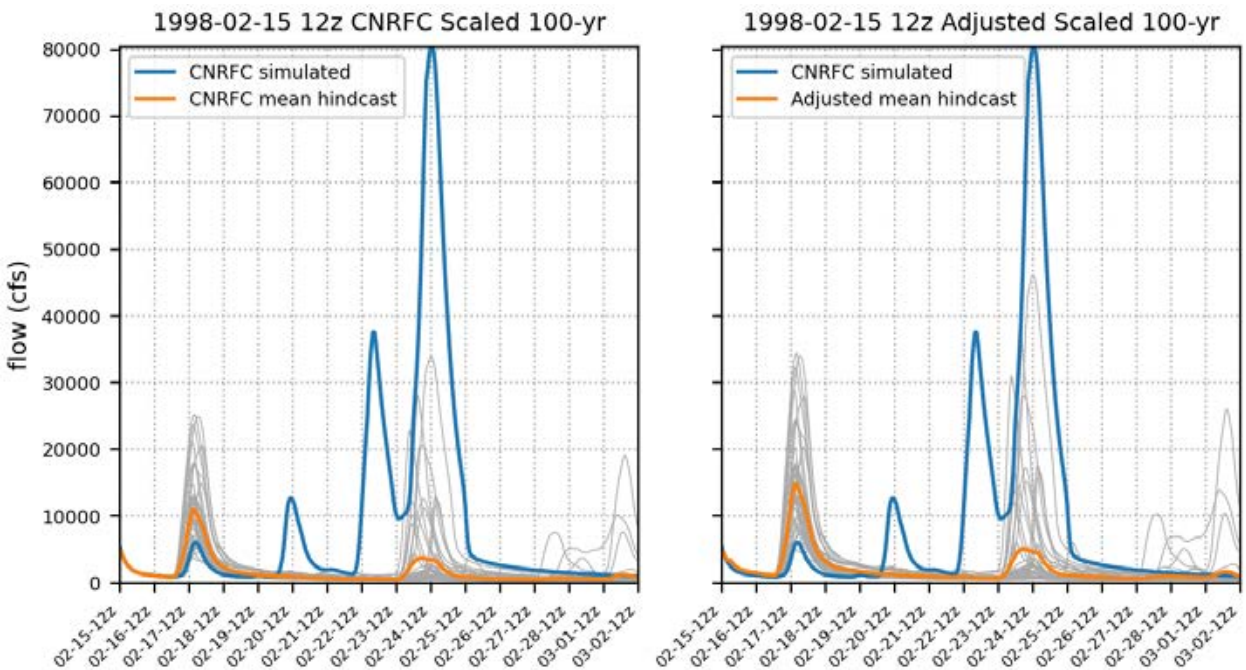

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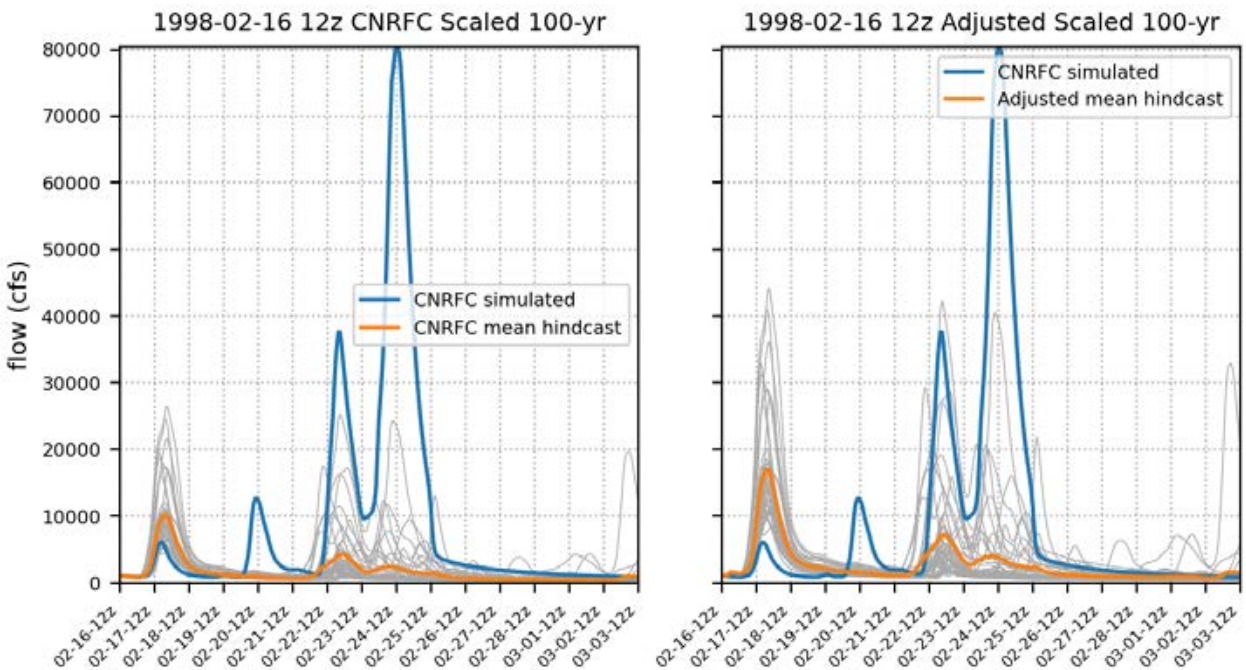

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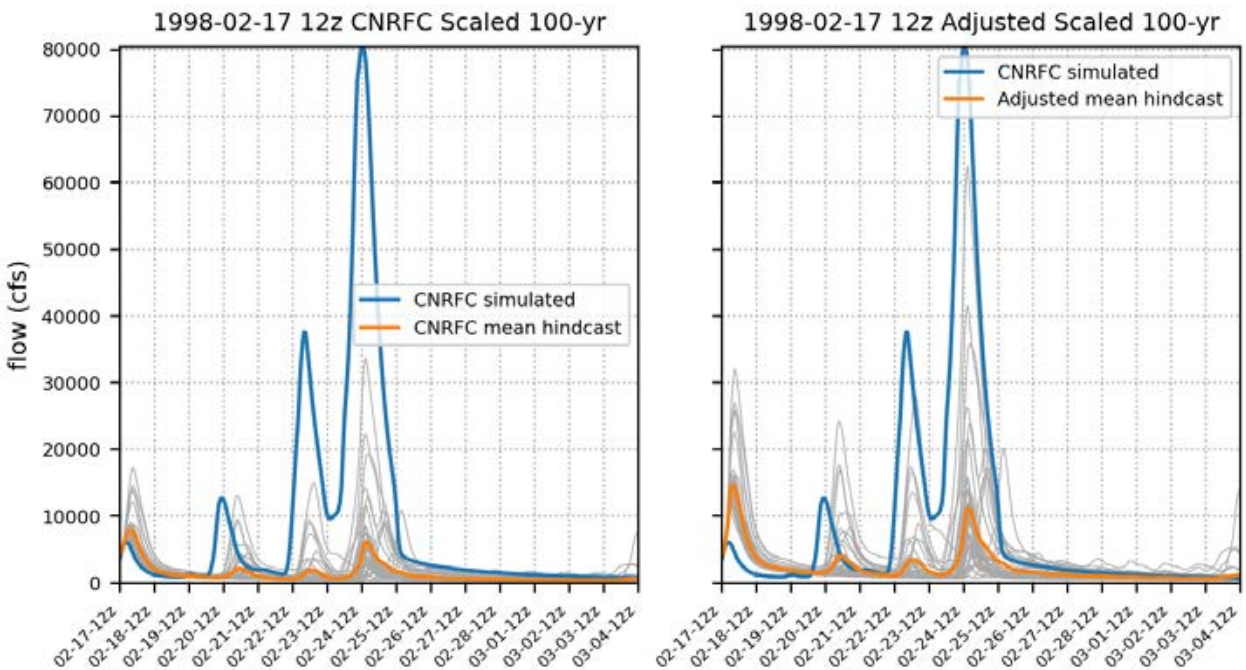

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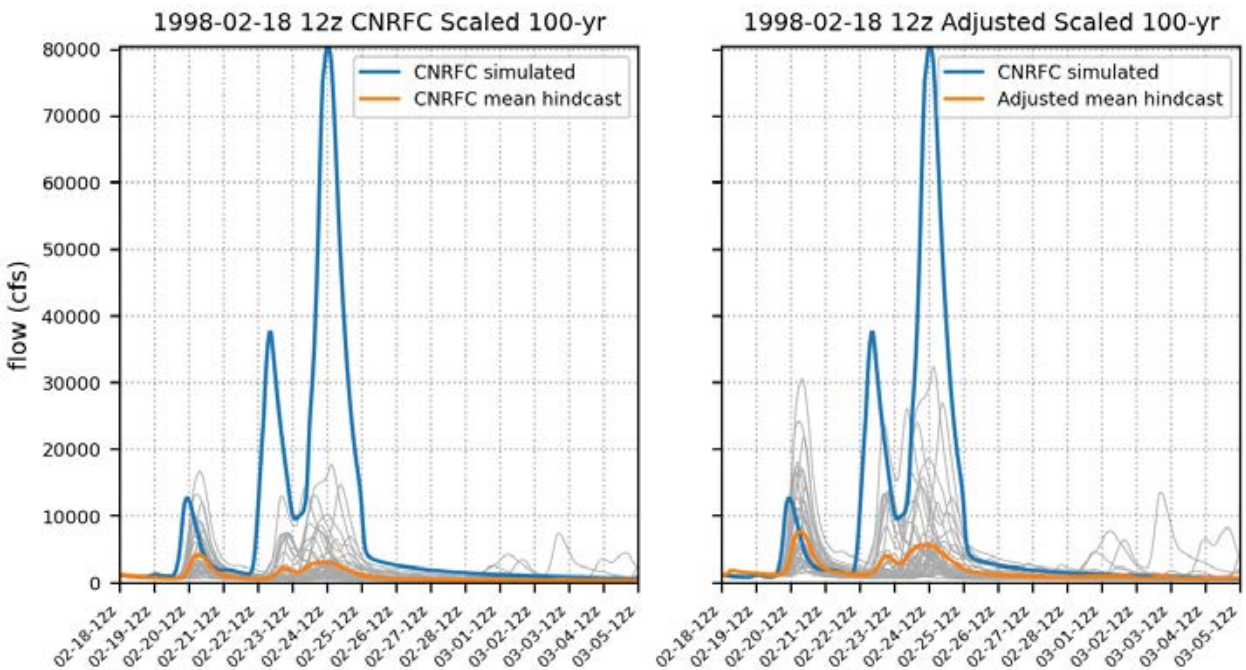

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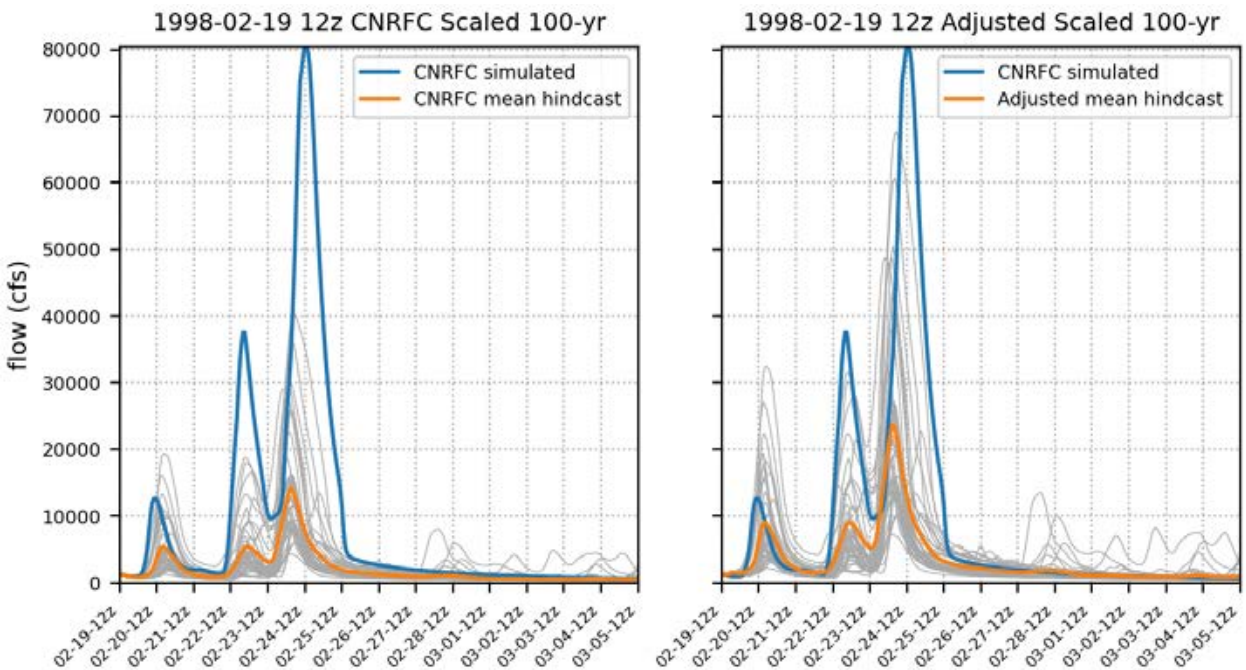

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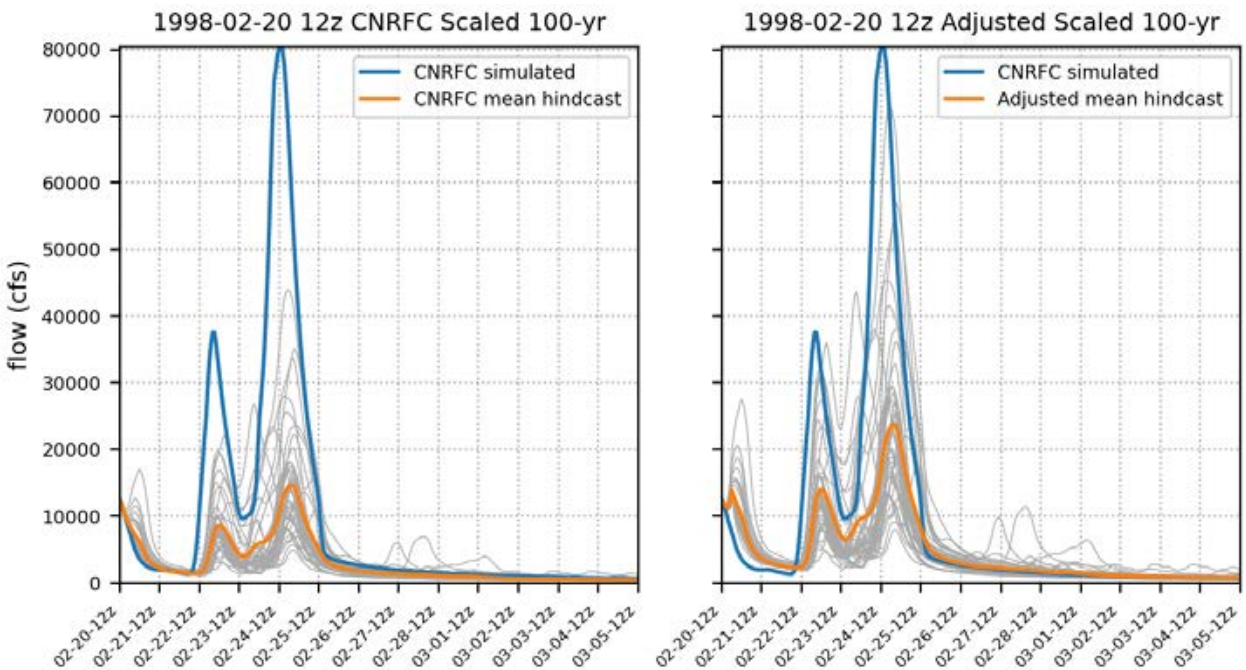

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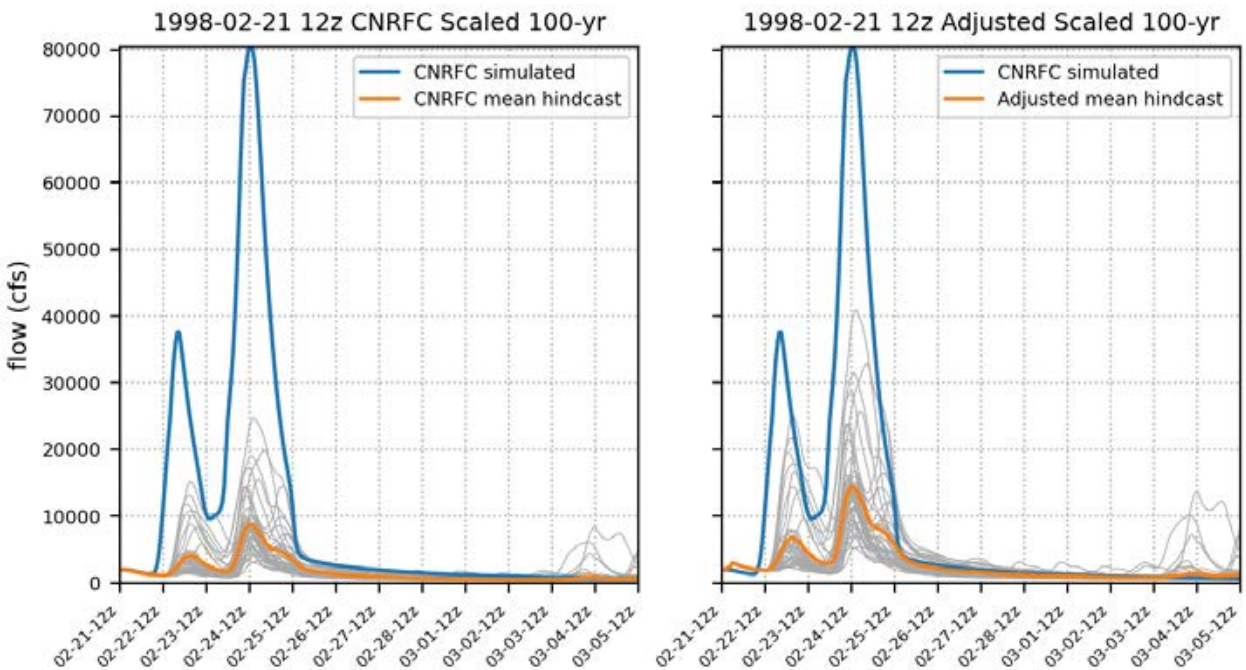

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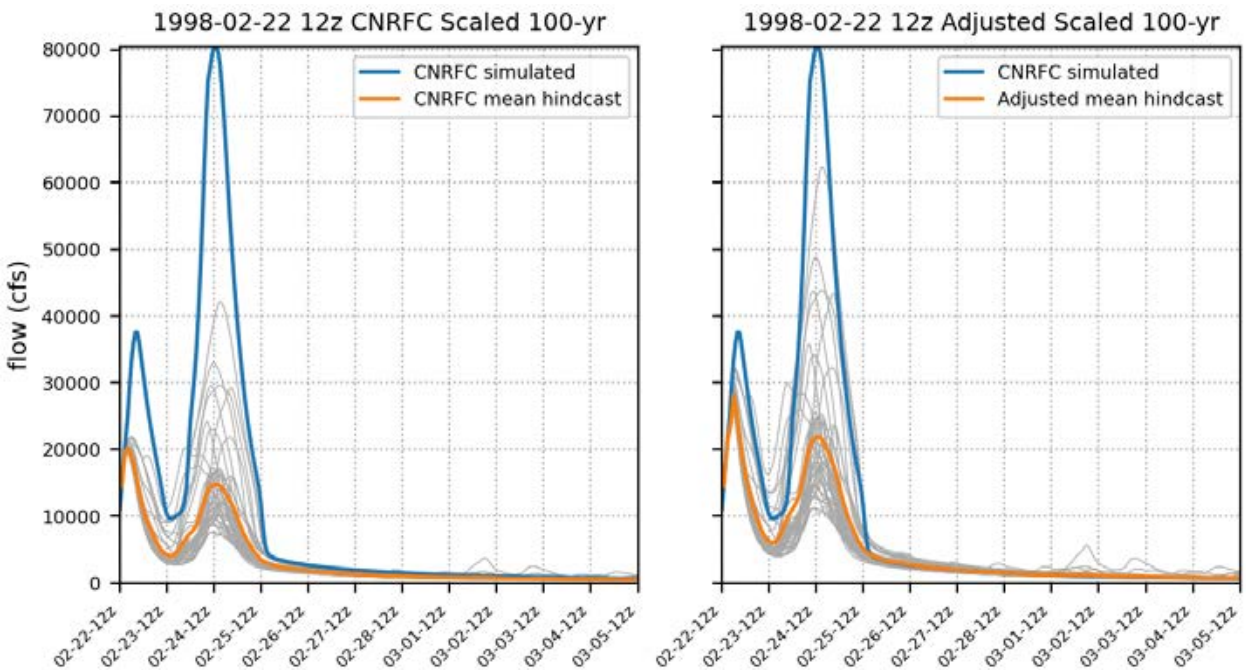

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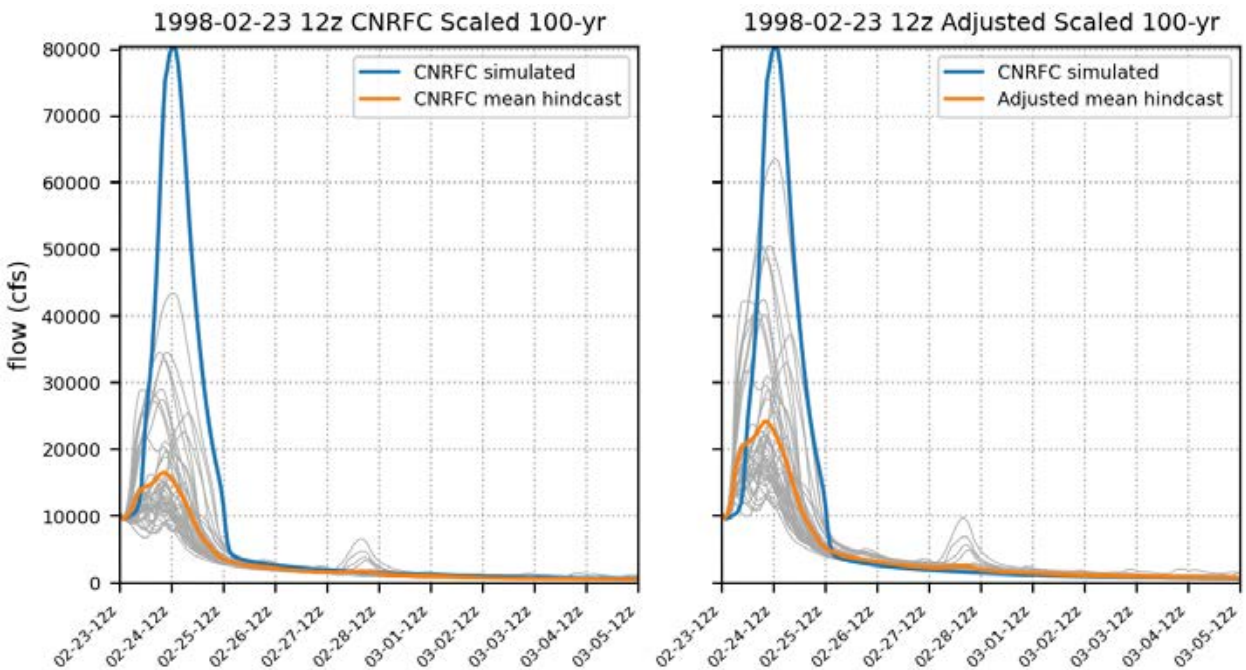

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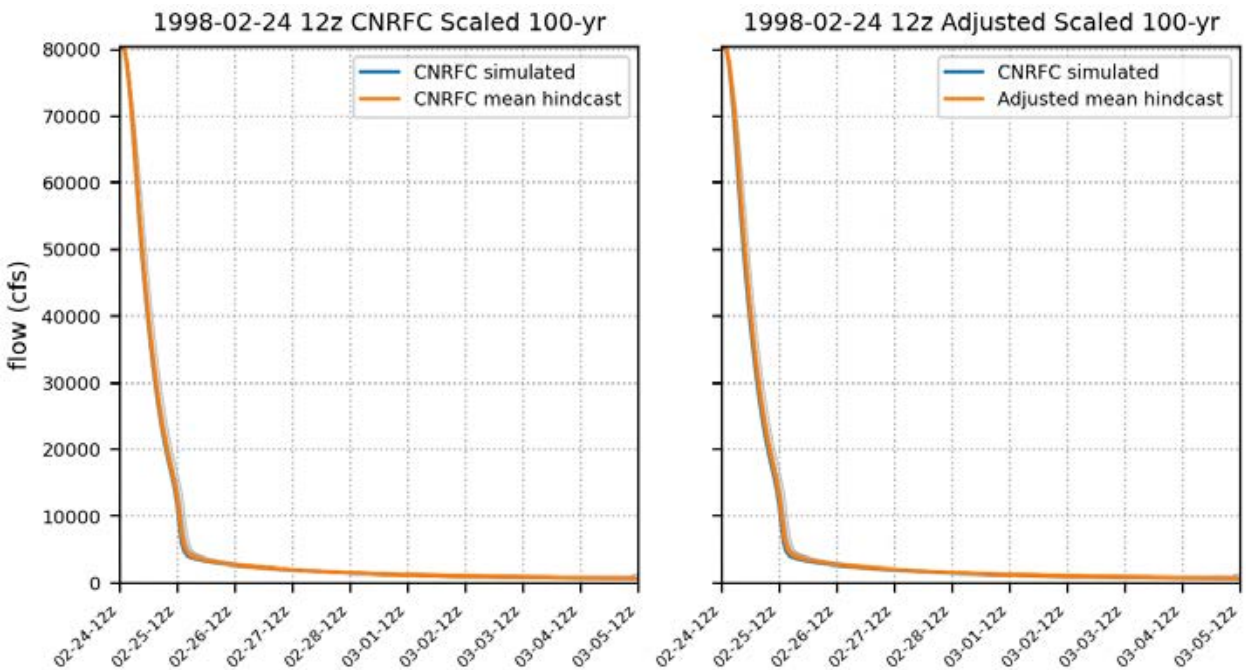

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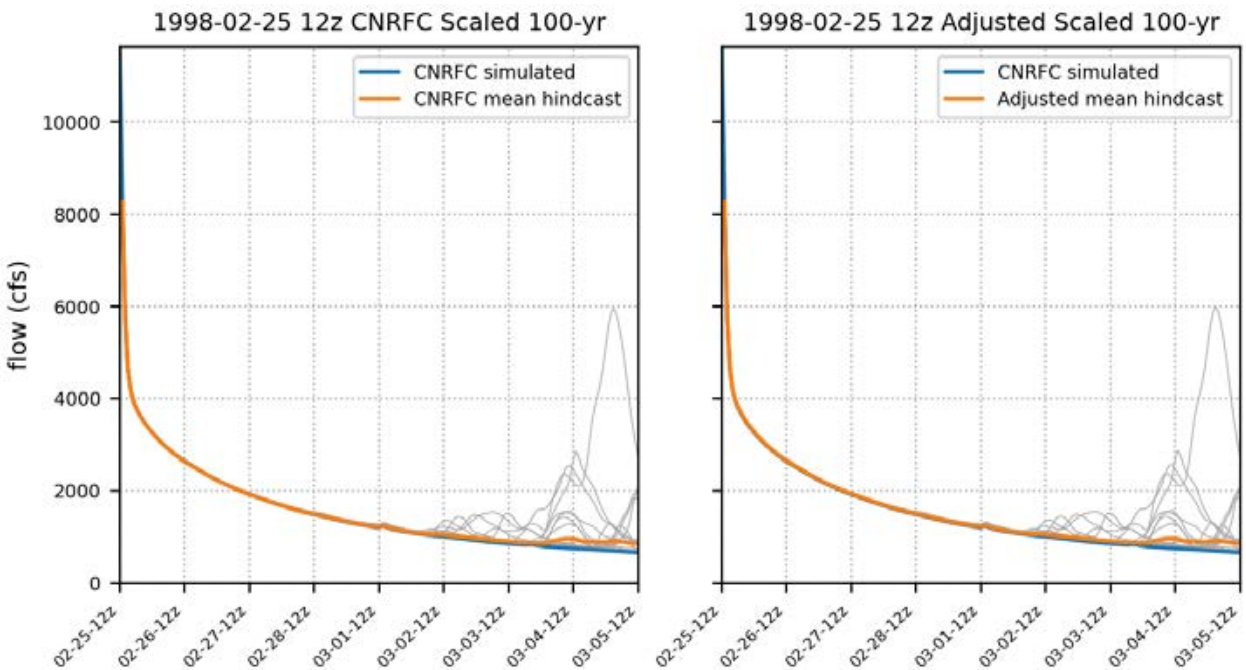

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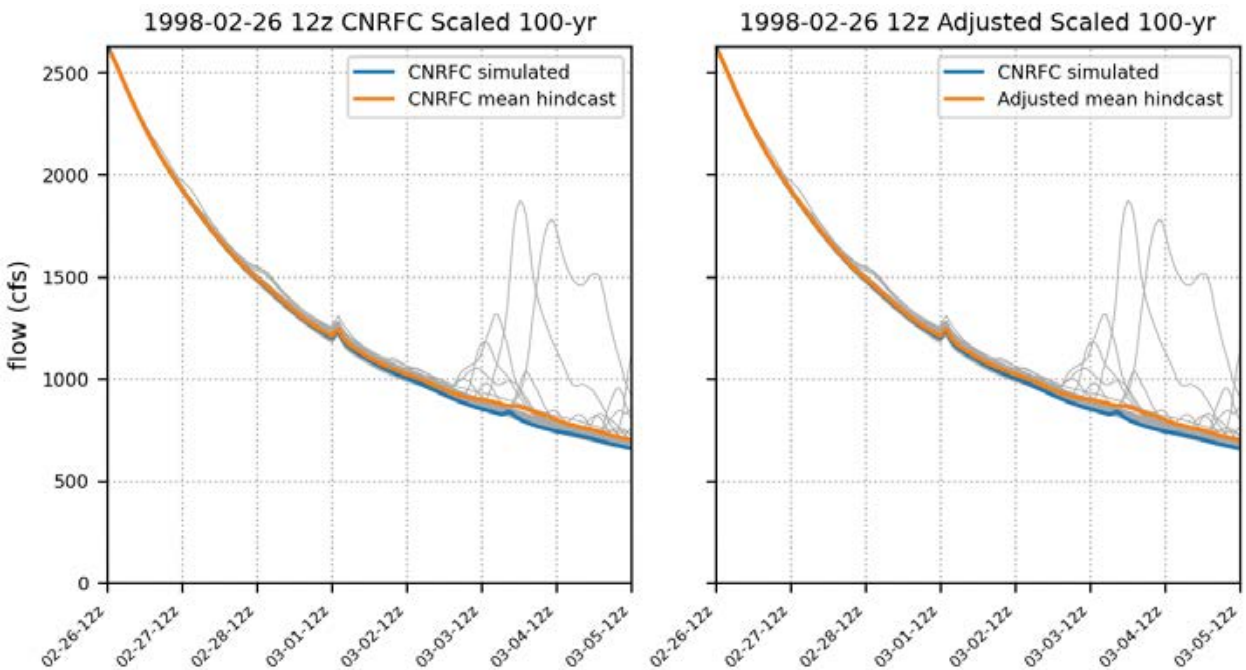

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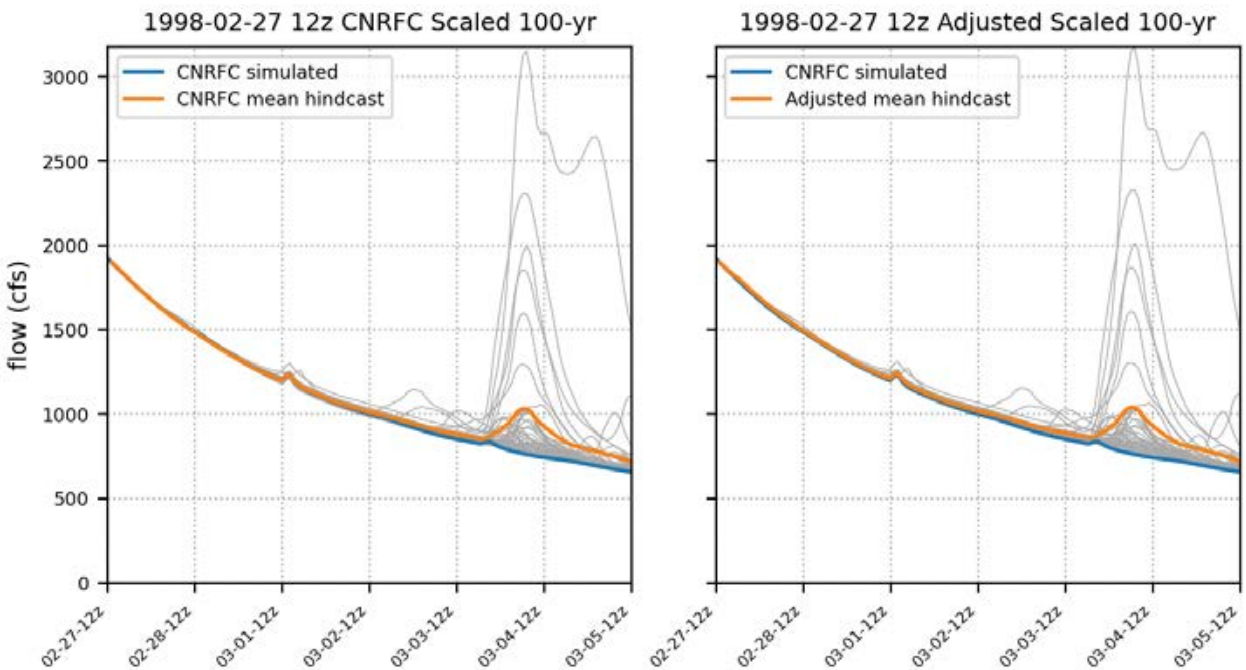

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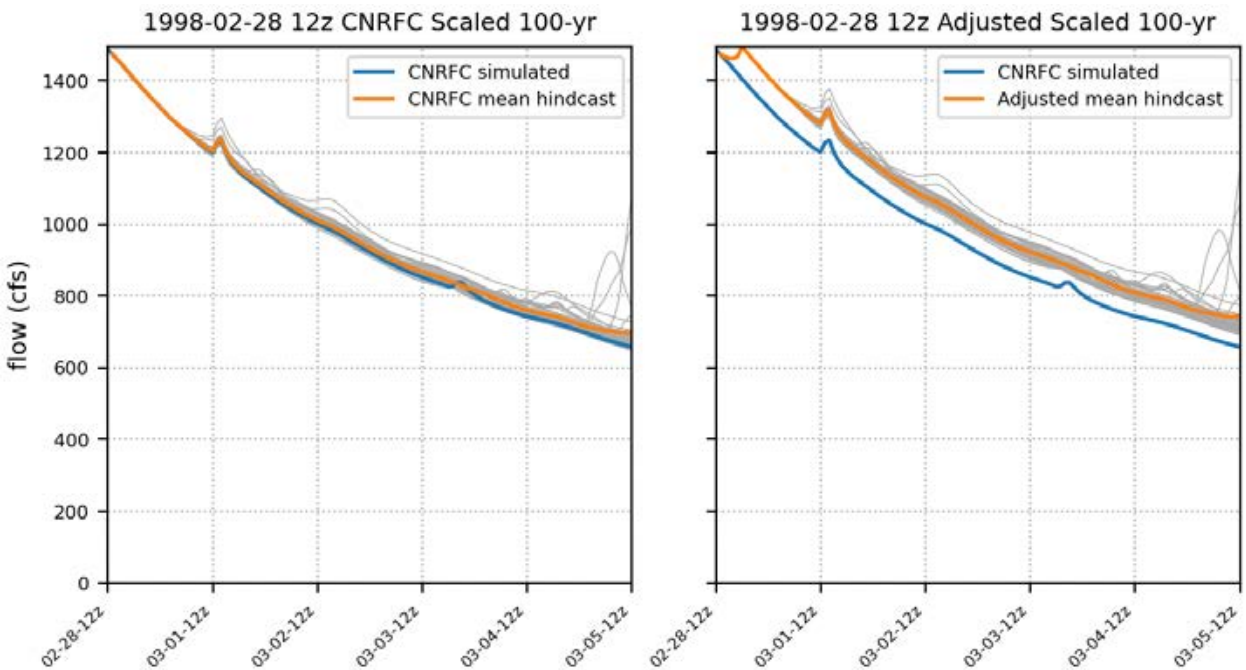

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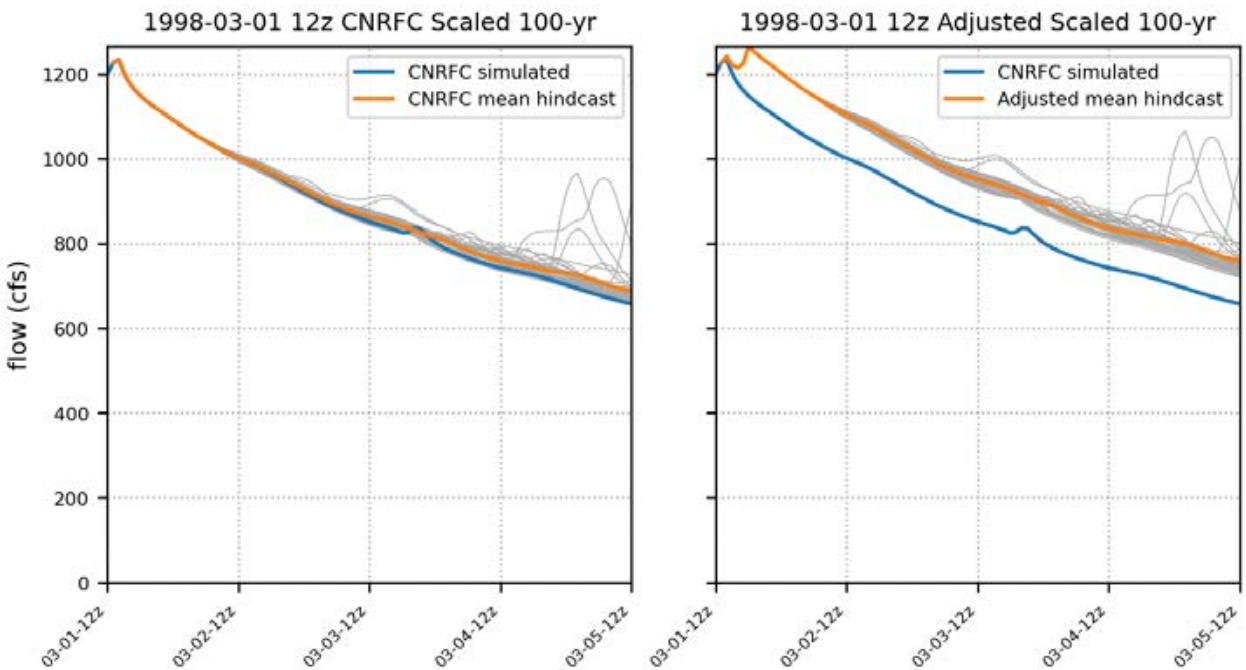

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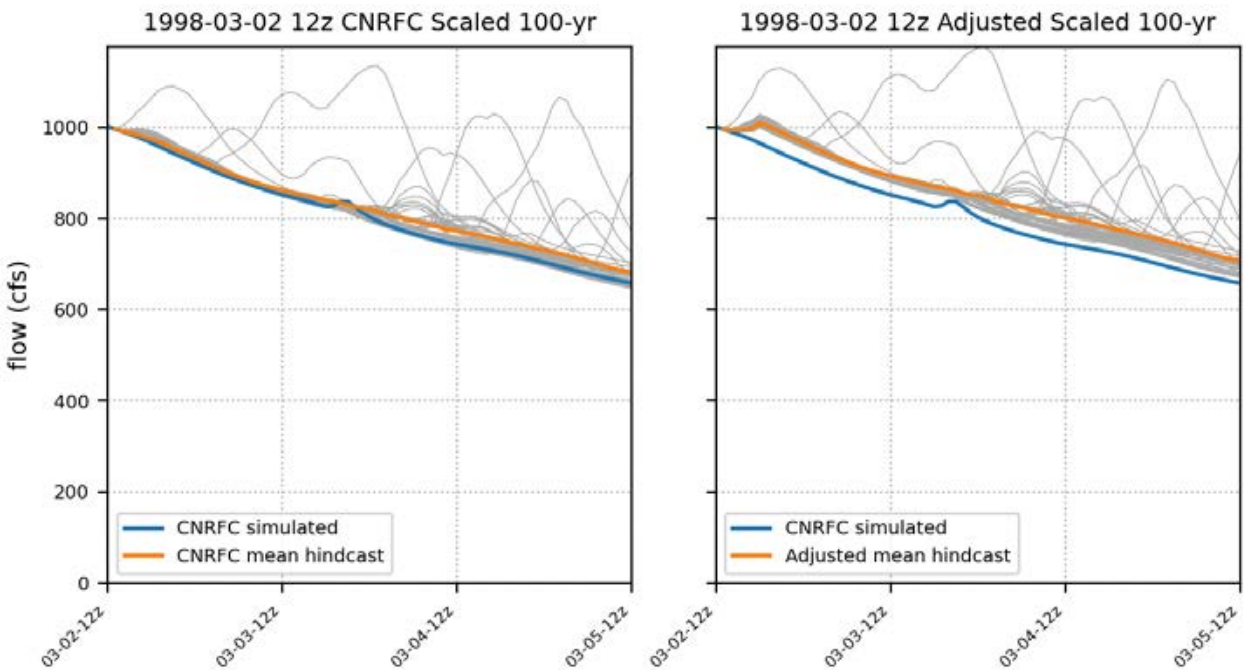

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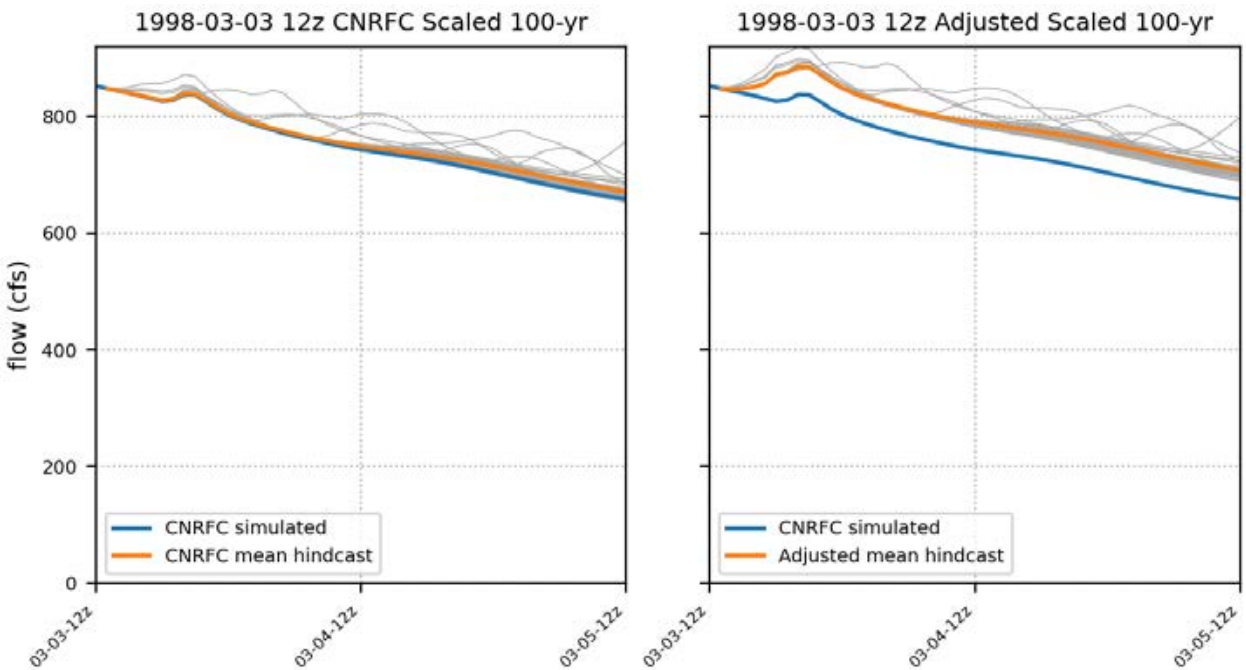
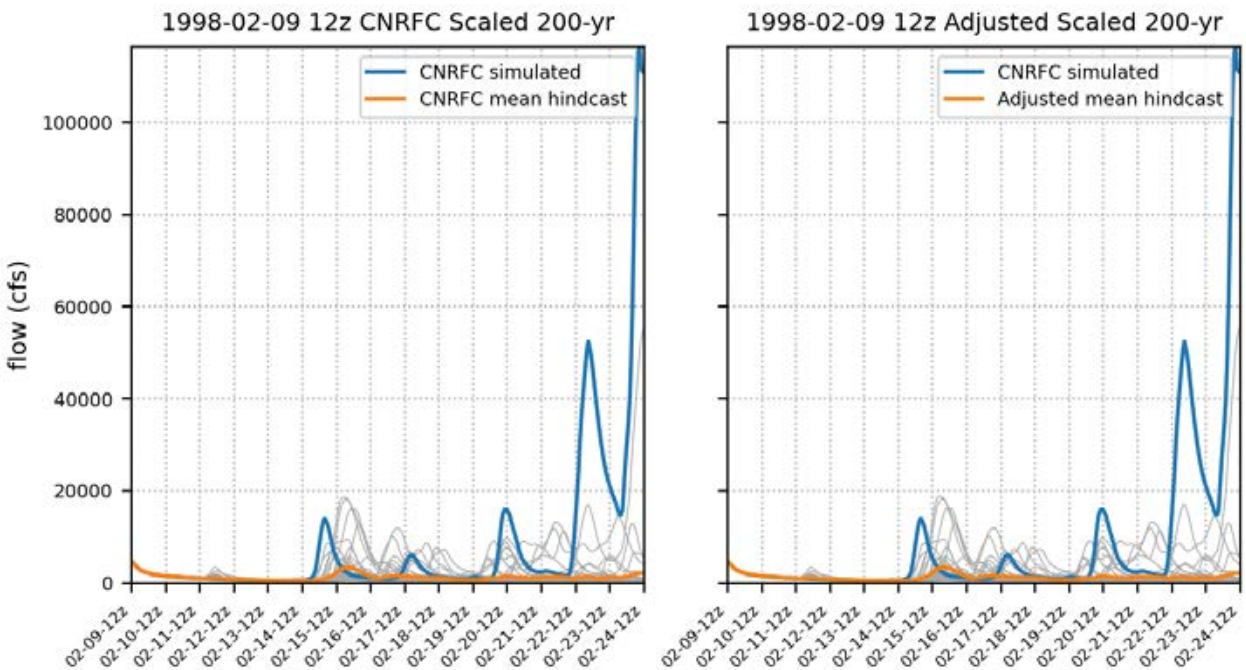


Adjusted Scaled Hindcast 1998 200-yr

2023-03-25

200-yr 2/9/1998



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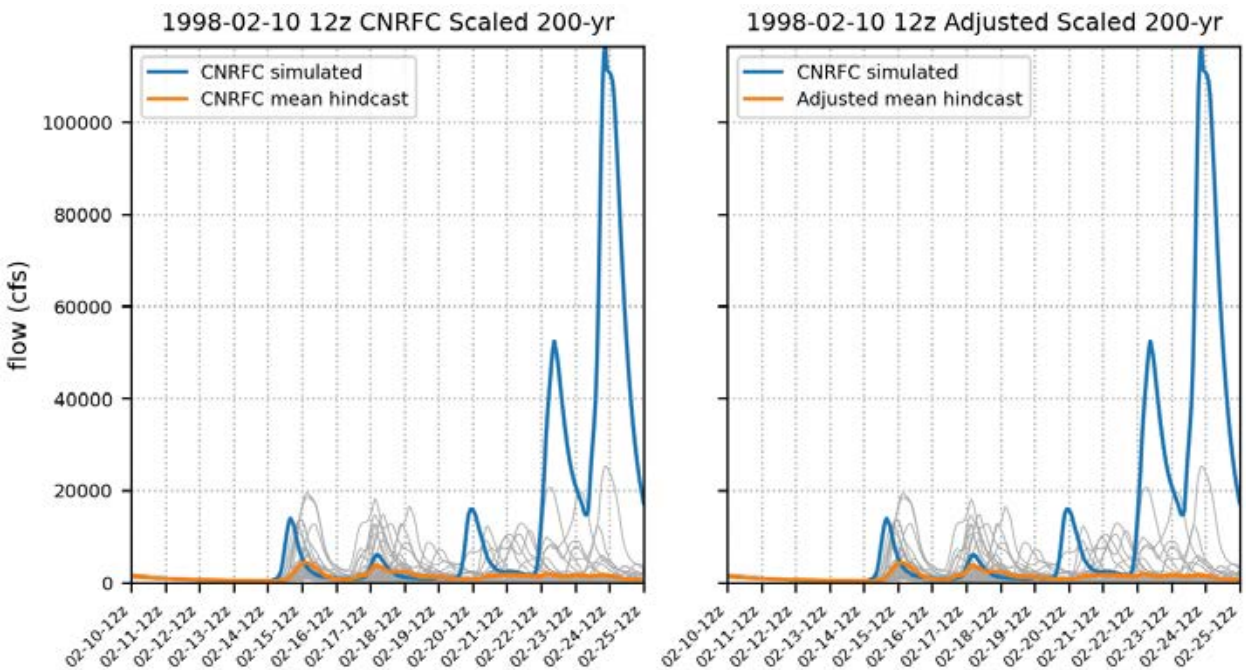

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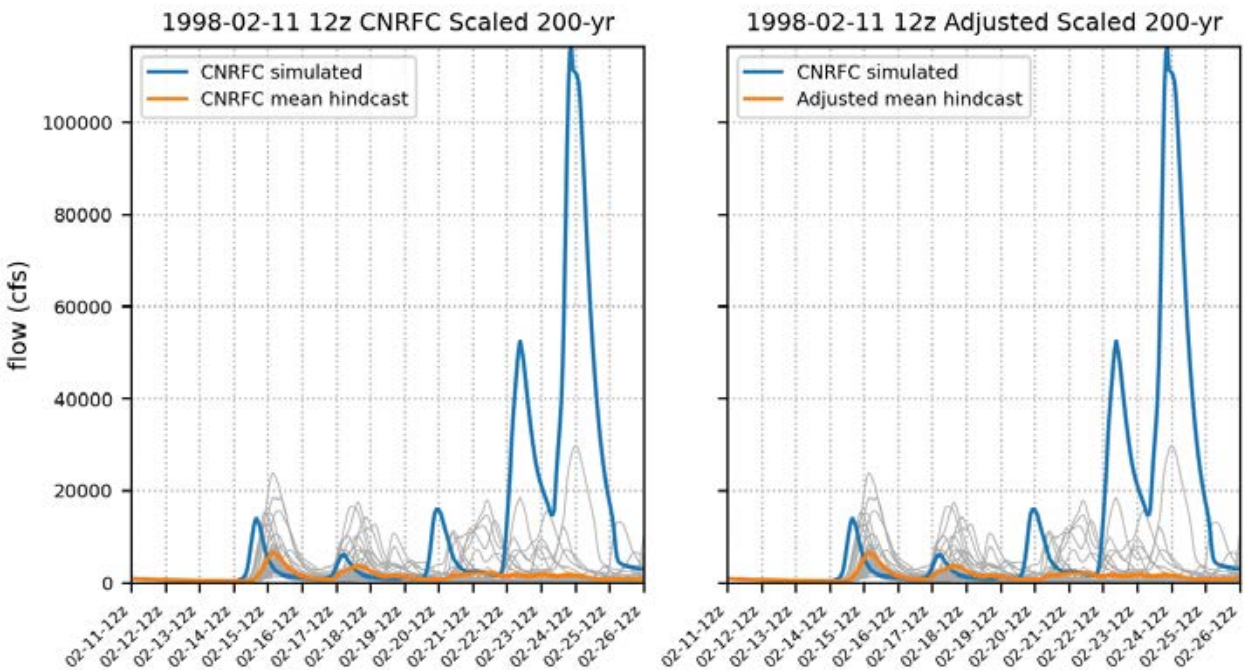

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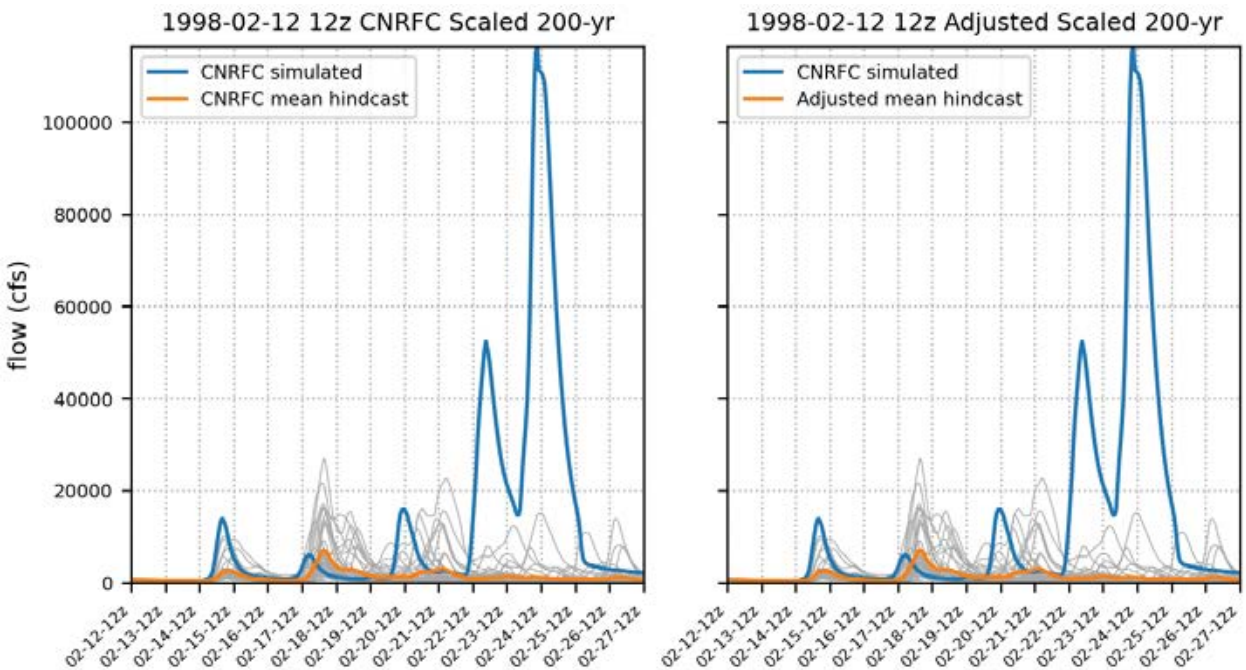

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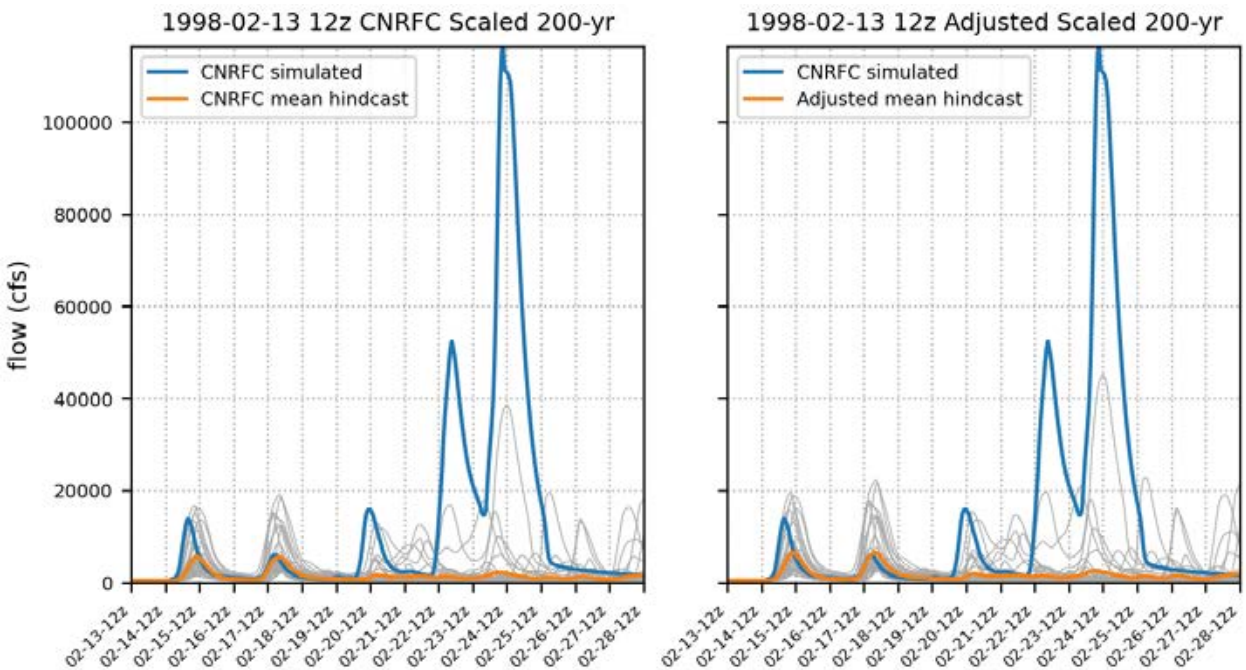

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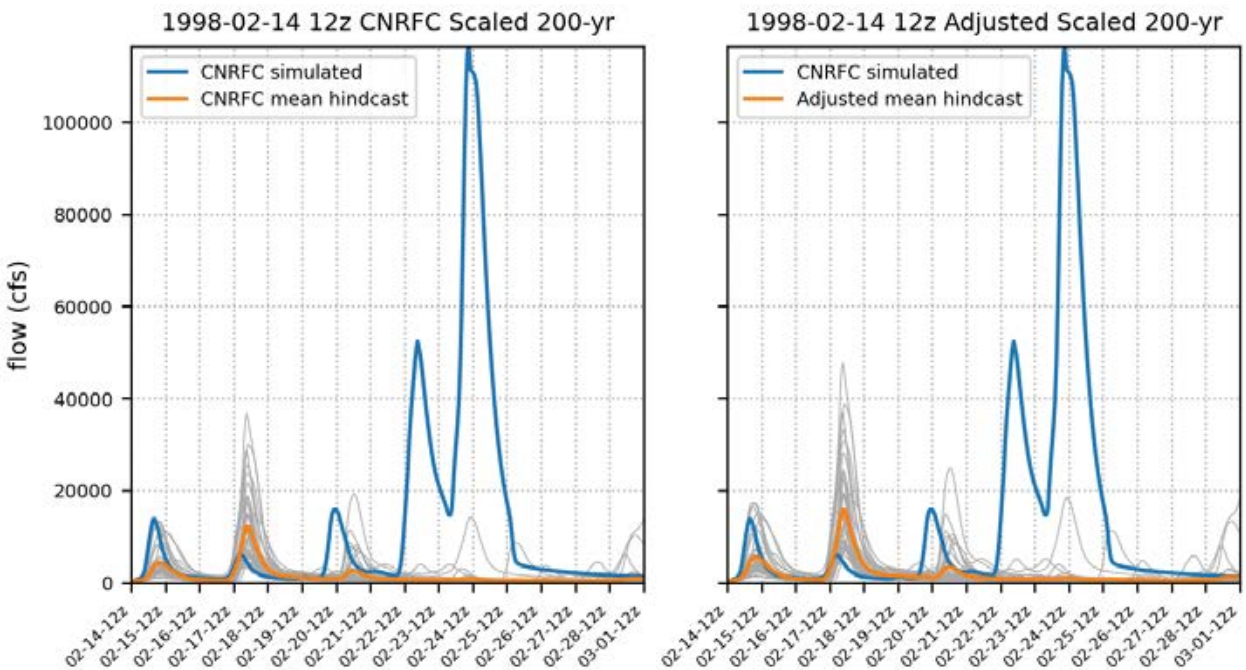

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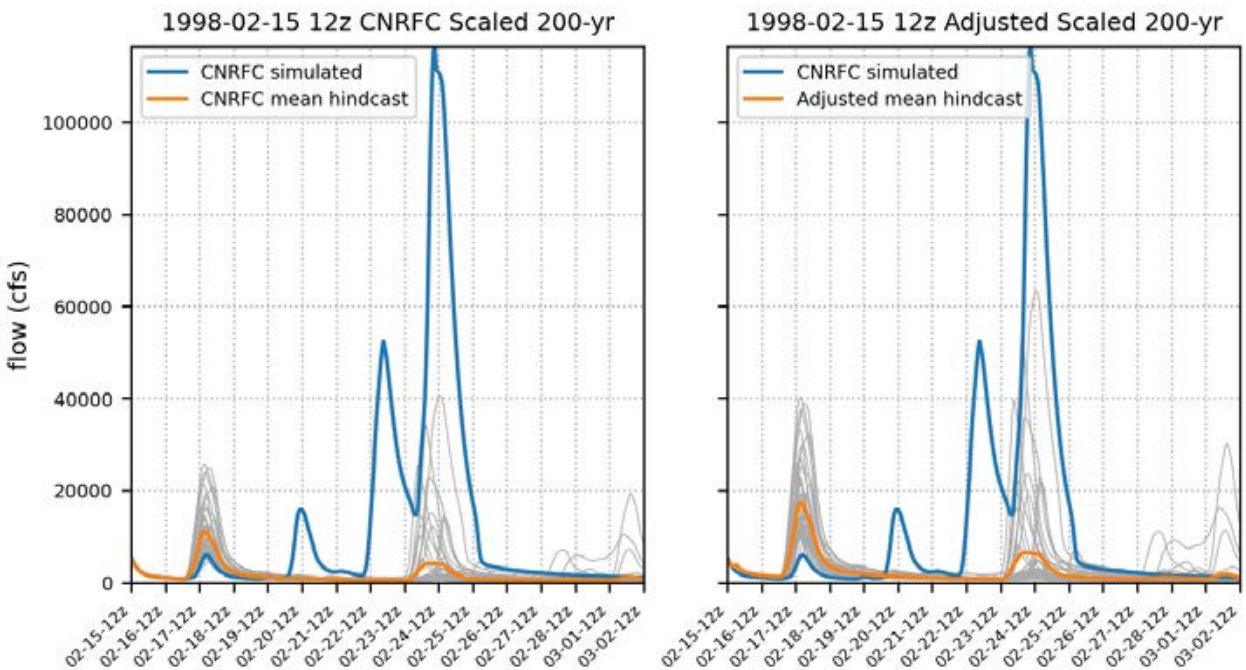

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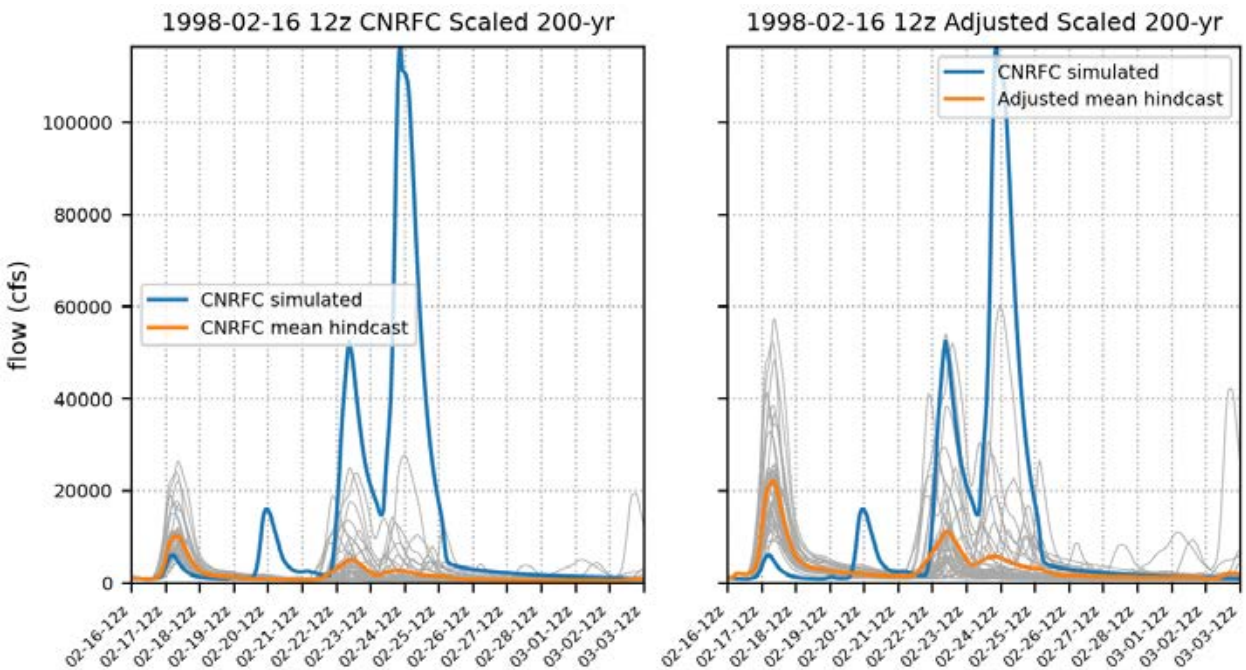

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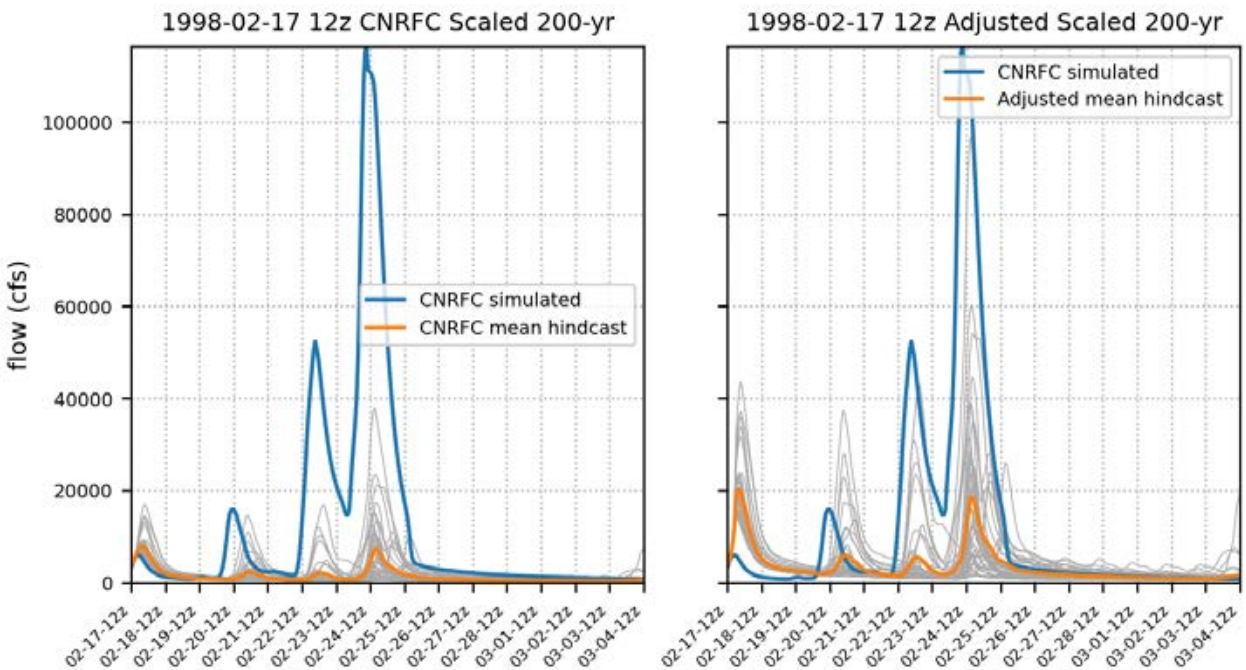

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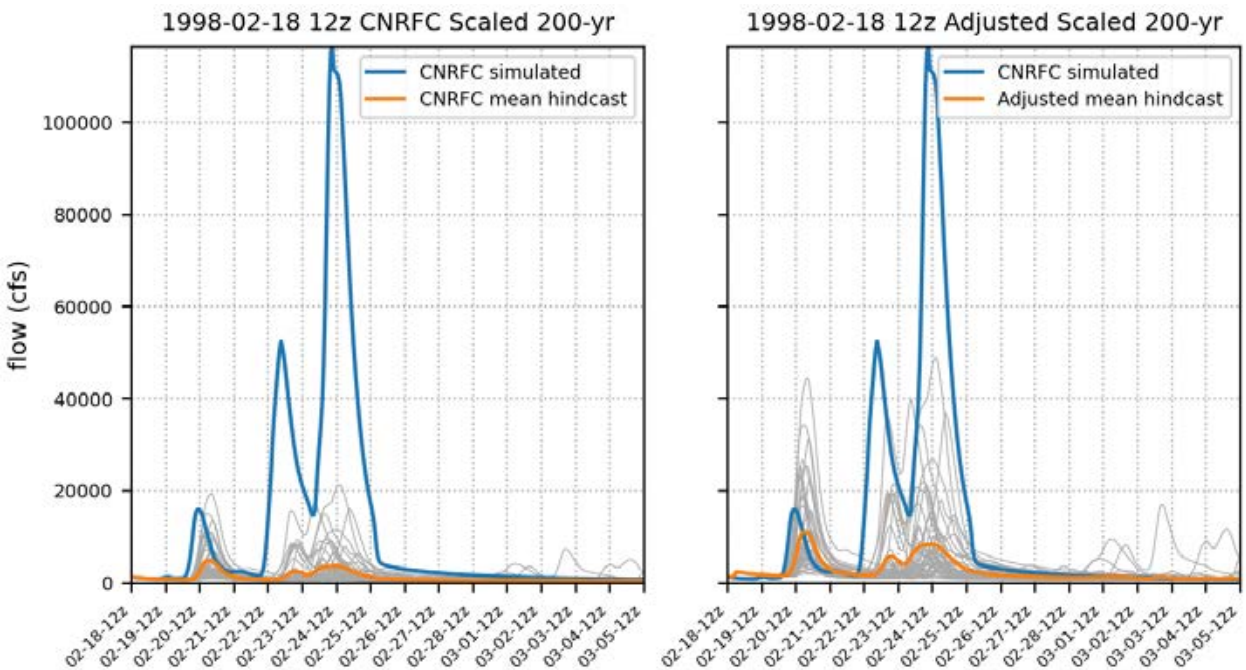

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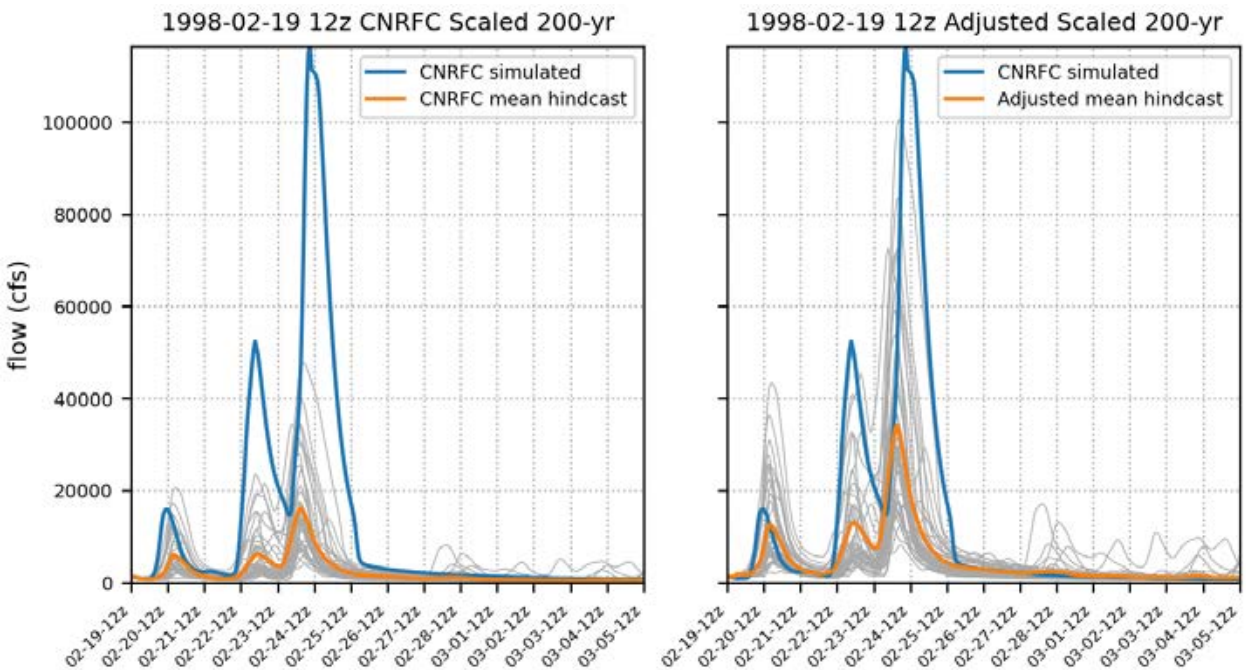

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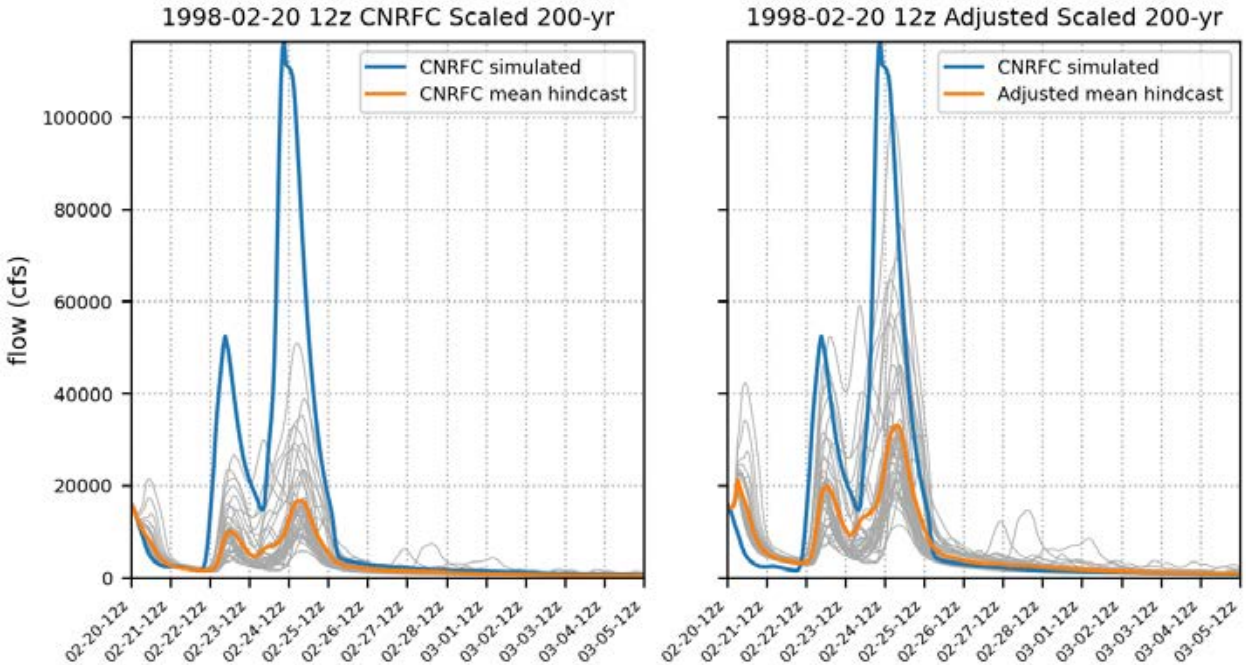

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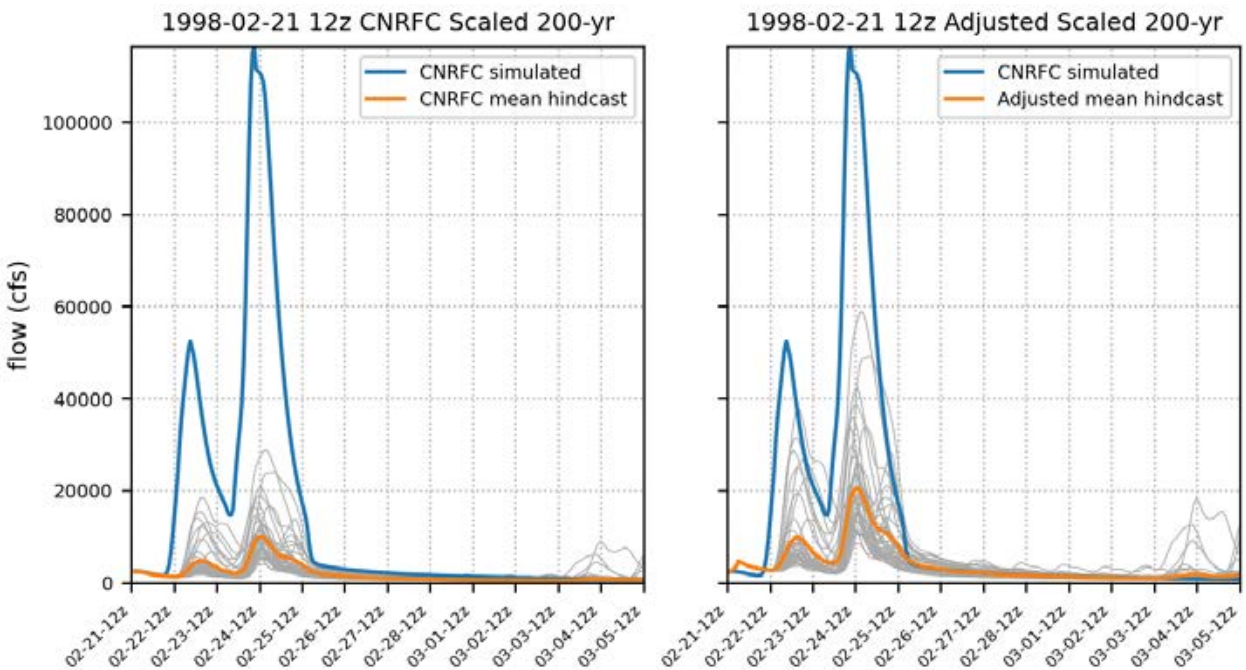
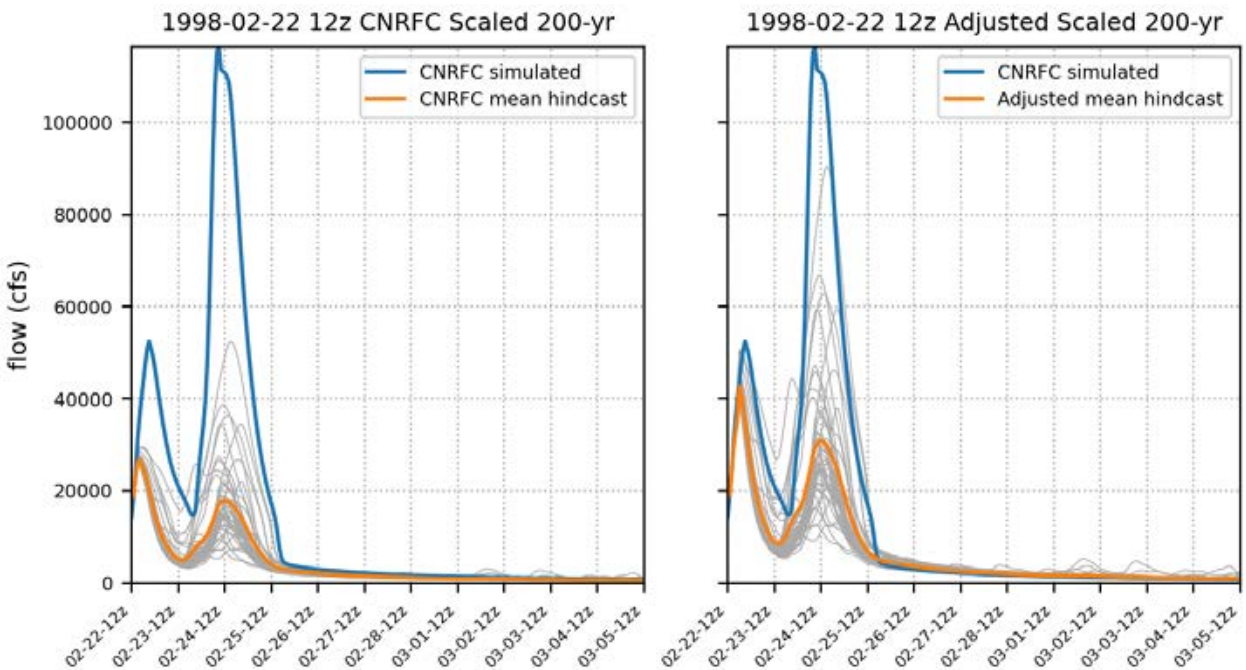
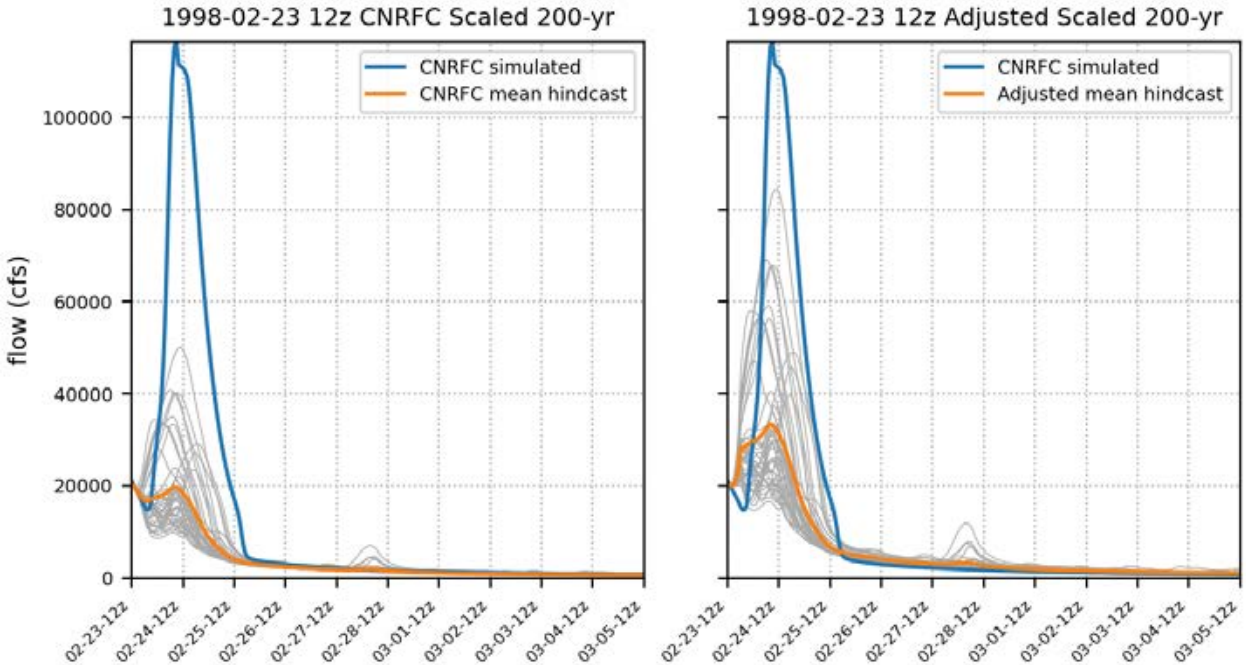


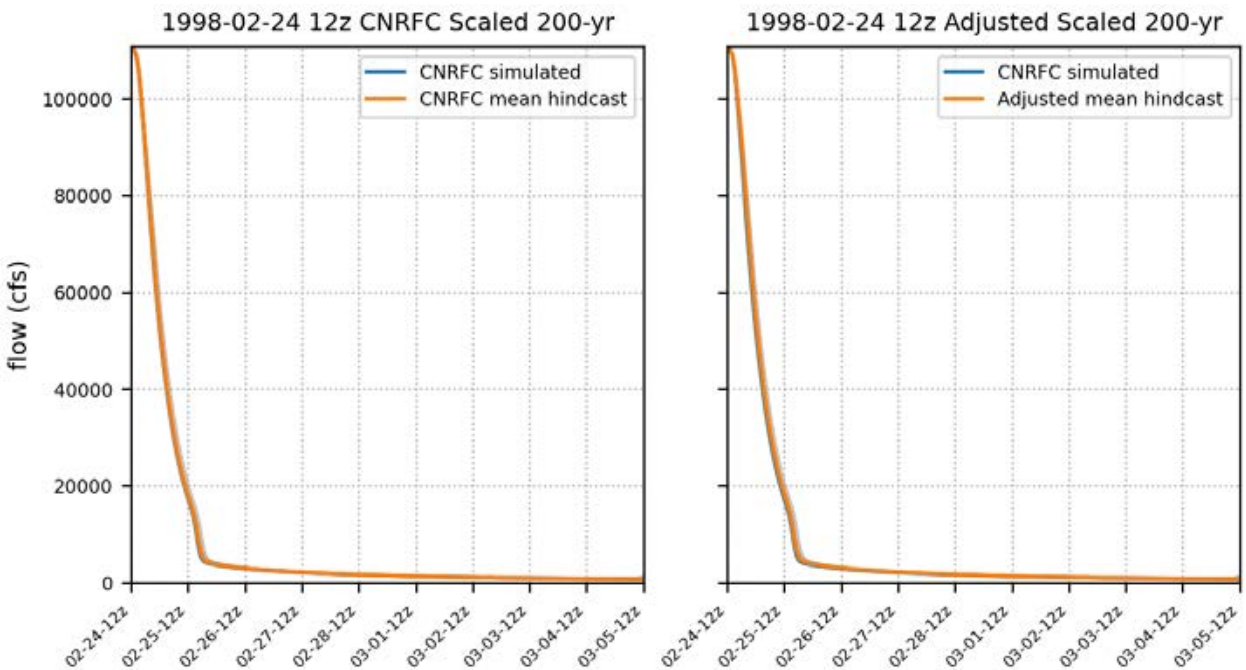
200-yr 2/22/1998



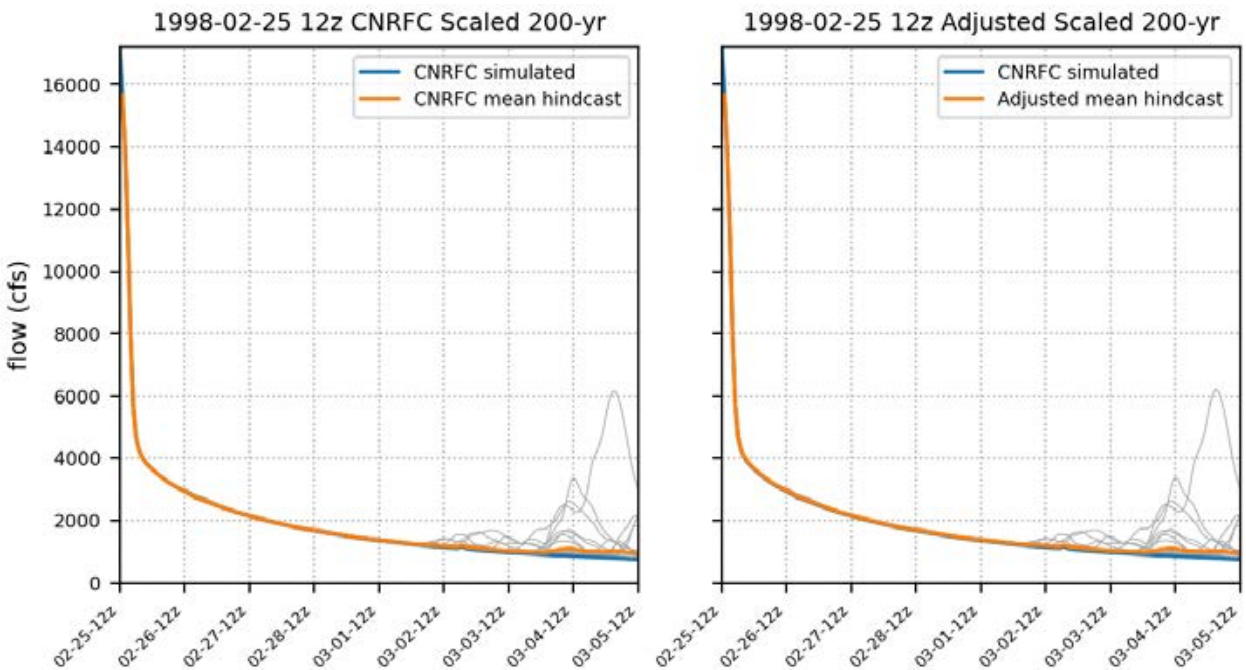
200-yr 2/23/1998



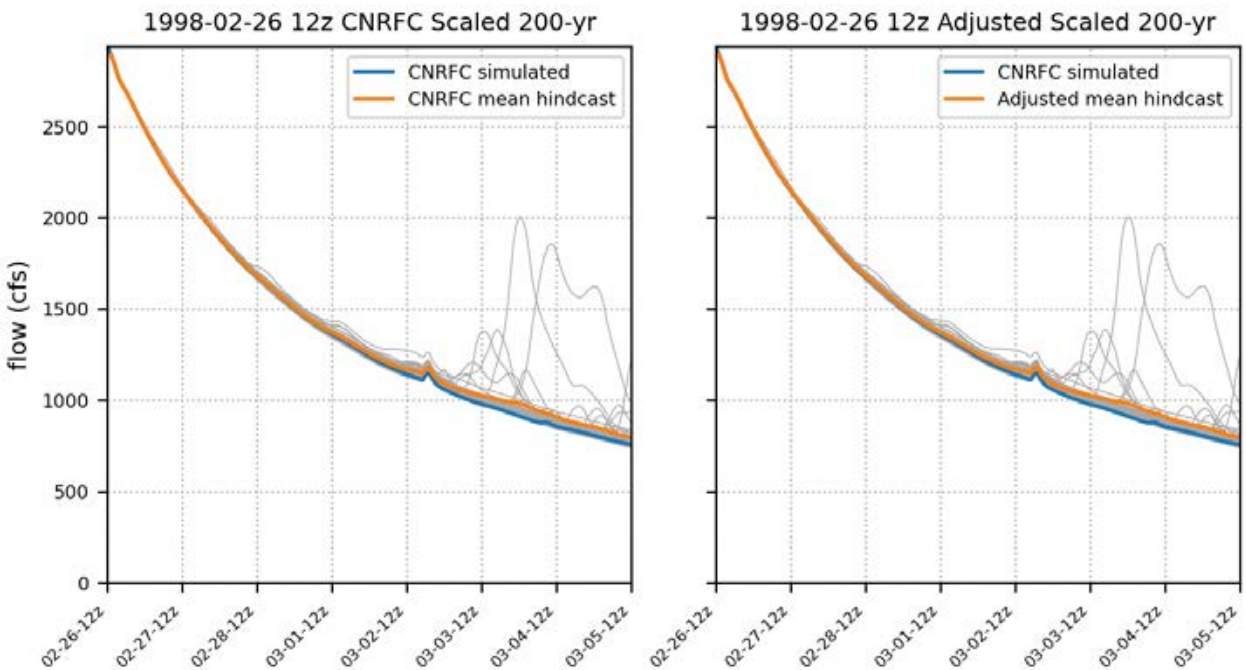
200-yr 2/24/1998



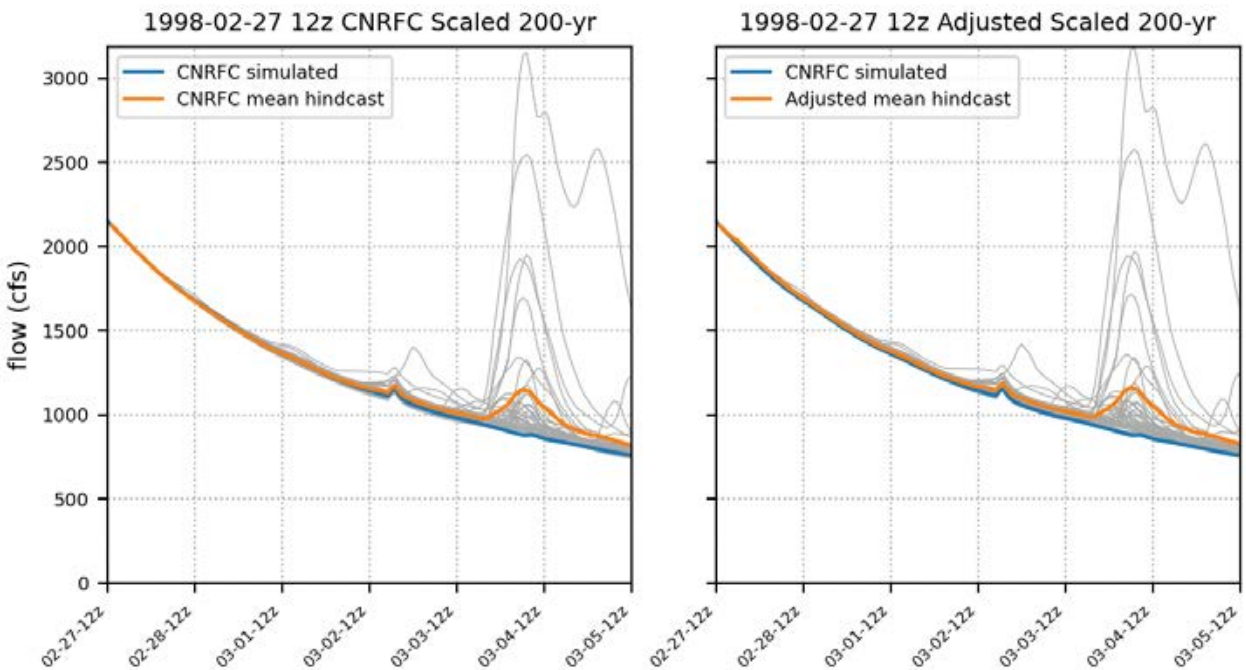
200-yr 2/25/1998



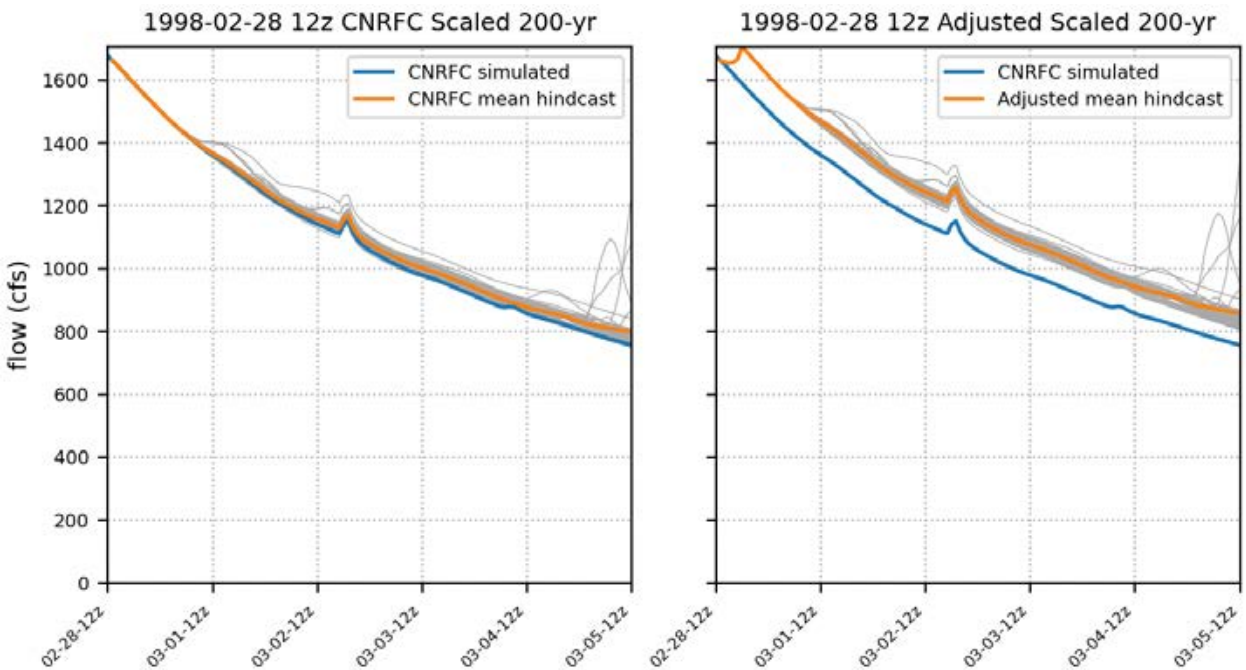
200-yr 2/26/1998



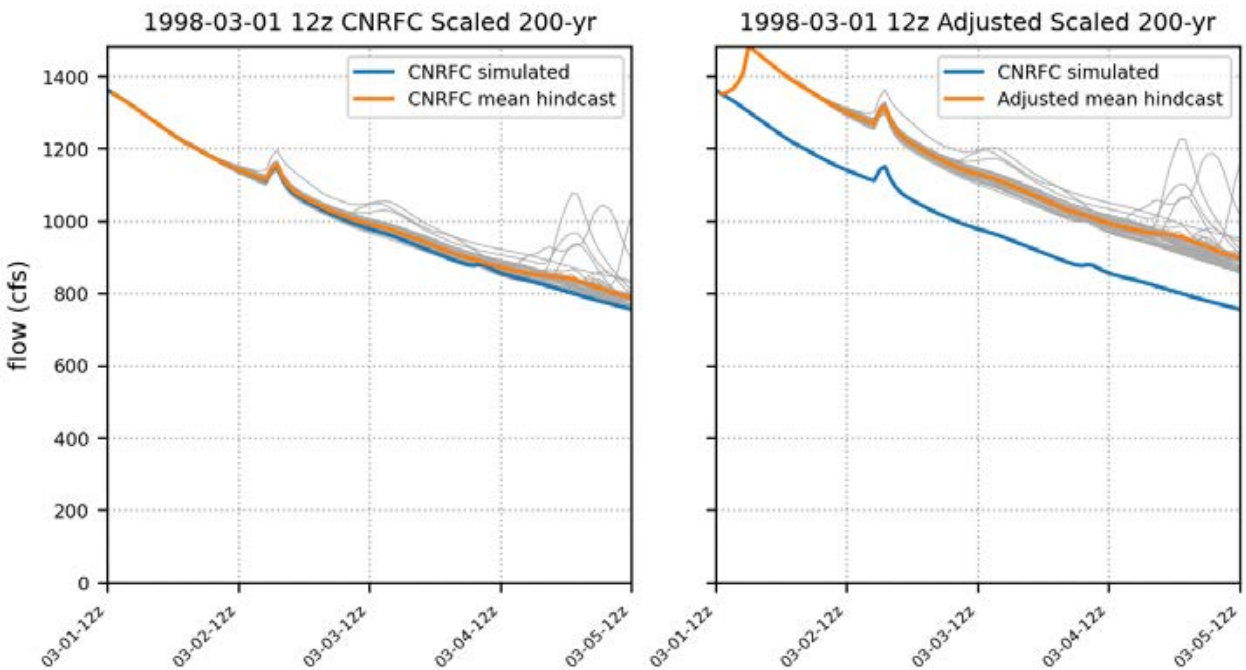
200-yr 2/27/1998



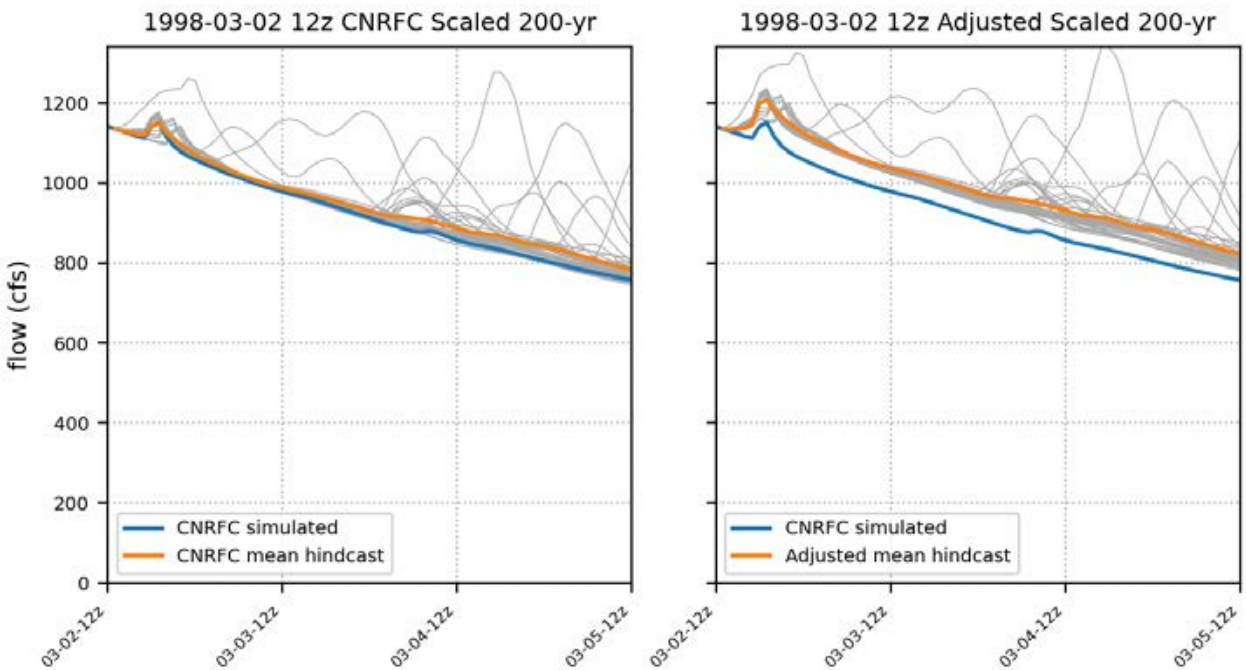
200-yr 2/28/1998



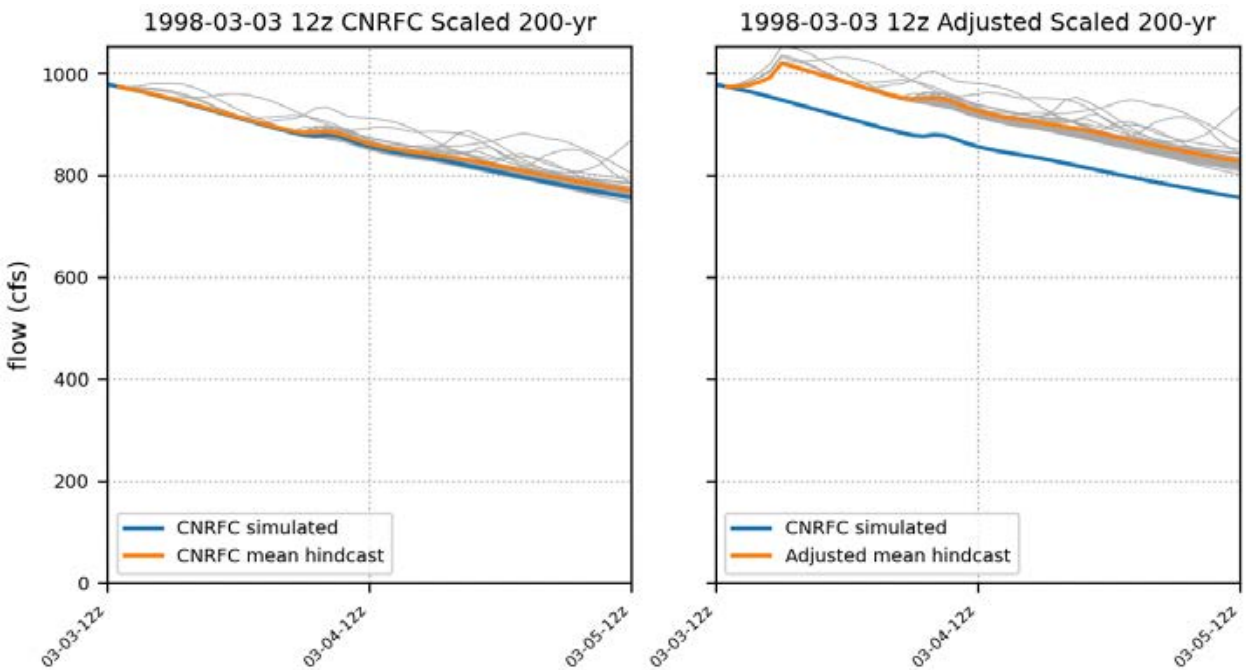
200-yr 3/1/1998



200-yr 3/2/1998



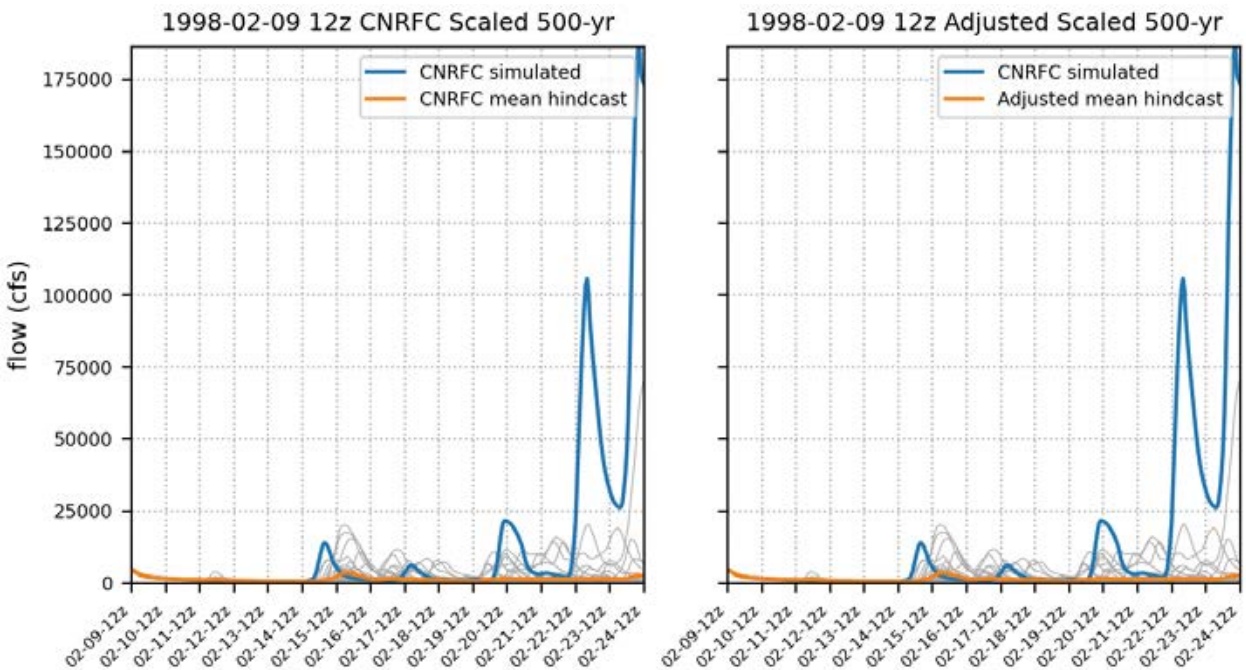
200-yr 3/3/1998



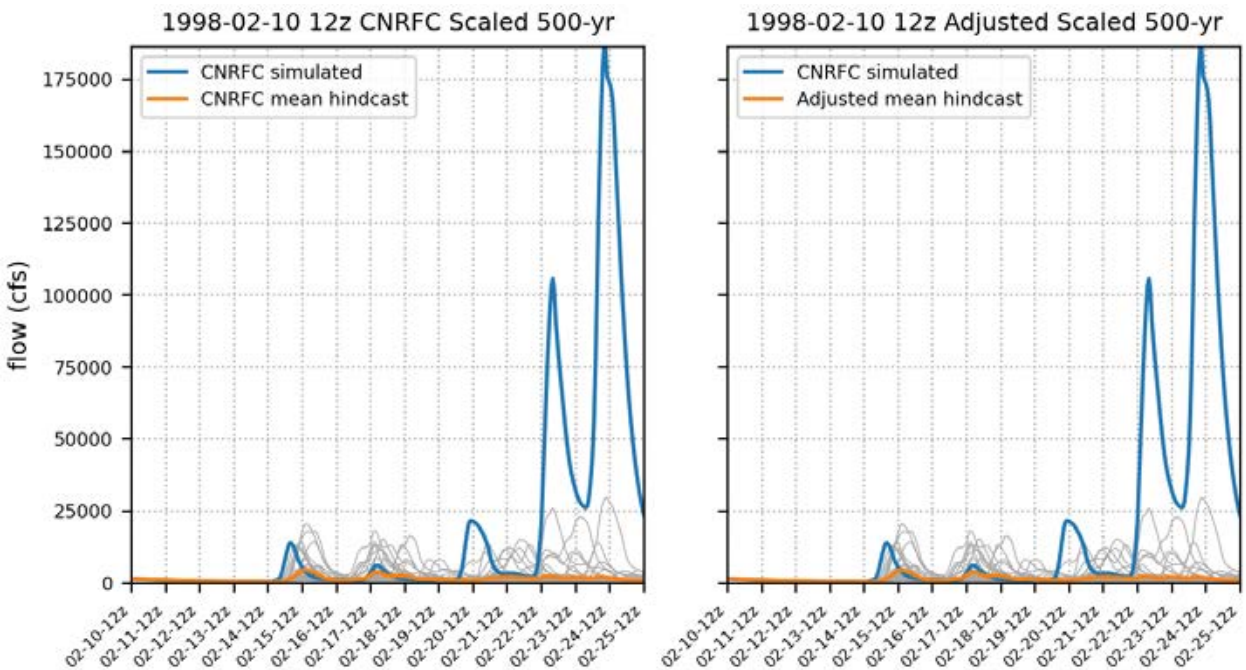
Adjusted Scaled Hindcast 1998 500-yr

2023-03-25

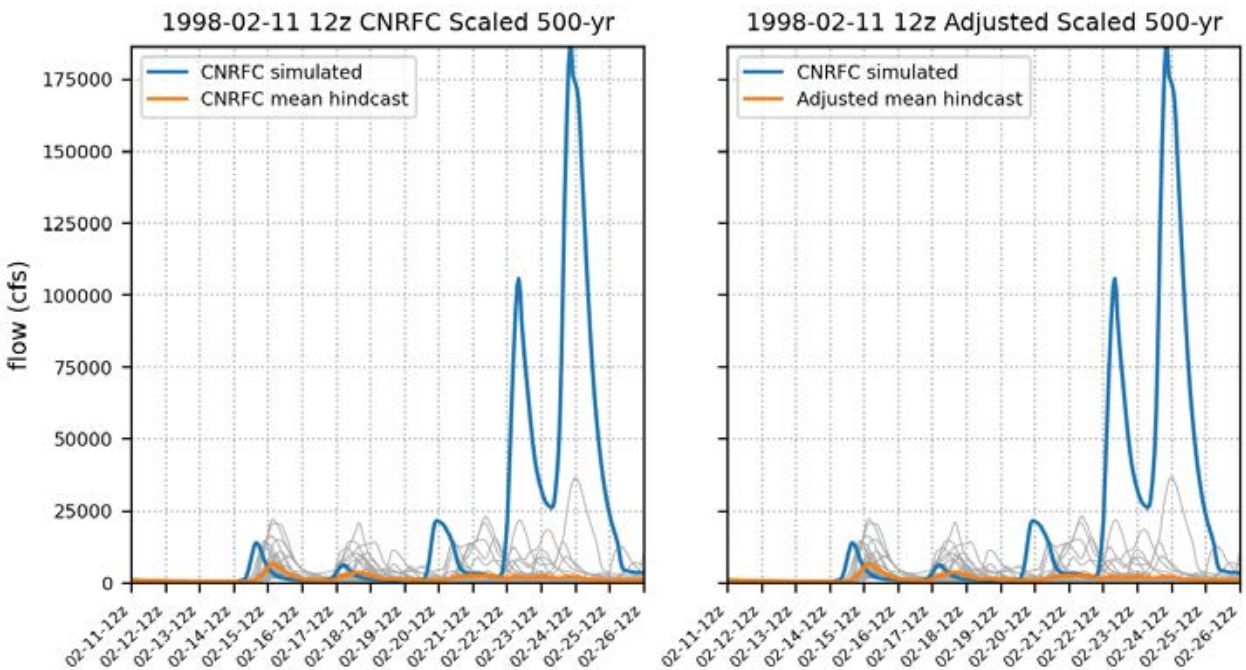
500-yr 2/9/1998



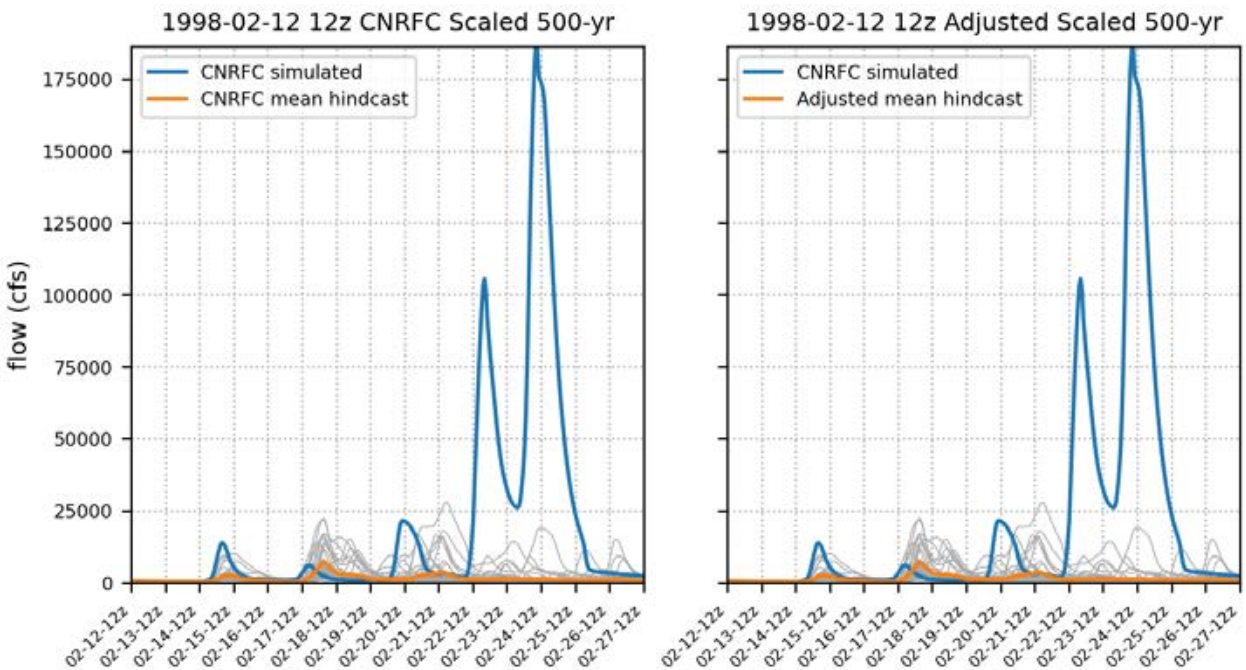
500-yr 2/10/1998



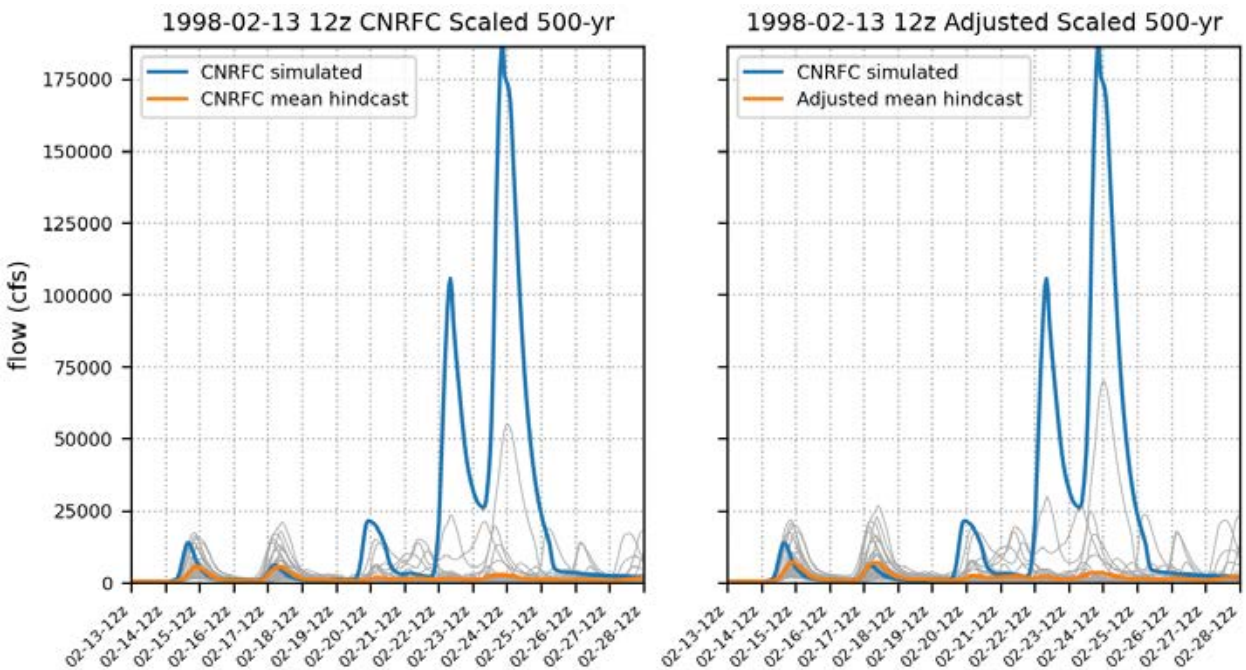
500-yr 2/11/1998



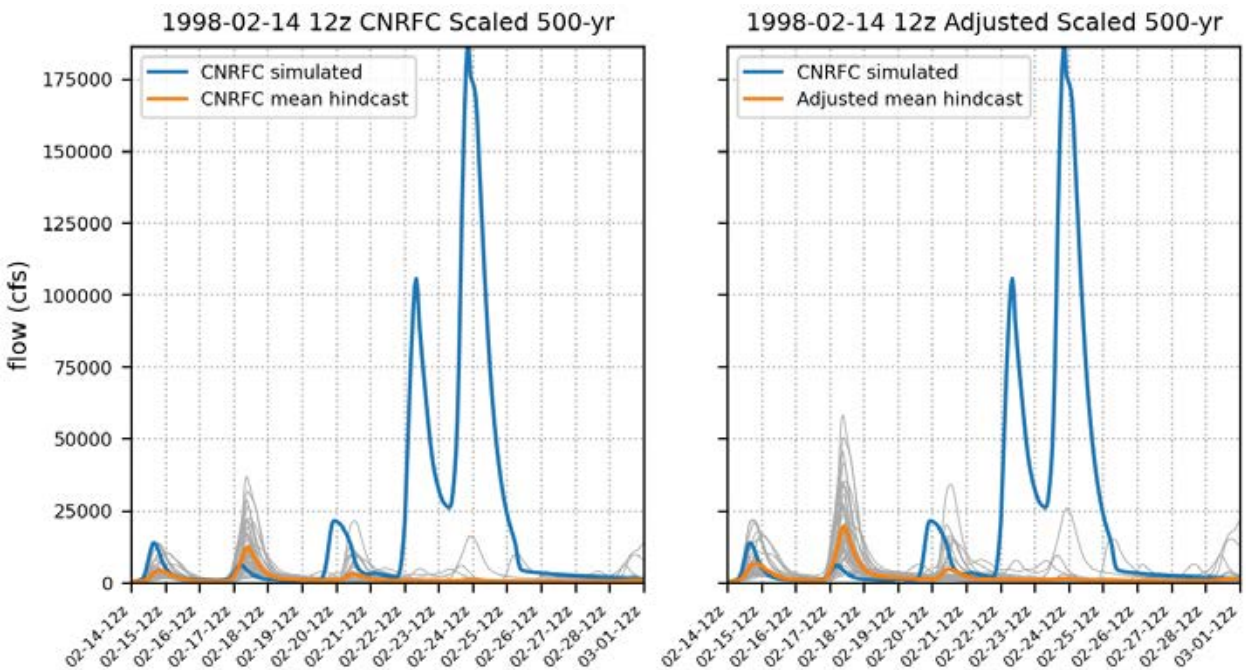
500-yr 2/12/1998



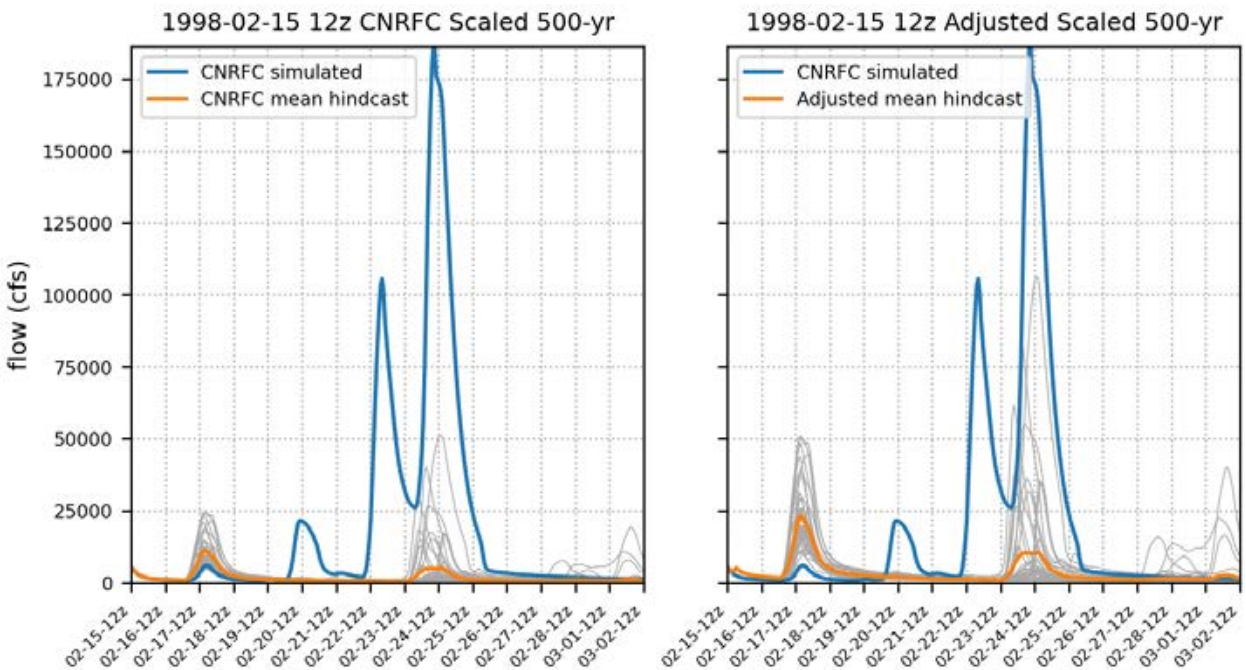
500-yr 2/13/1998



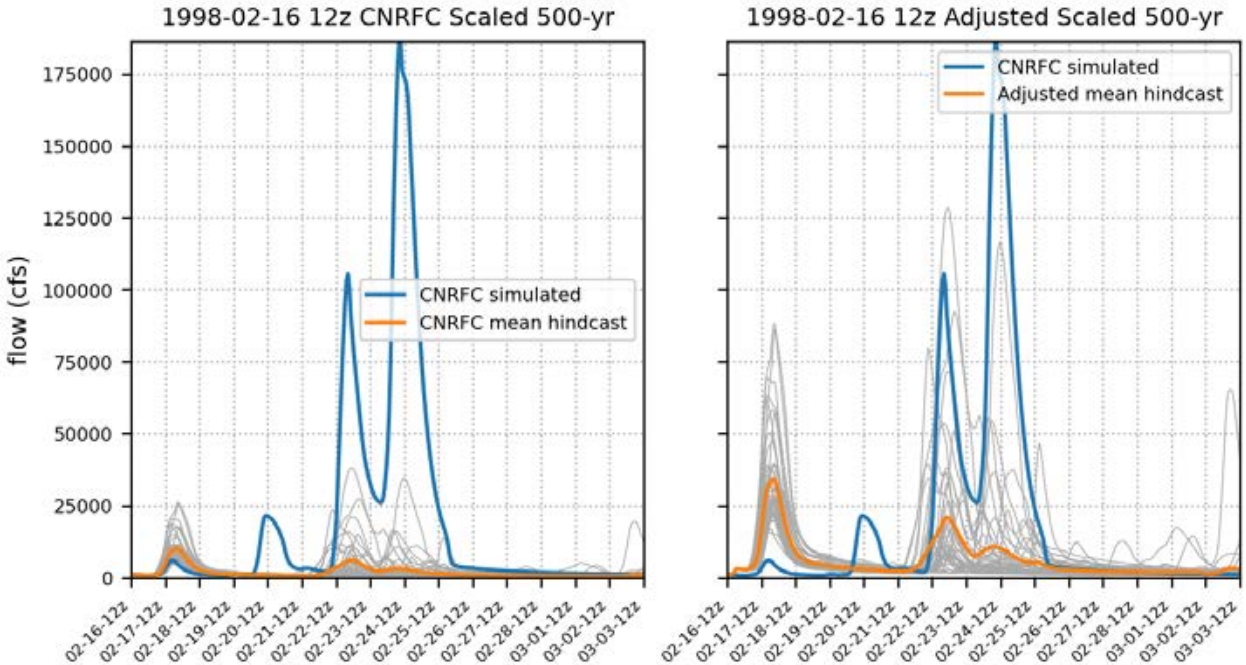
500-yr 2/14/1998



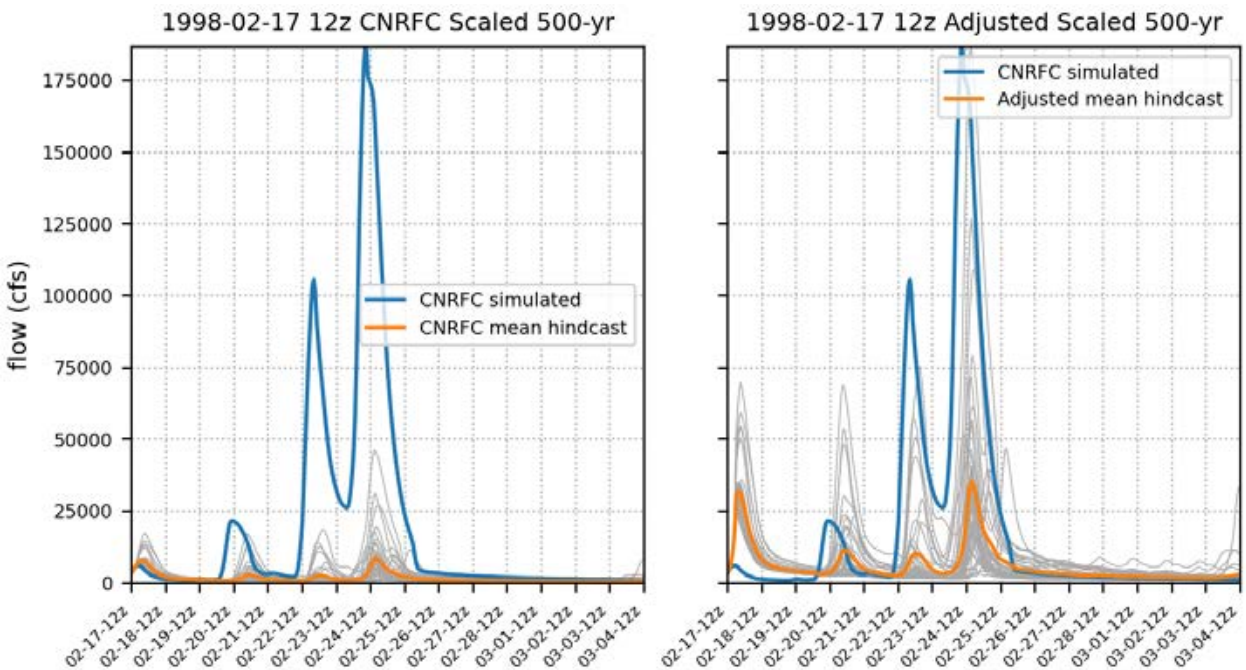
500-yr 2/15/1998



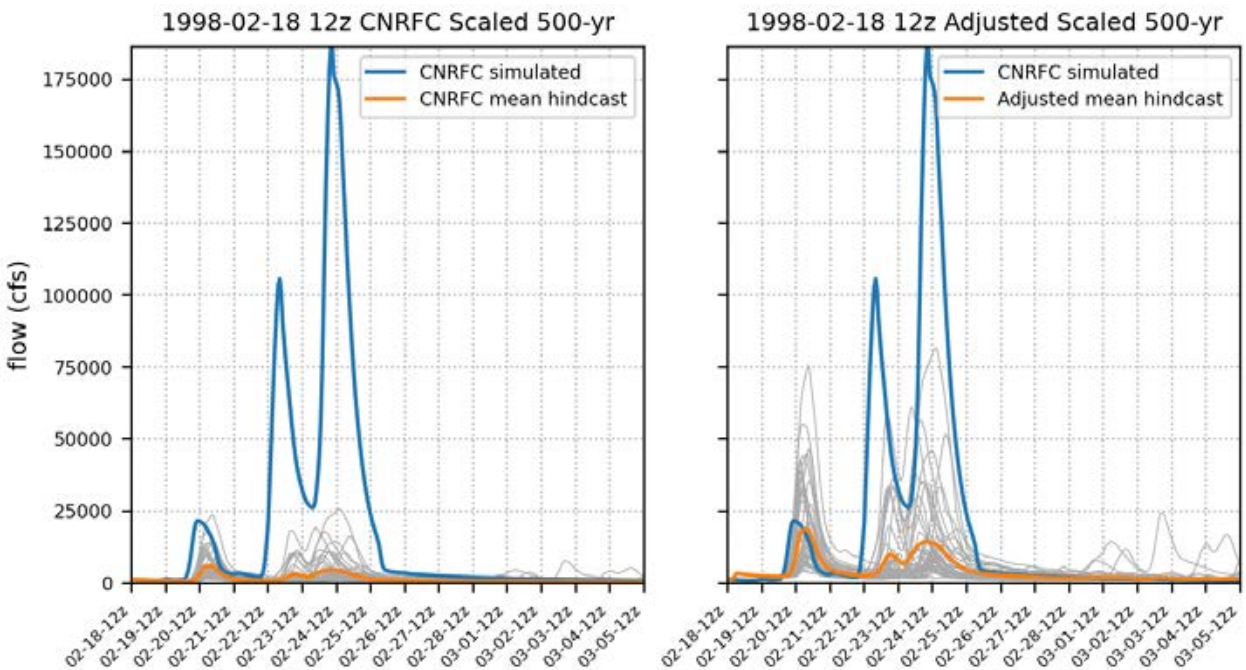
500-yr 2/16/1998



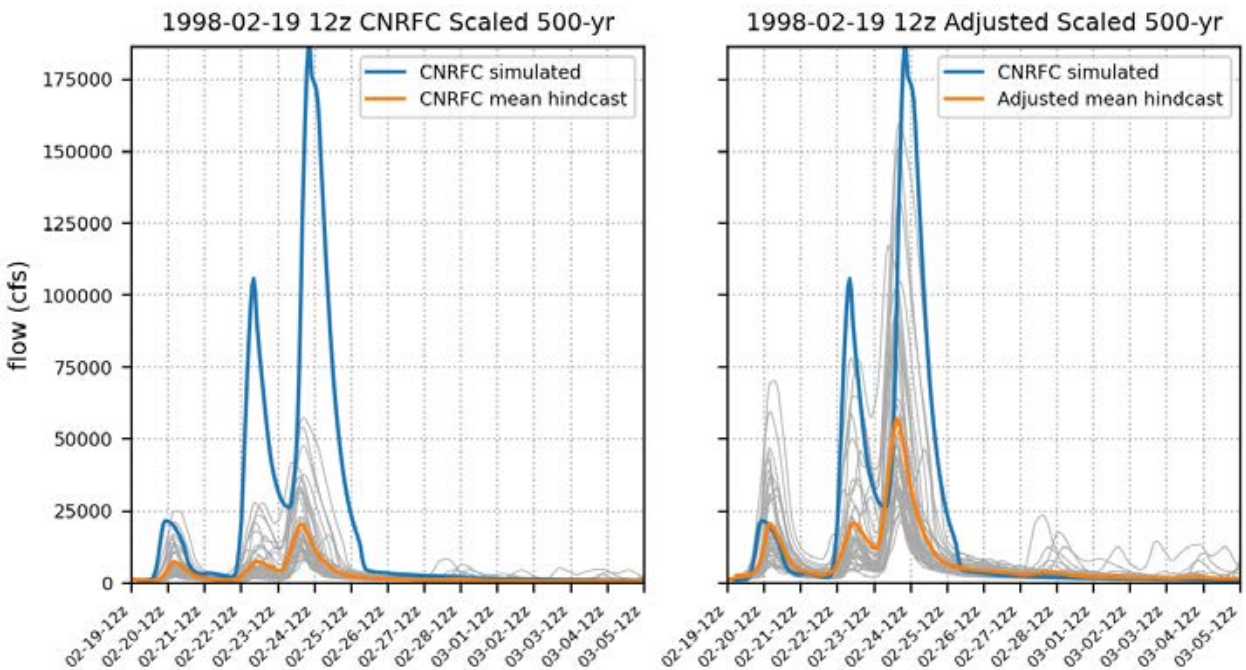
500-yr 2/17/1998



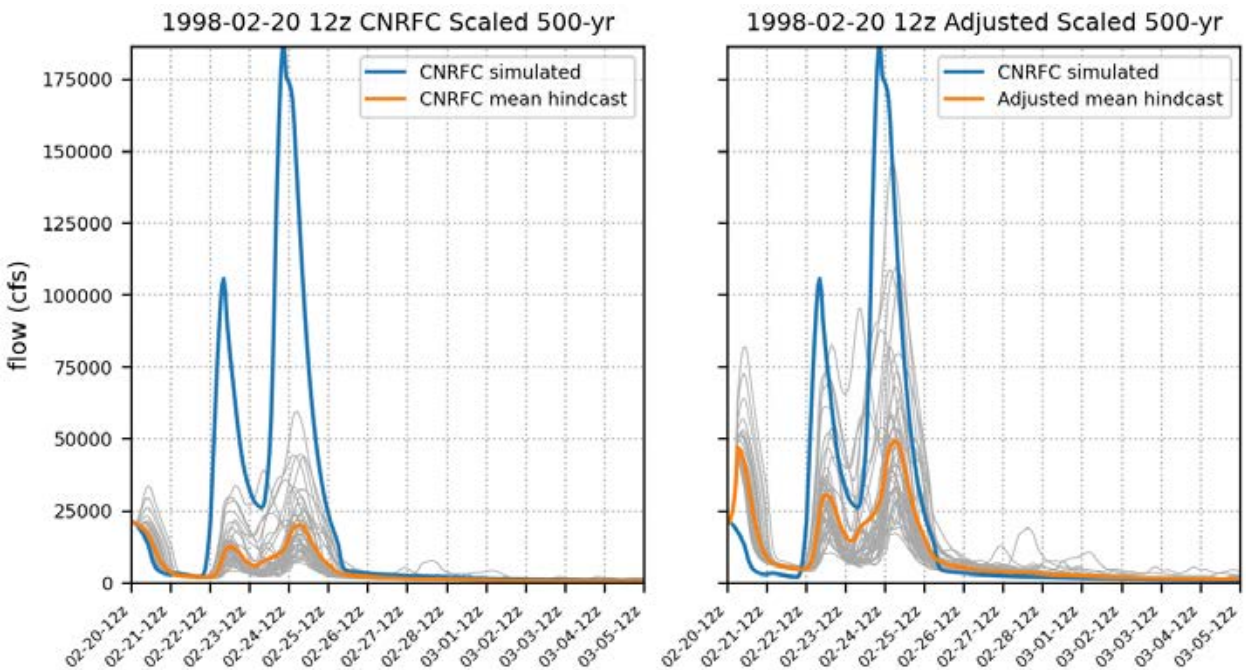
500-yr 2/18/1998



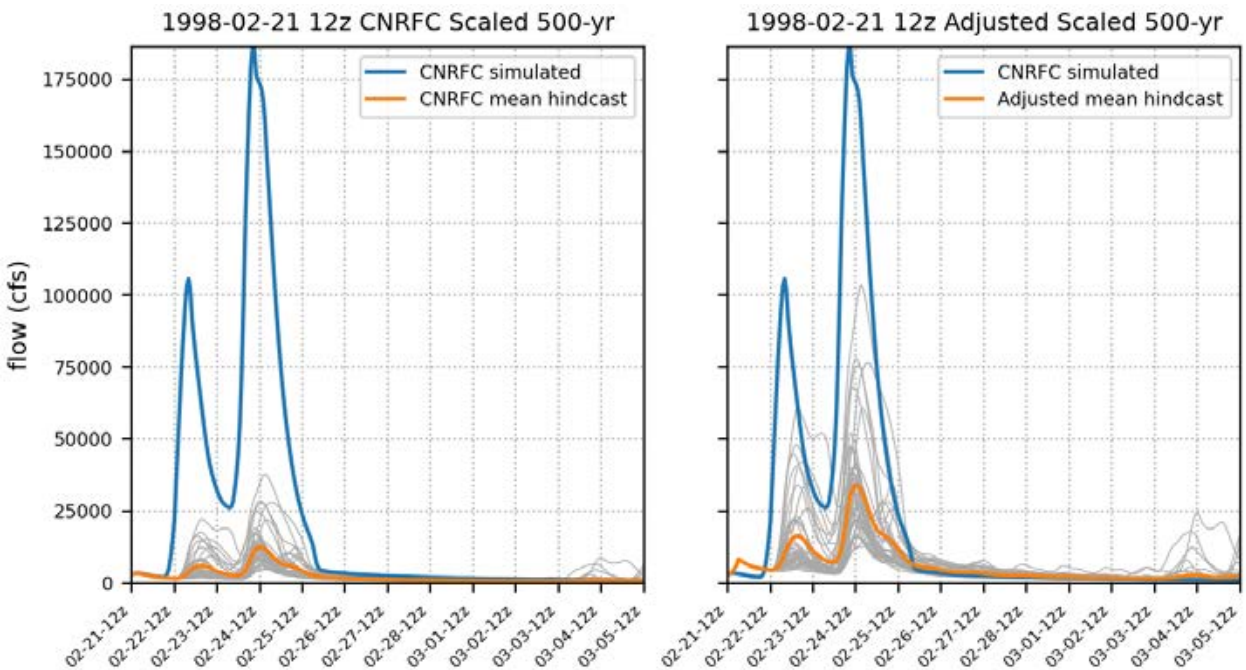
500-yr 2/19/1998



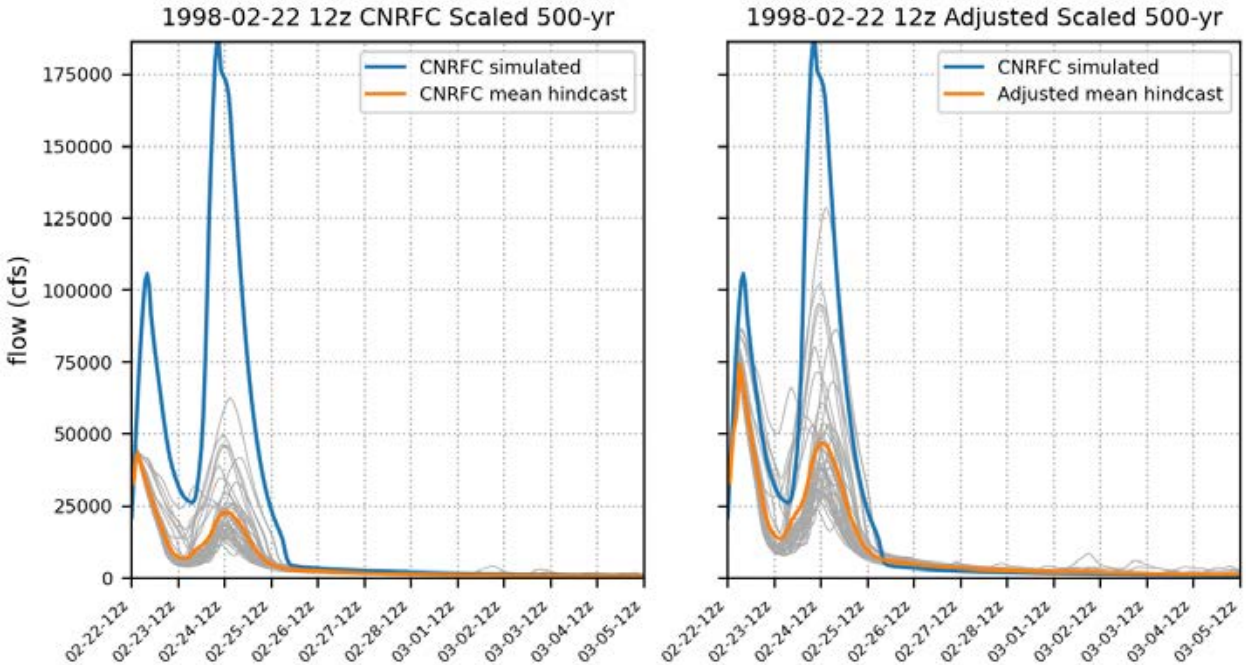
500-yr 2/20/1998



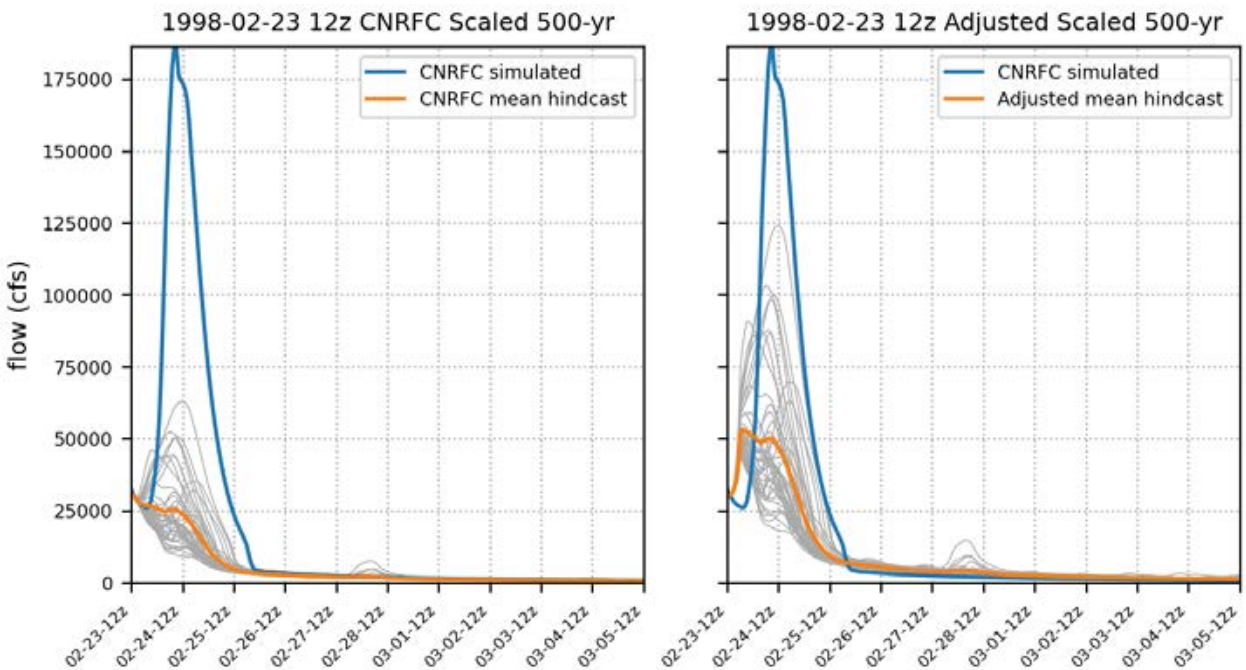
500-yr 2/21/1998



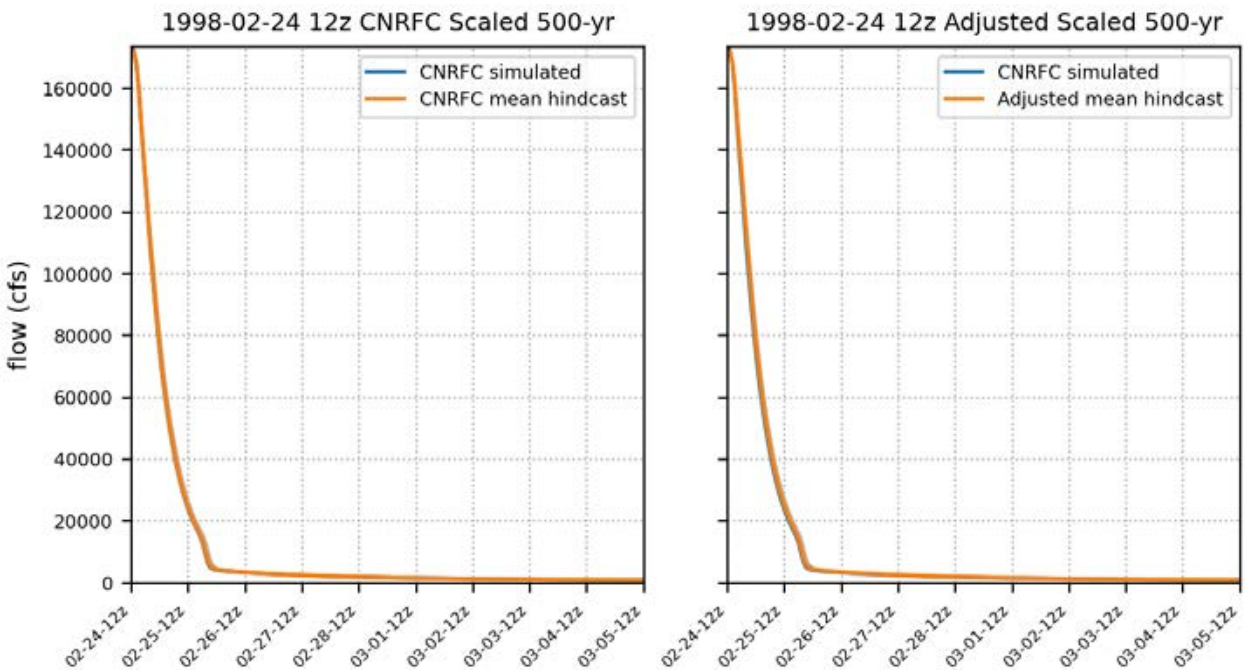
500-yr 2/22/1998



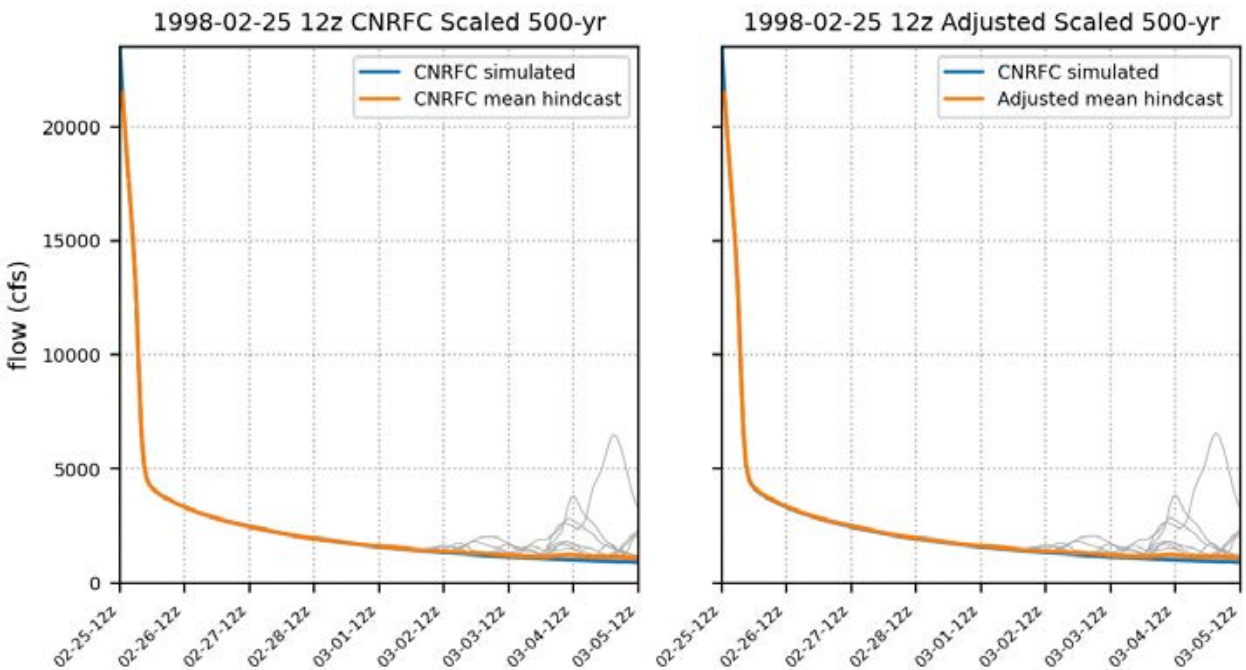
500-yr 2/23/1998



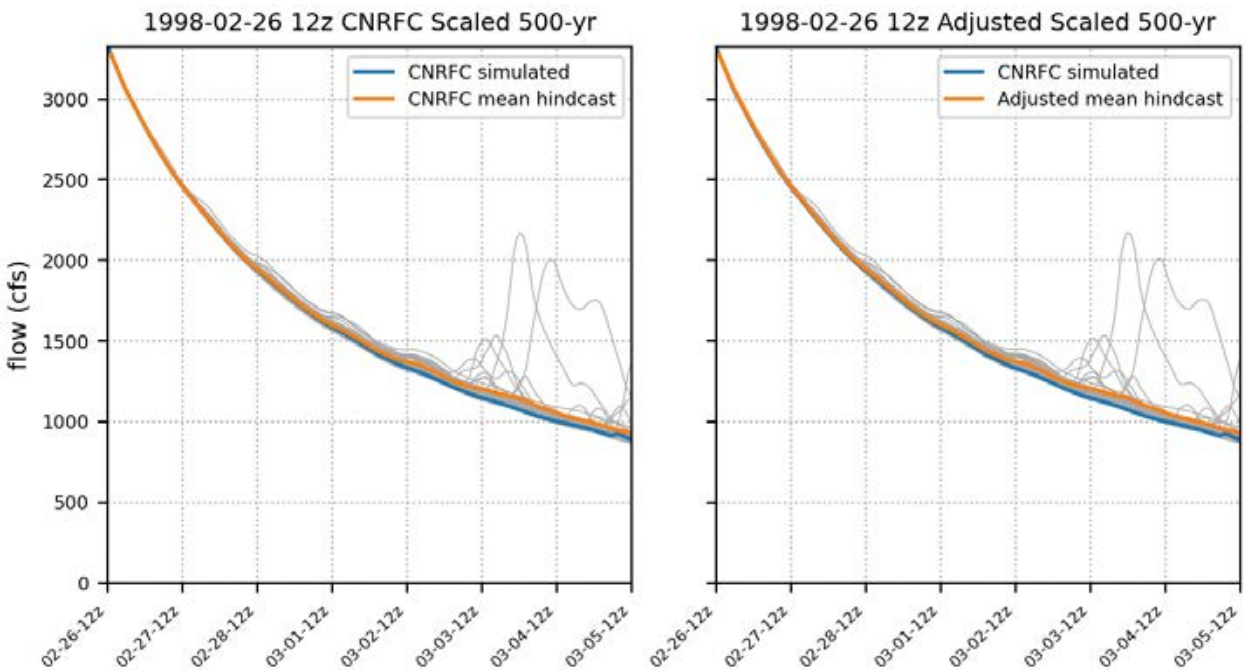
500-yr 2/24/1998



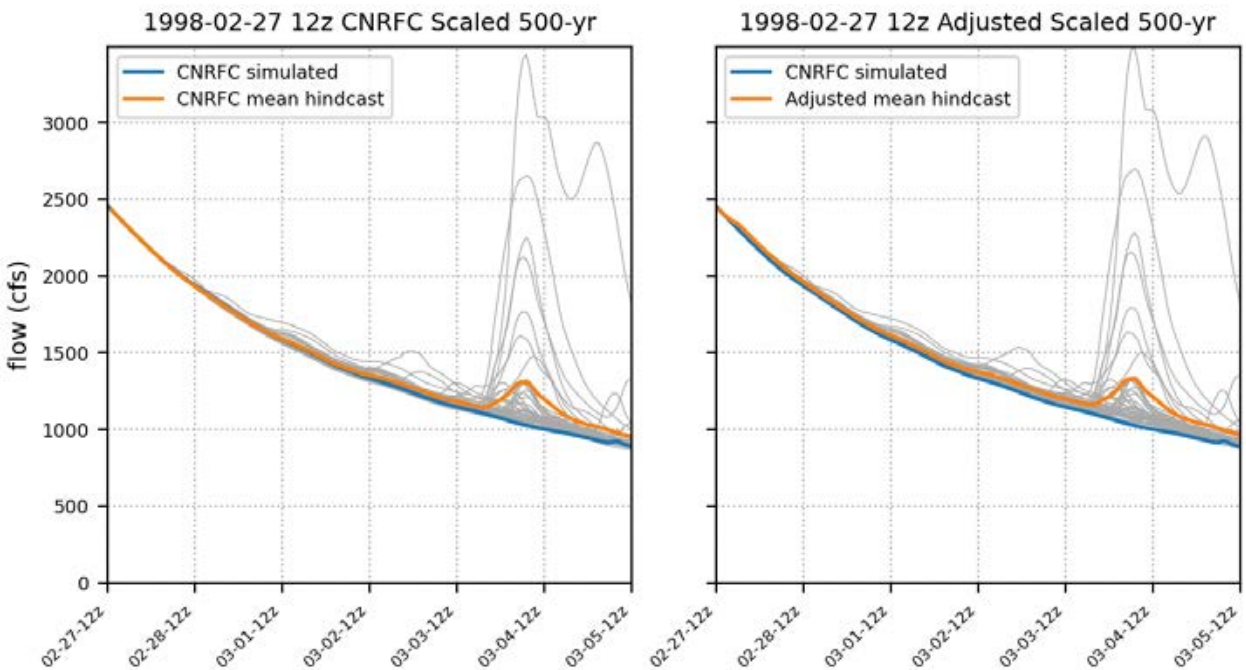
500-yr 2/25/1998



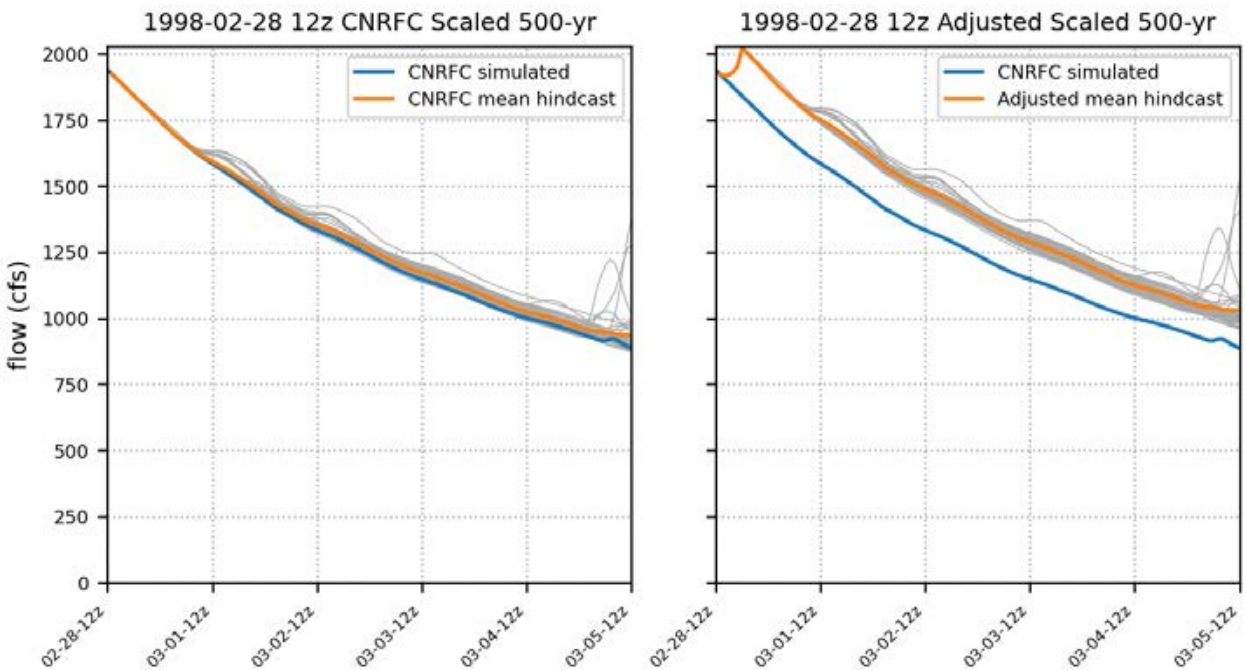
500-yr 2/26/1998



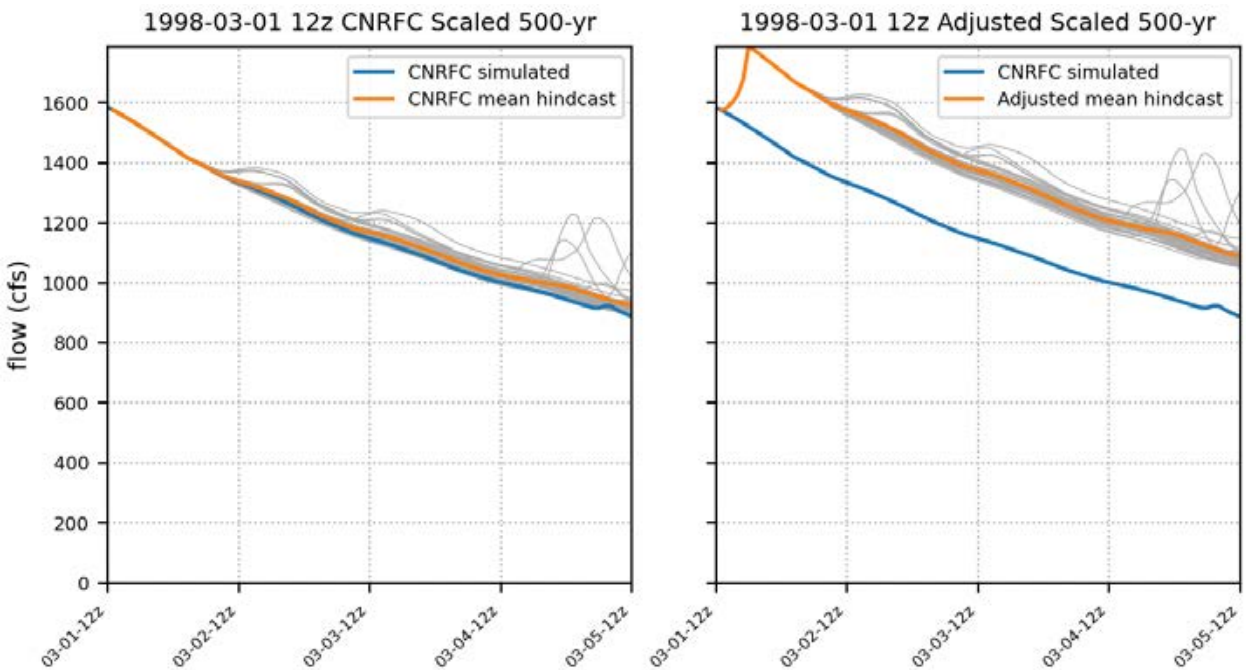
500-yr 2/27/1998



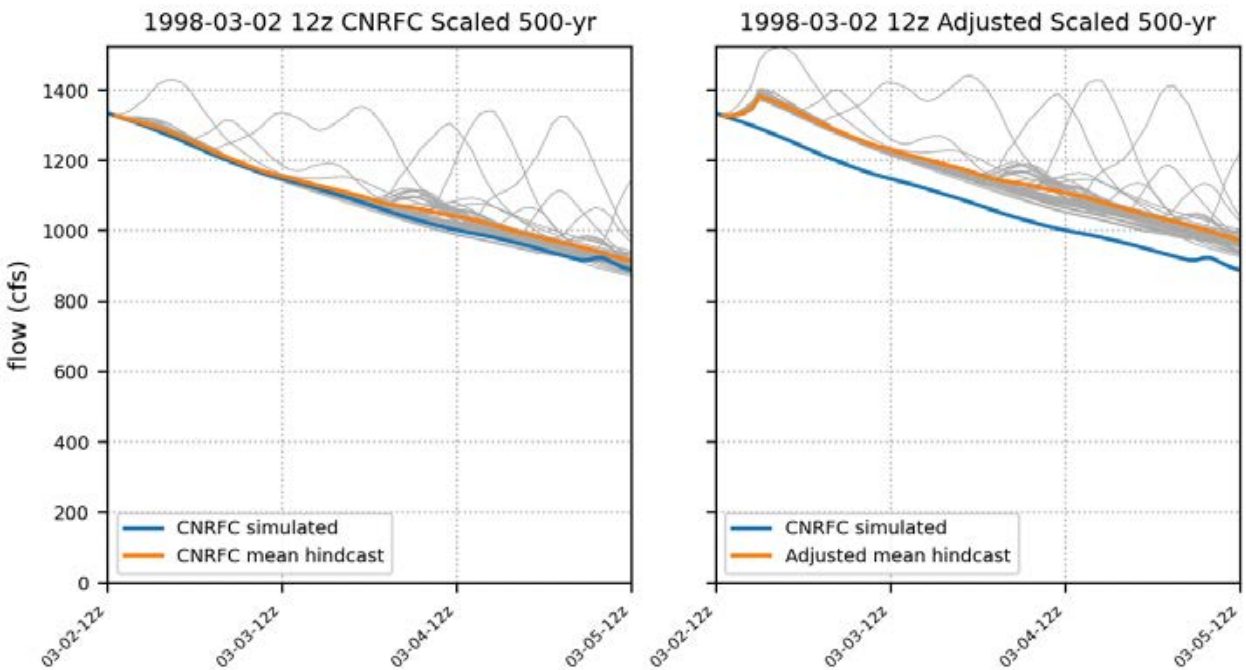
500-yr 2/28/1998



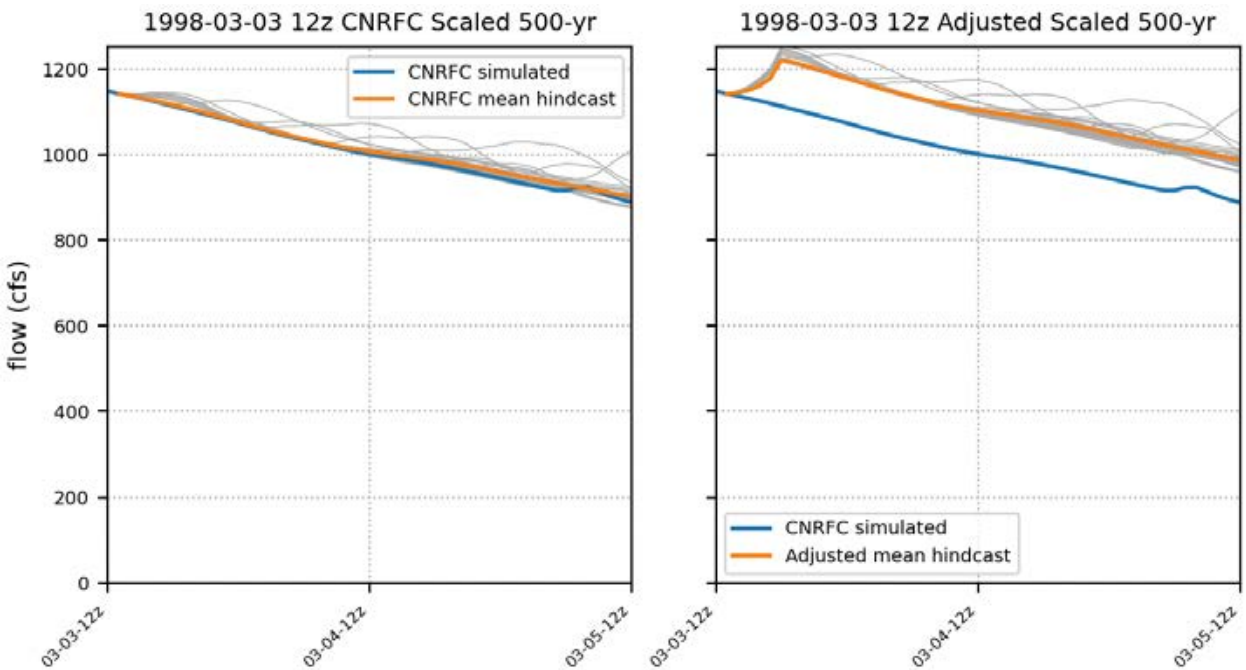
500-yr 3/1/1998



500-yr 3/2/1998



500-yr 3/3/1998



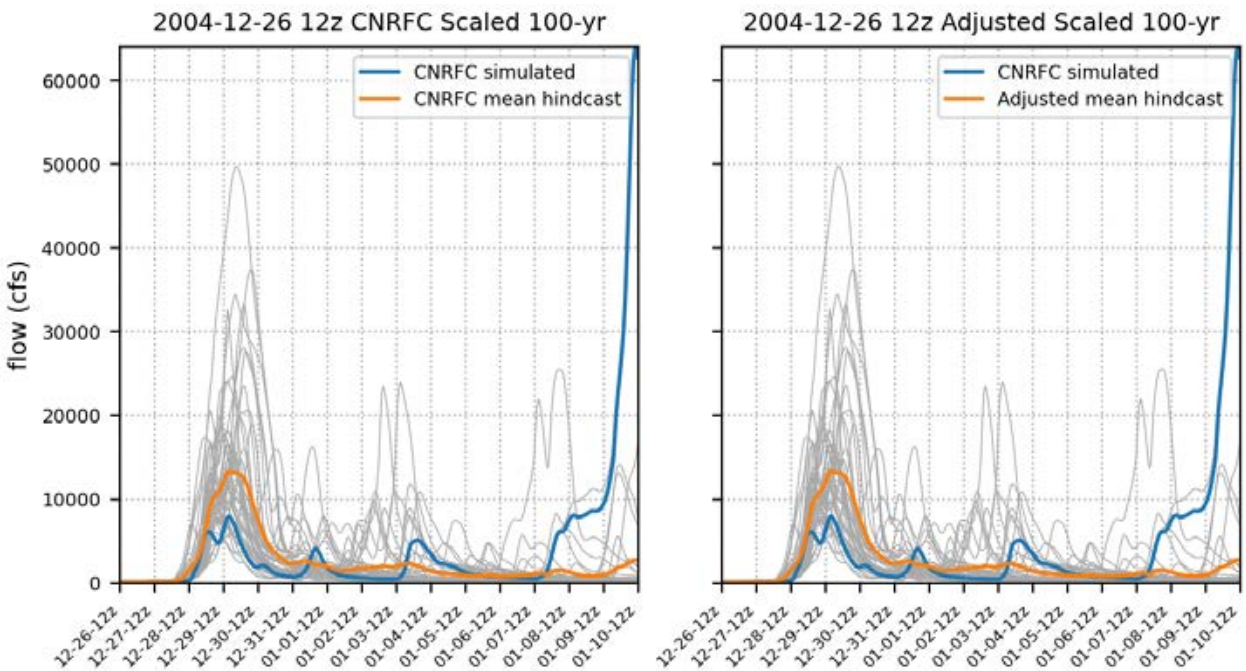
Adjusted Scaled Hindcasts

- December 2005
  - 12/26/2005 through 1/17/2006
- 100-yr – slides 2-25
- 200-yr – slides 26-49
- 500-yr – slides 50-73

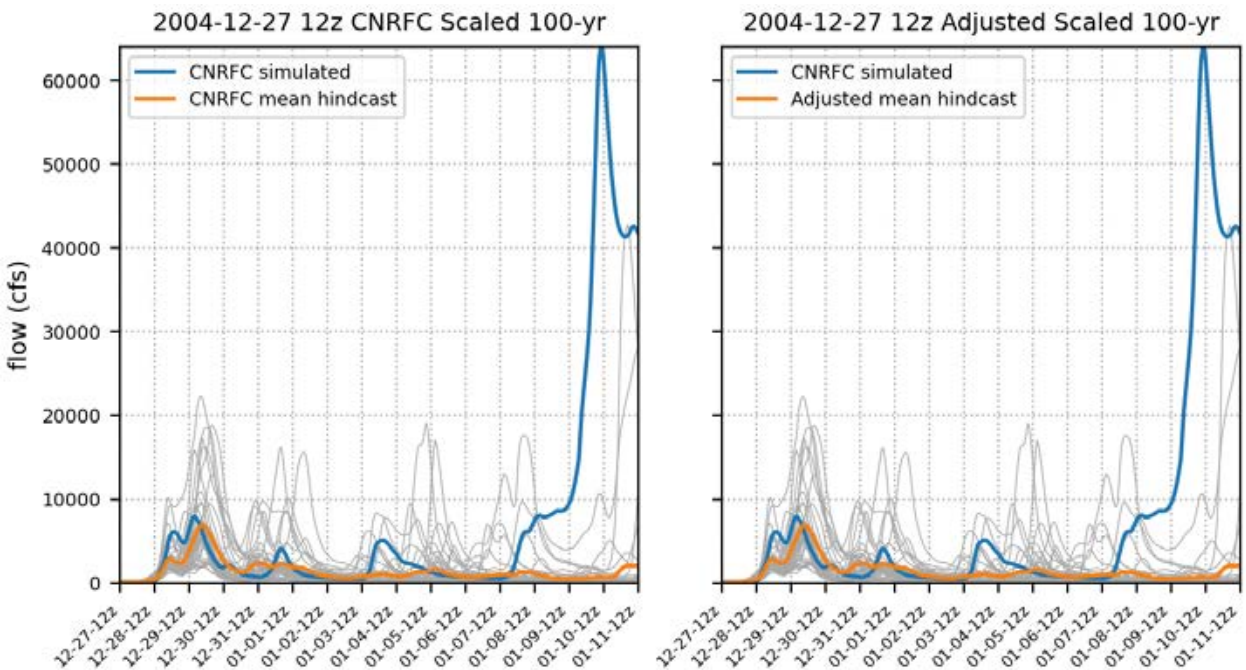
Adjusted Scaled Hindcast 2005 100-yr

2023-03-25

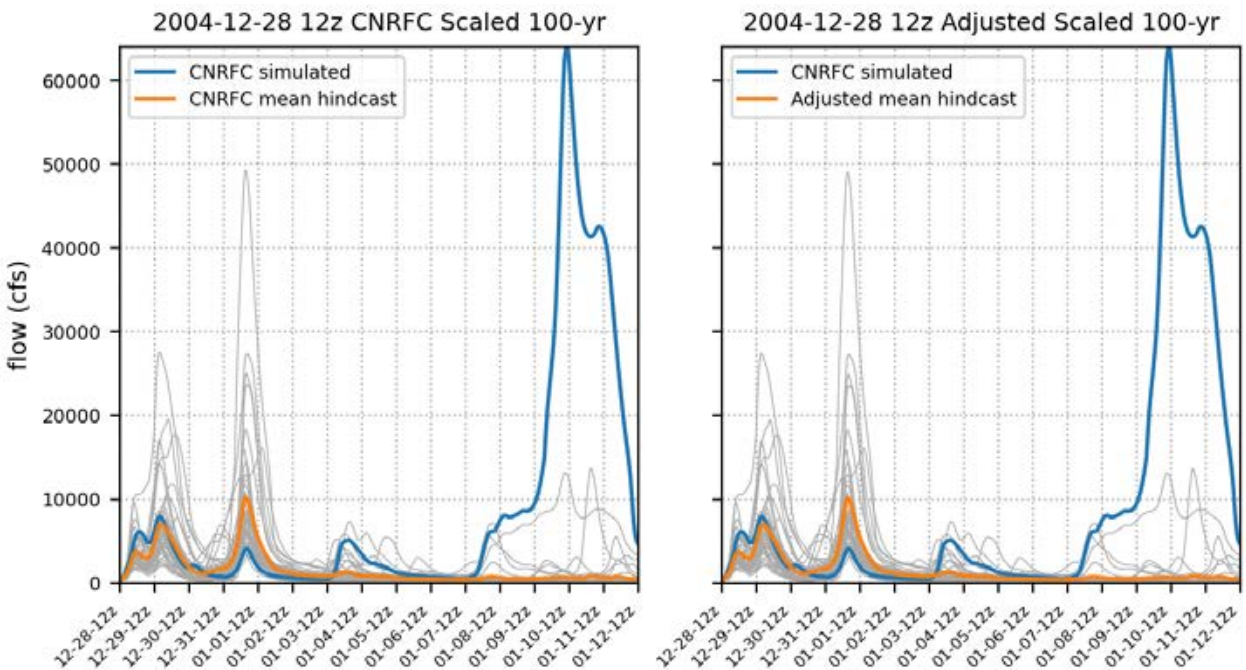
100-yr 12/26/2005



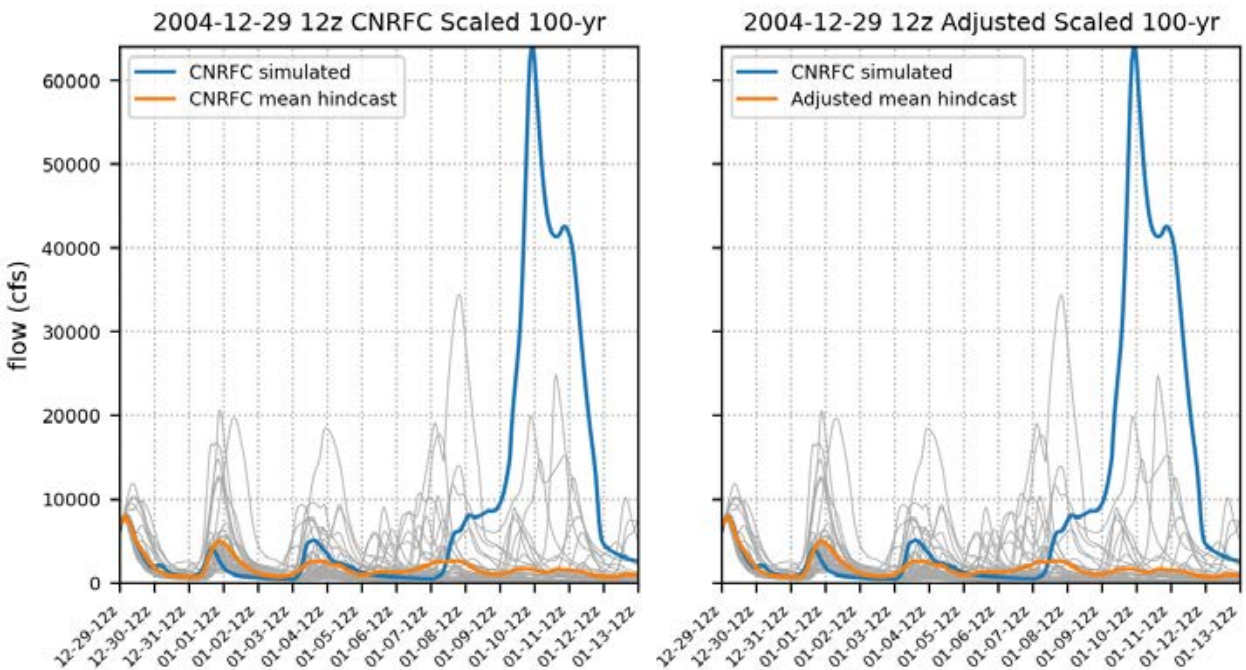
100-yr 12/27/2005



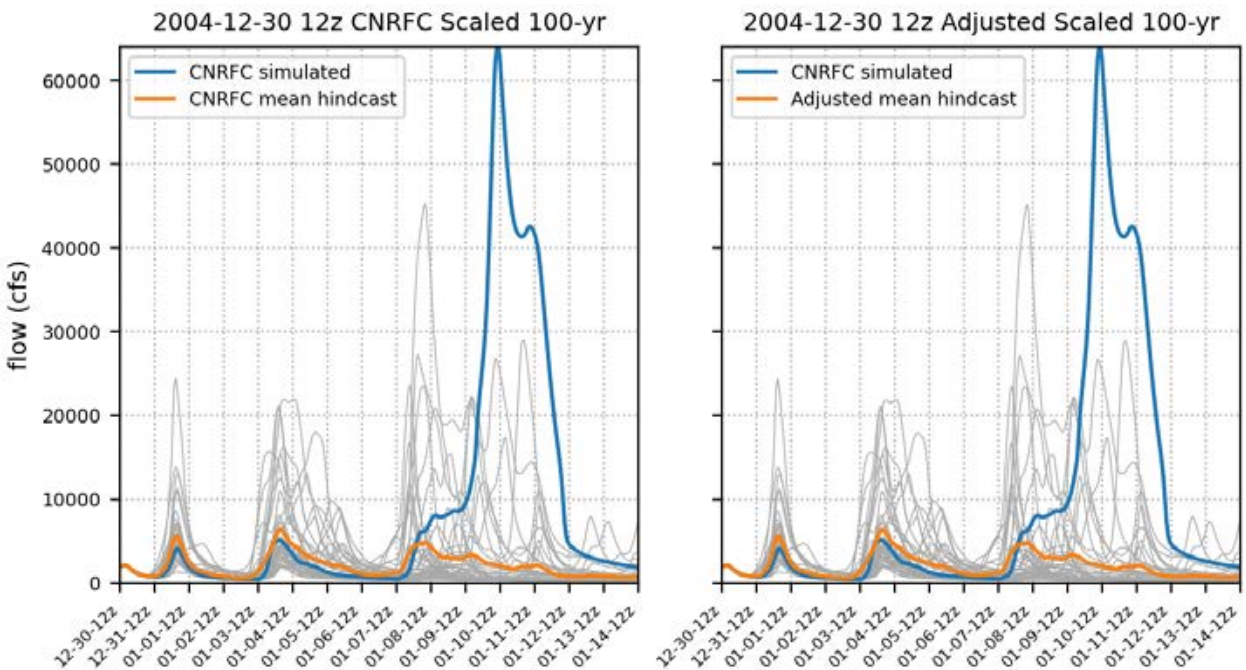
100-yr 12/28/2005



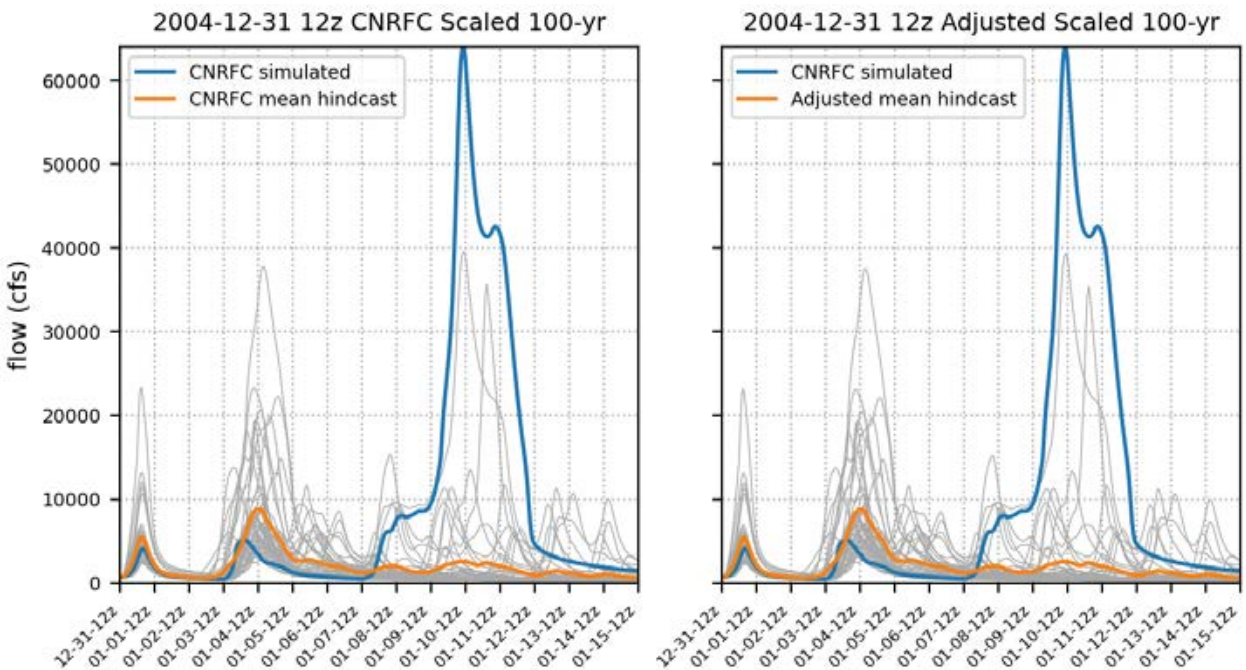
100-yr 12/29/2005



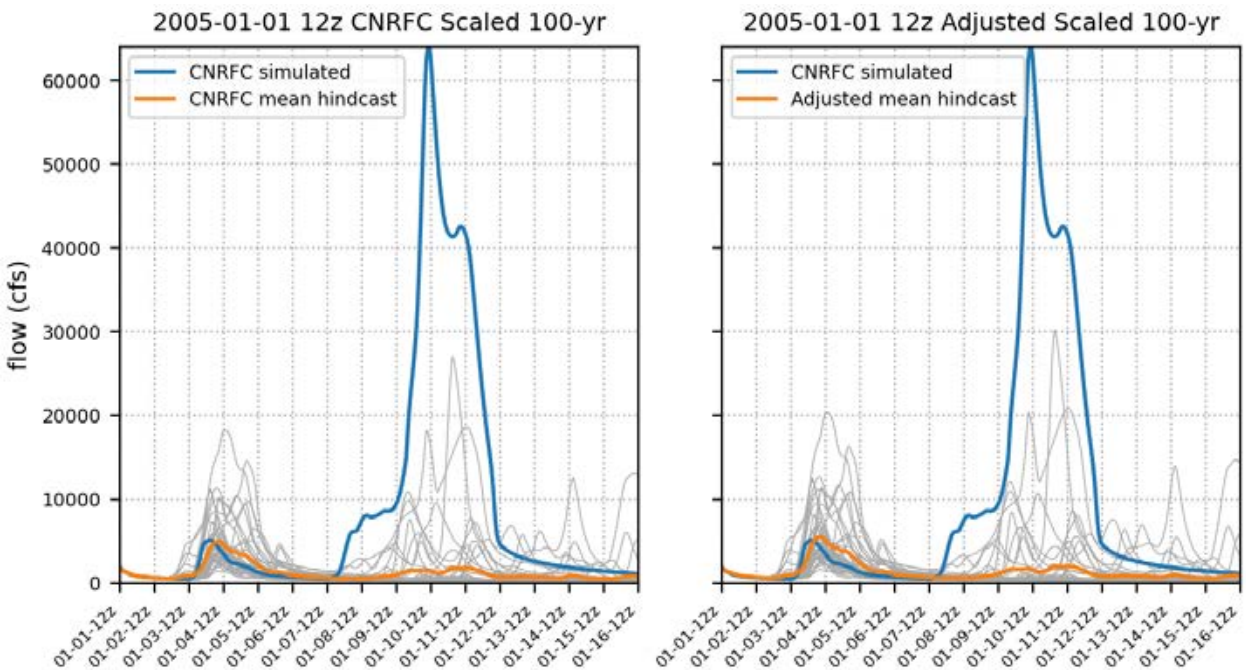
100-yr 12/30/2005



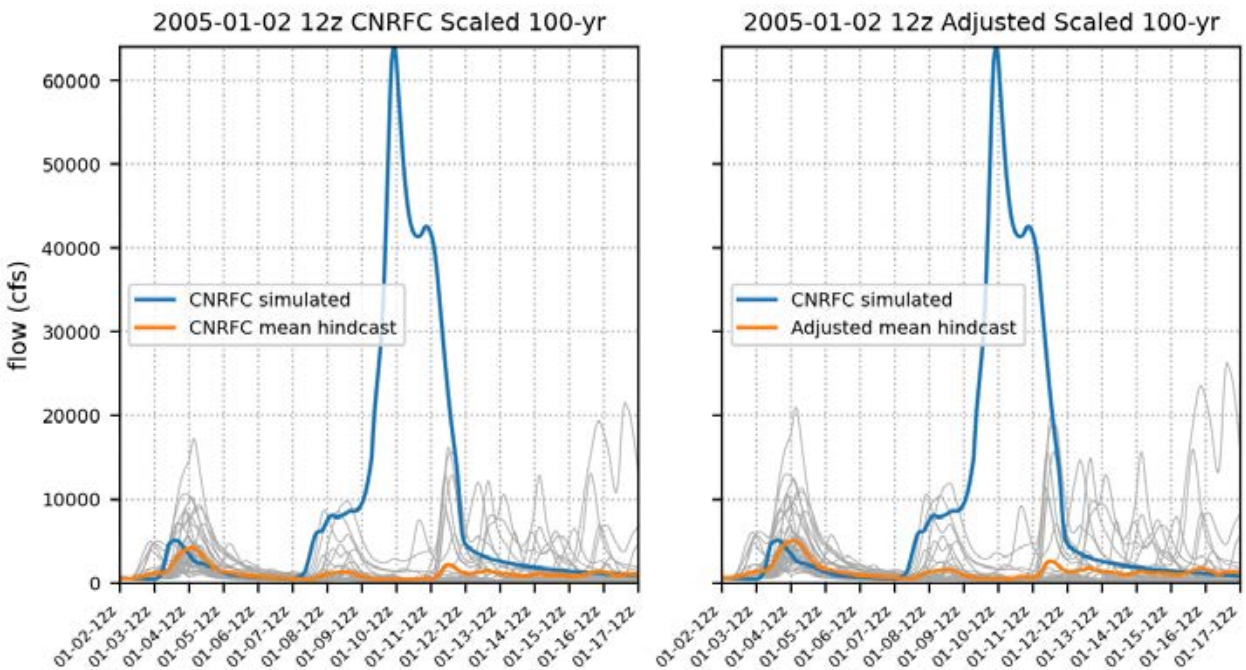
100-yr 12/31/2005



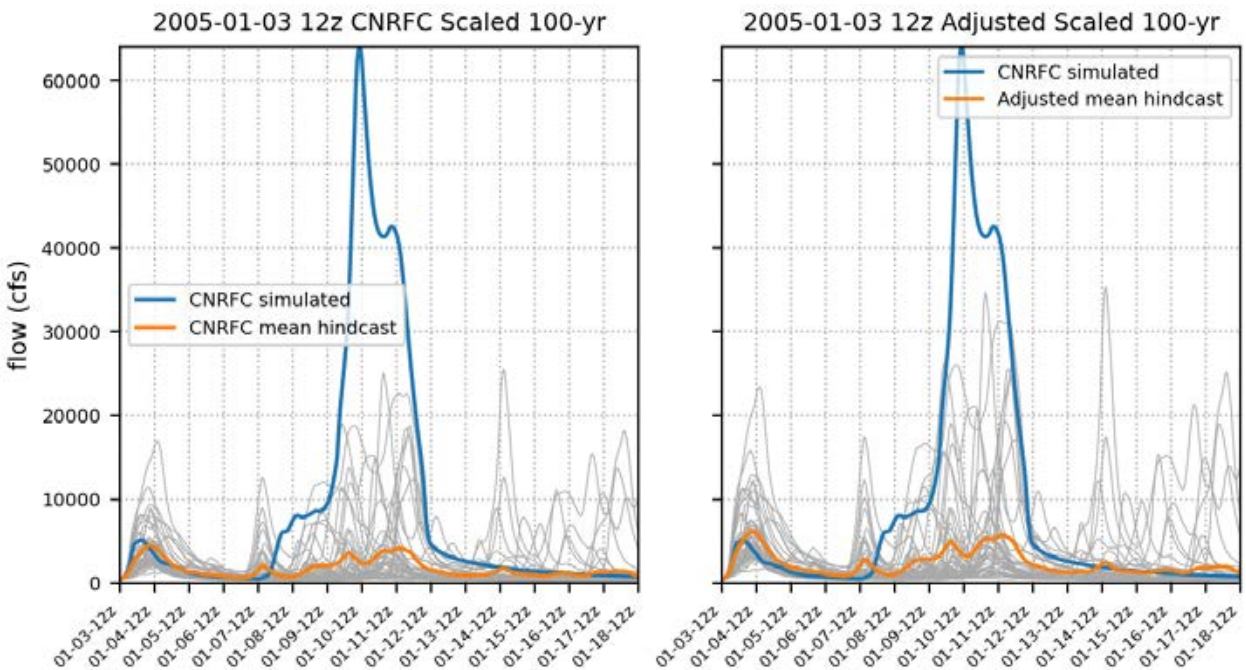
100-yr 1/1/2005



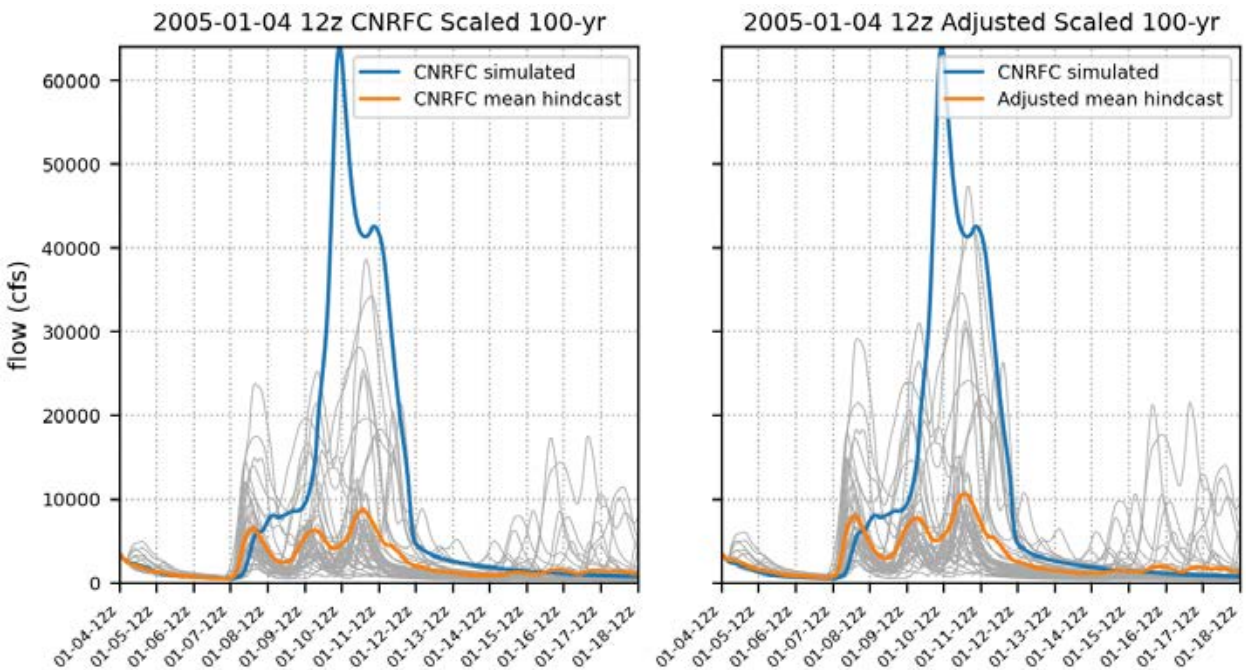
100-yr 1/2/2005



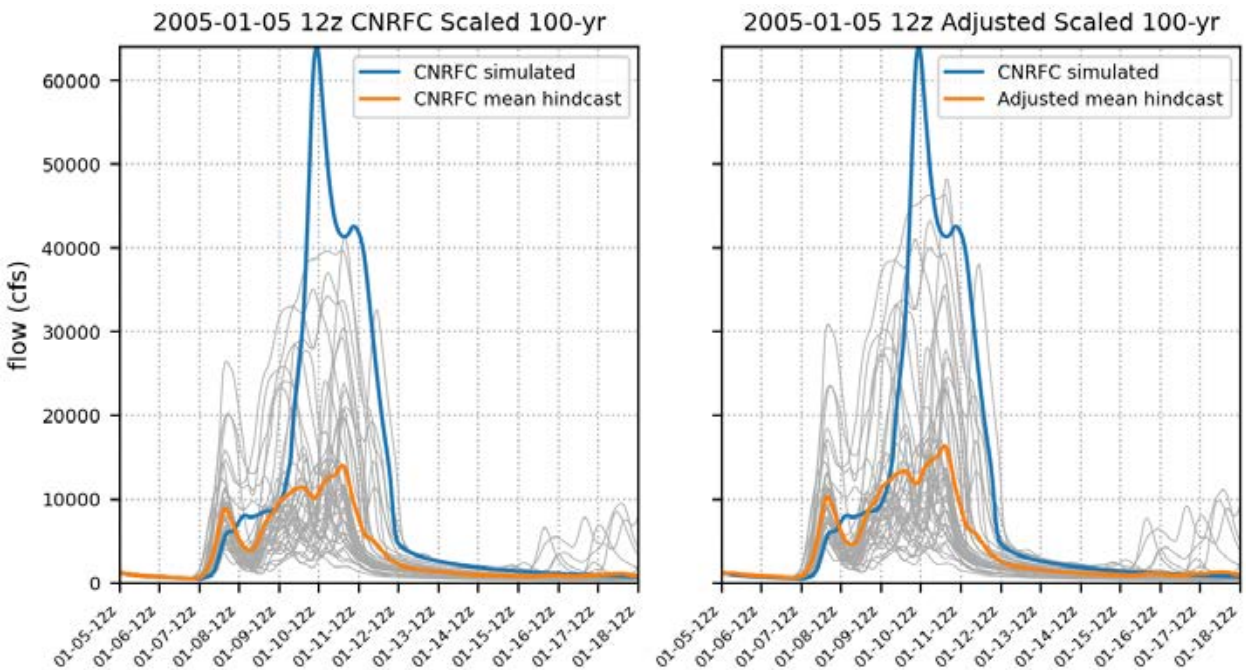
100-yr 1/3/2005



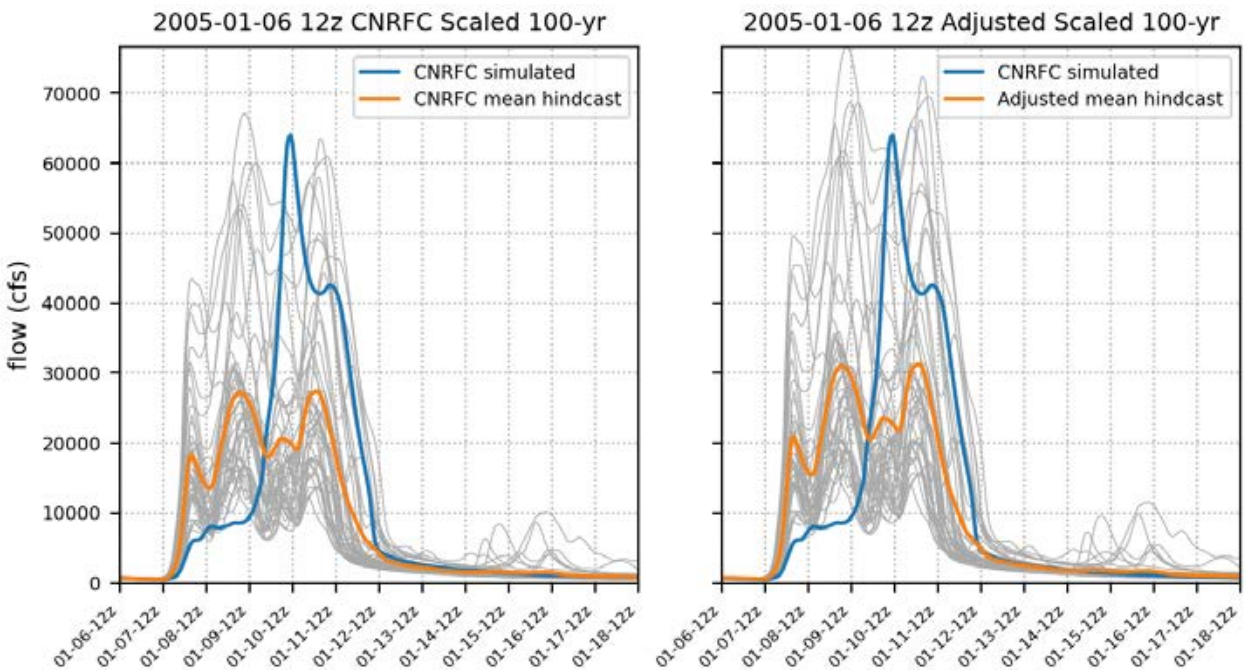
100-yr 1/4/2005



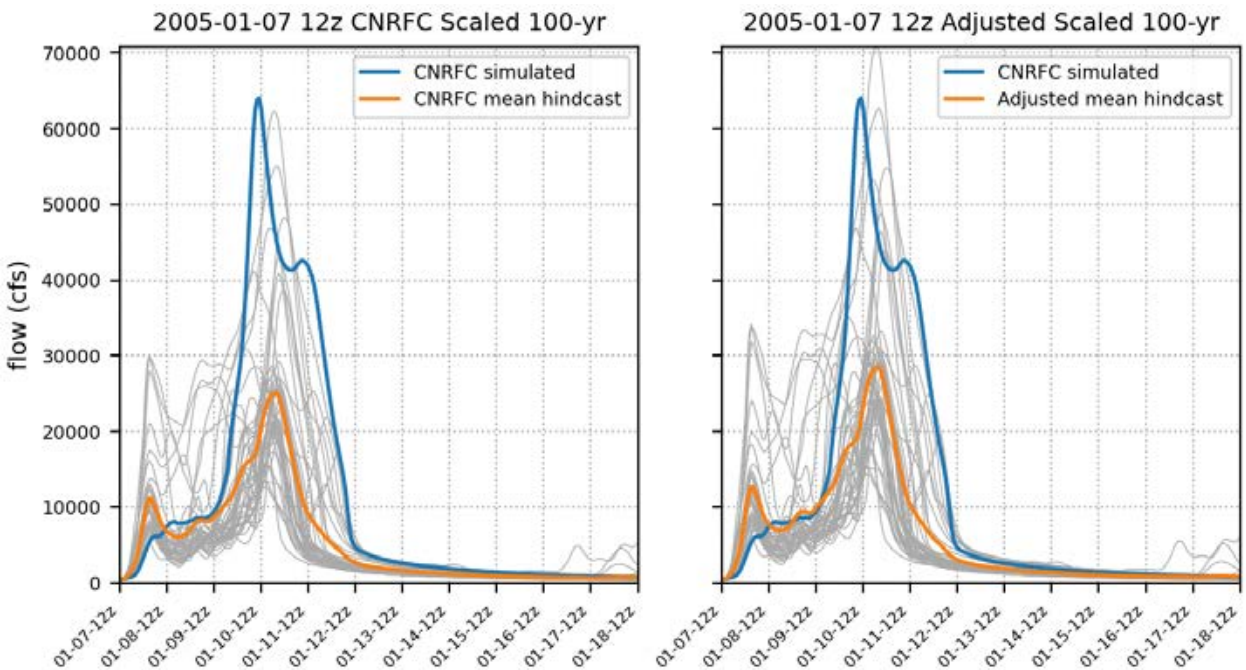
100-yr 1/5/2005



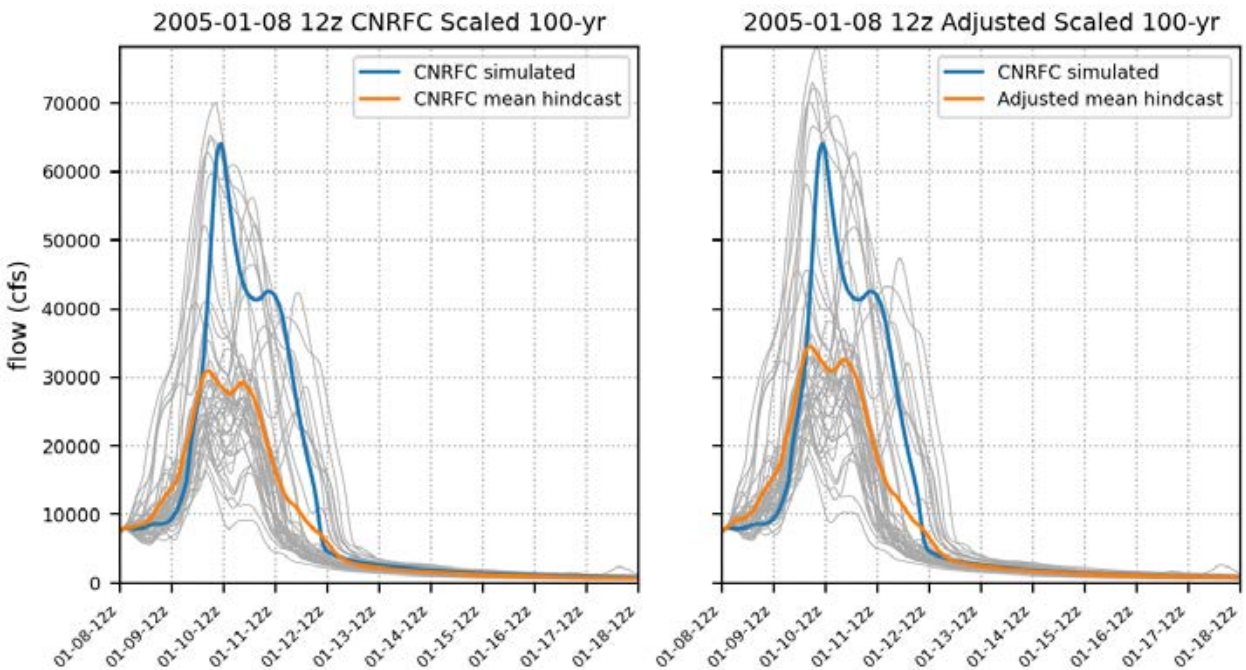
100-yr 1/6/2005



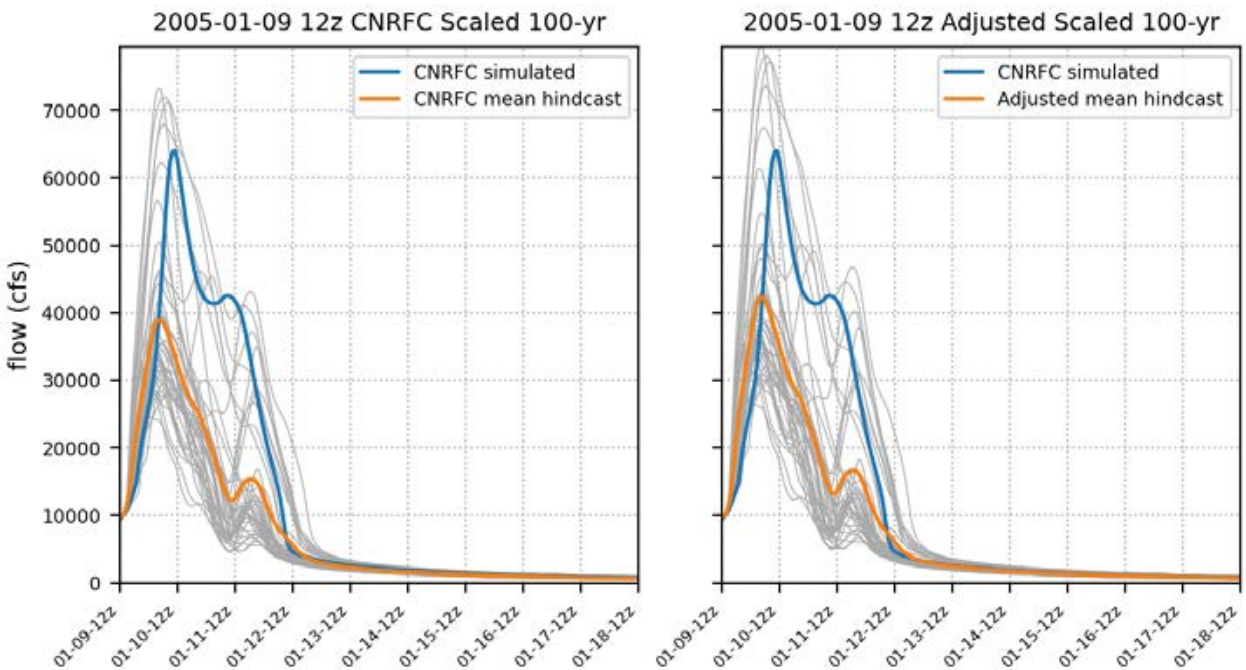
100-yr 1/7/2005



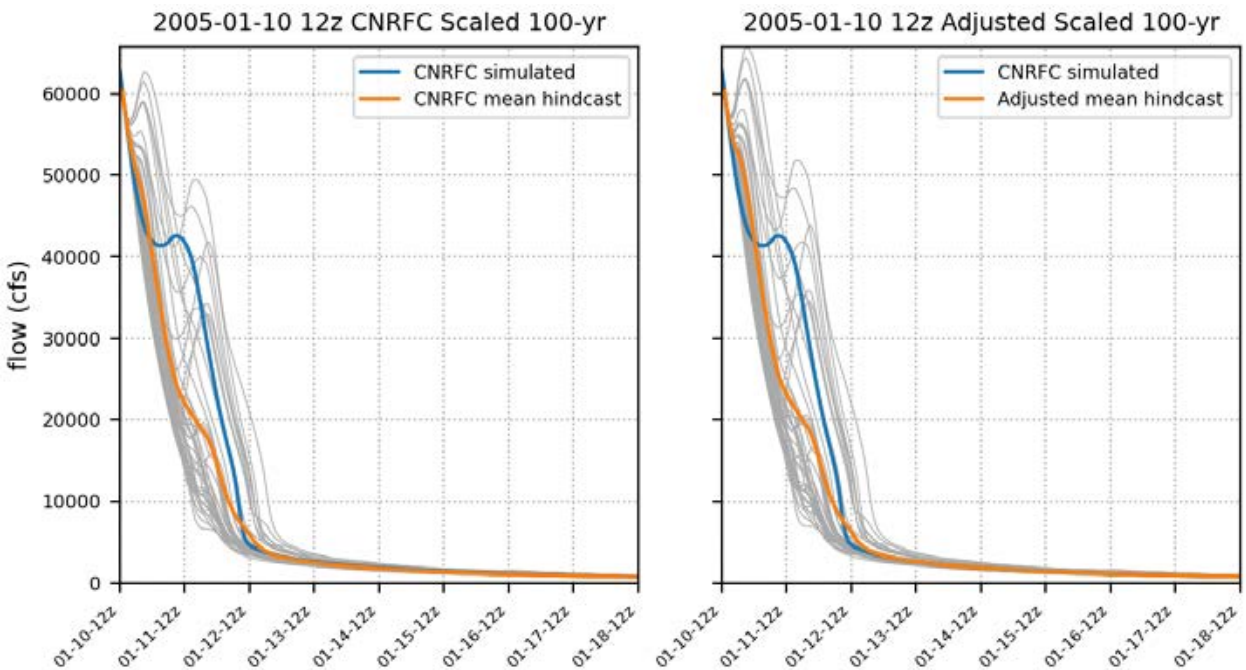
100-yr 1/8/2005



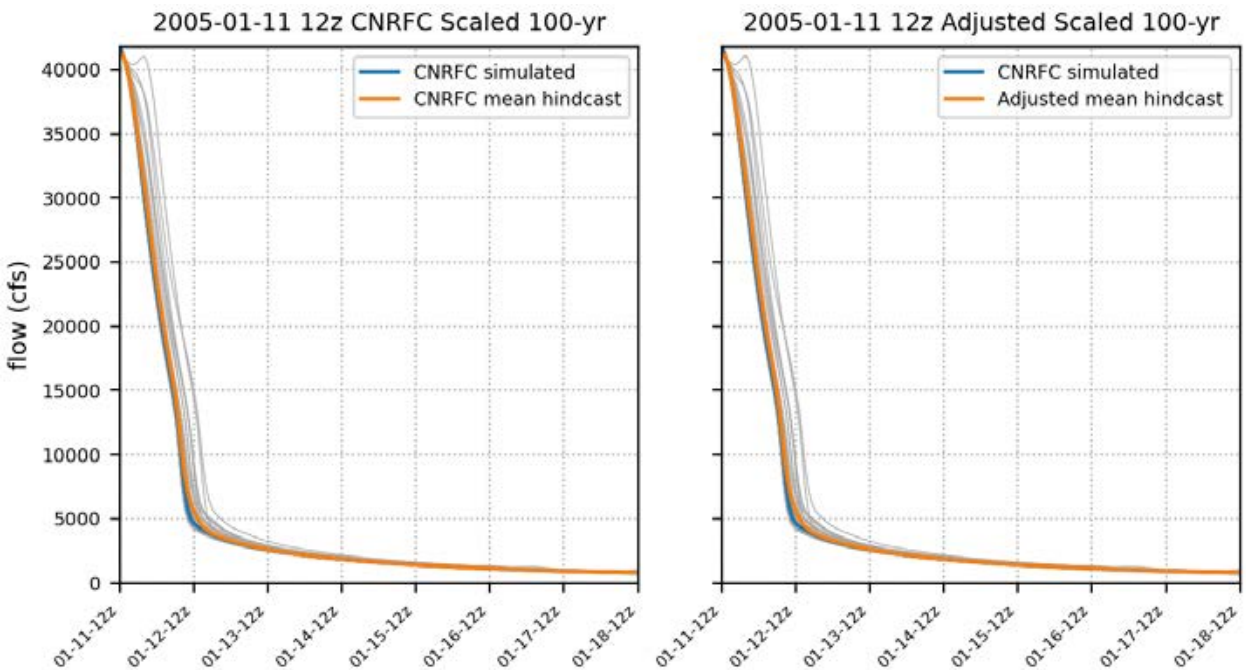
100-yr 1/9/2005



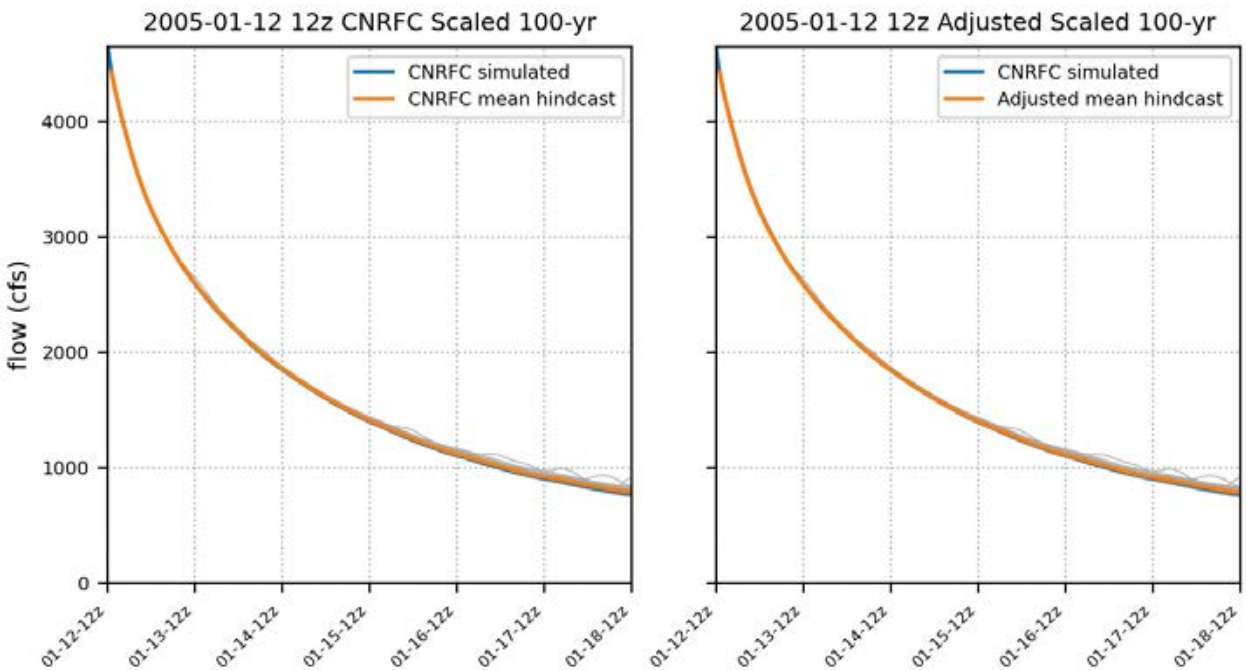
100-yr 1/10/2005



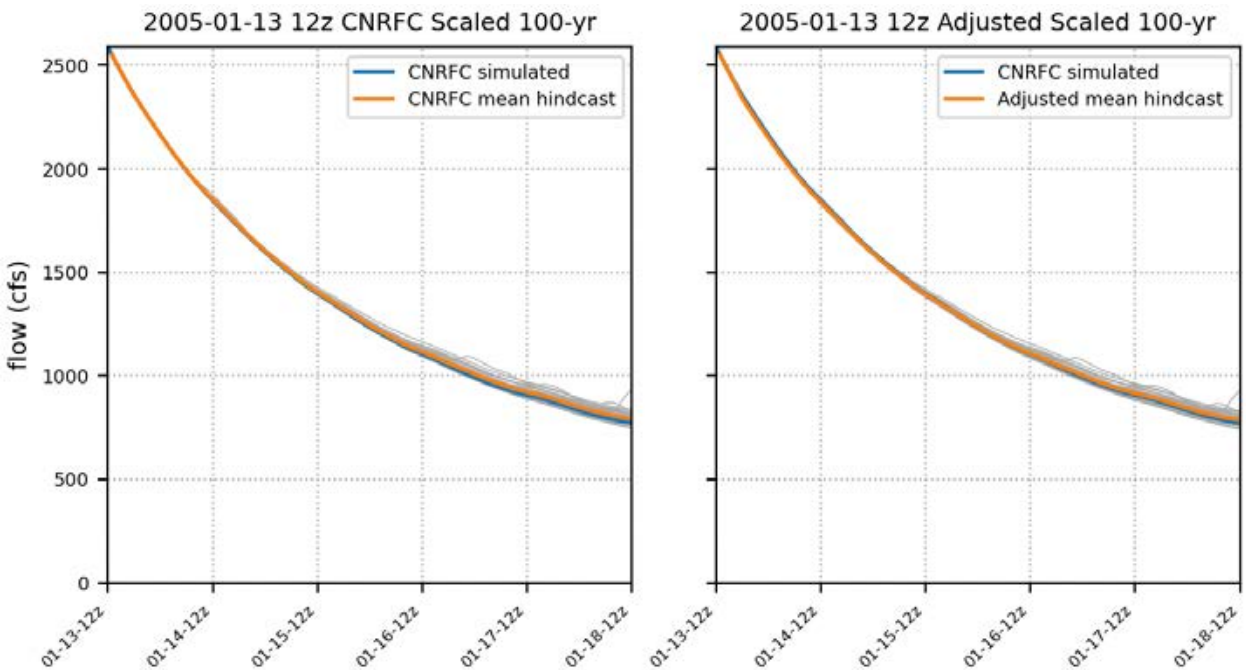
100-yr 1/11/2005



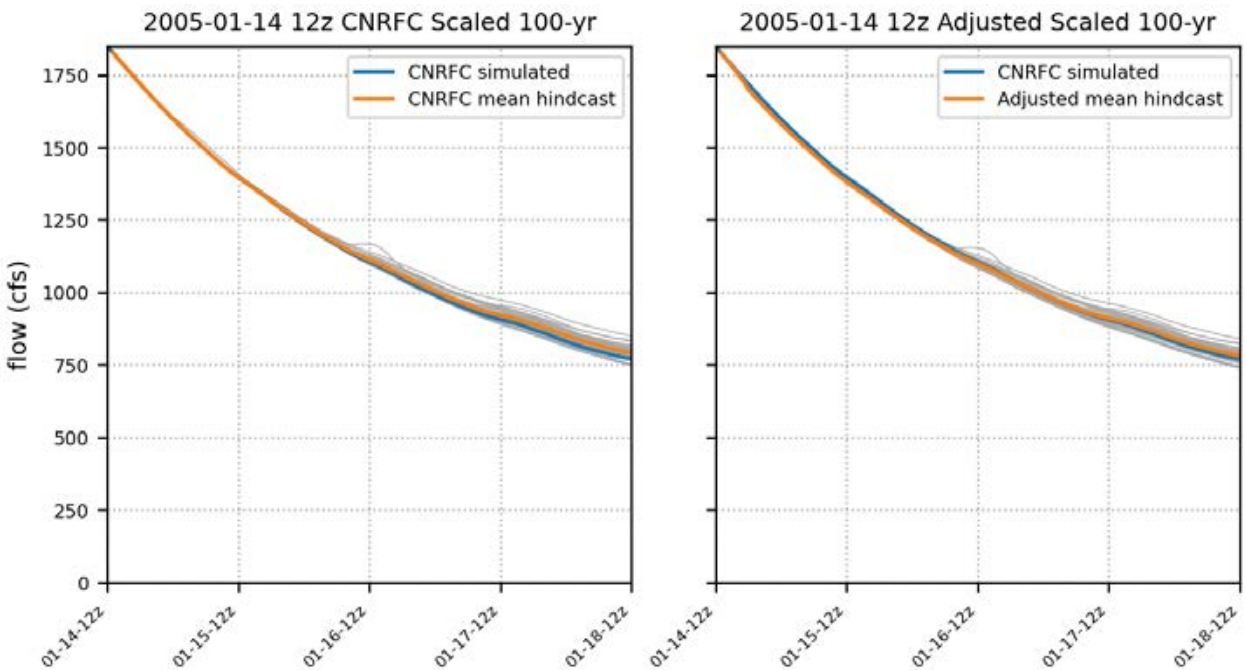
100-yr 1/12/2005



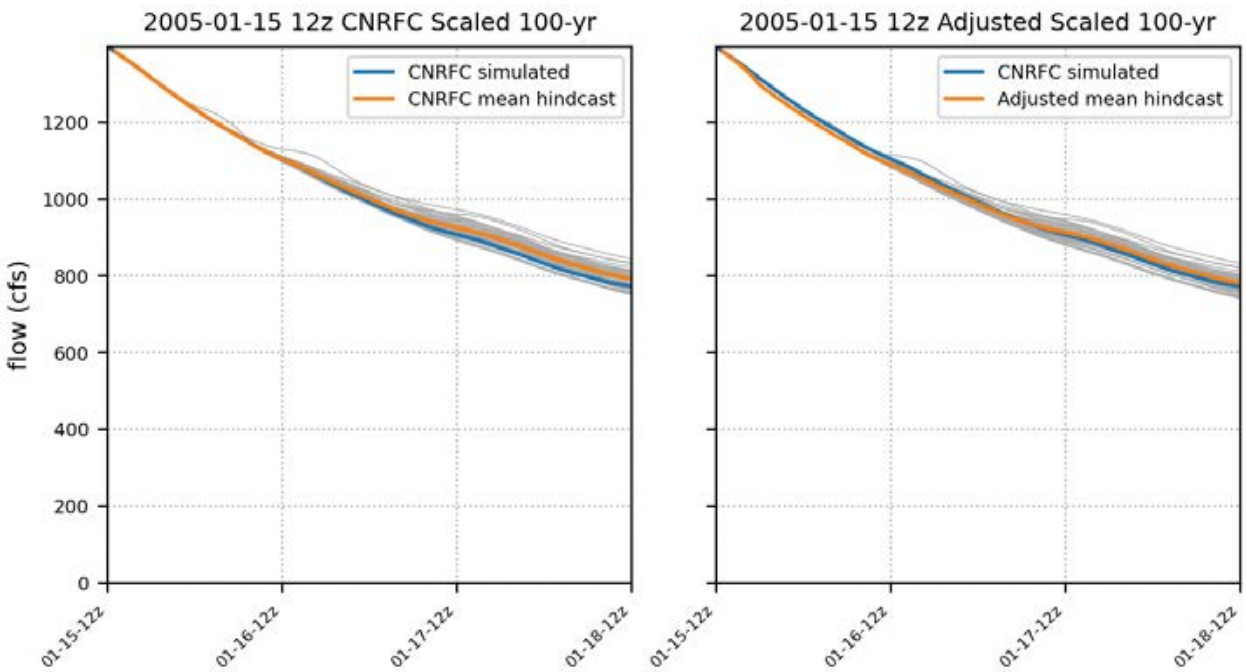
100-yr 1/13/2005



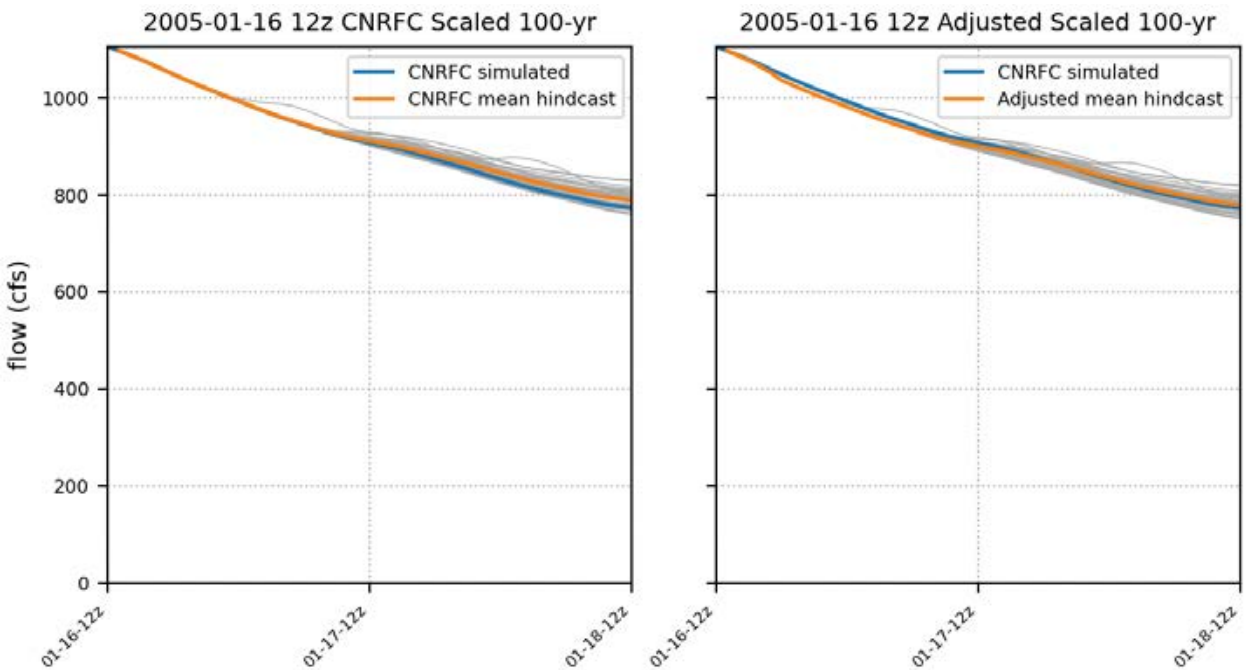
100-yr 1/14/2005



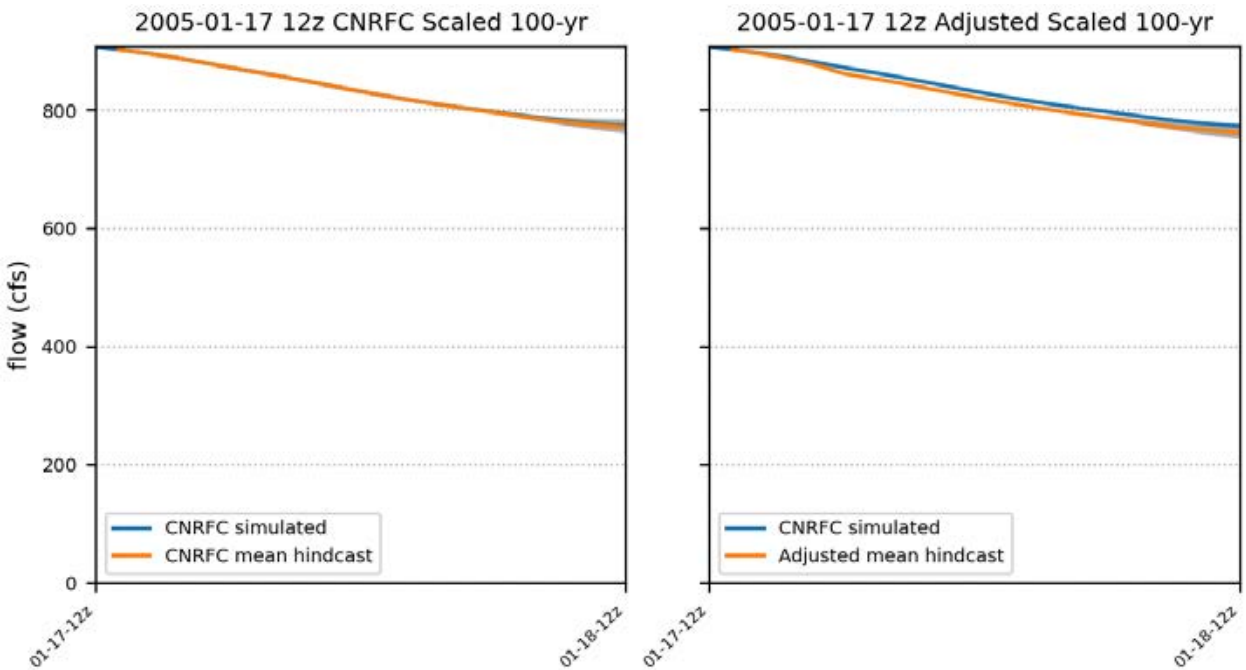
100-yr 1/15/2005



100-yr 1/16/2005



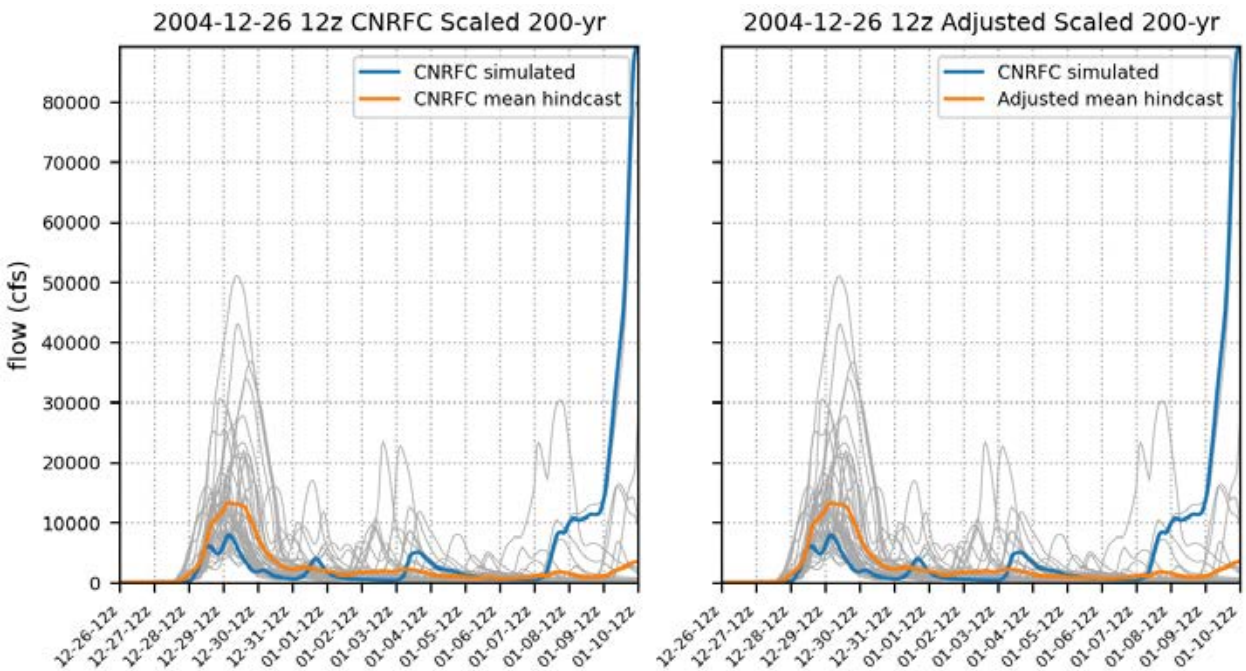
100-yr 1/17/2005



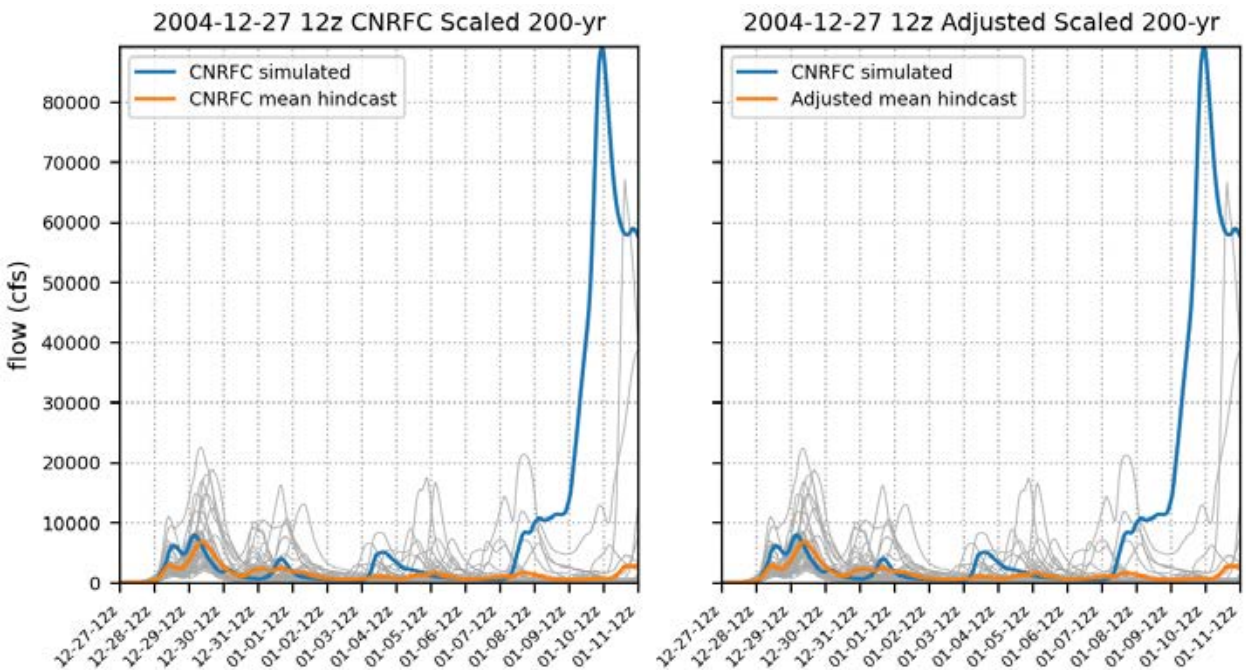
Adjusted Scaled Hindcast 2005 200-yr

2023-03-25

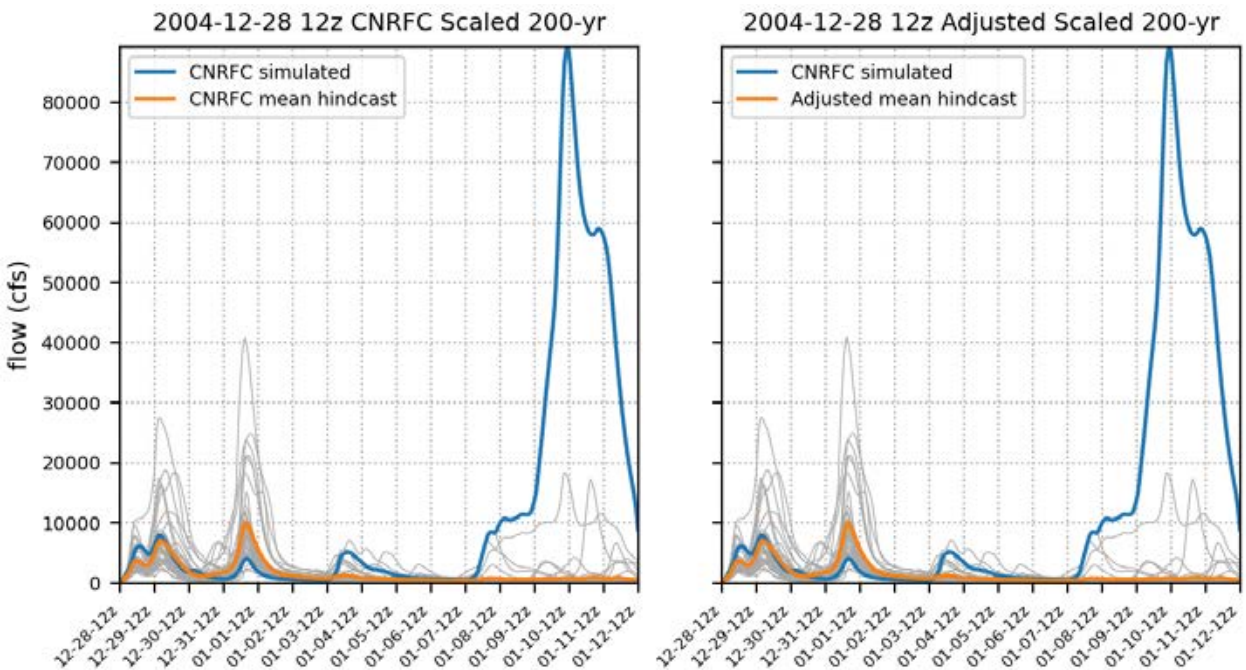
200-yr 12/26/2005



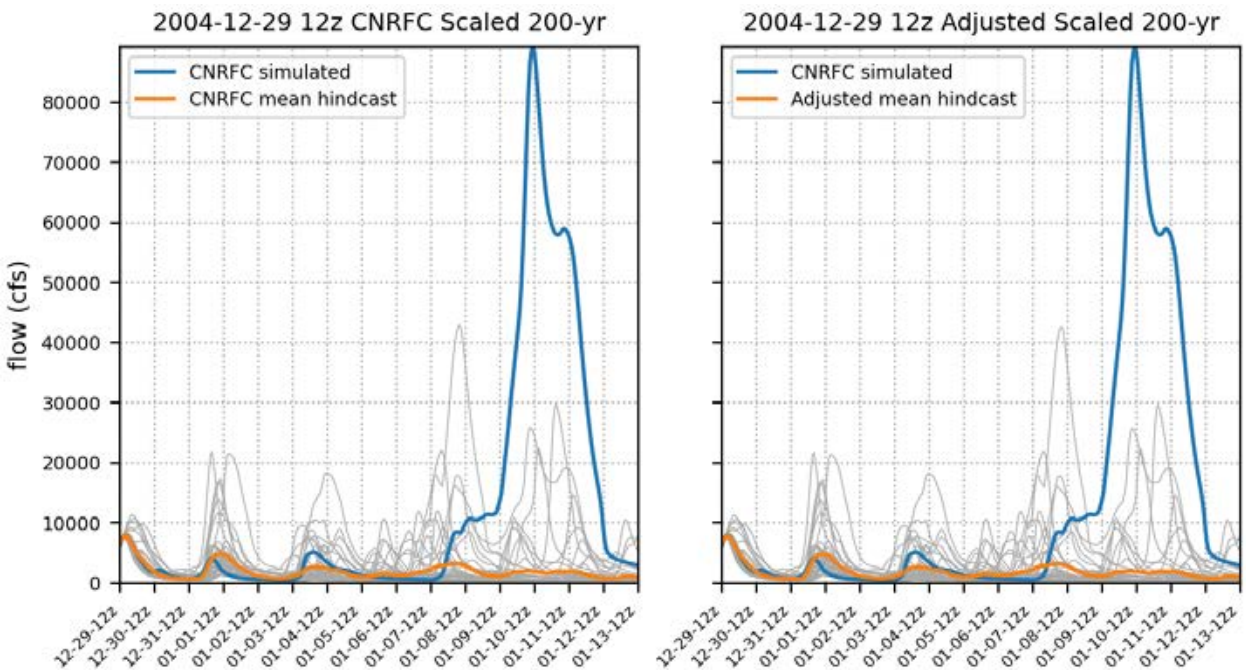
200-yr 12/27/2005



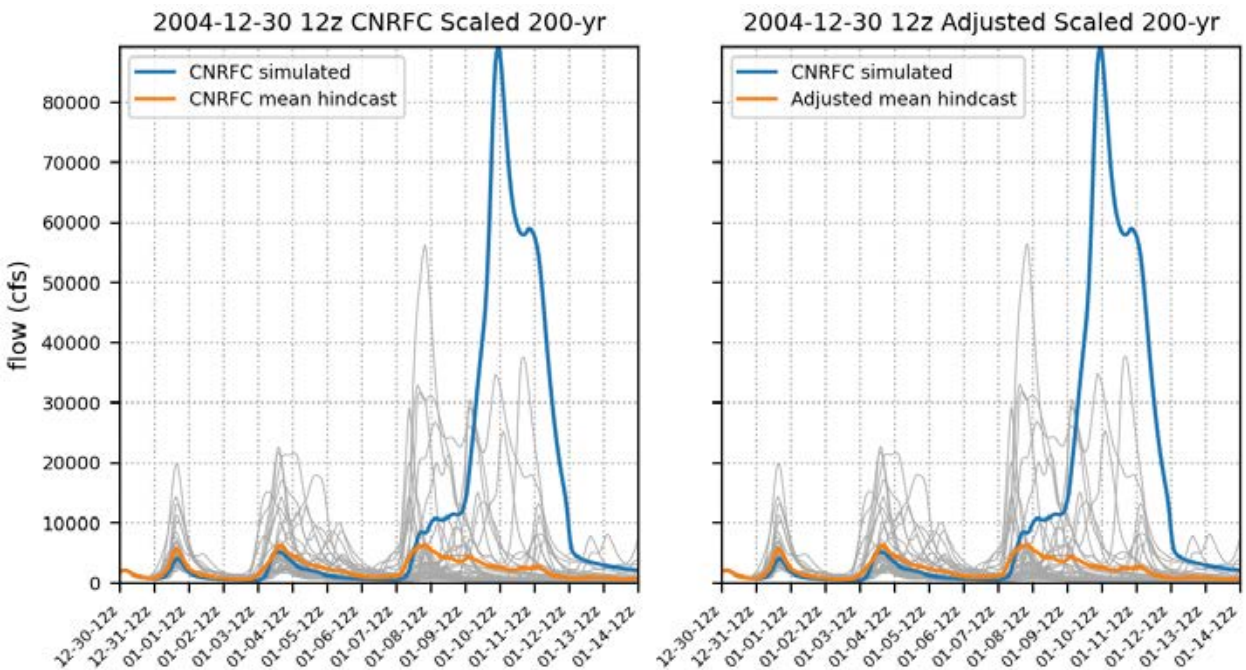
200-yr 12/28/2005



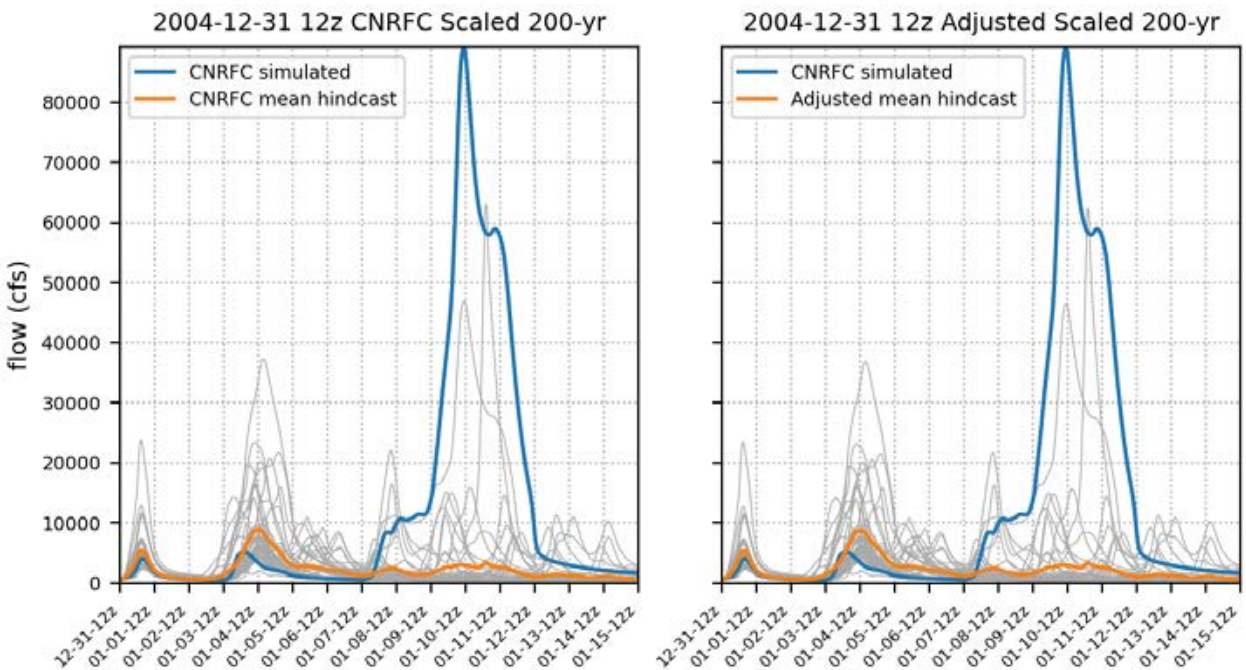
200-yr 12/29/2005



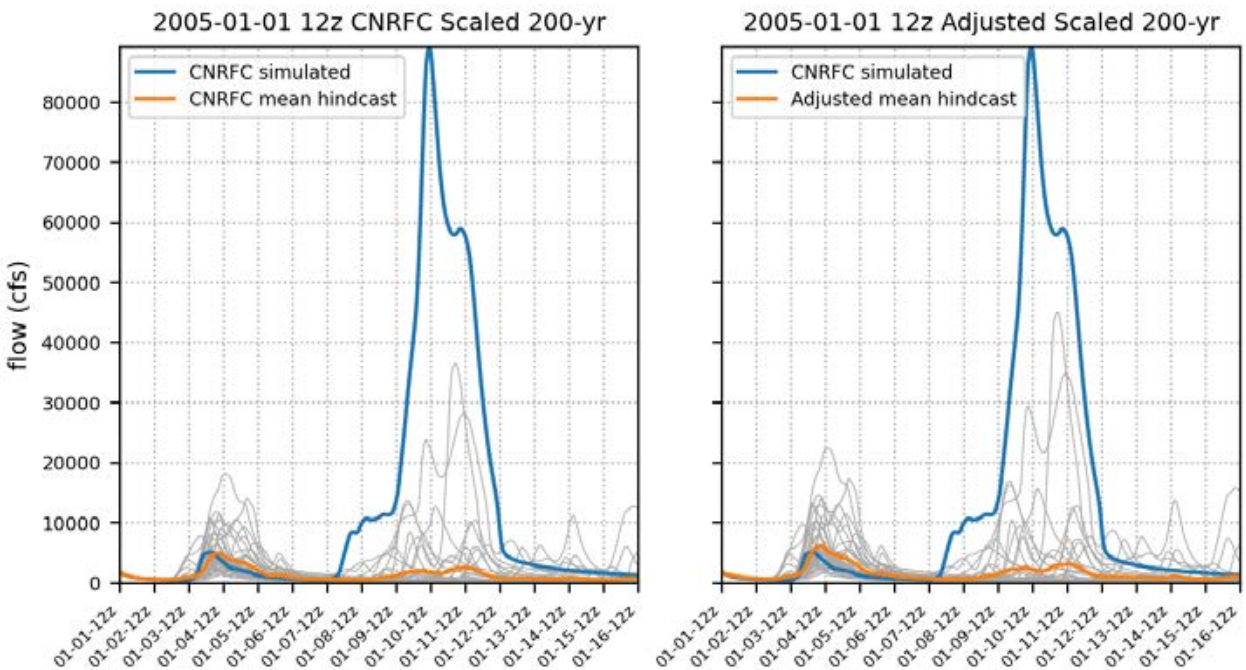
200-yr 12/30/2005



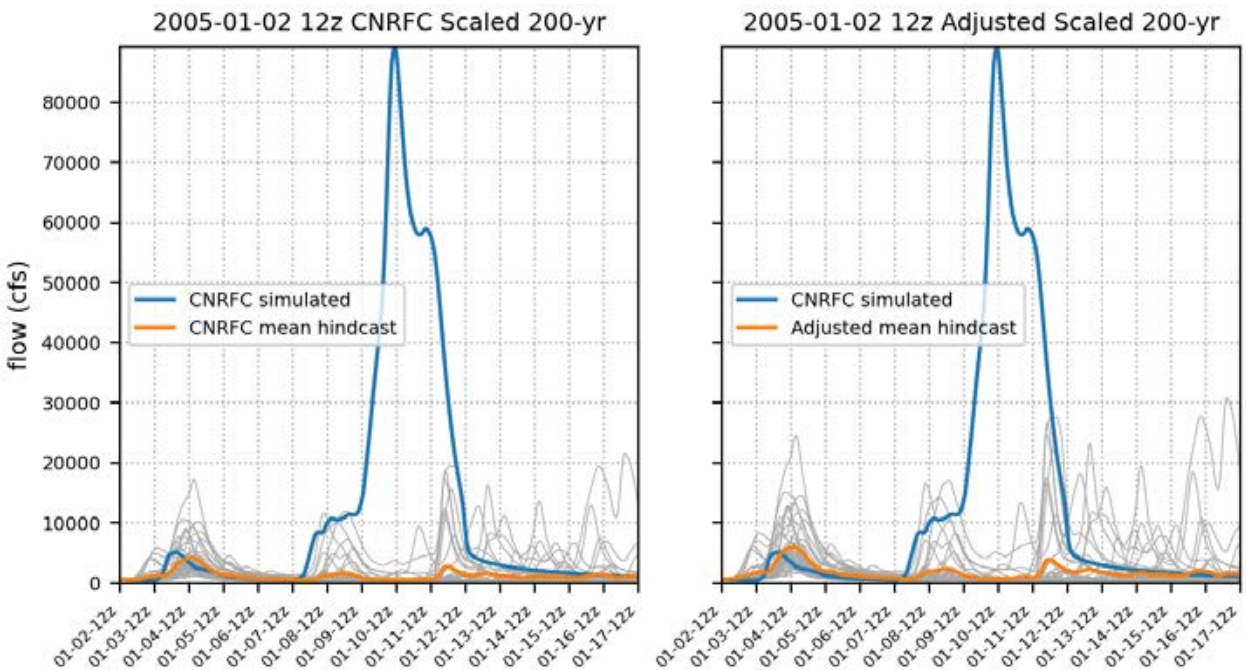
200-yr 12/31/2005



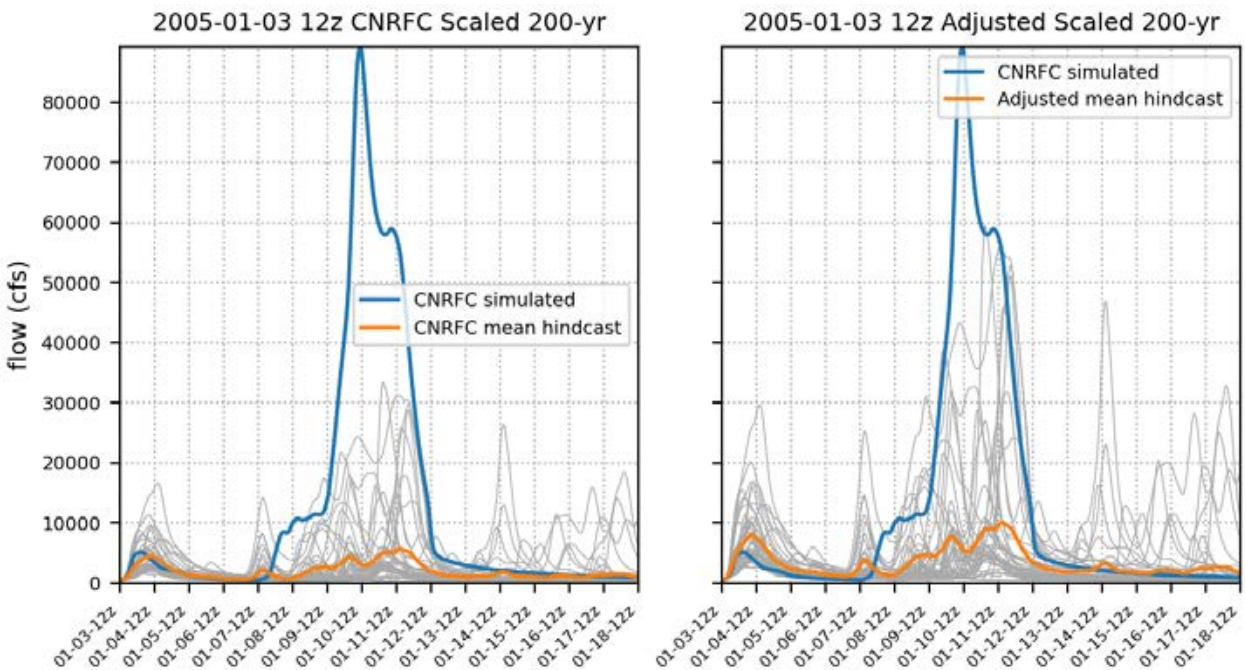
200-yr 1/1/2005



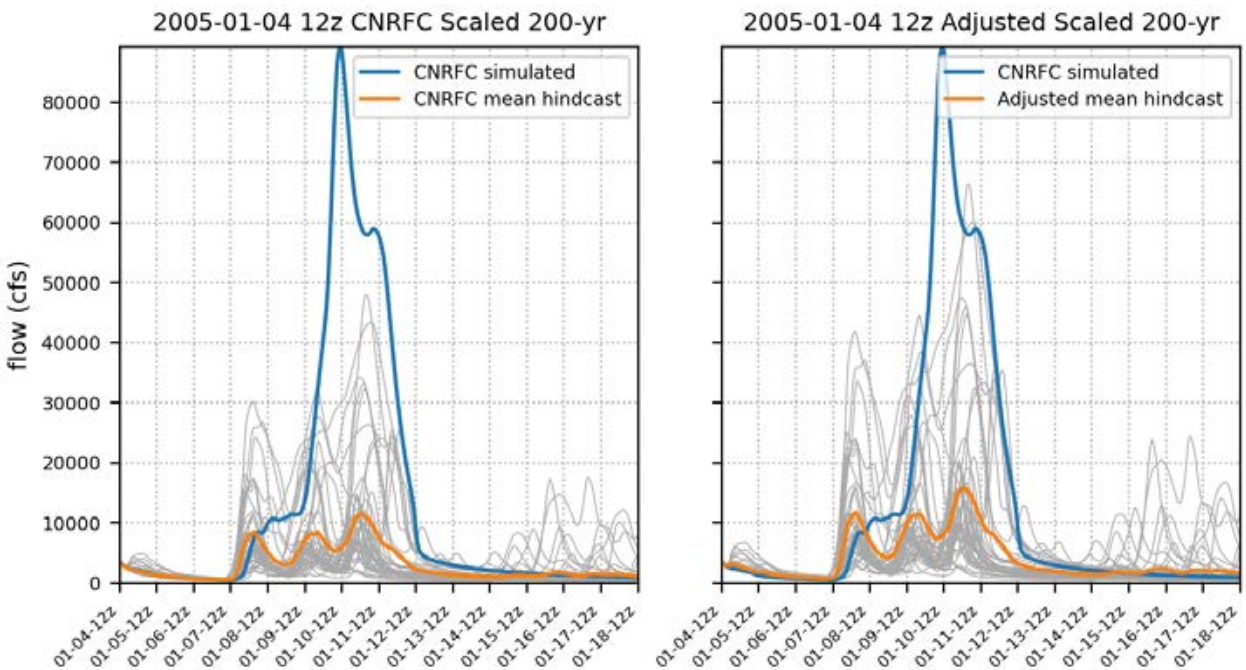
200-yr 1/2/2005



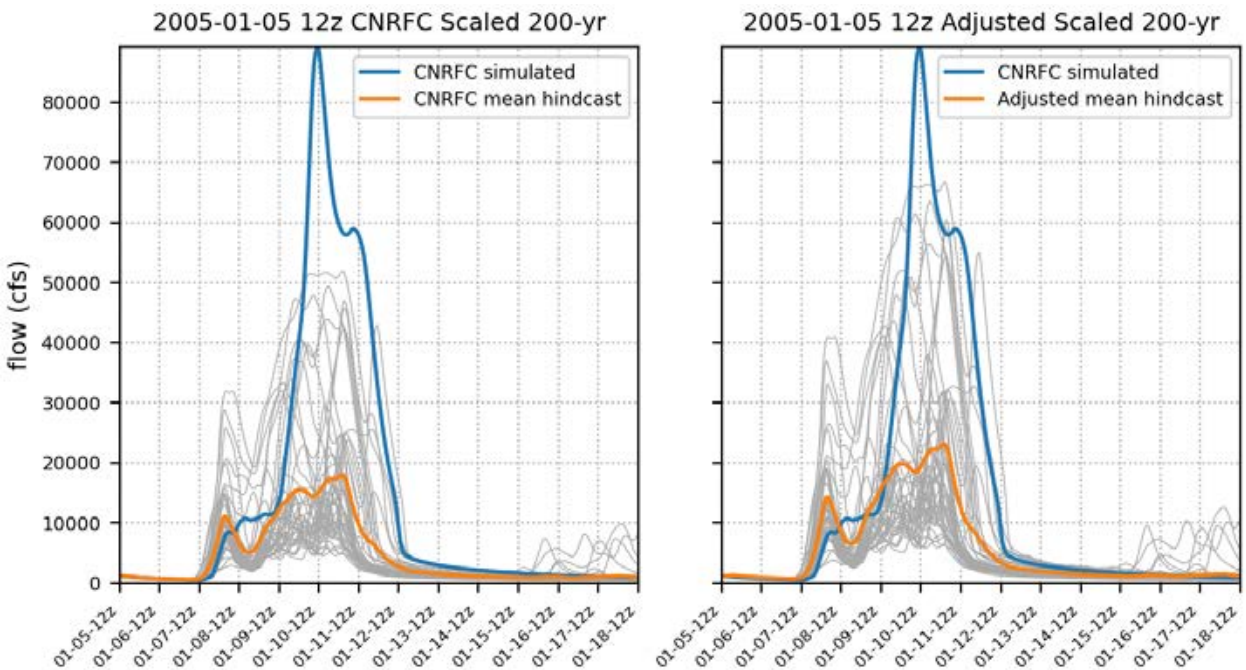
200-yr 1/3/2005



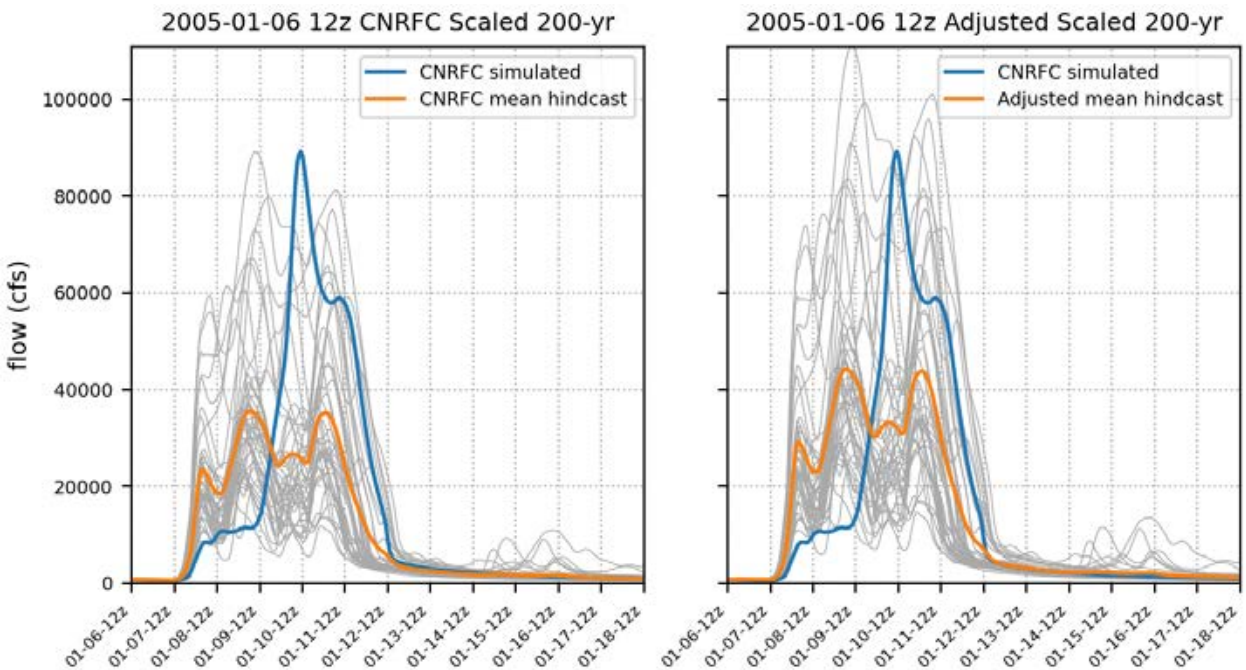
200-yr 1/4/2005



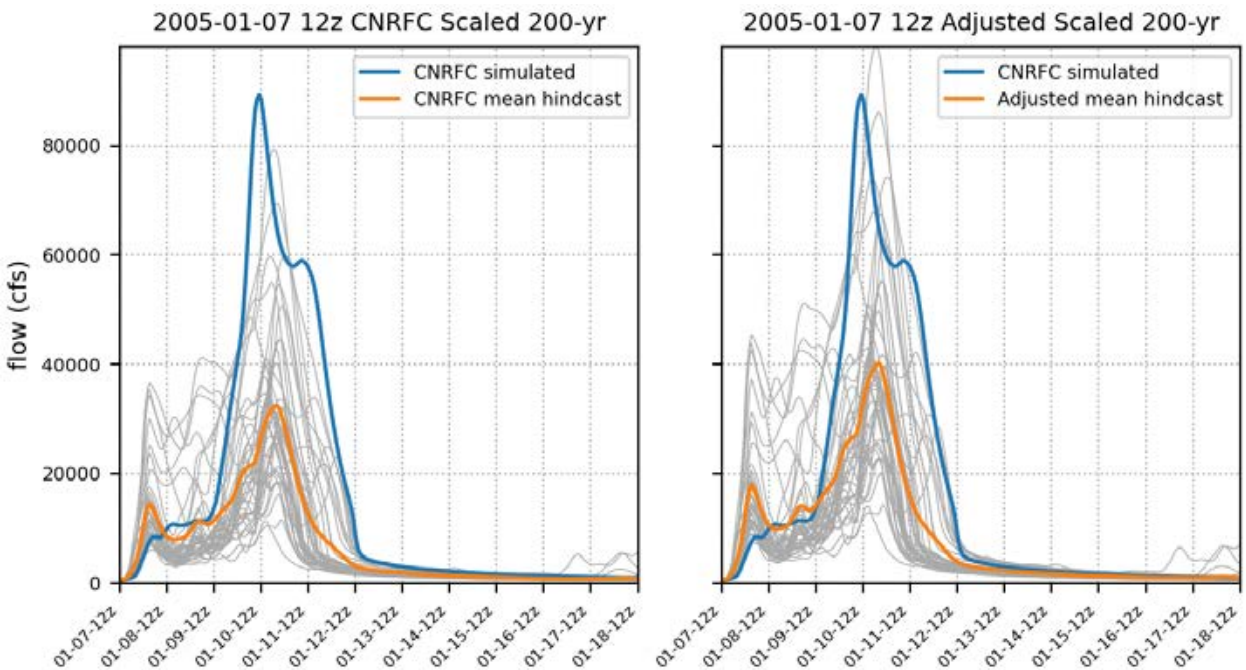
200-yr 1/5/2005



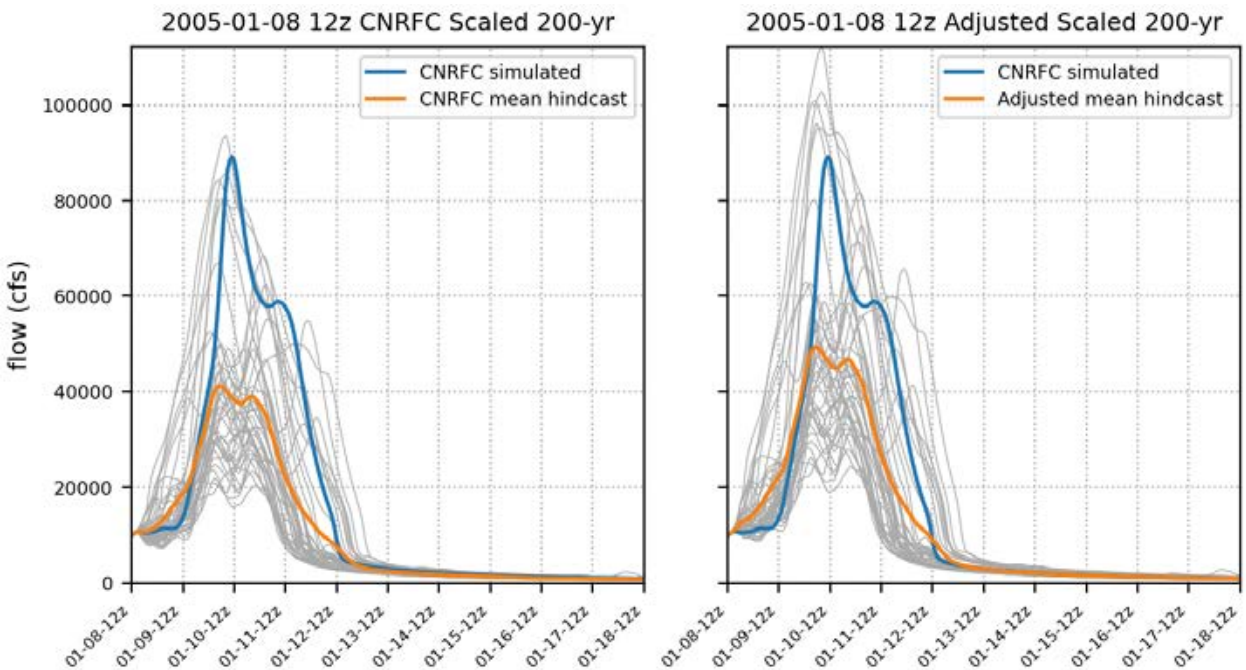
200-yr 1/6/2005



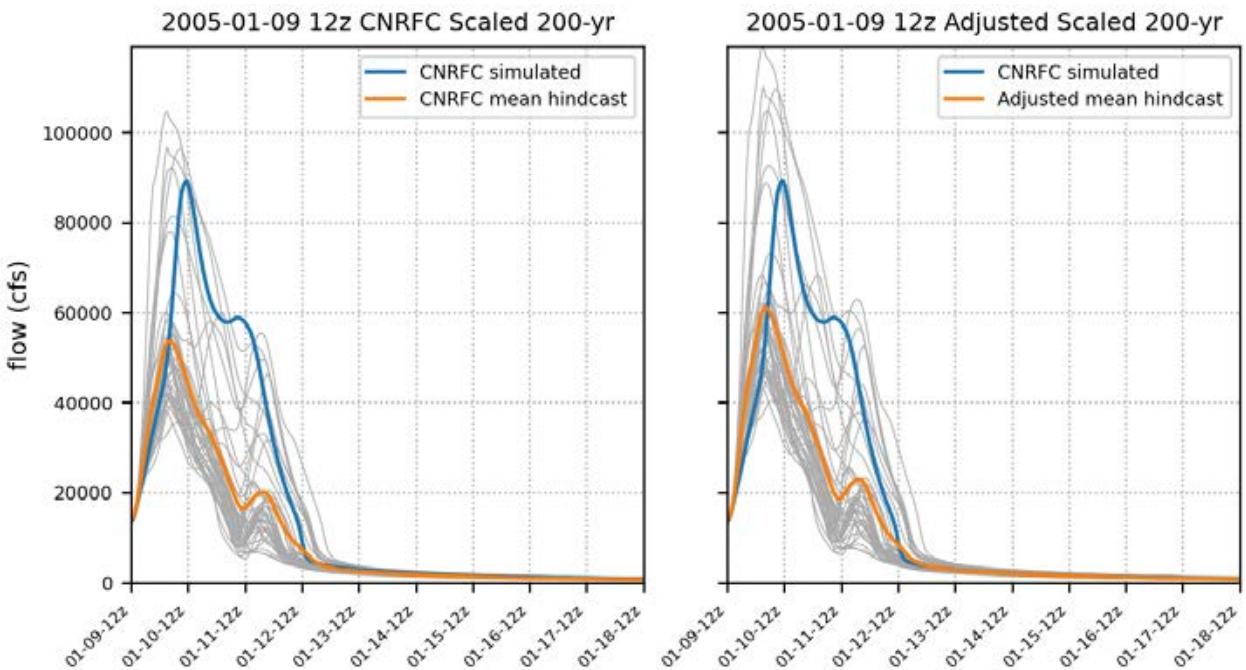
200-yr 1/7/2005



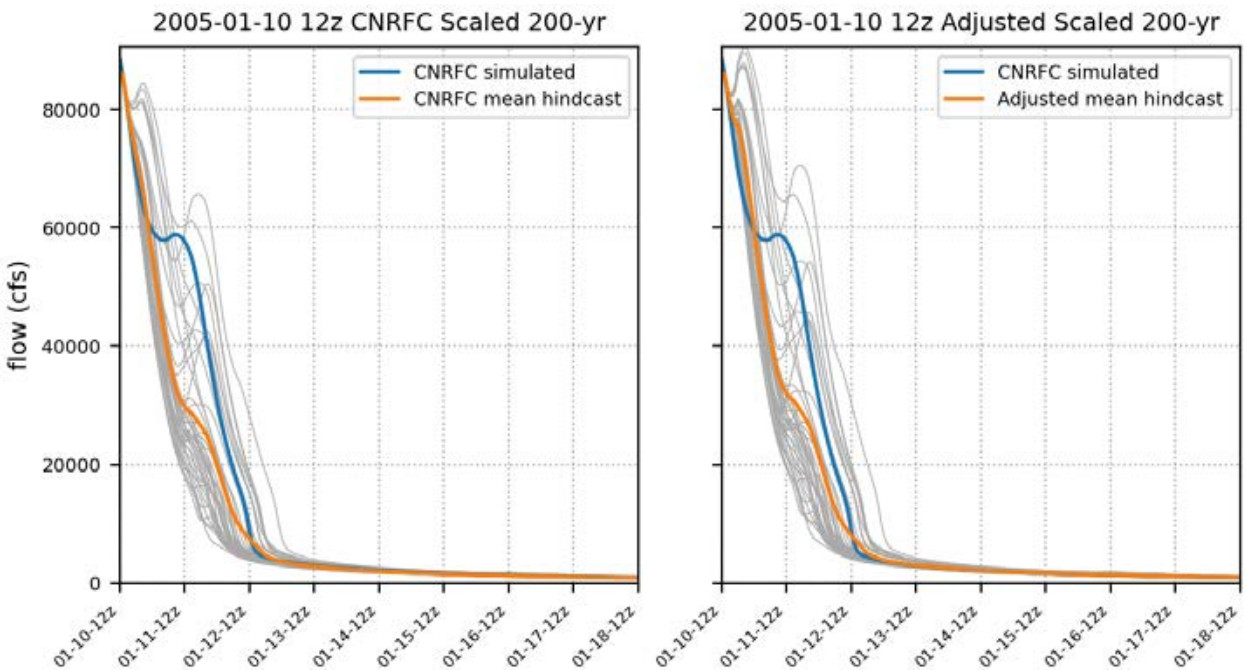
200-yr 1/8/2005



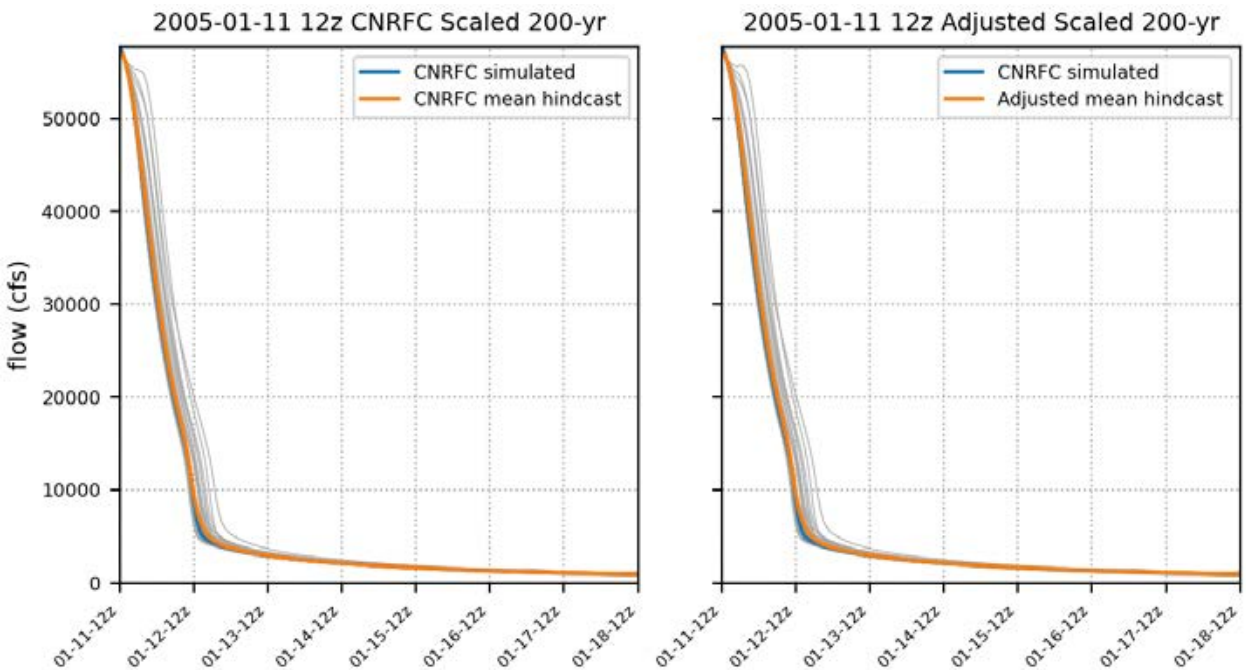
200-yr 1/9/2005



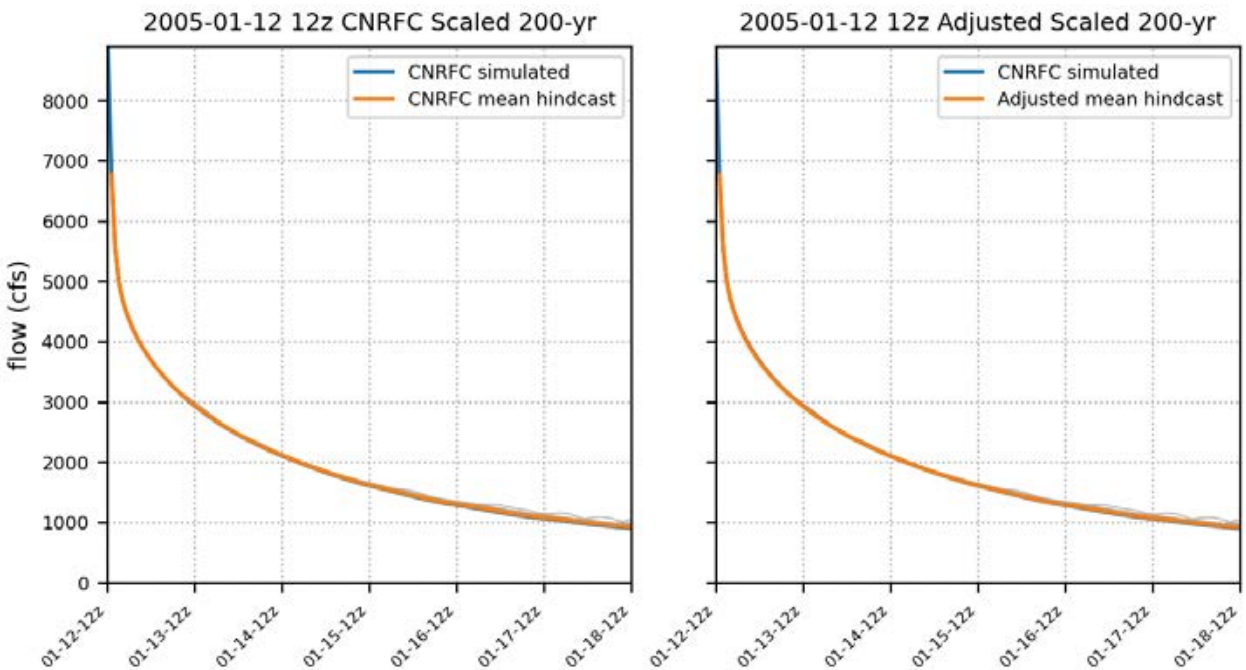
200-yr 1/10/2005



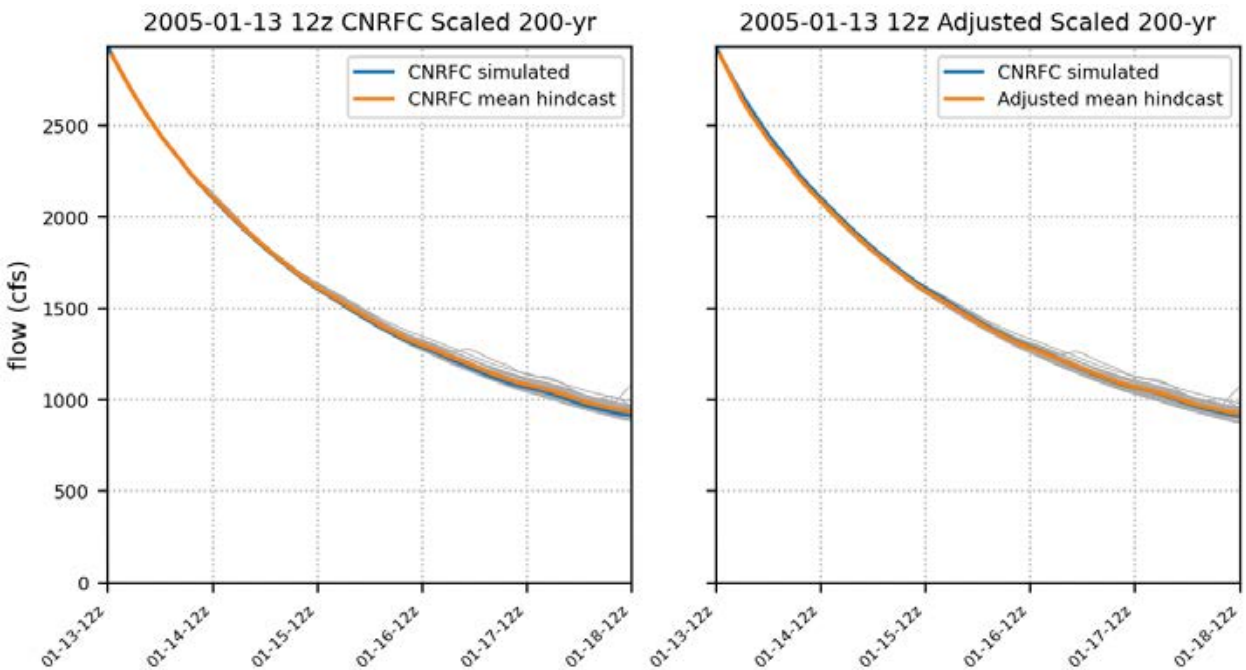
200-yr 1/11/2005



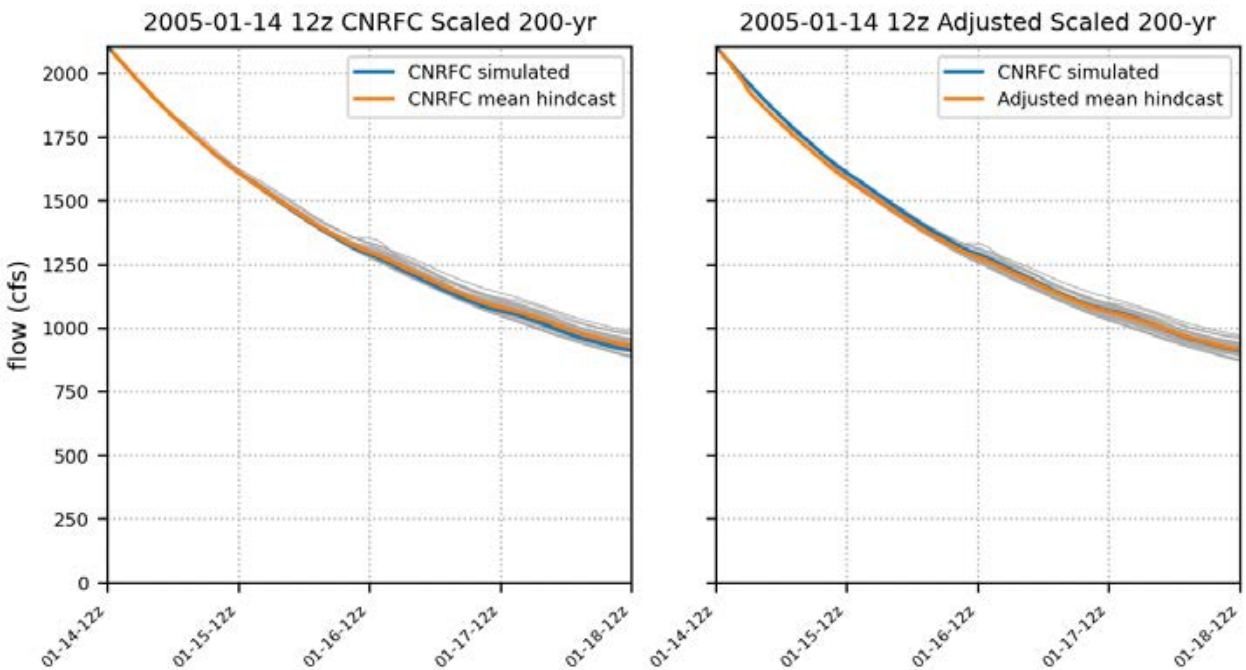
200-yr 1/12/2005



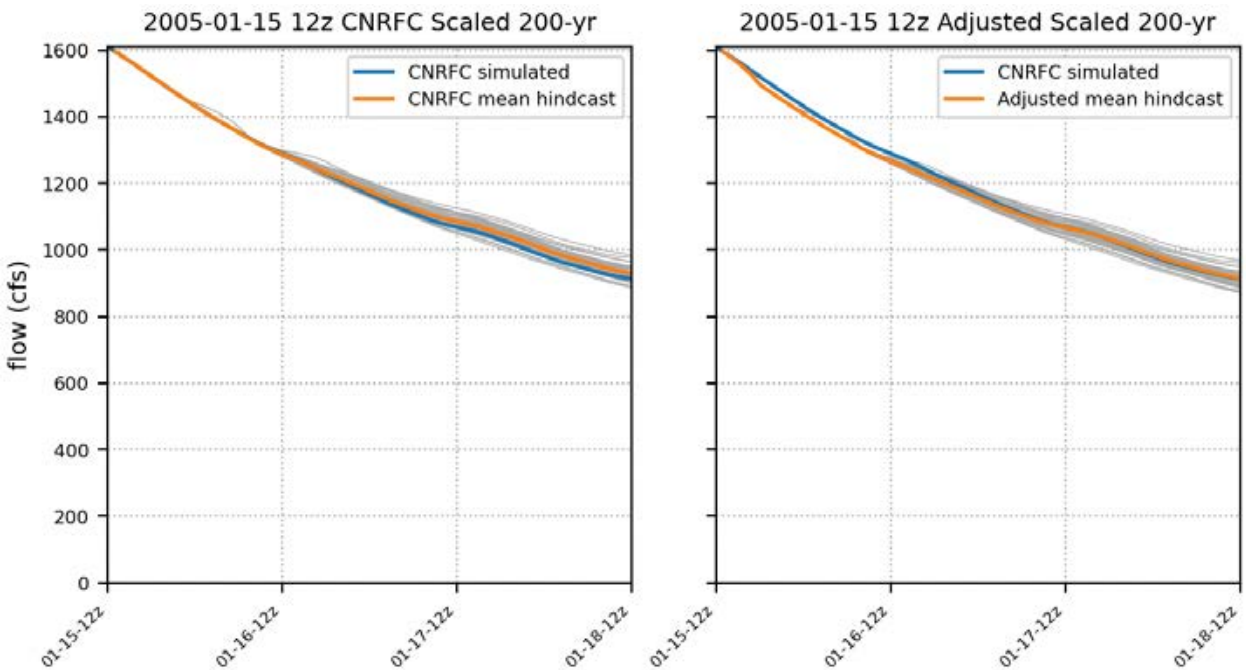
200-yr 1/13/2005



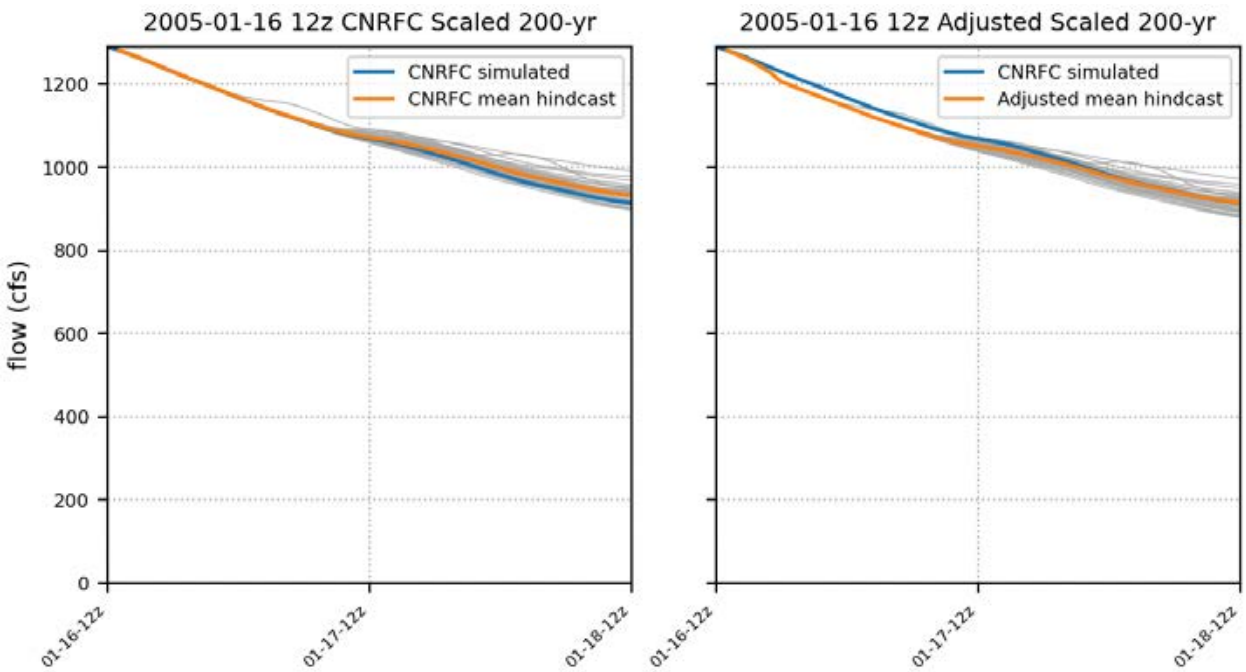
200-yr 1/14/2005



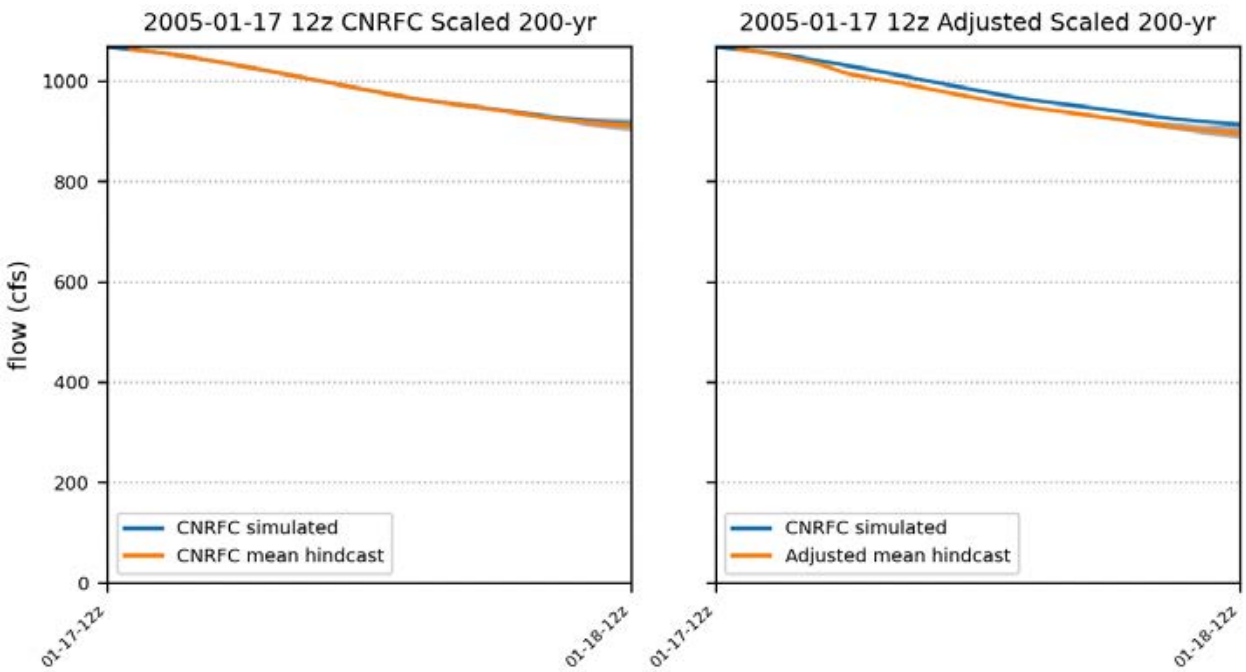
200-yr 1/15/2005



200-yr 1/16/2005



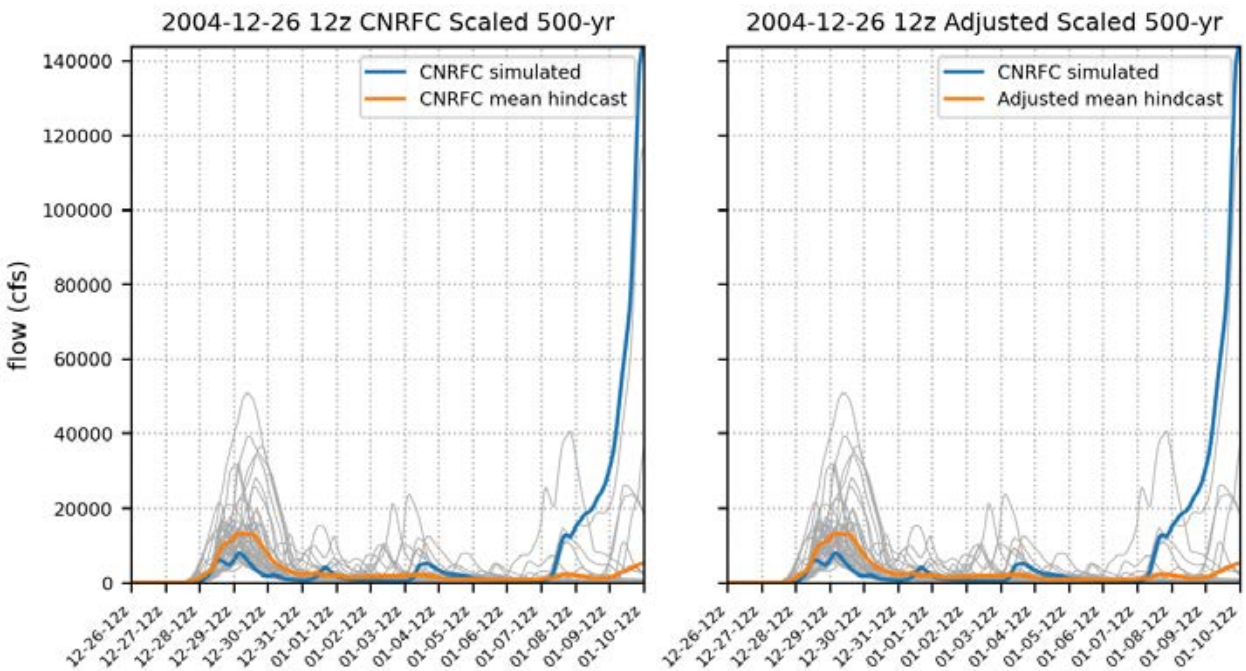
200-yr 1/17/2005



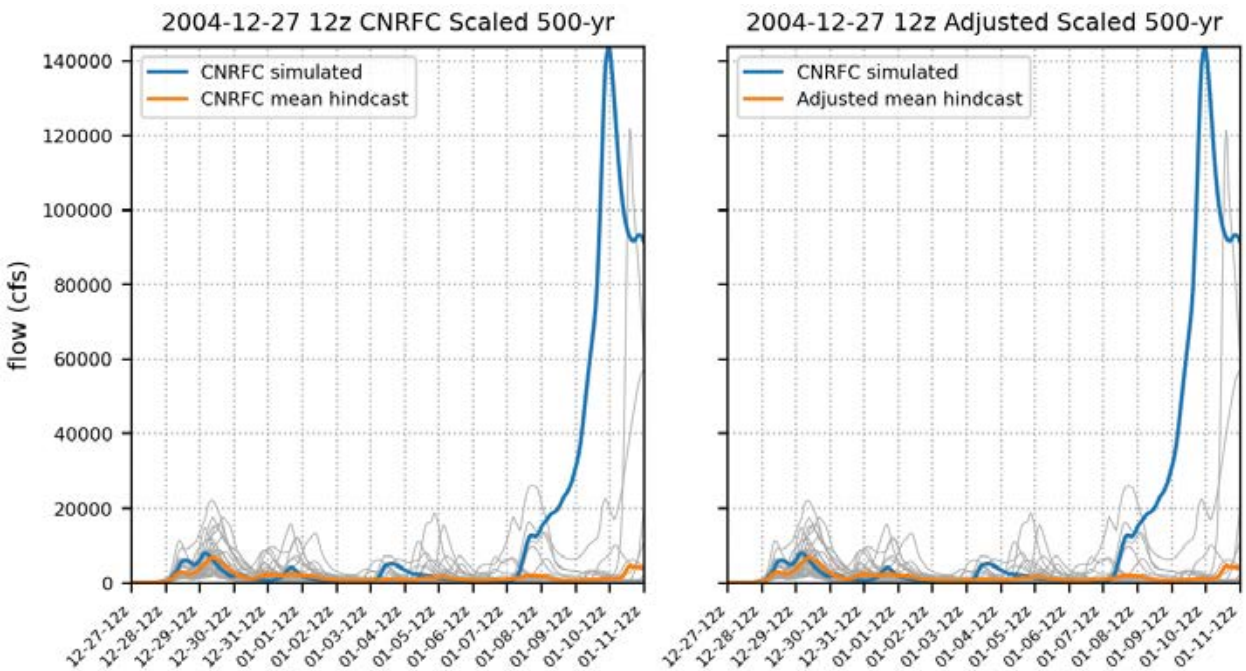
Adjusted Scaled Hindcast 2005 500-yr

2023-03-25

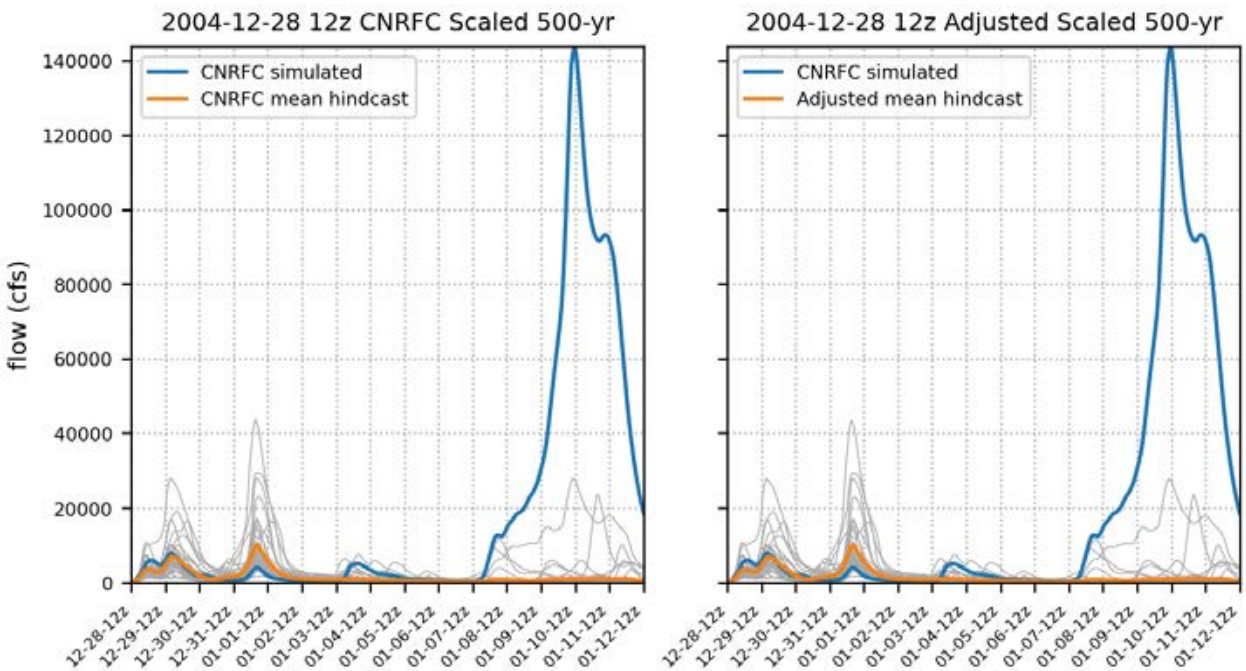
500-yr 12/26/2005



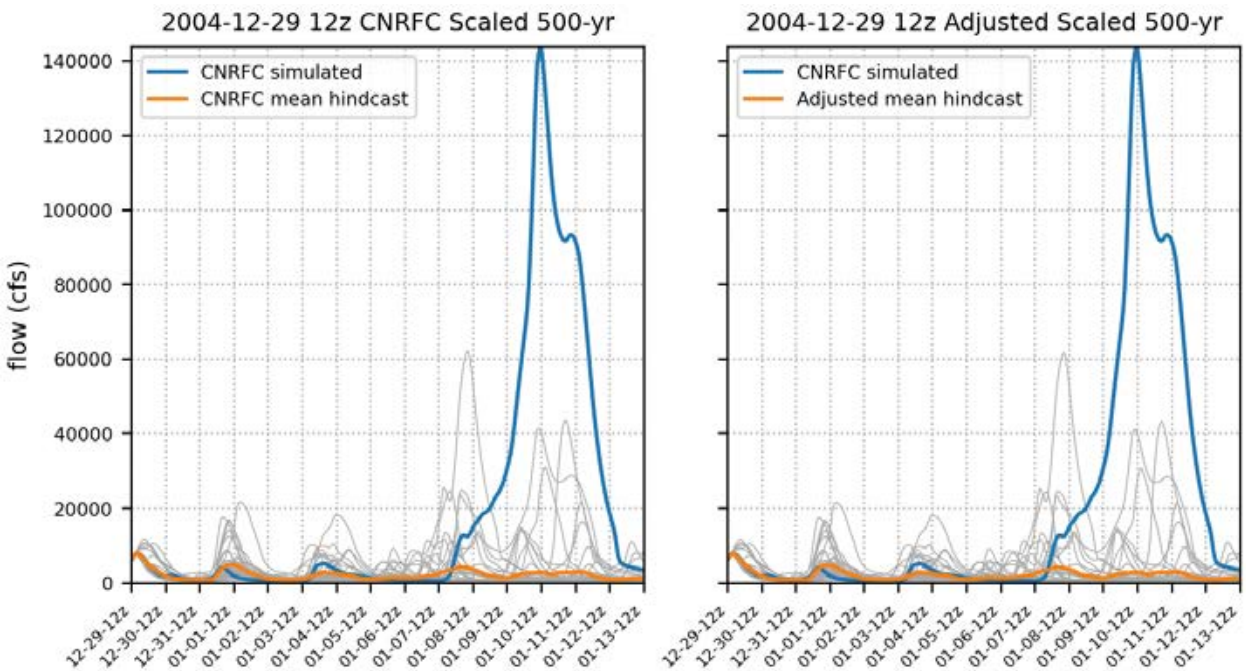
500-yr 12/27/2005



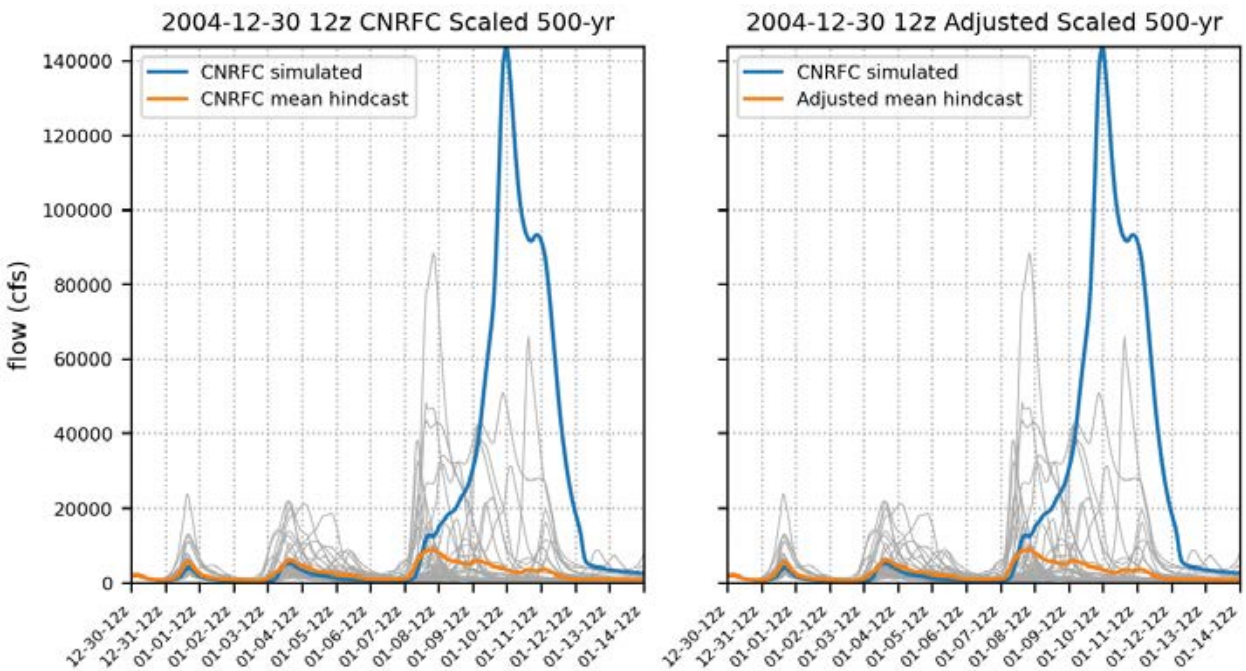
500-yr 12/28/2005



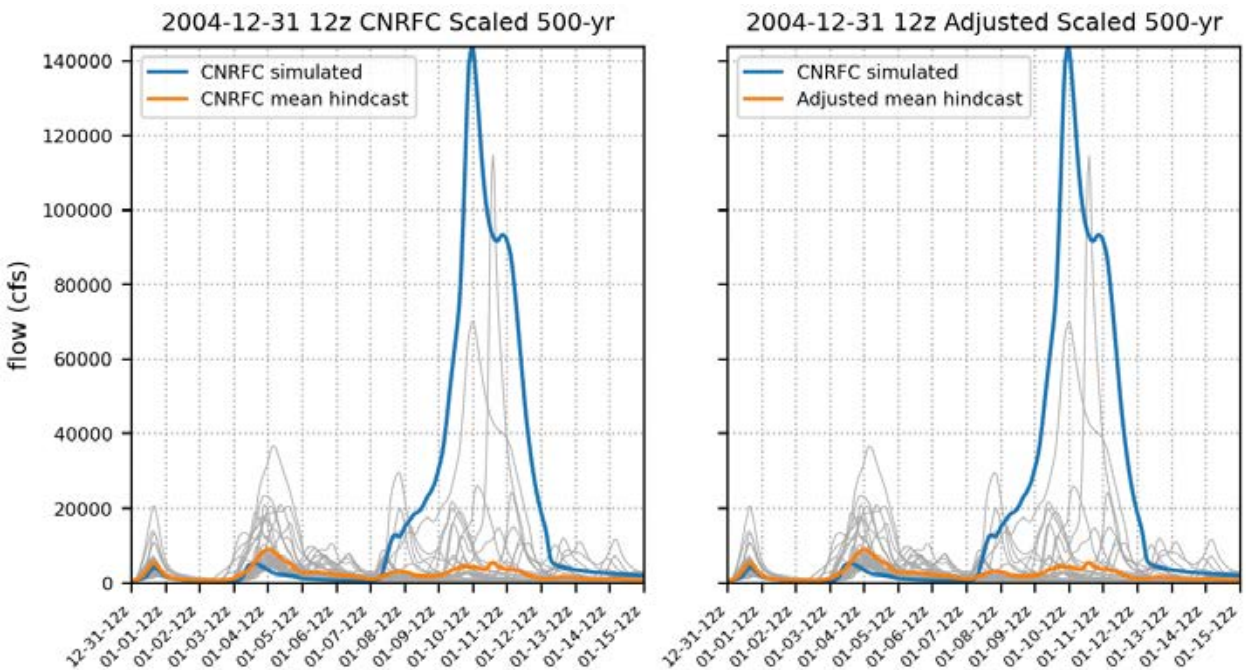
500-yr 12/29/2005



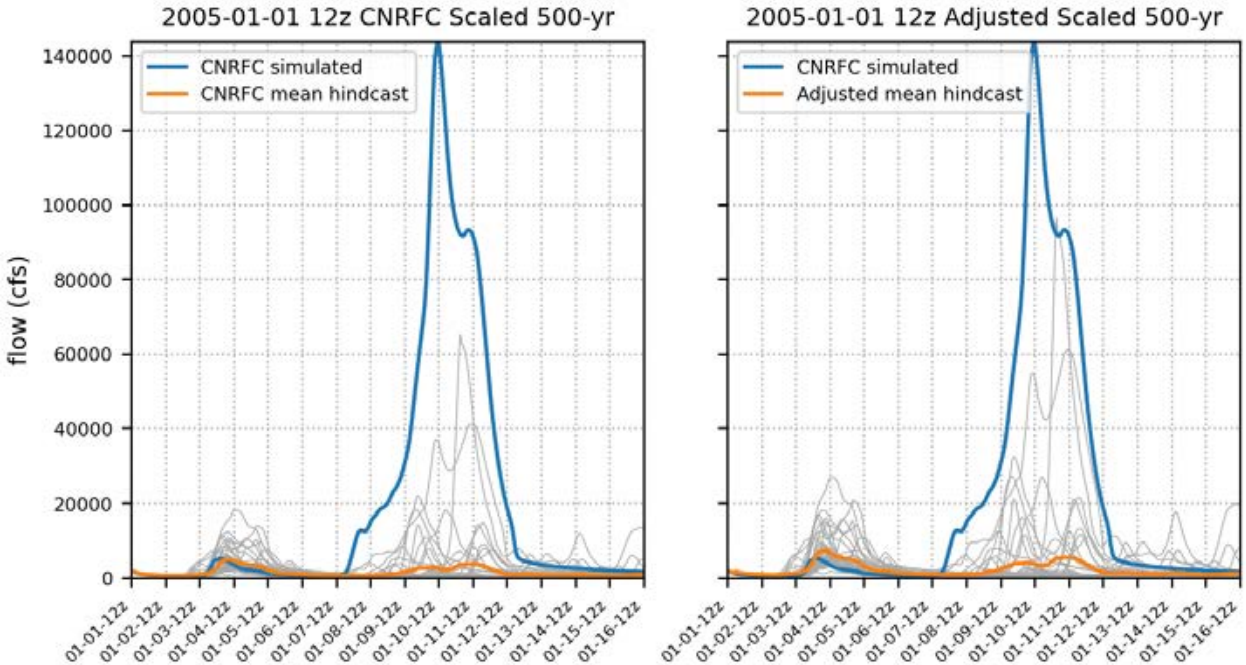
500-yr 12/30/2005



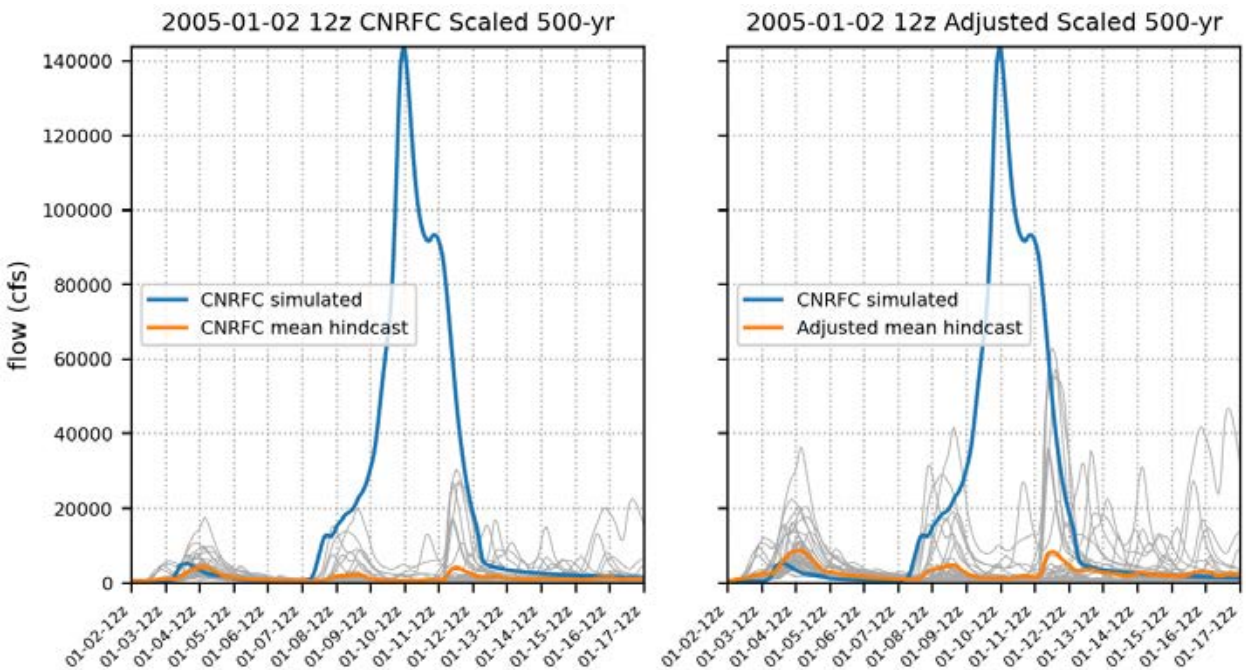
500-yr 12/31/2005



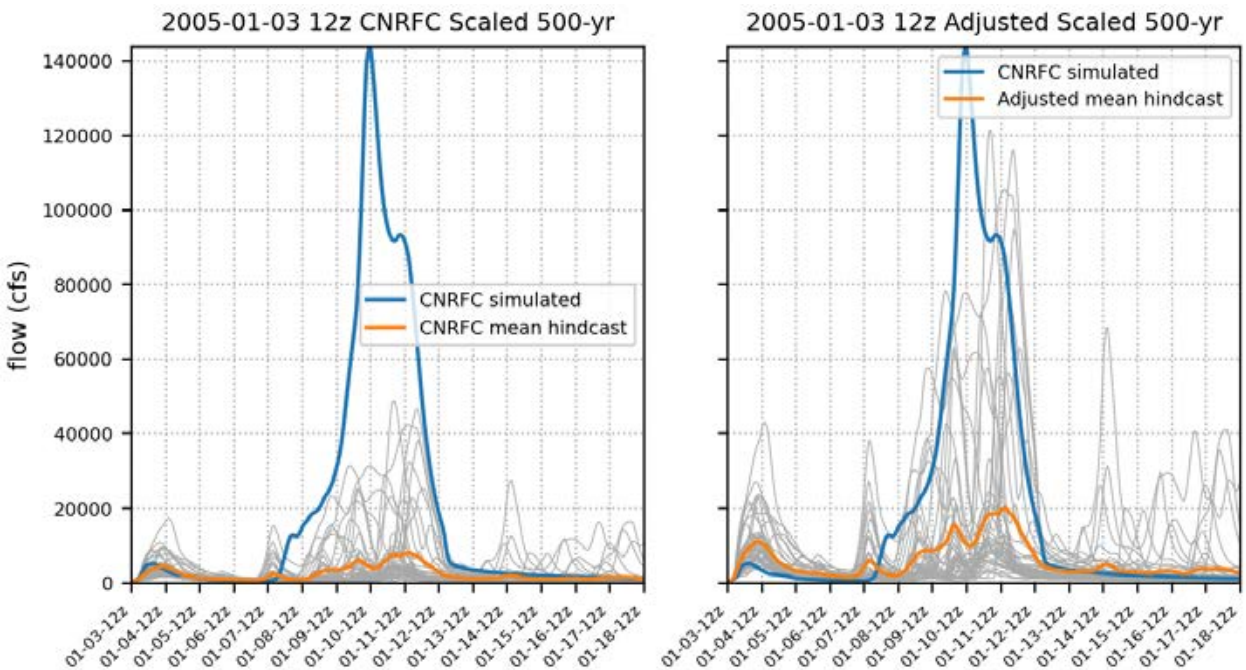
500-yr 1/1/2005



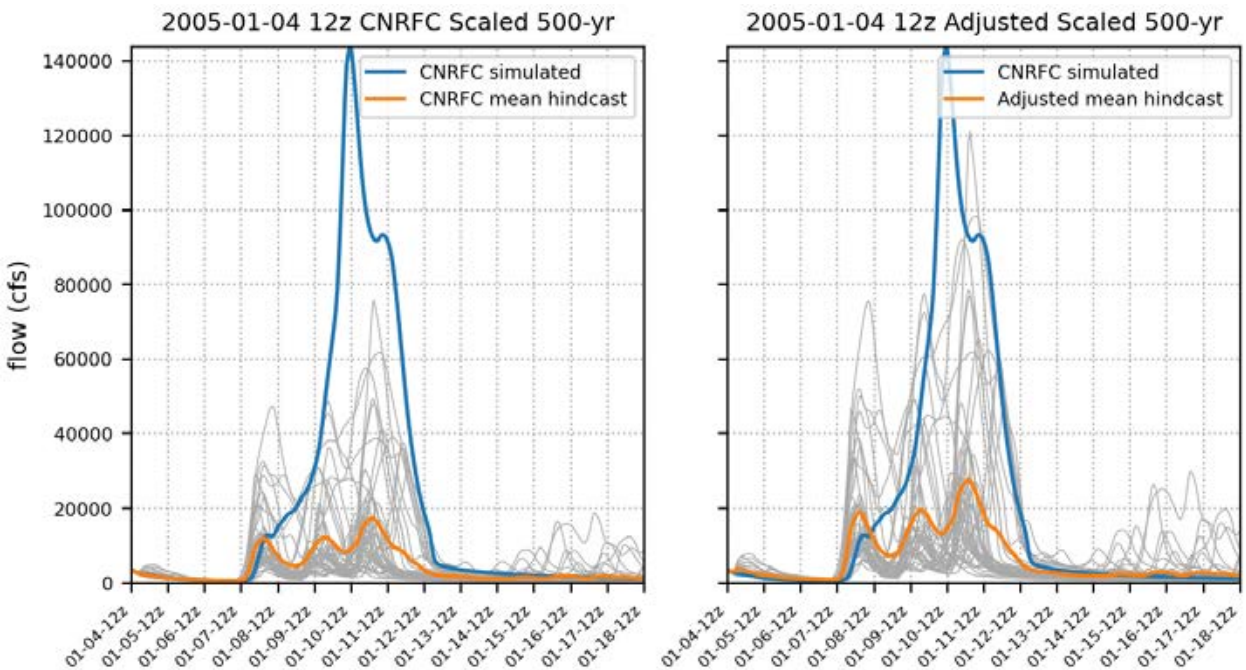
500-yr 1/2/2005



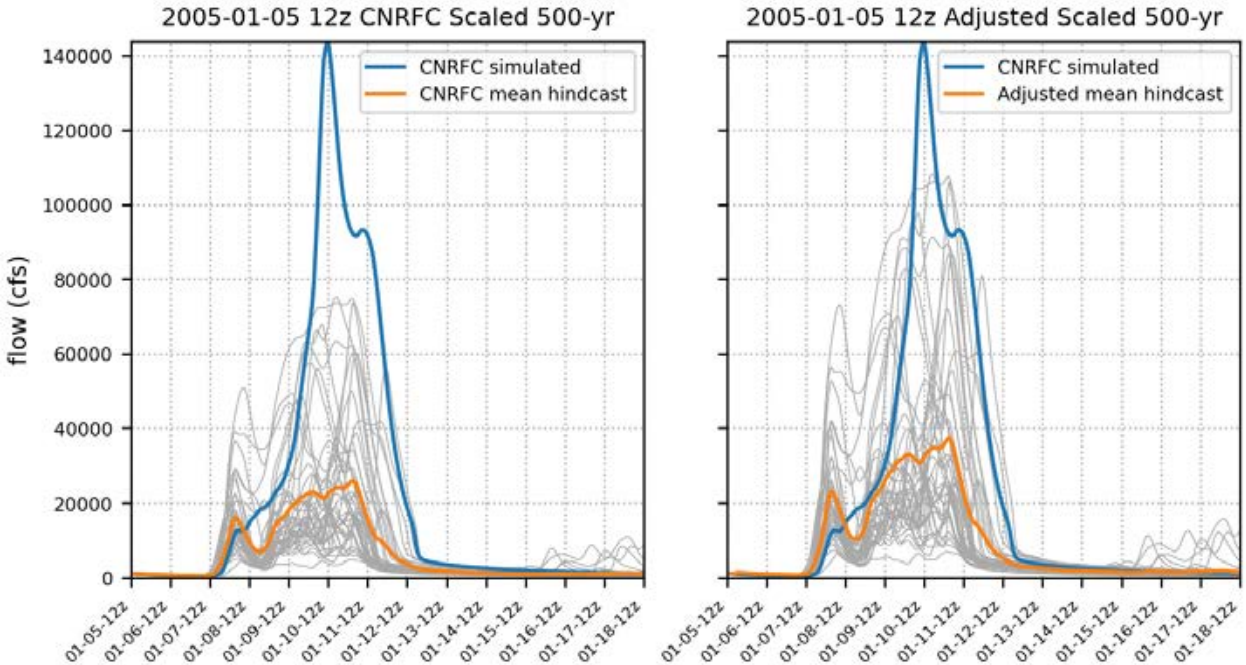
500-yr 1/3/2005



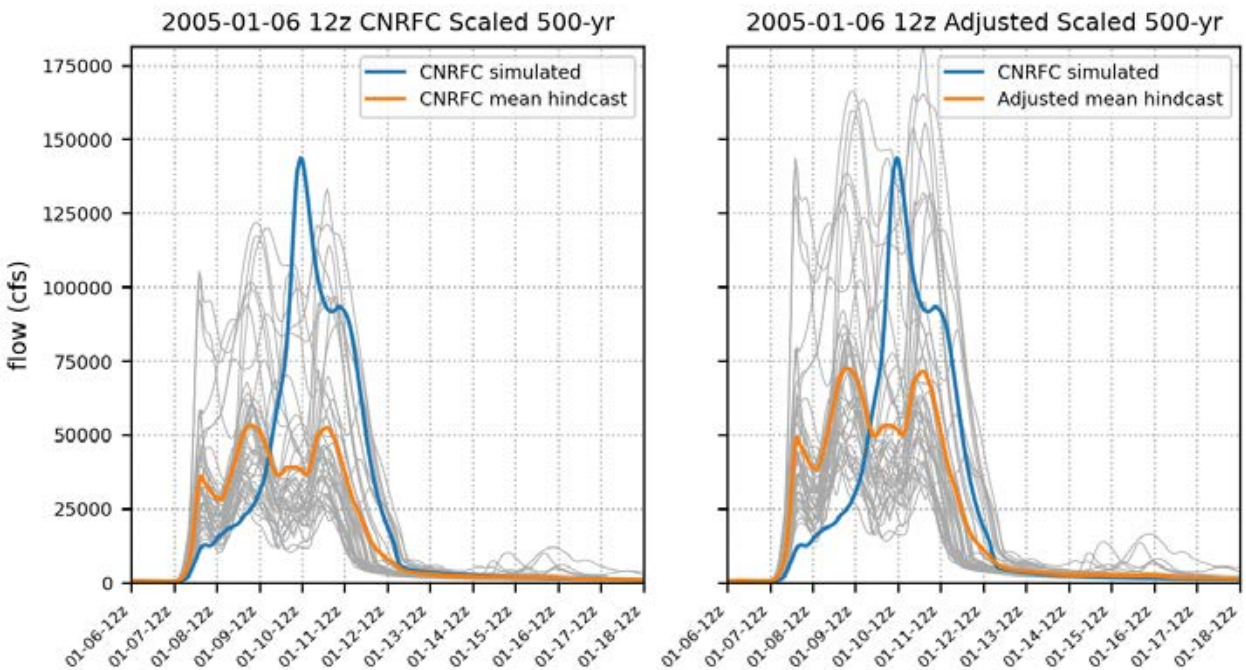
500-yr 1/4/2005



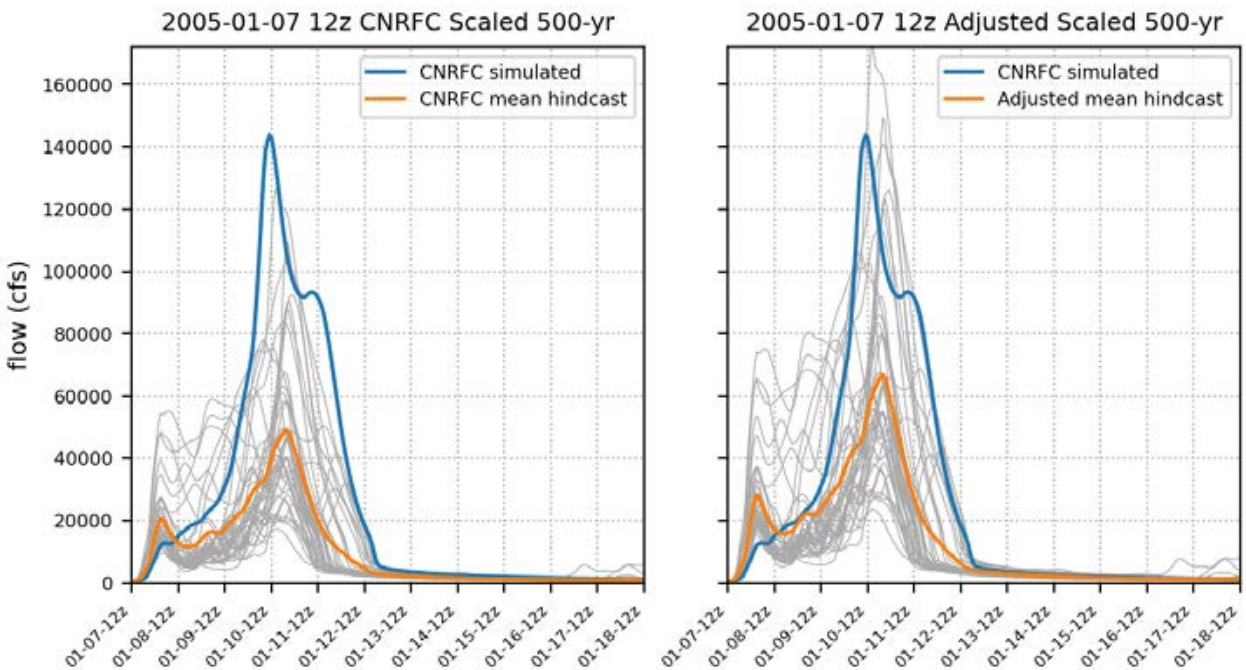
500-yr 1/5/2005



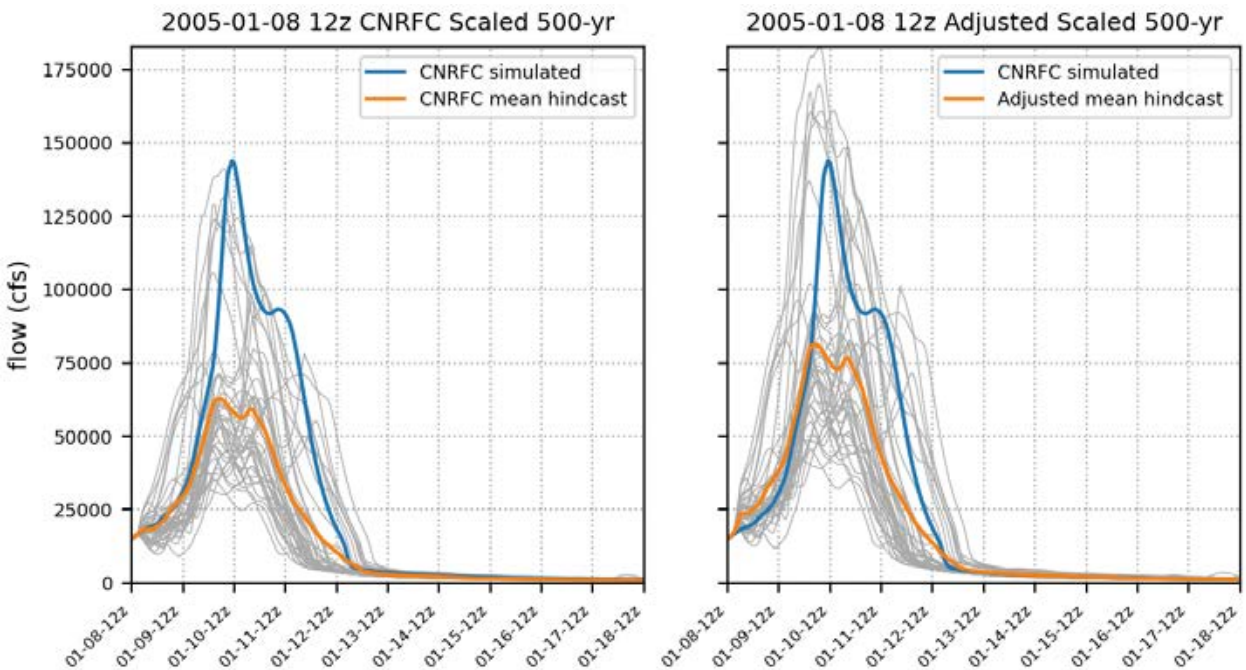
500-yr 1/6/2005



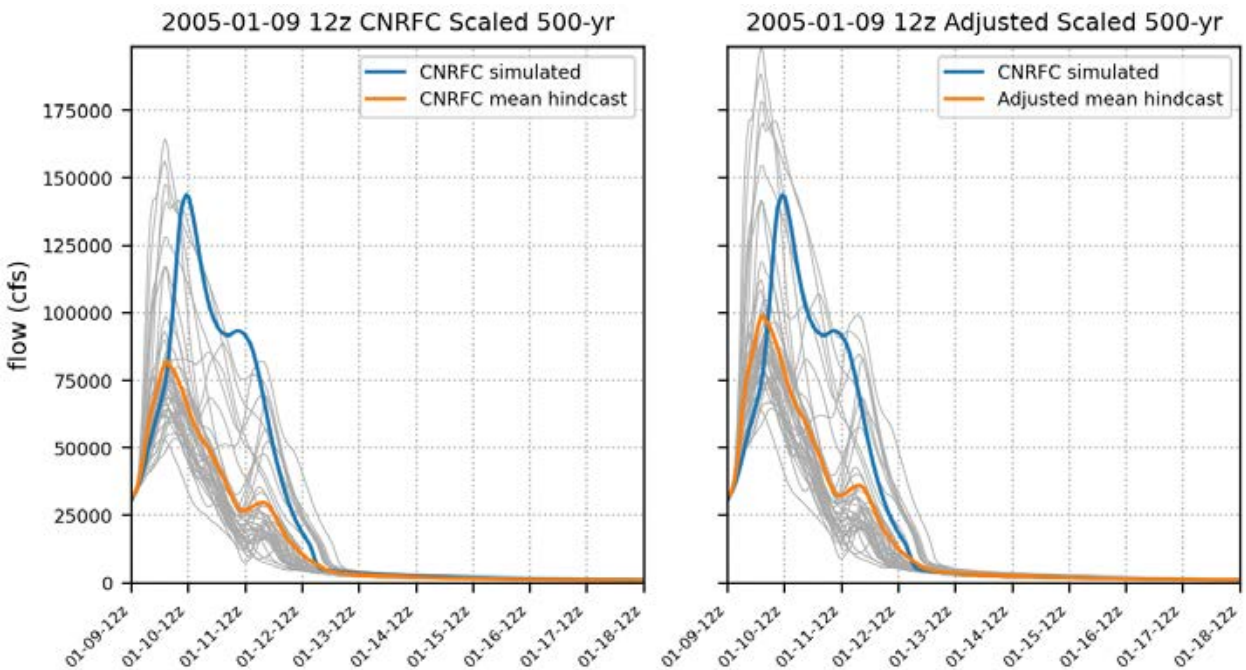
500-yr 1/7/2005



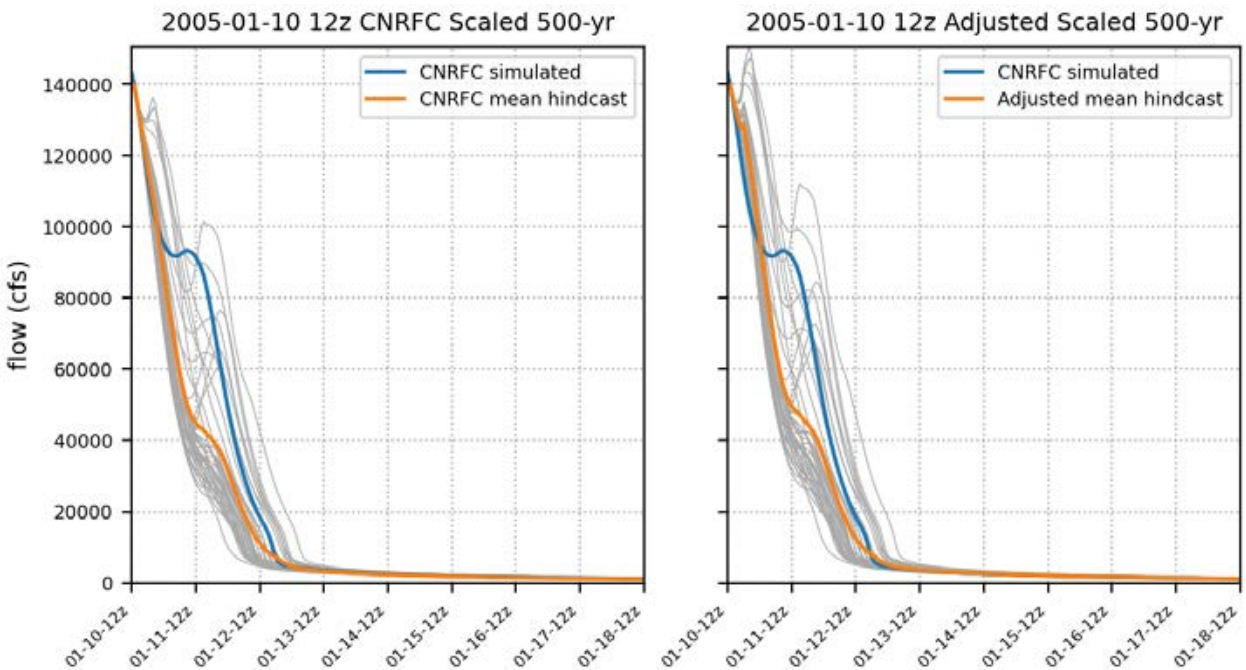
500-yr 1/8/2005



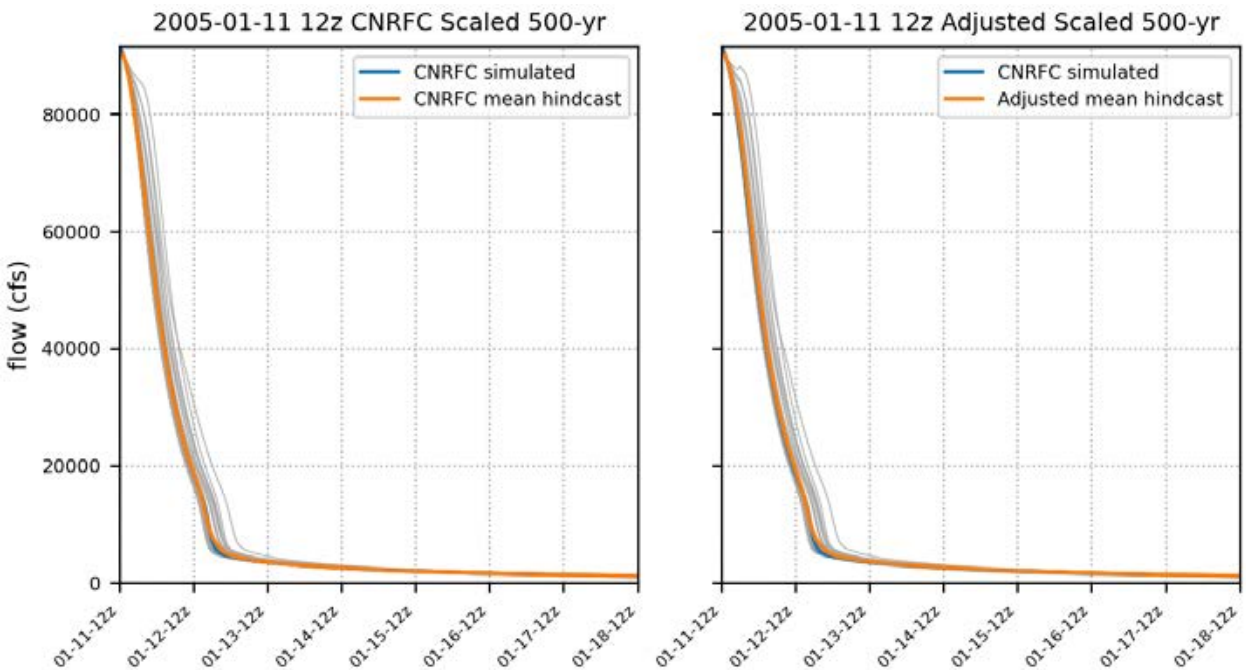
500-yr 1/9/2005



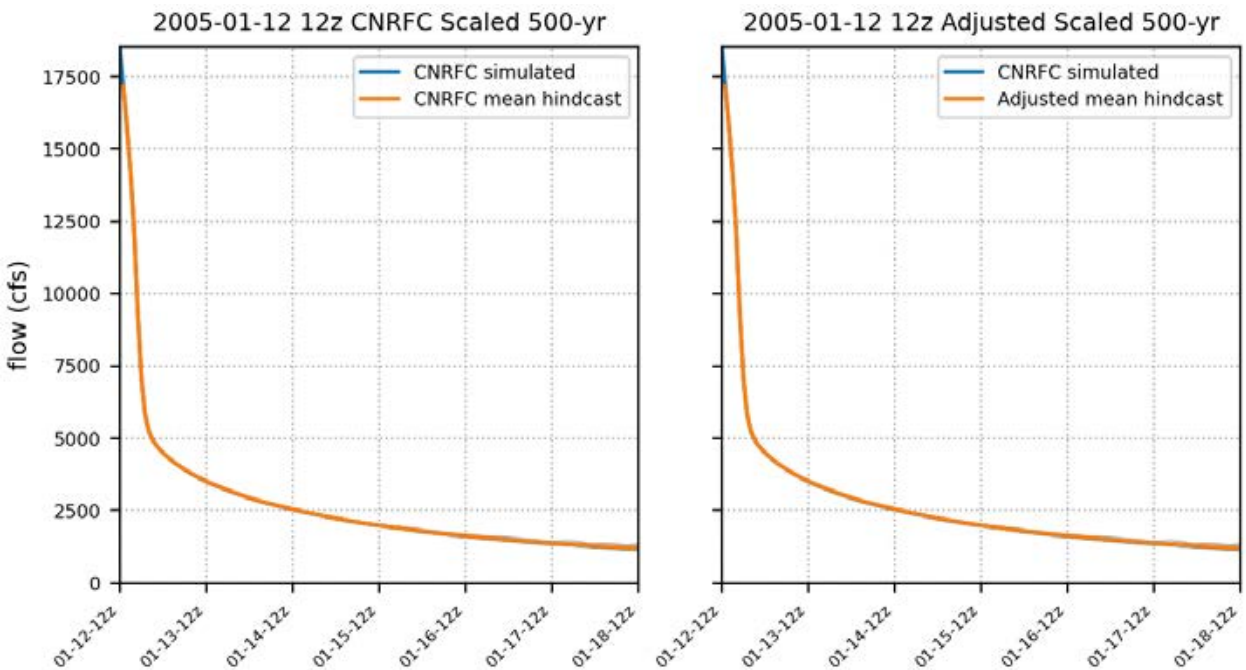
500-yr 1/10/2005



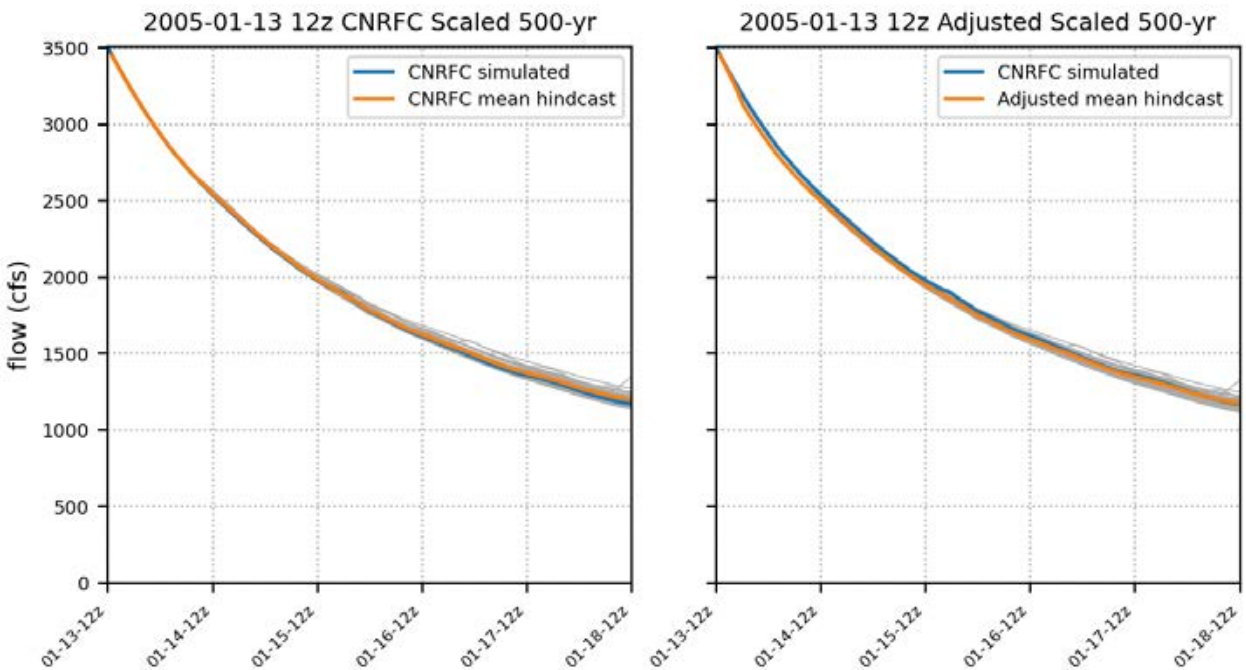
500-yr 1/11/2005



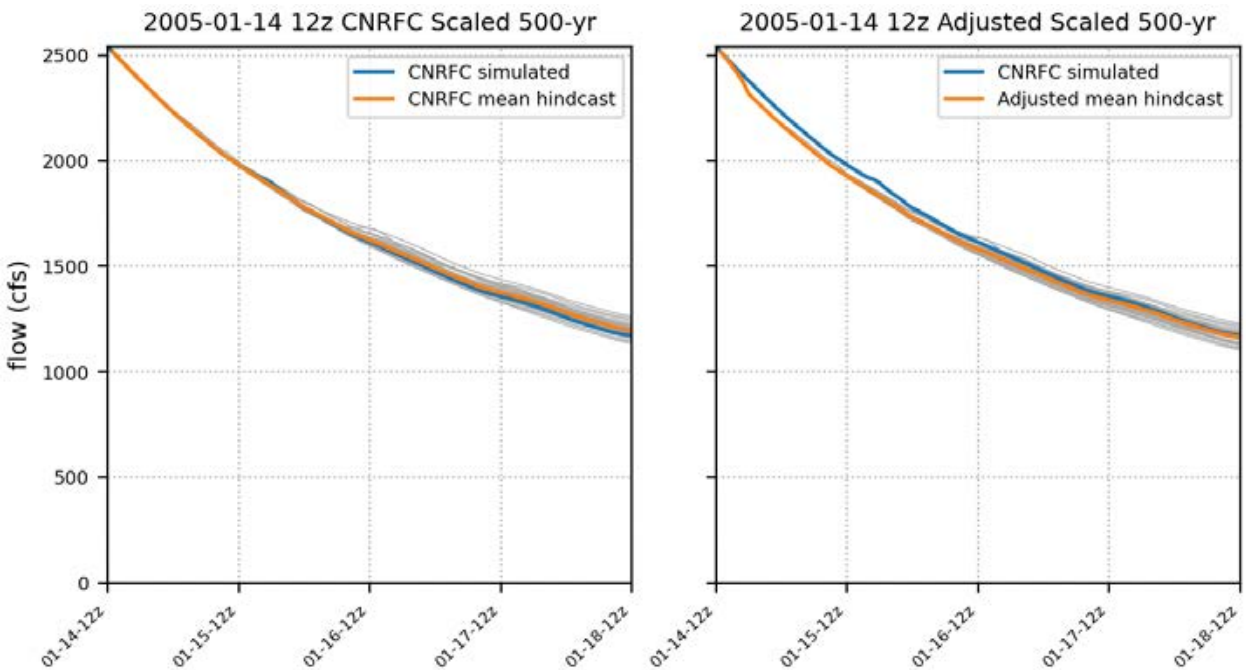
500-yr 1/12/2005



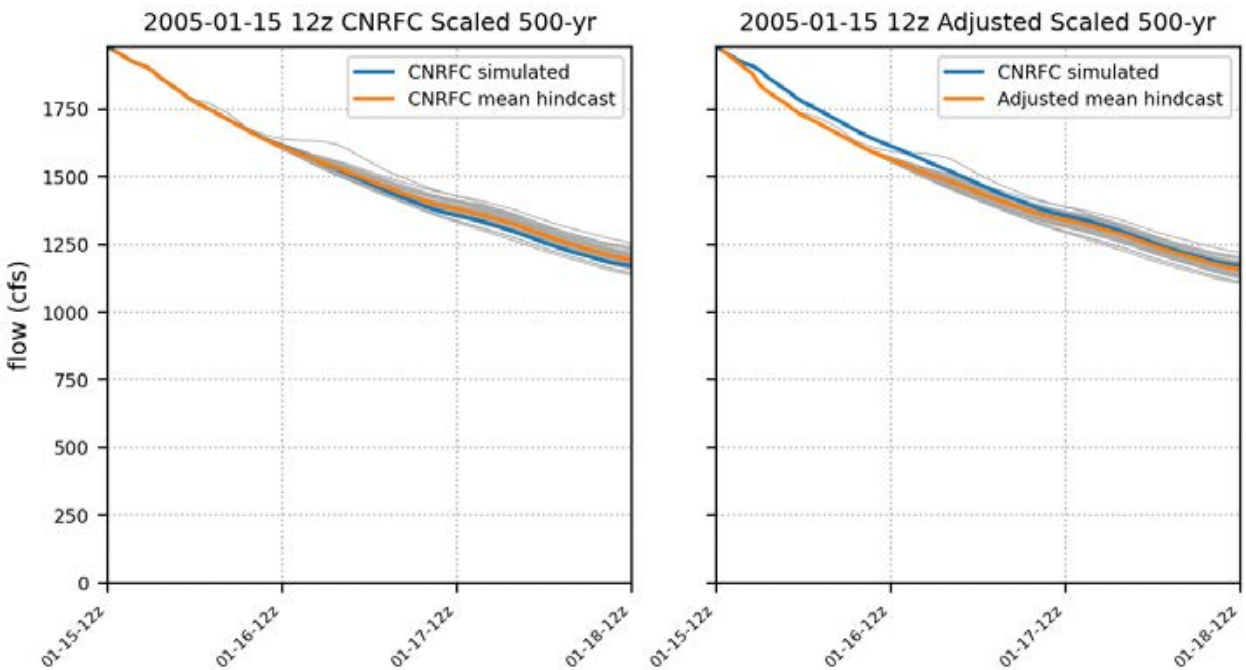
500-yr 1/13/2005



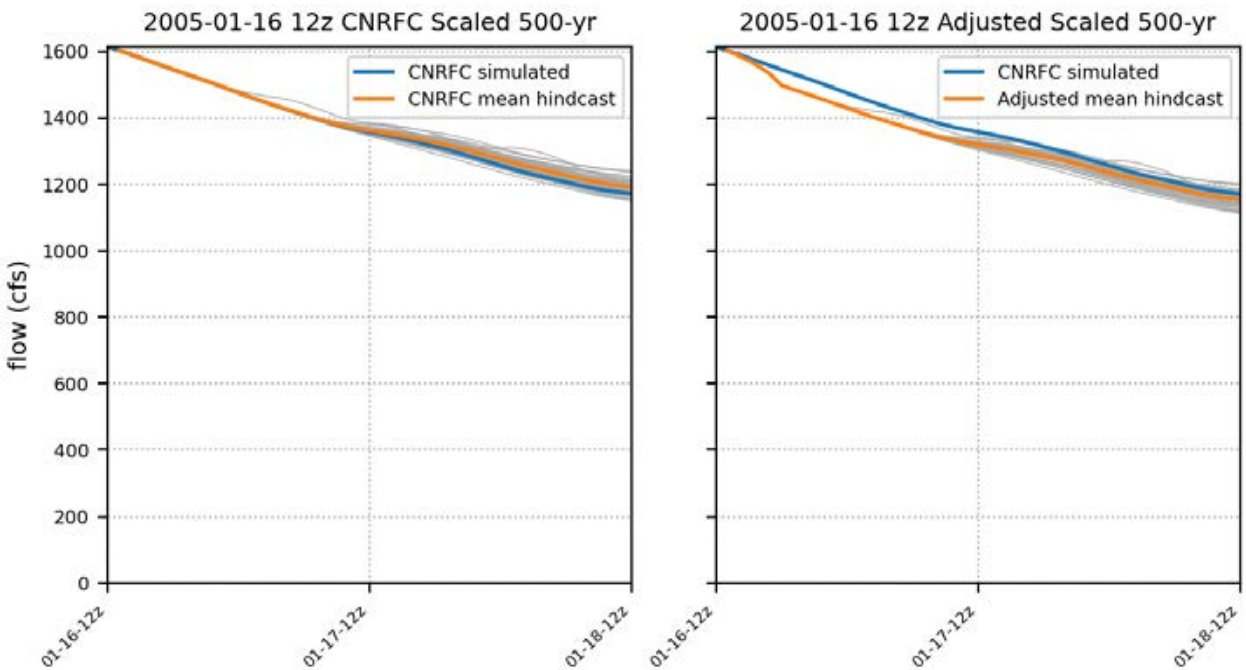
500-yr 1/14/2005



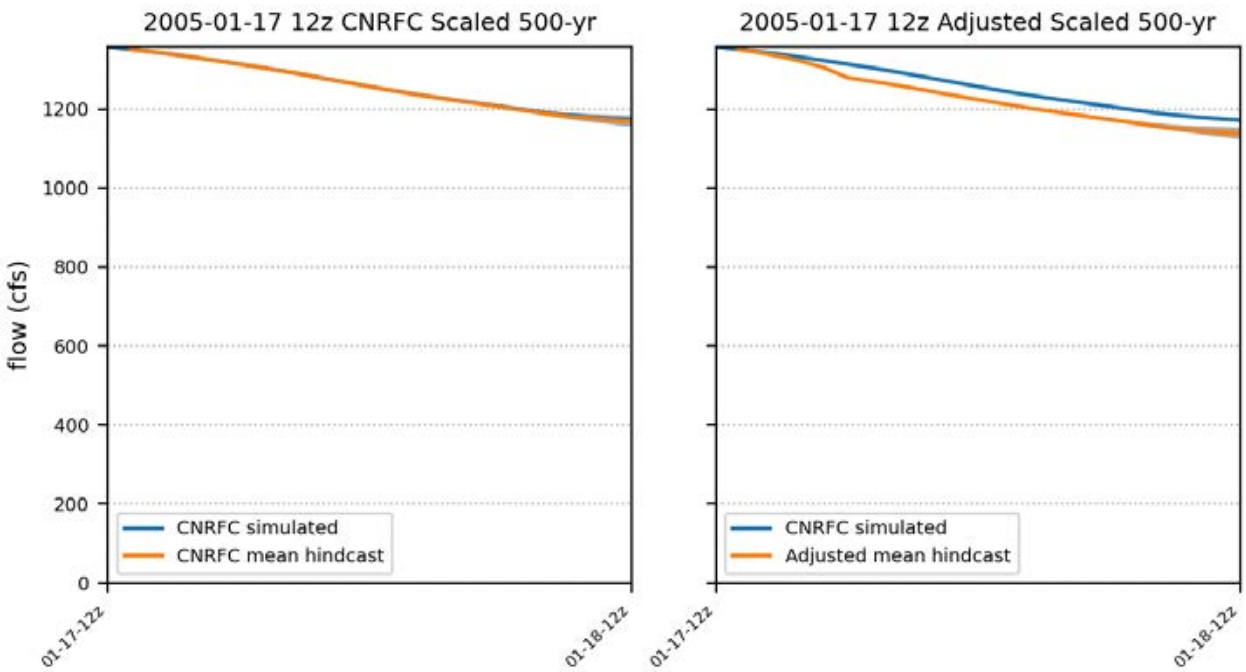
500-yr 1/15/2005



500-yr 1/16/2005



500-yr 1/17/2005



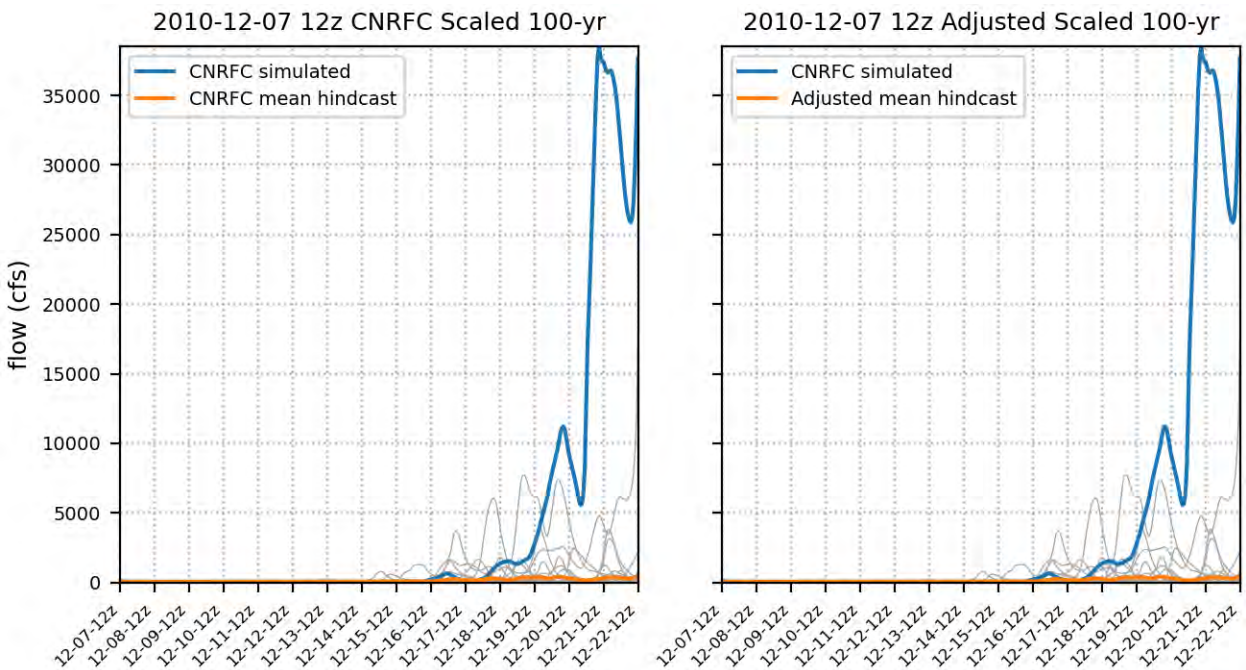
Adjusted Scaled Hindcasts

- December 2020
  - 12/7/2010 through 12/29/2010
- 100-yr – slides 2-25
- 200-yr – slides 26-49
- 500-yr – slides 50-73

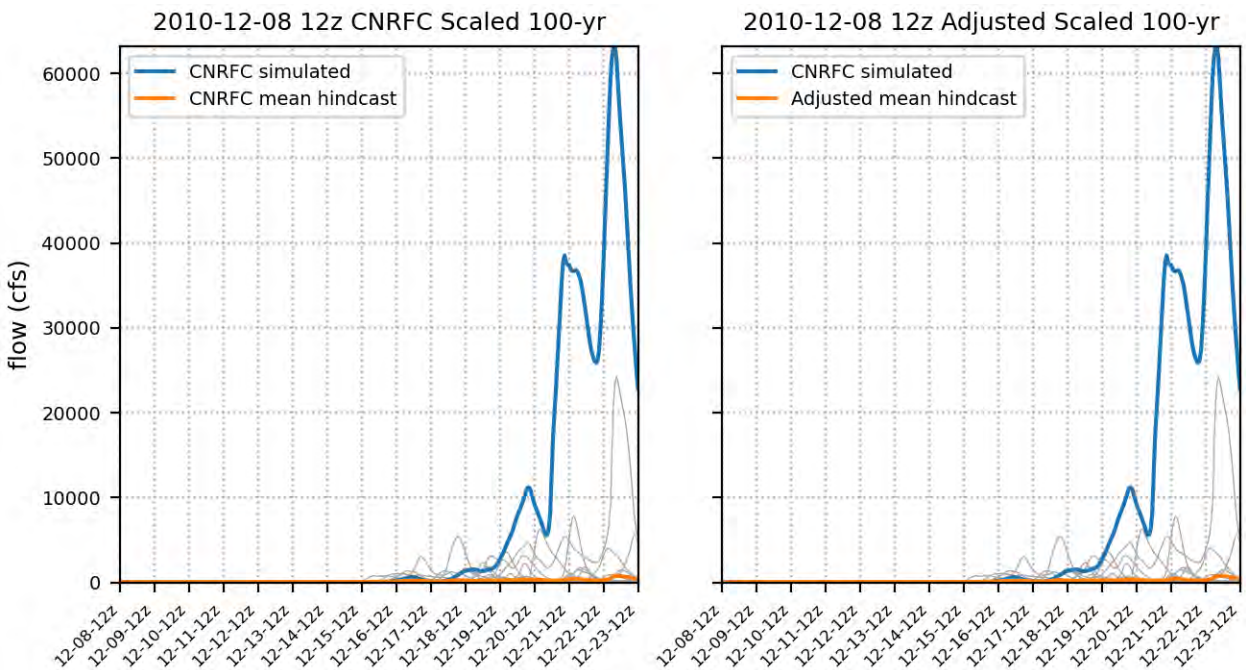
Adjusted Scaled Hindcast 2010 100-yr

2023-03-25

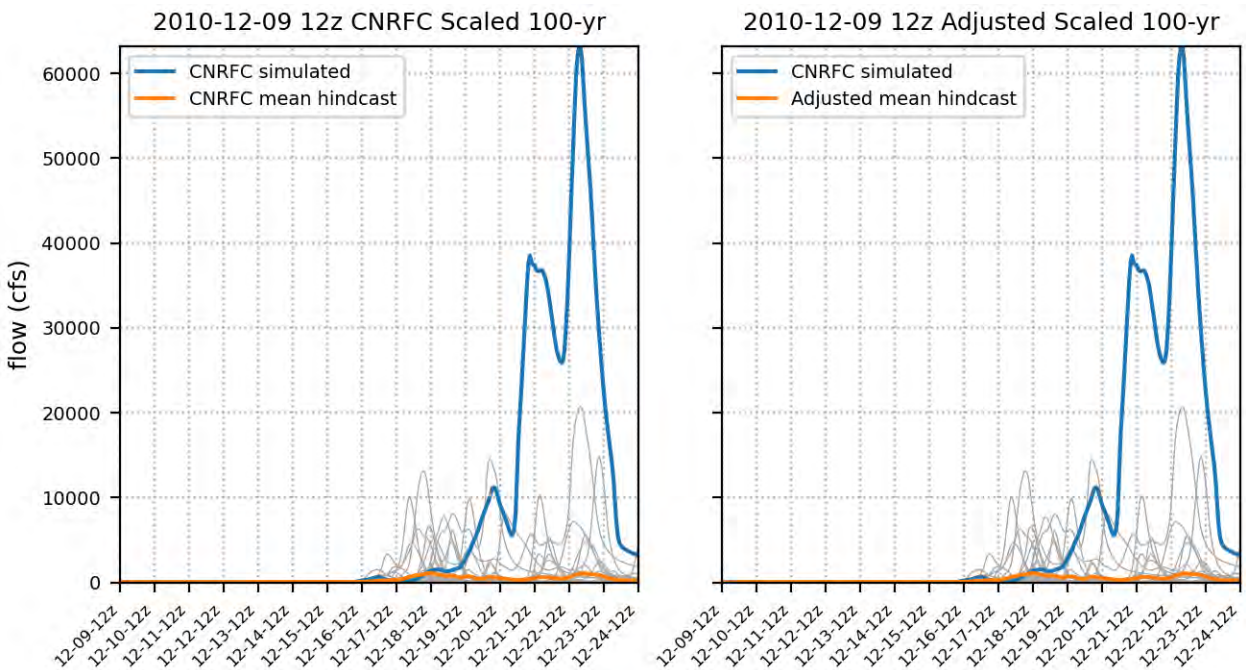
100-yr 12/7/2010



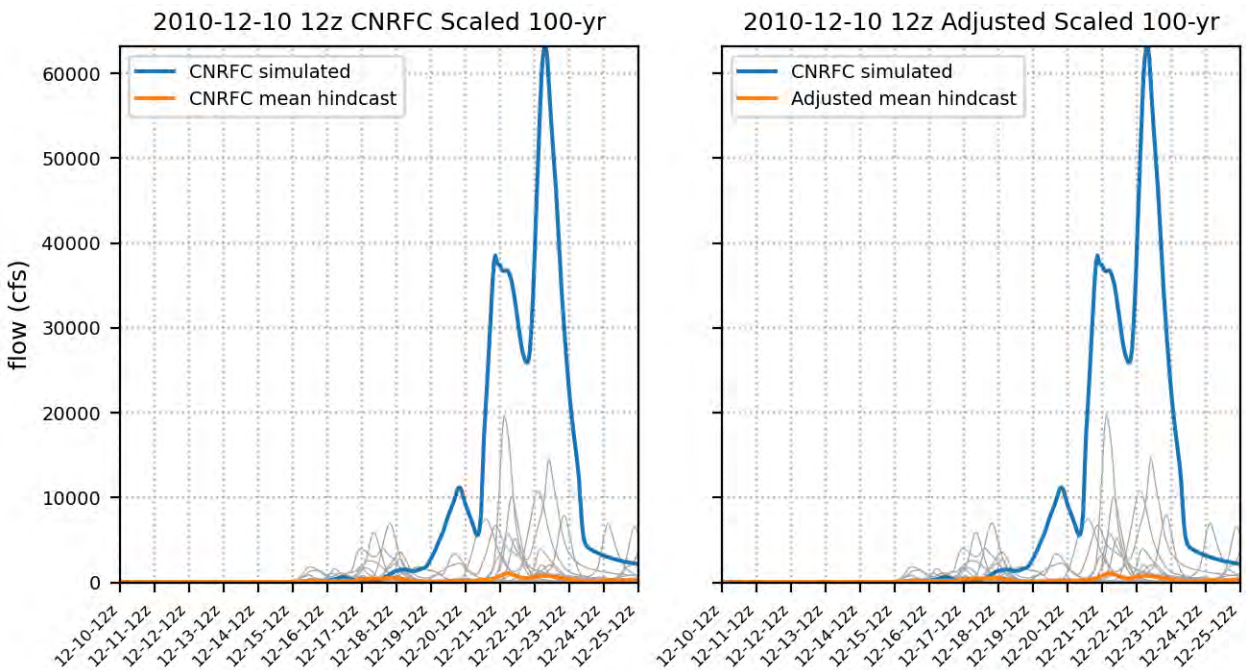
100-yr 12/8/2010



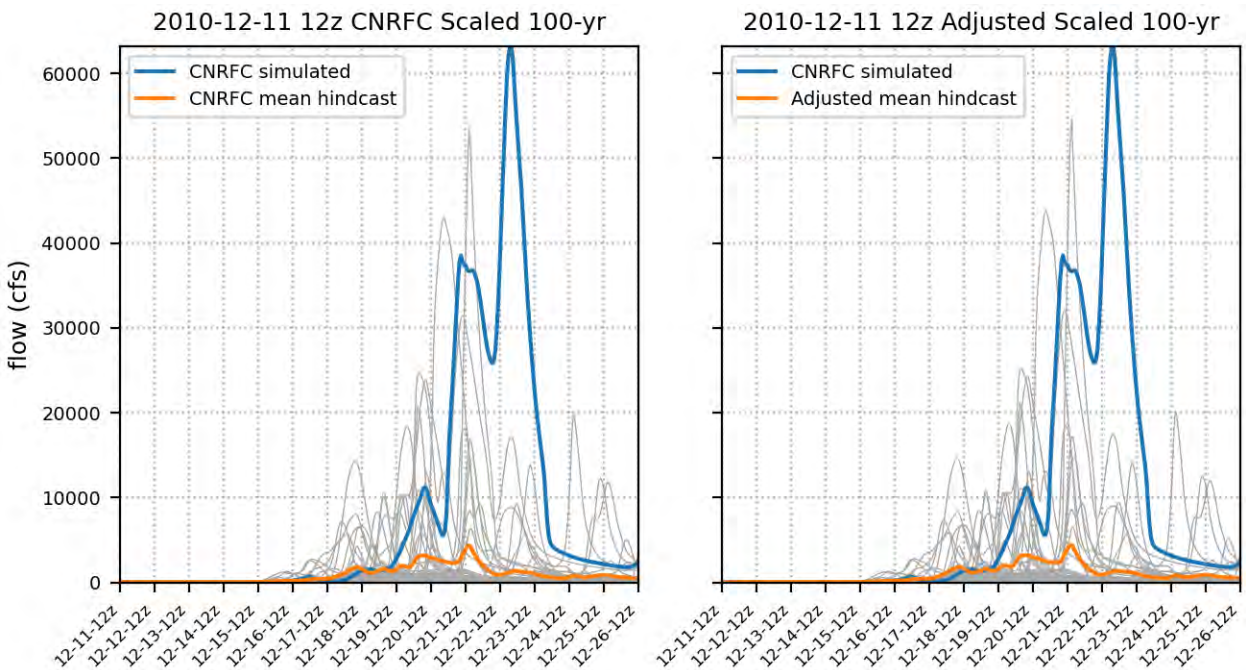
100-yr 12/9/2010



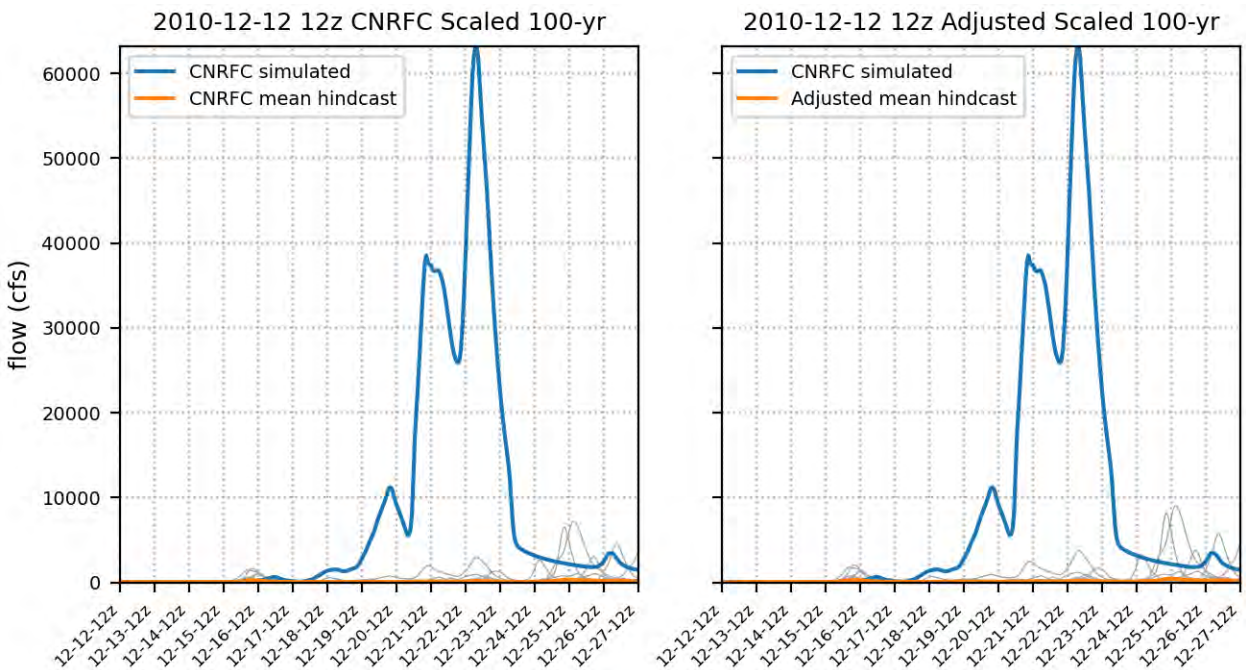
100-yr 12/10/2010



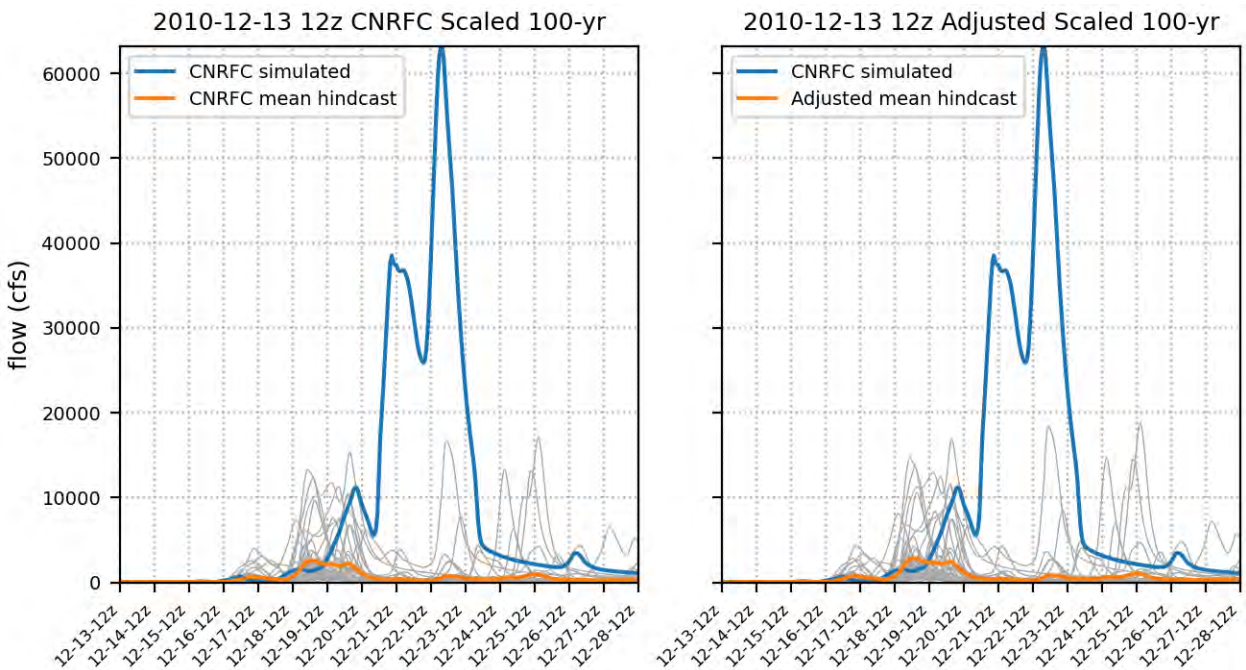
100-yr 12/11/2010



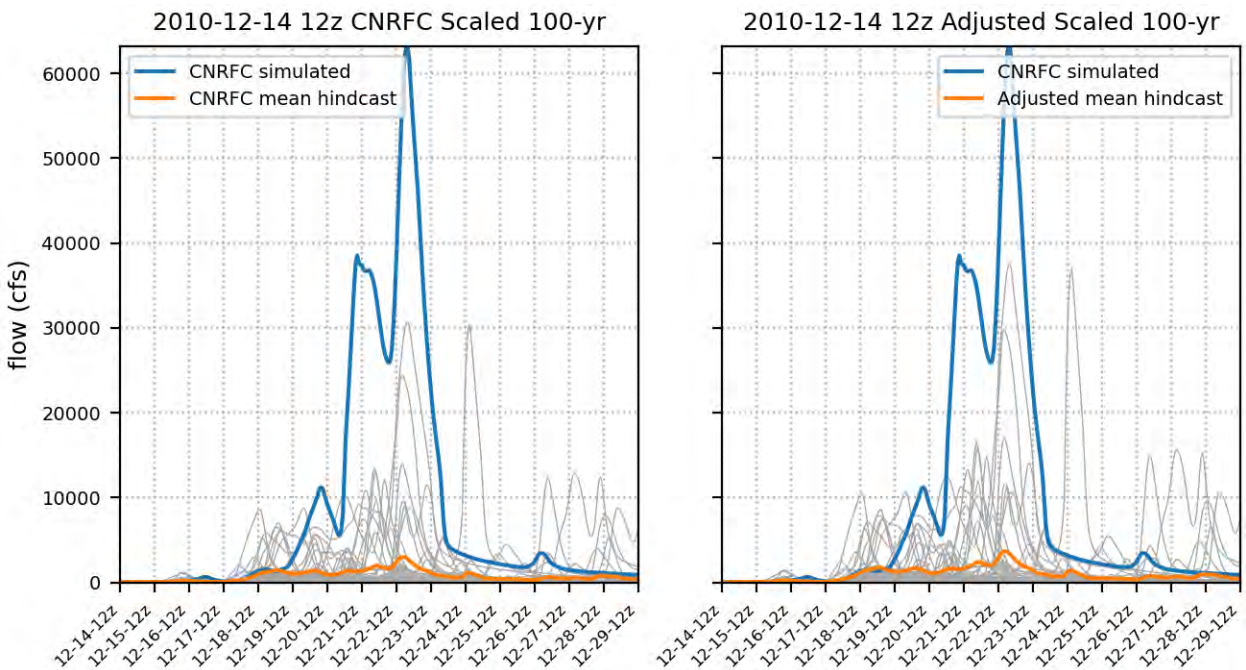
100-yr 12/12/2010



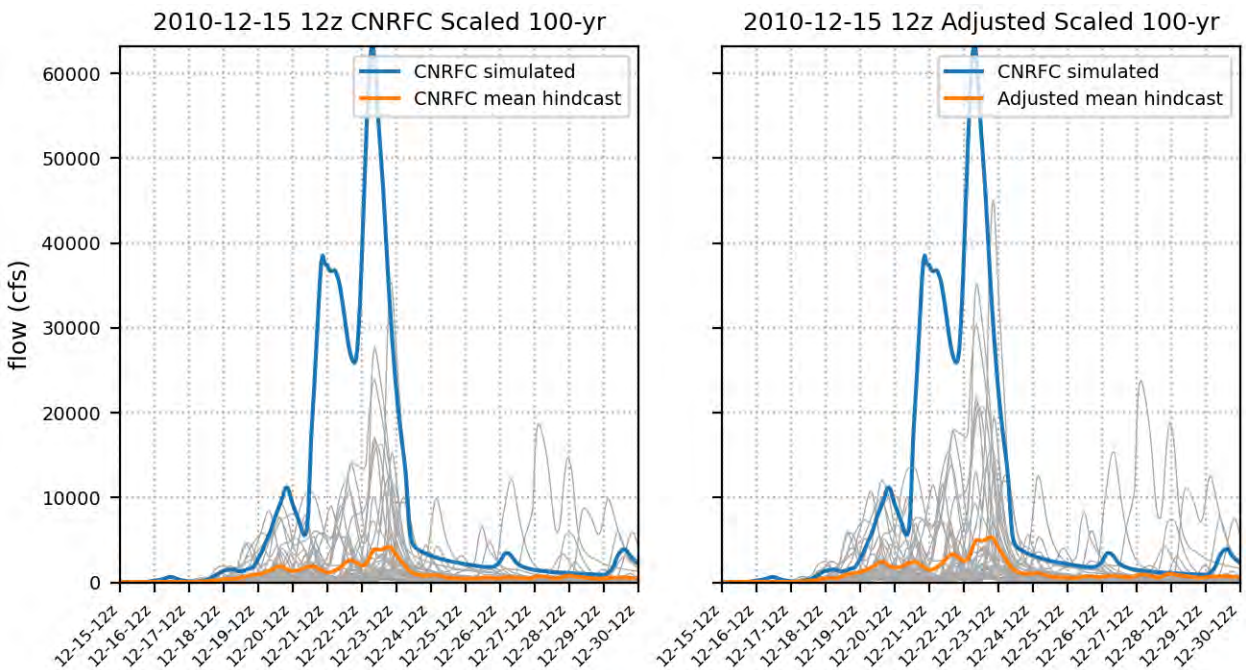
100-yr 12/13/2010



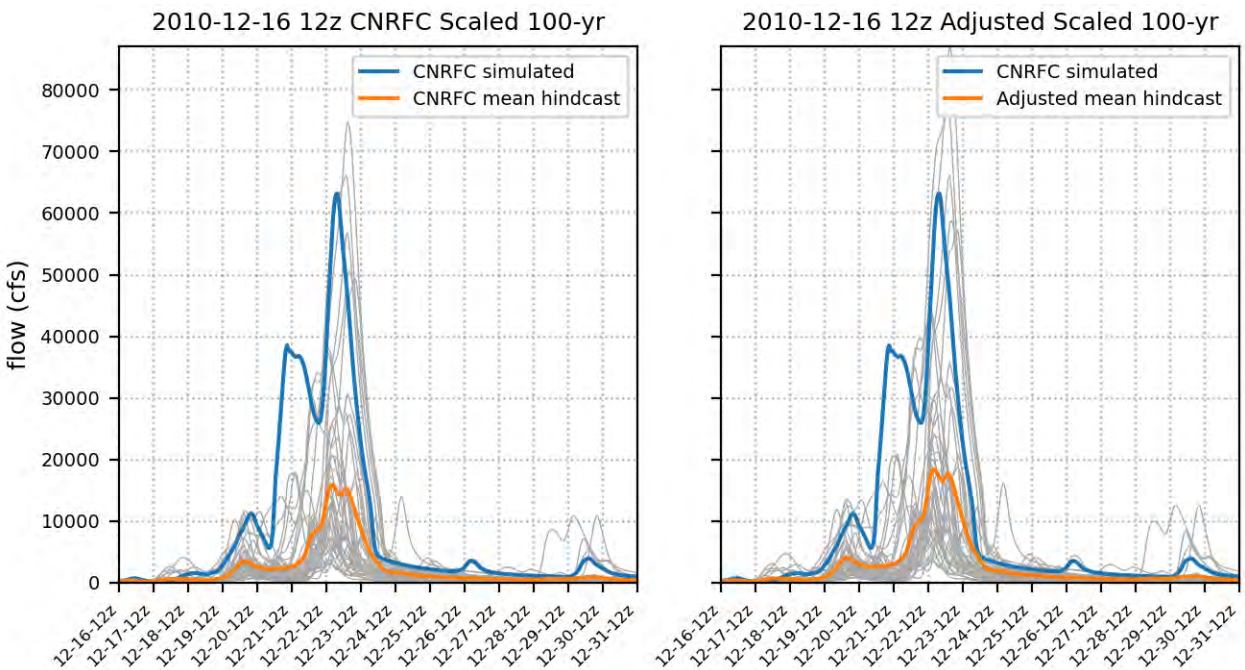
100-yr 12/14/2010



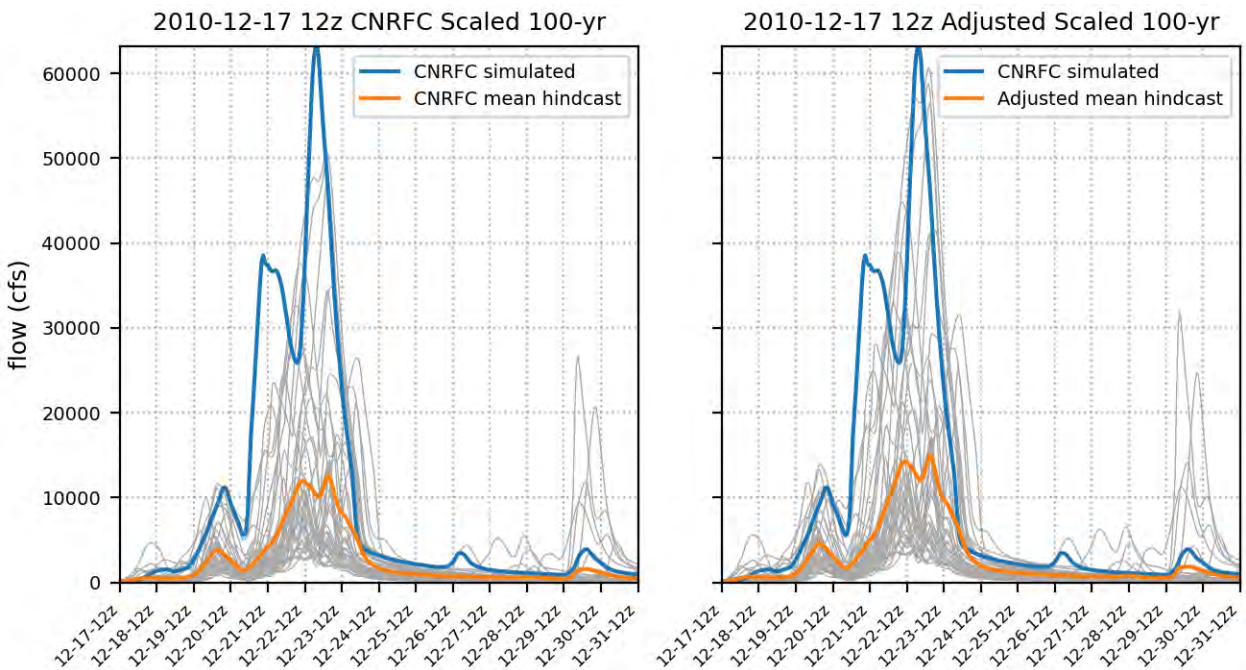
100-yr 12/15/2010



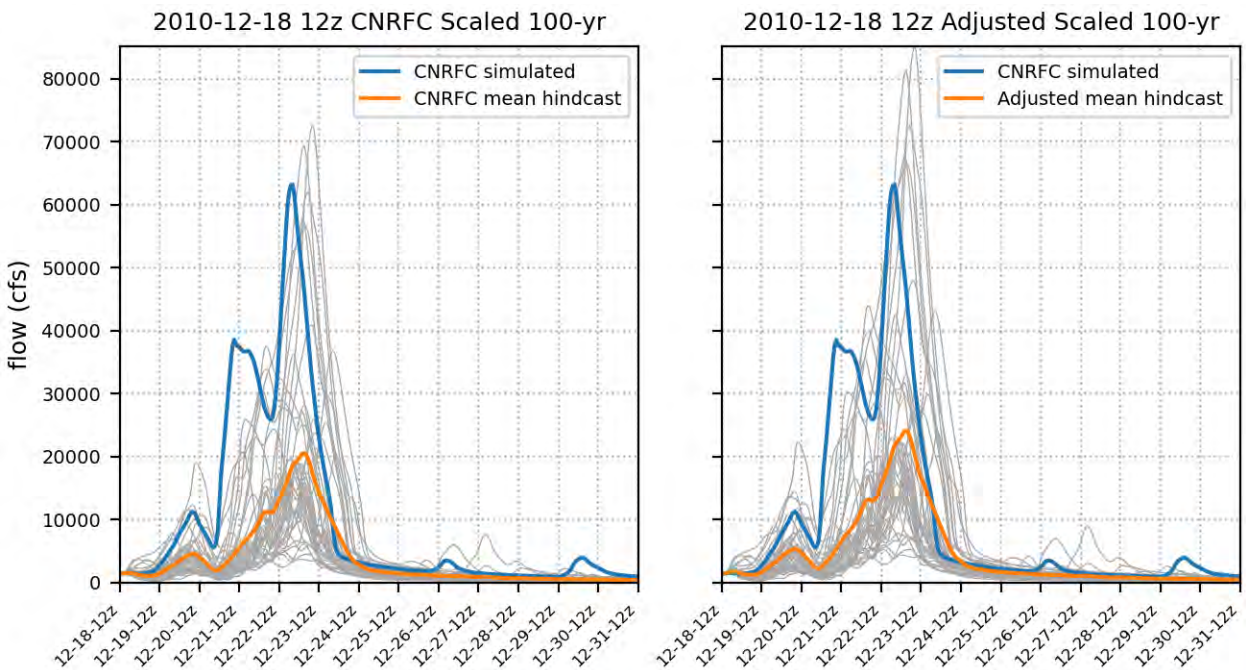
100-yr 12/16/2010



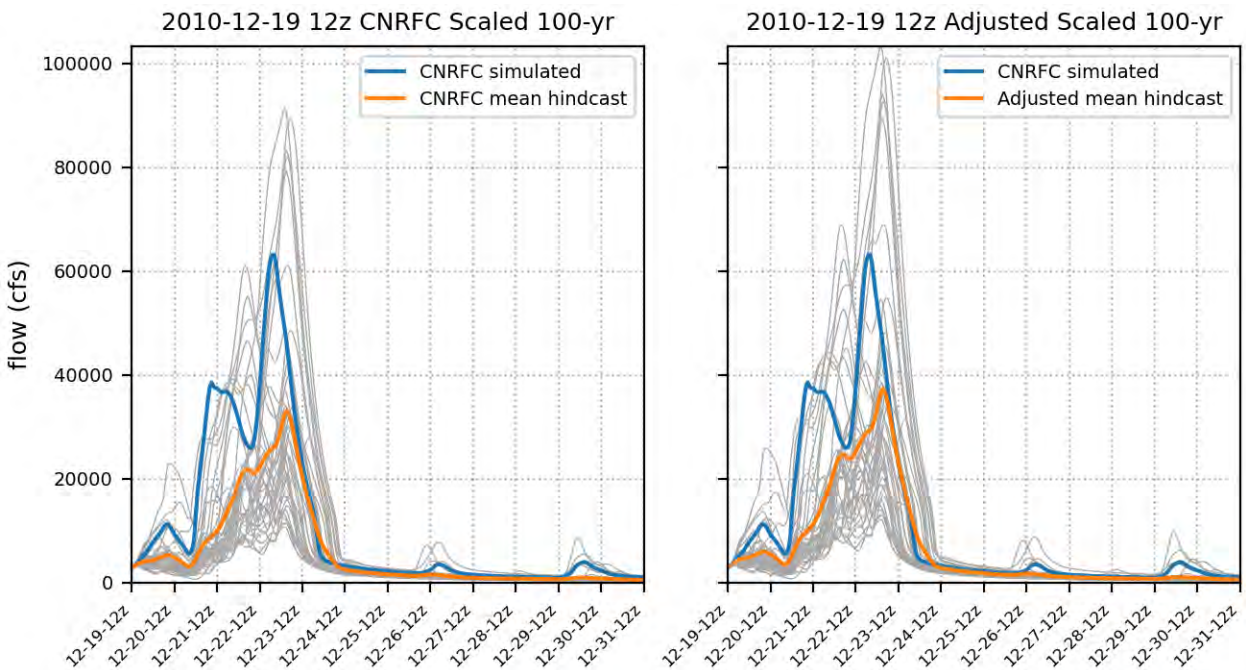
100-yr 12/17/2010



100-yr 12/18/2010



100-yr 12/19/2010



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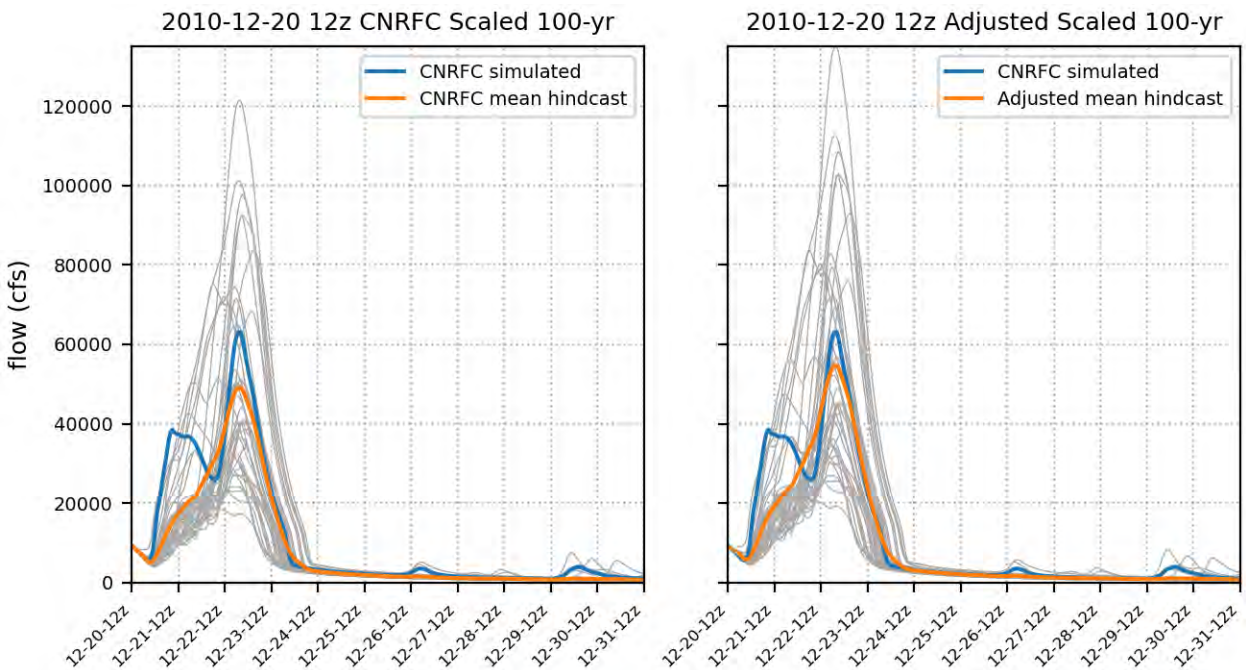

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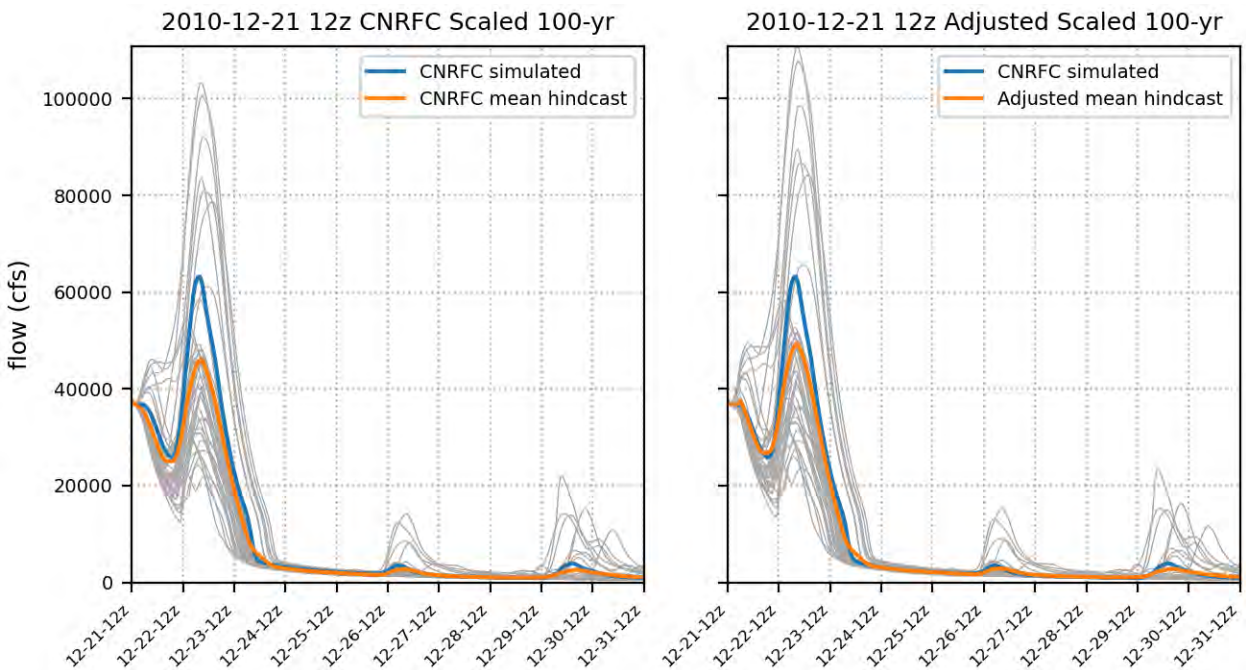

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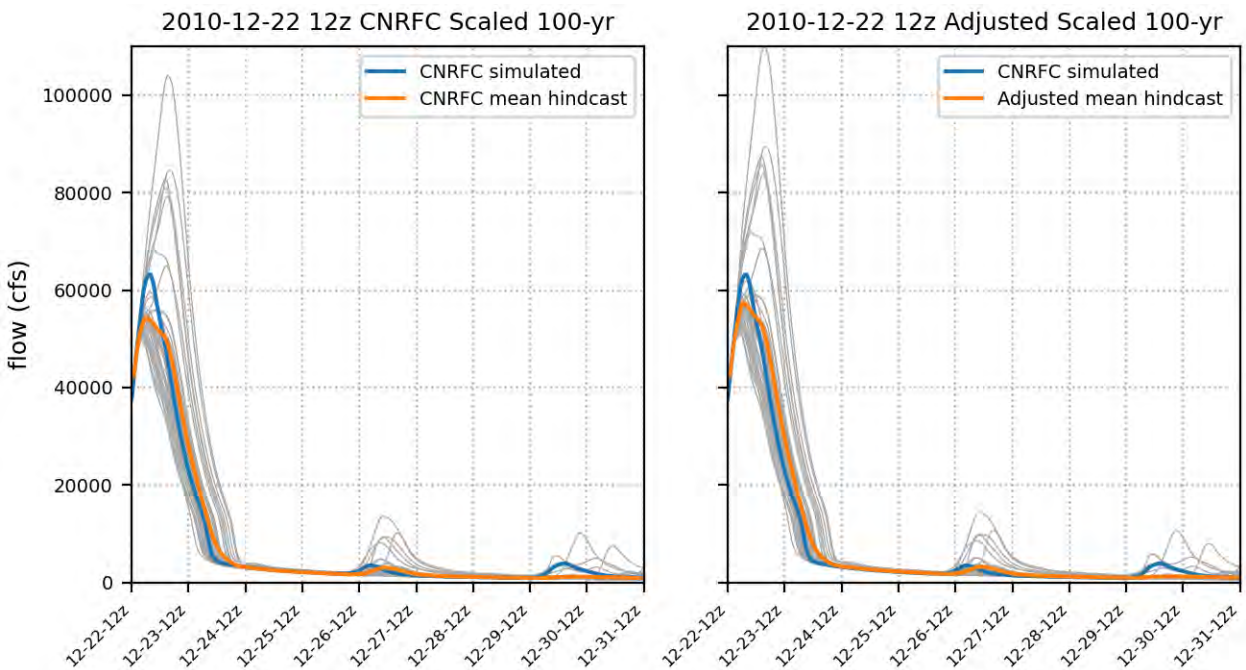

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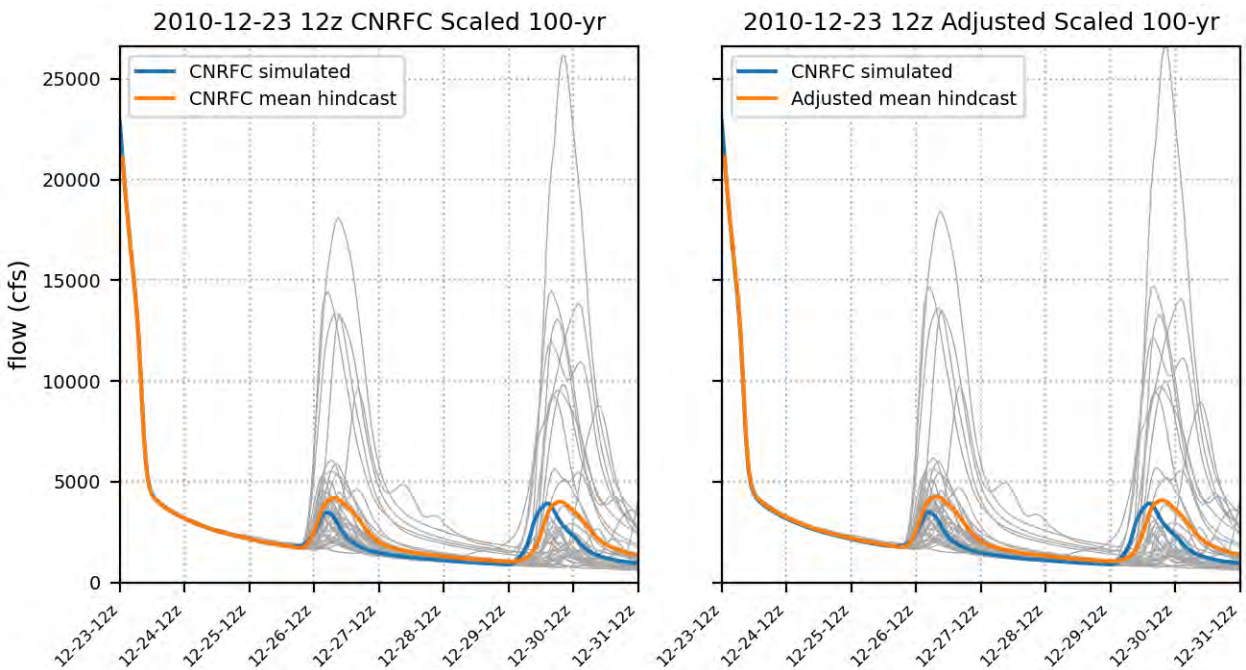

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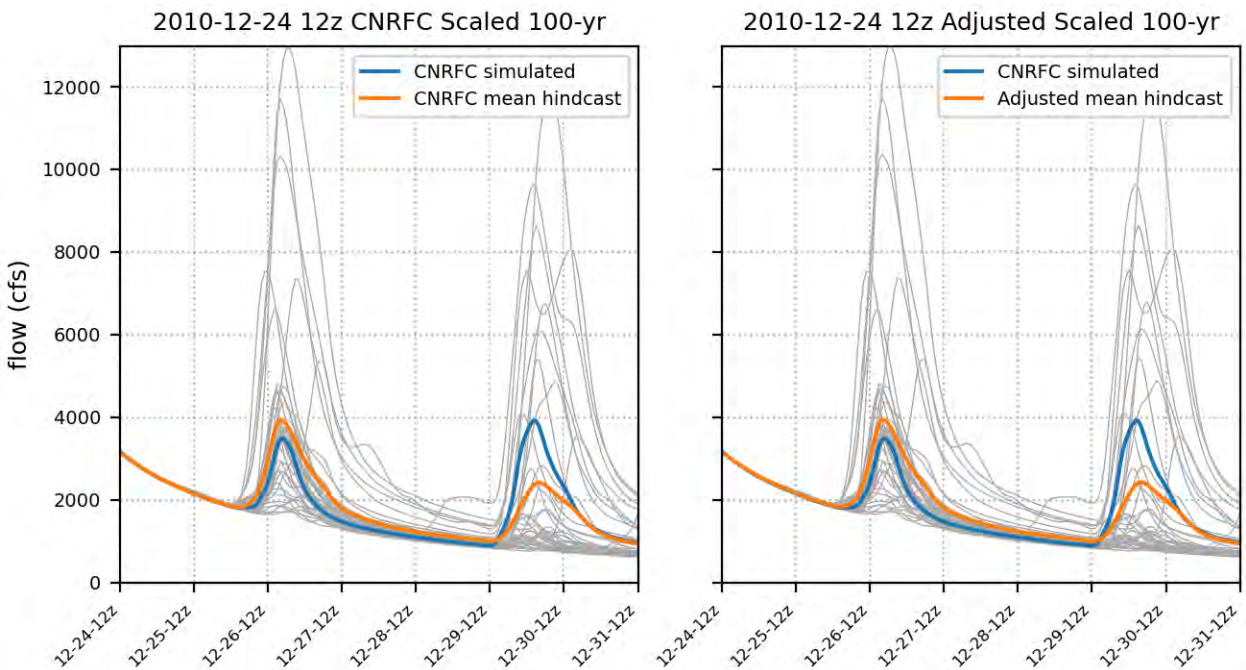

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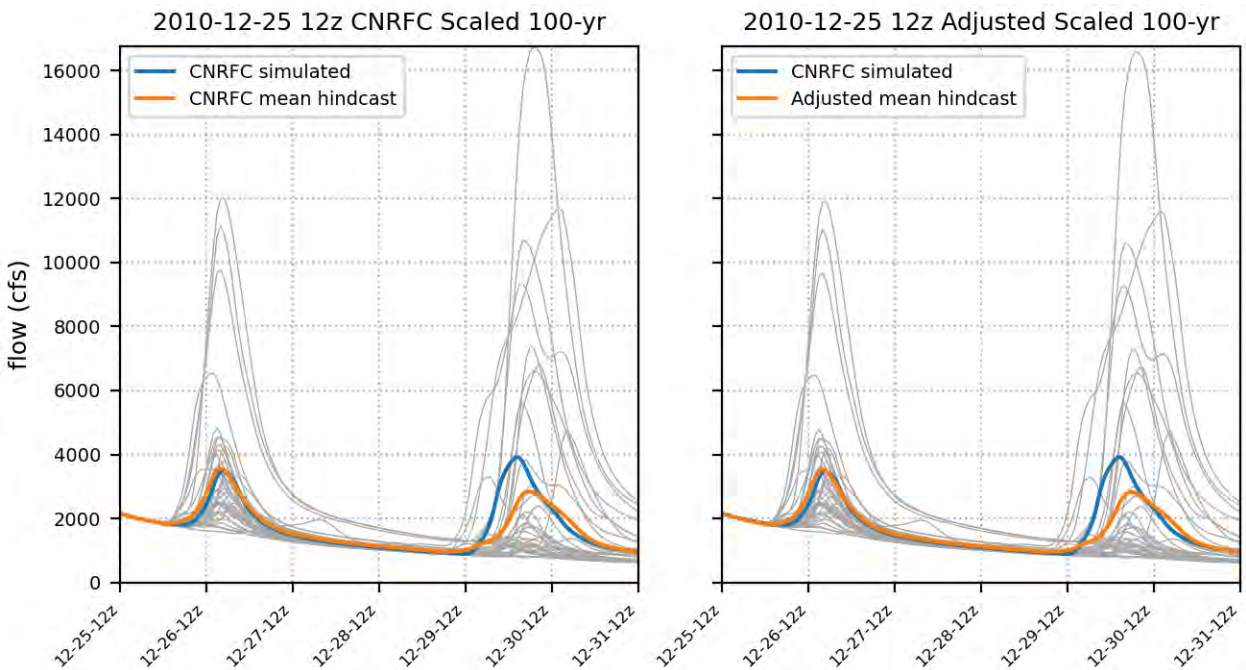

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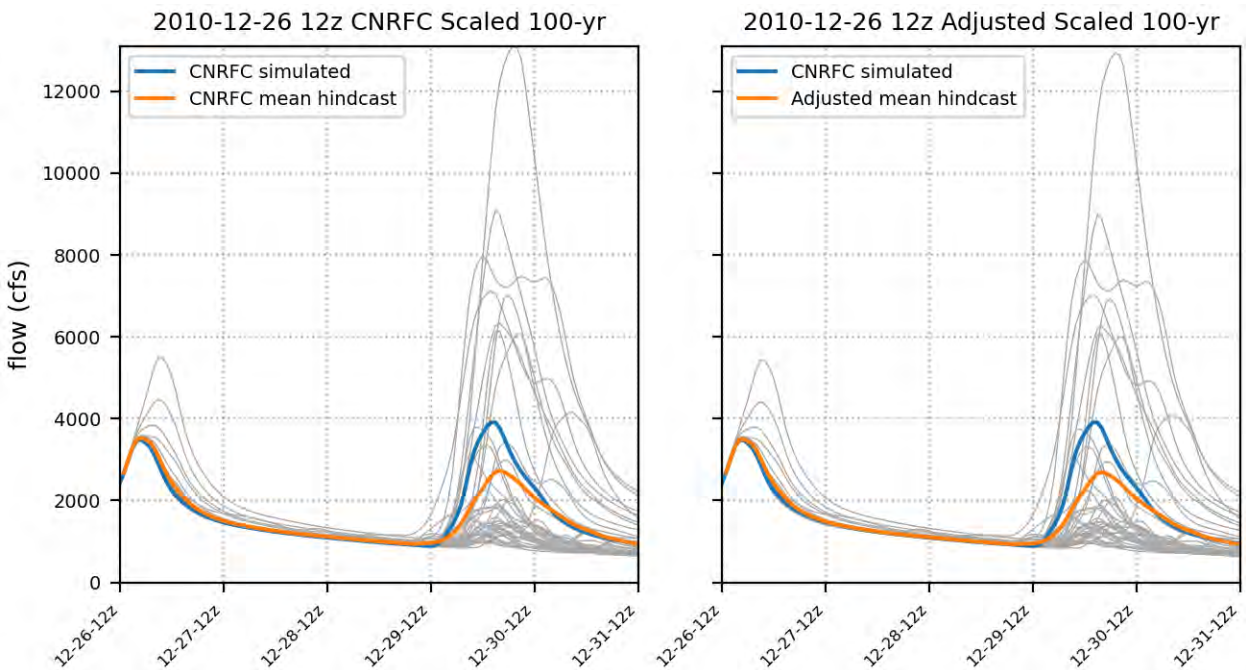

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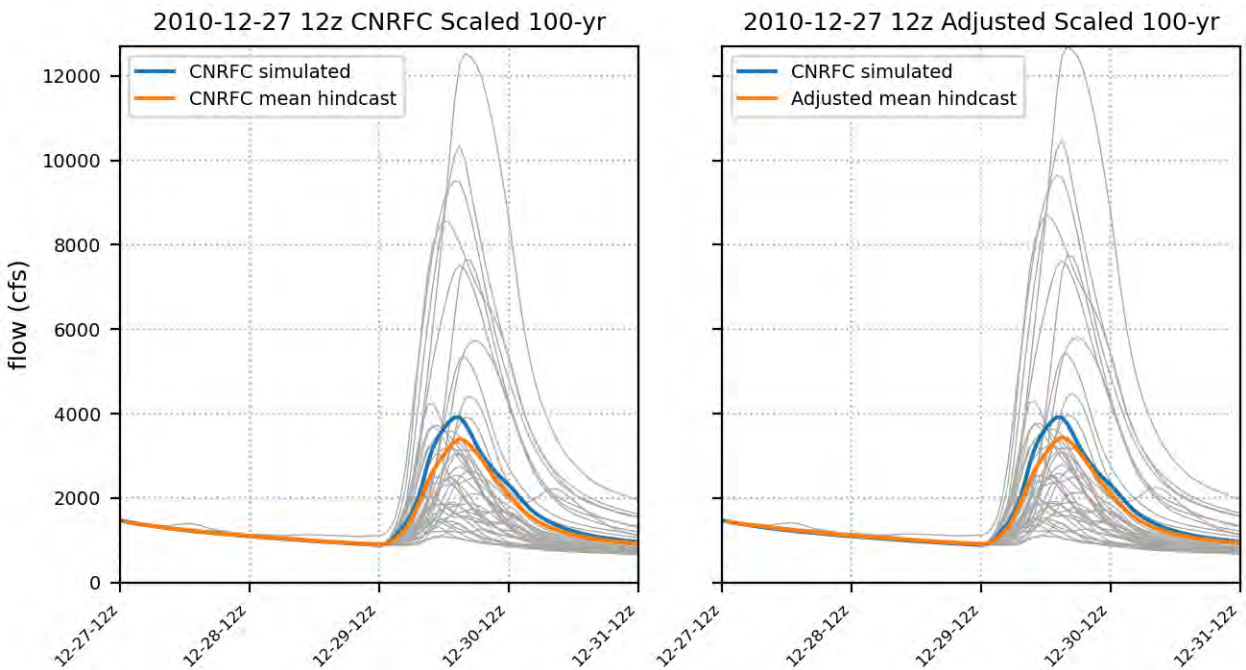

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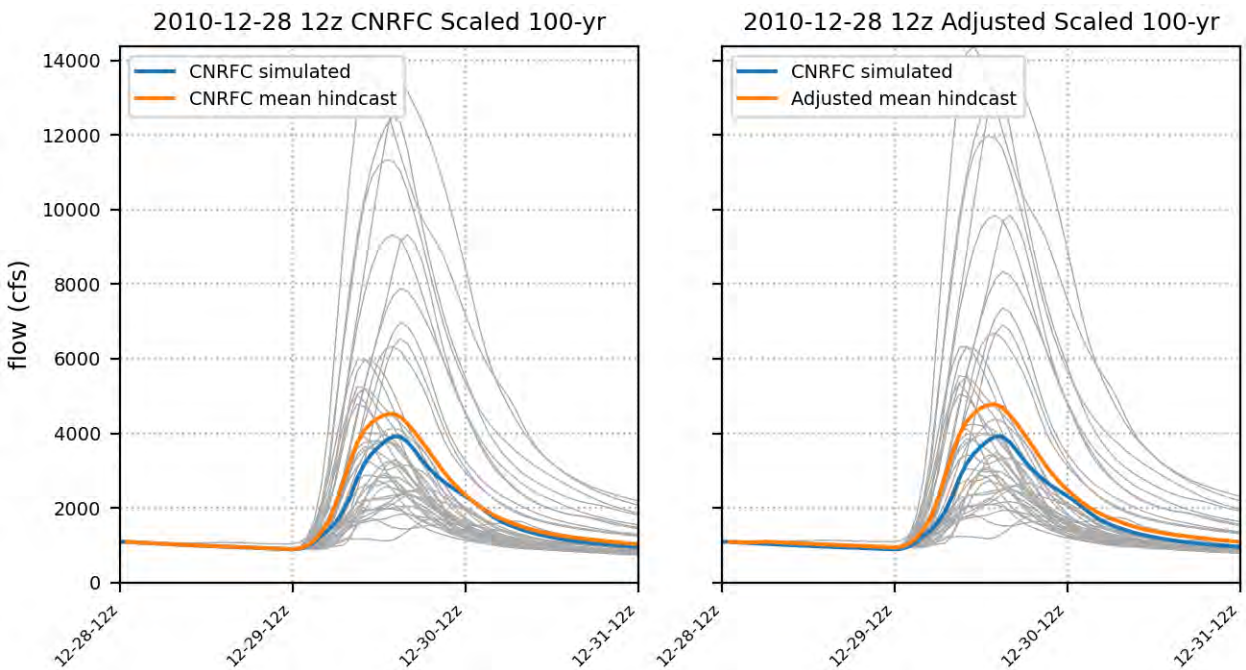

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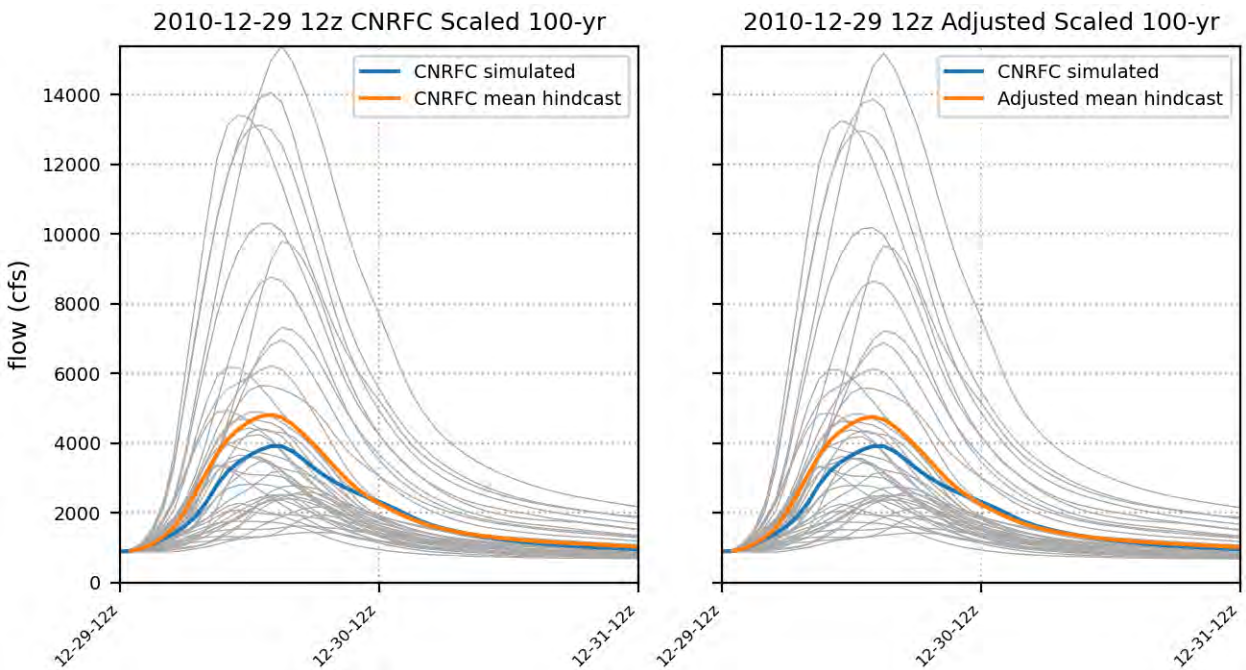
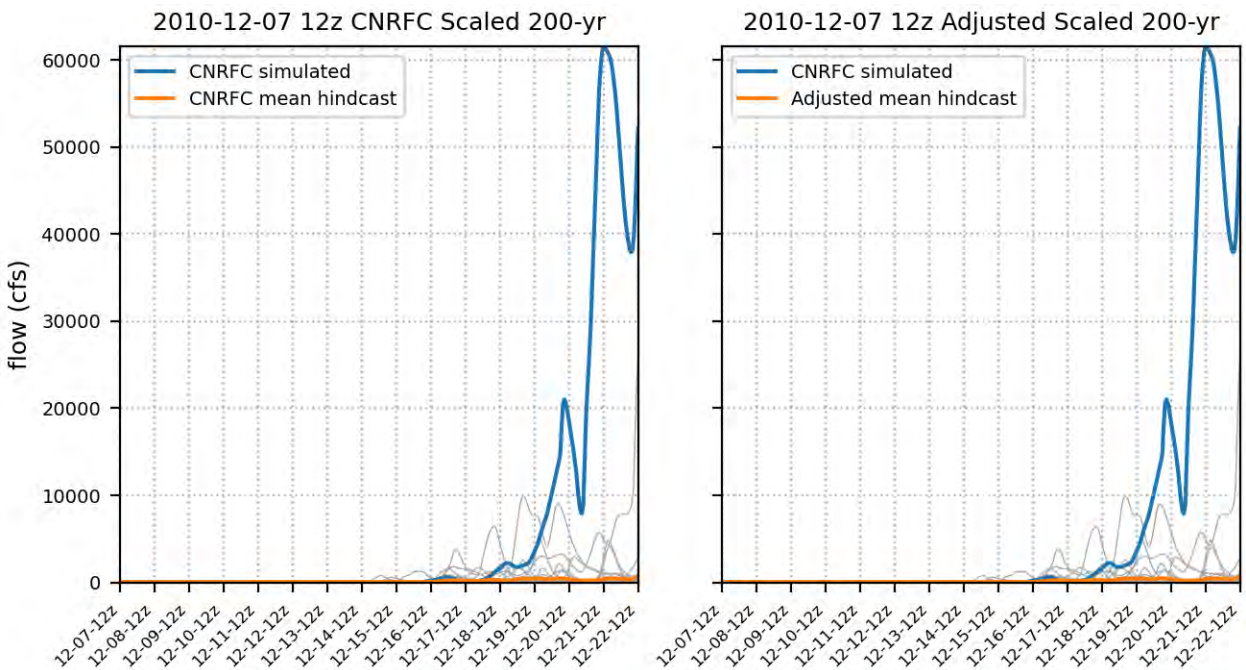


Adjusted Scaled Hindcast 2010 200-yr

2023-03-25

200-yr 12/7/2010



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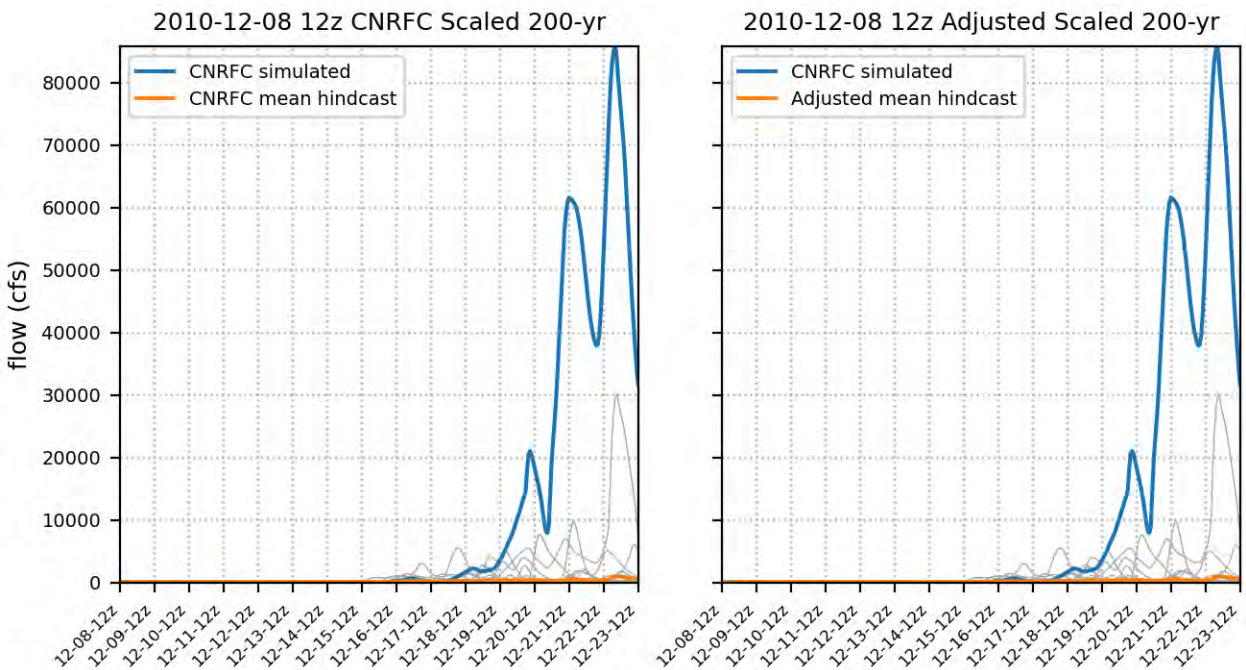

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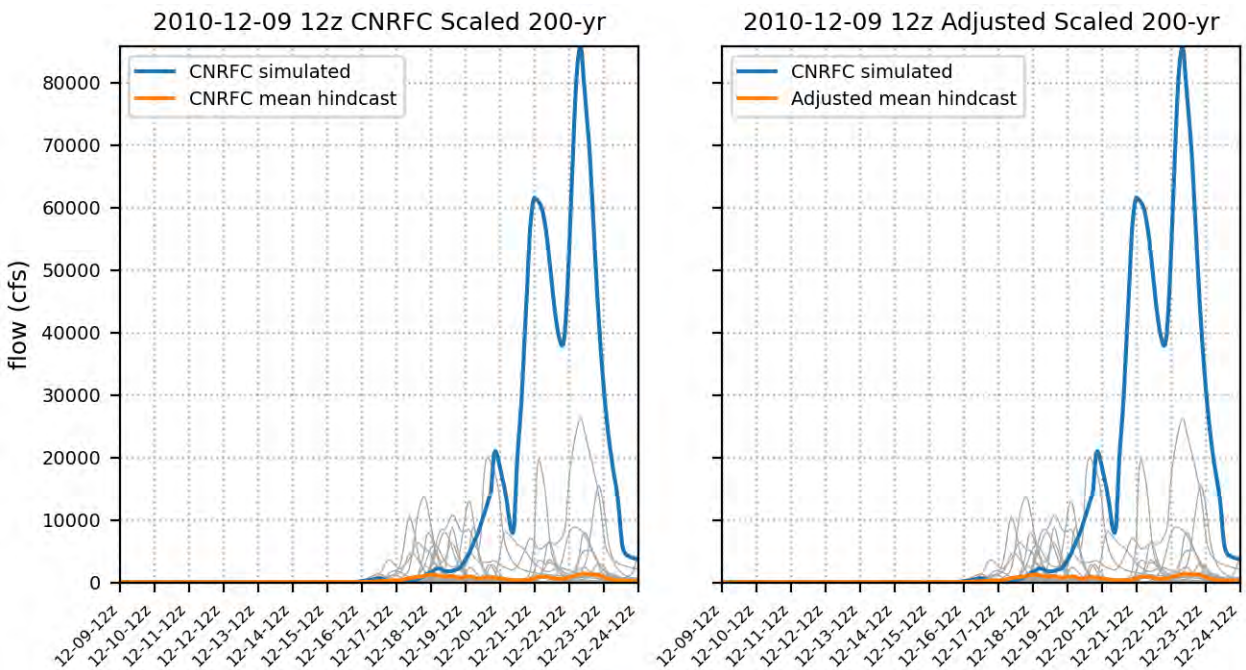

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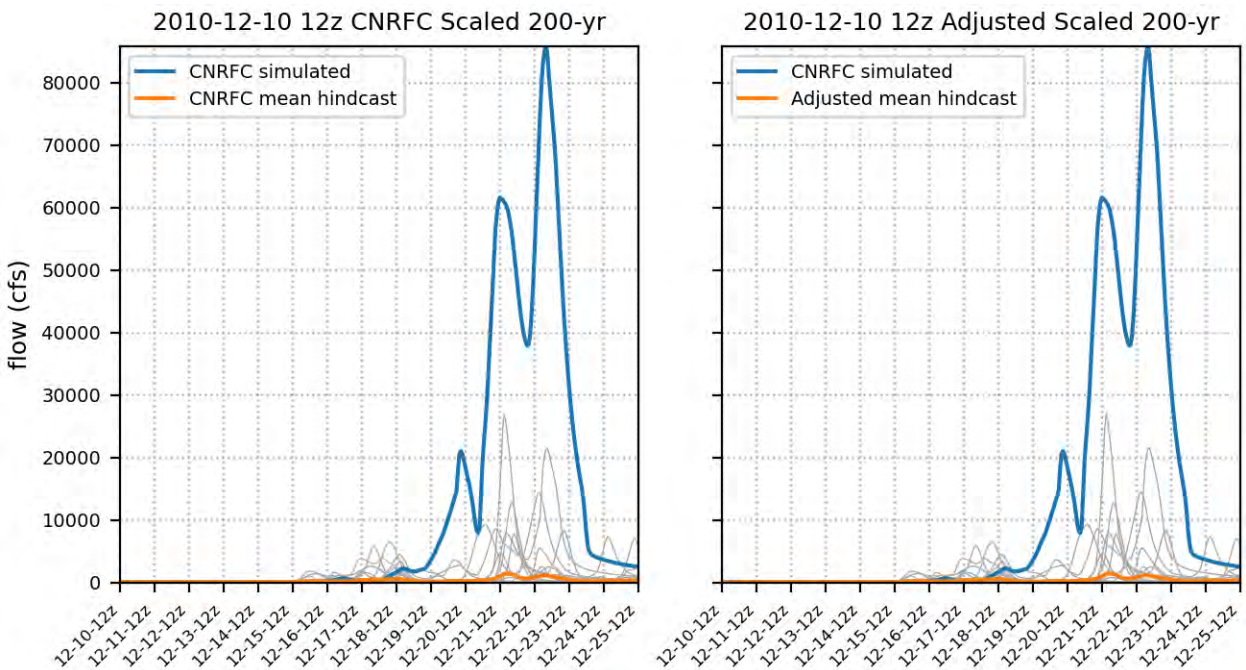

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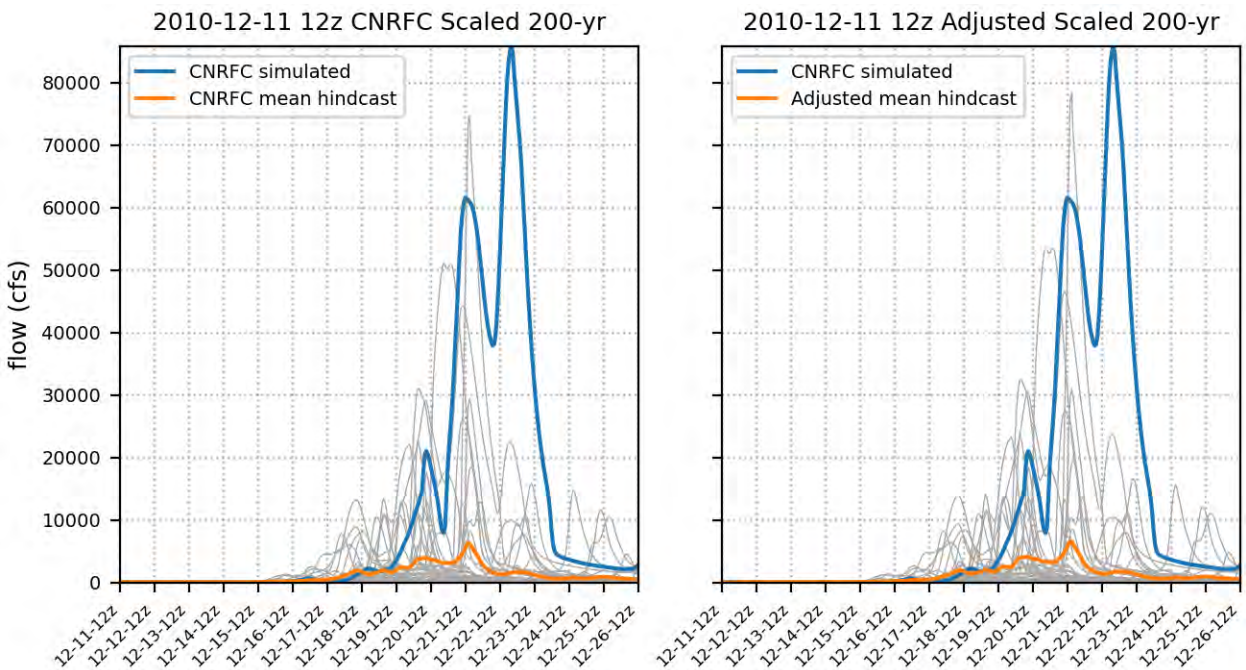

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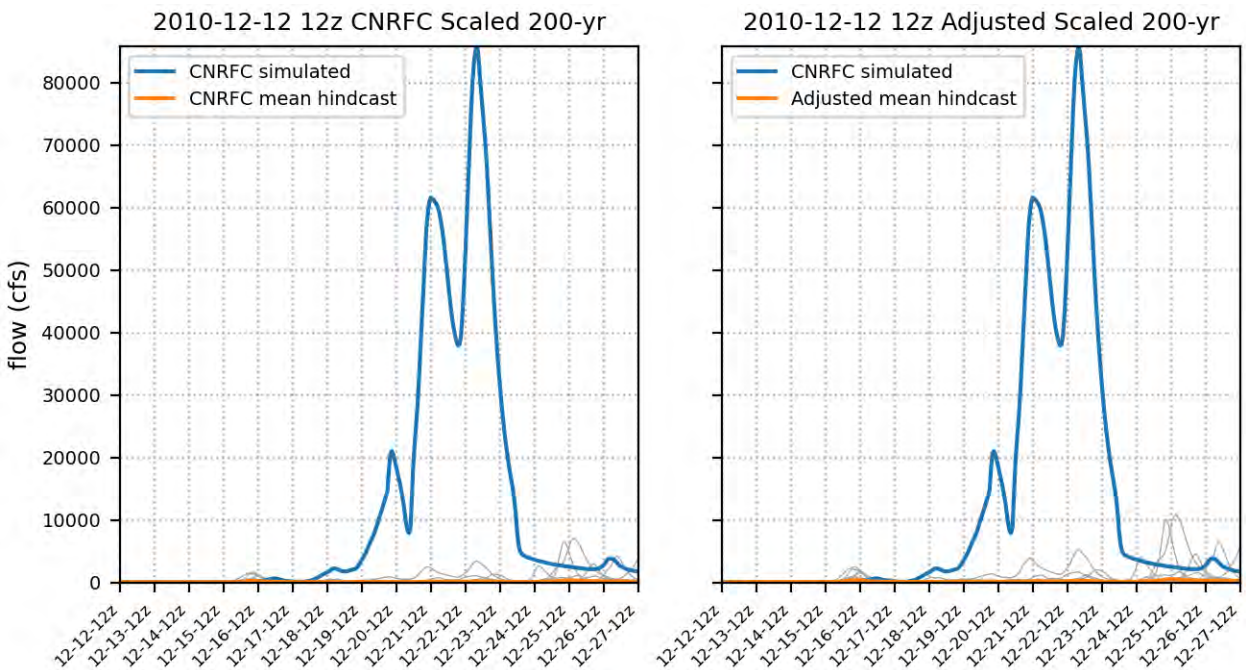

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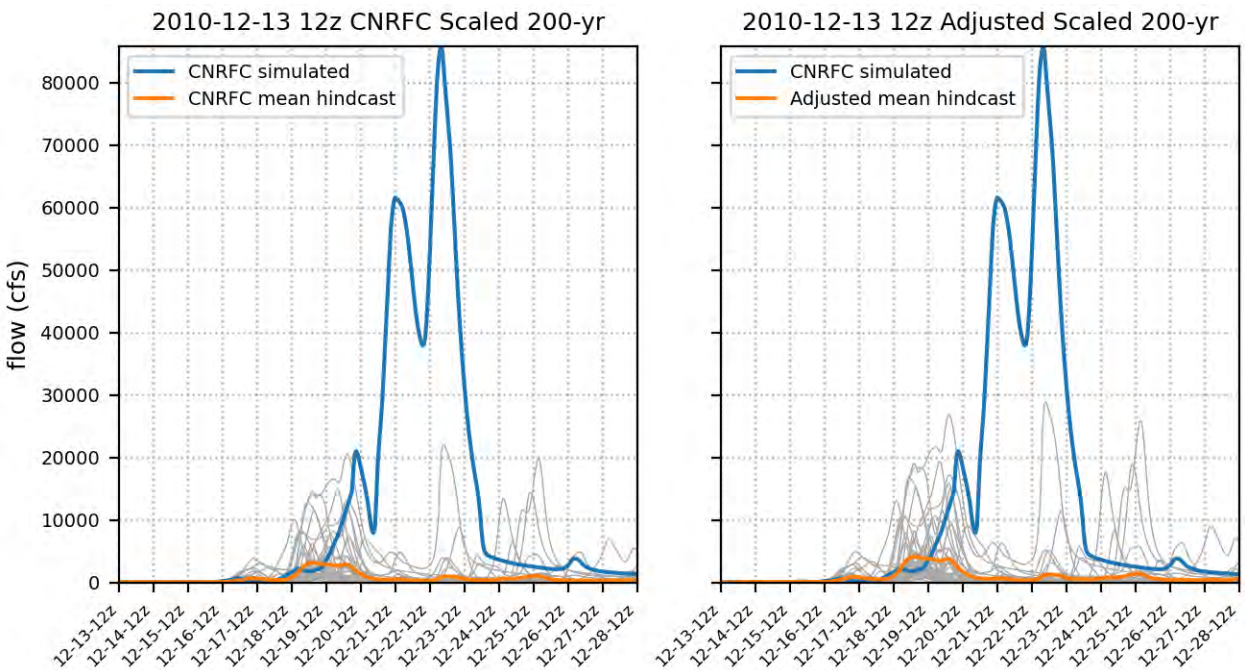

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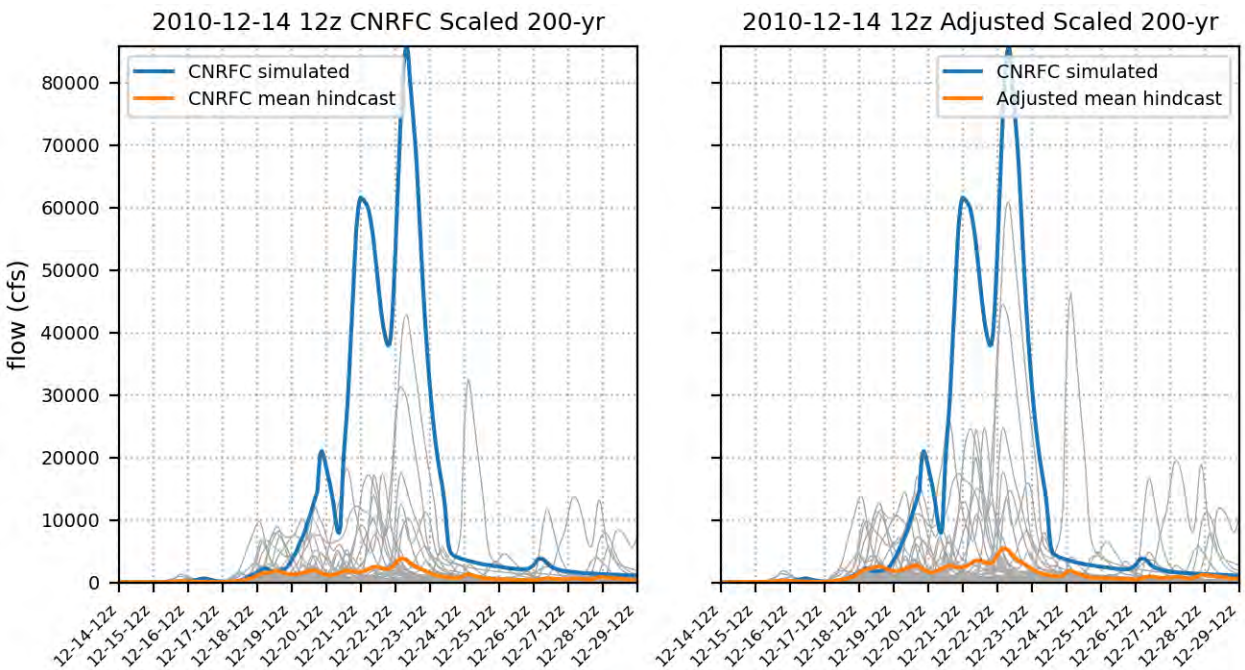

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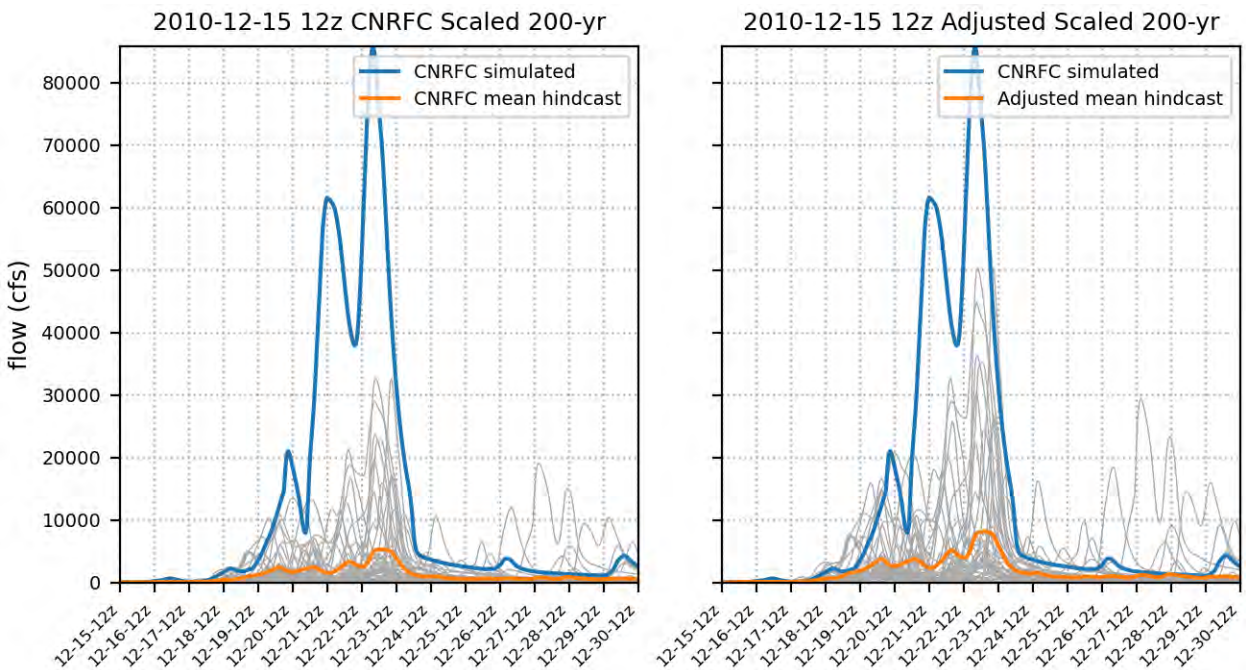

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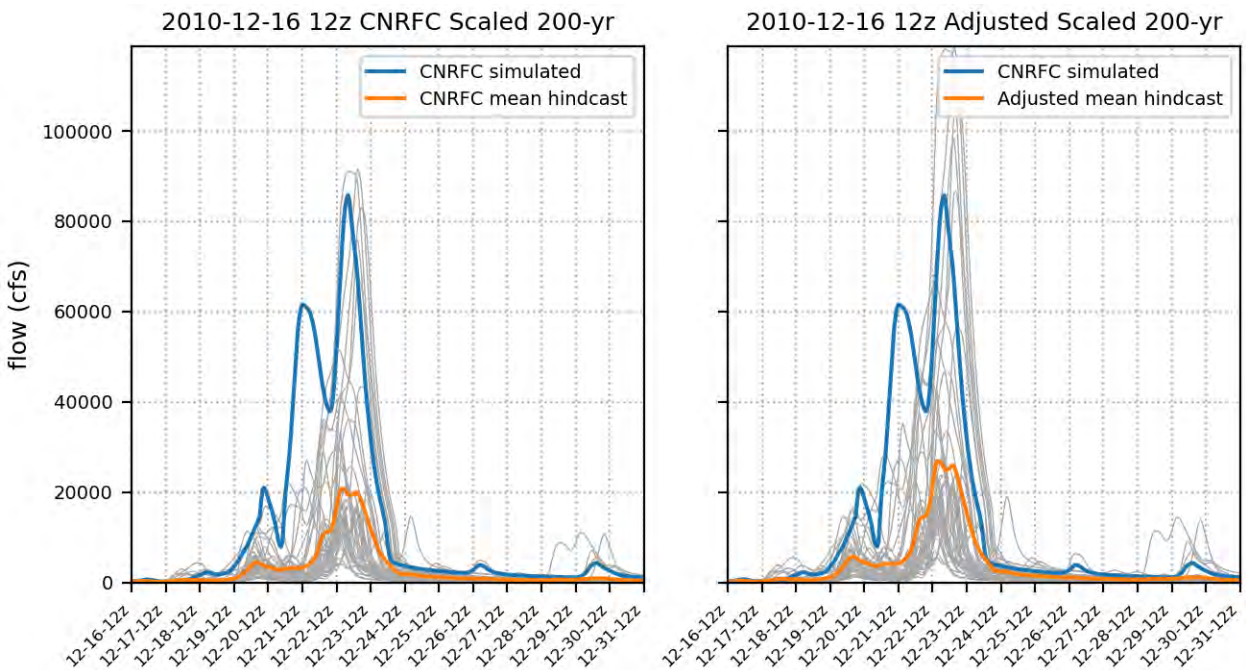

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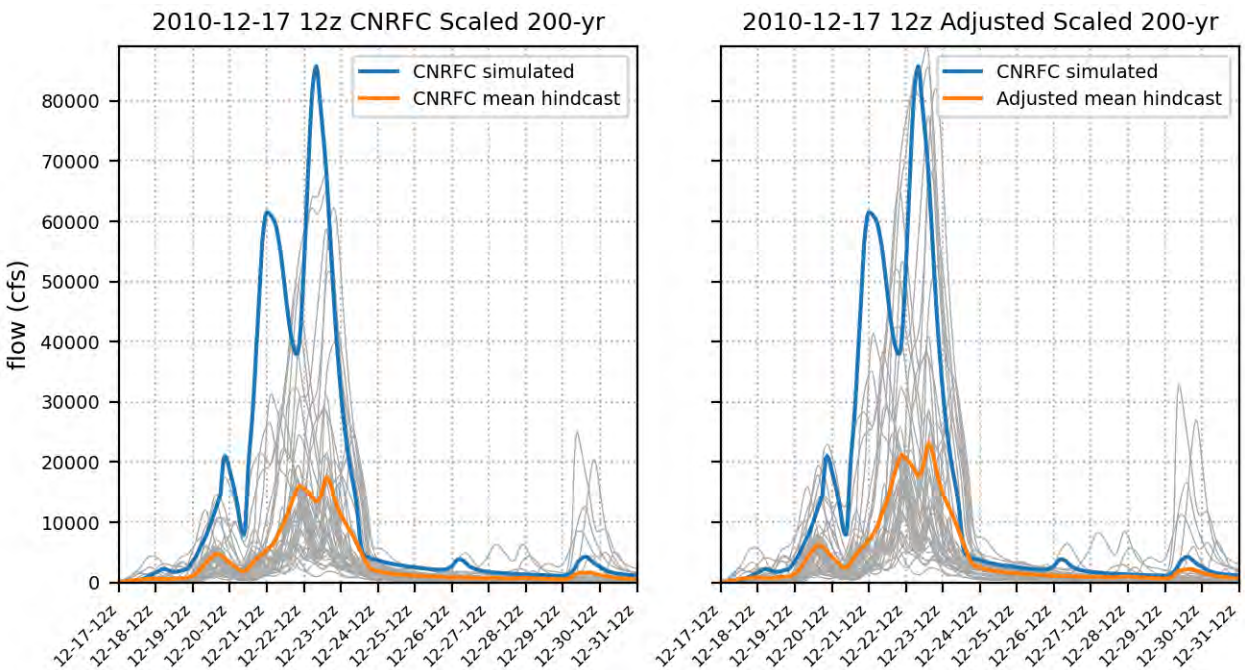

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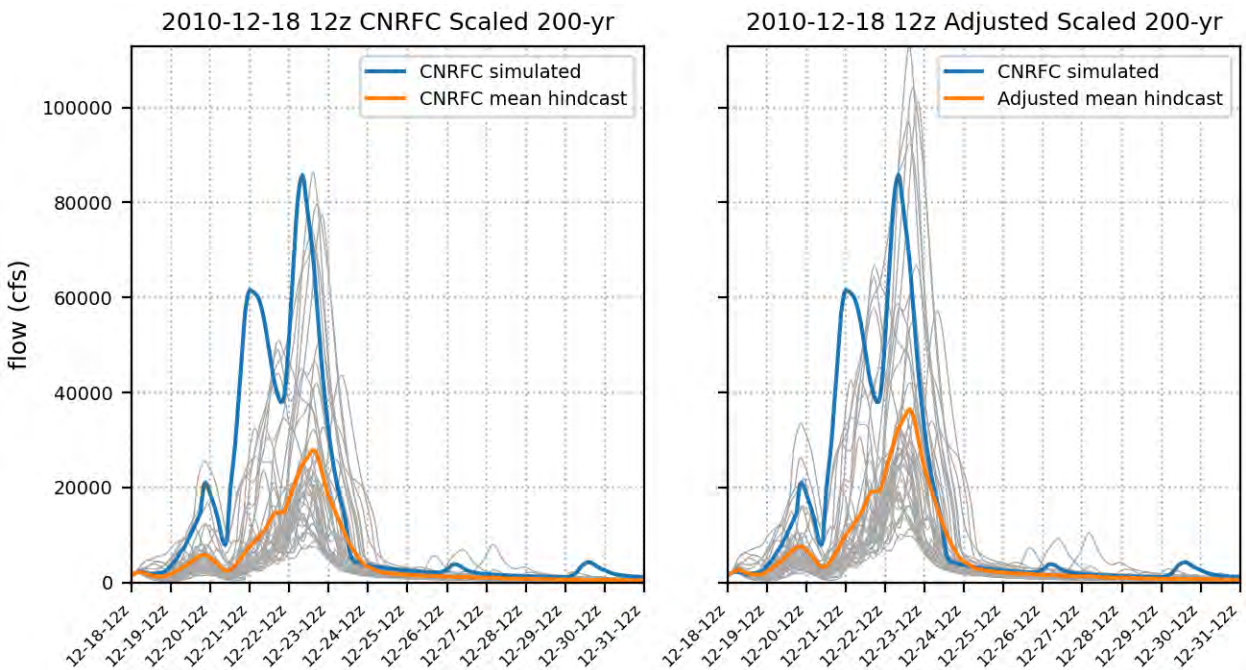

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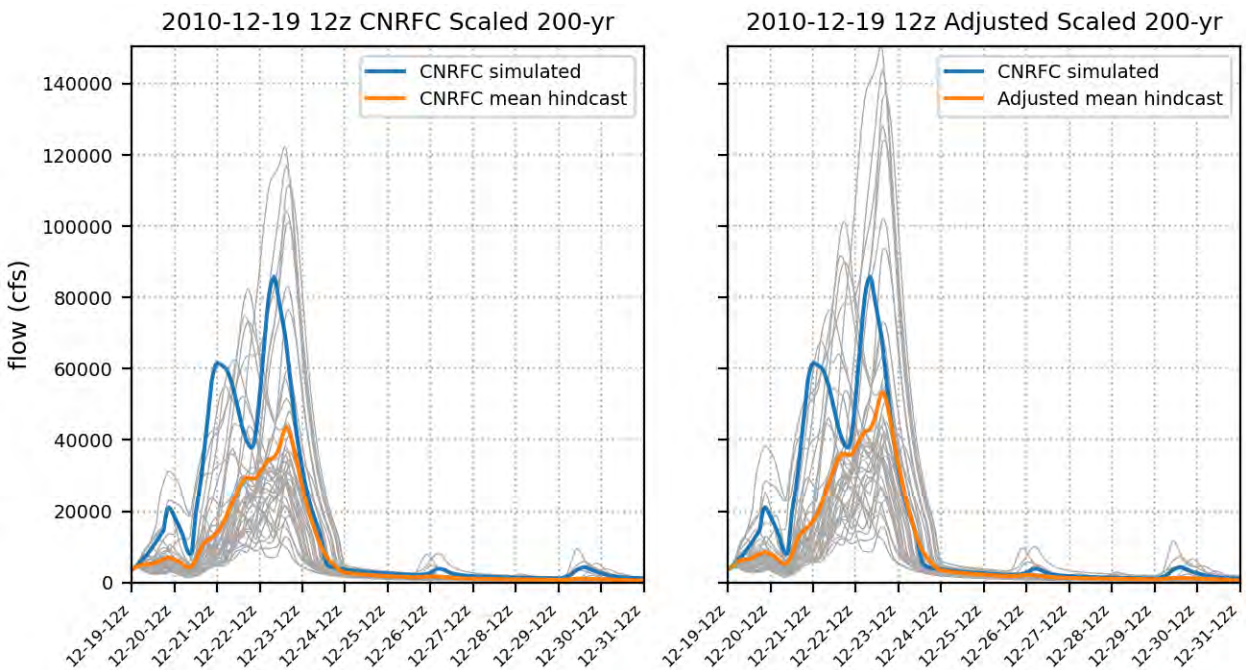

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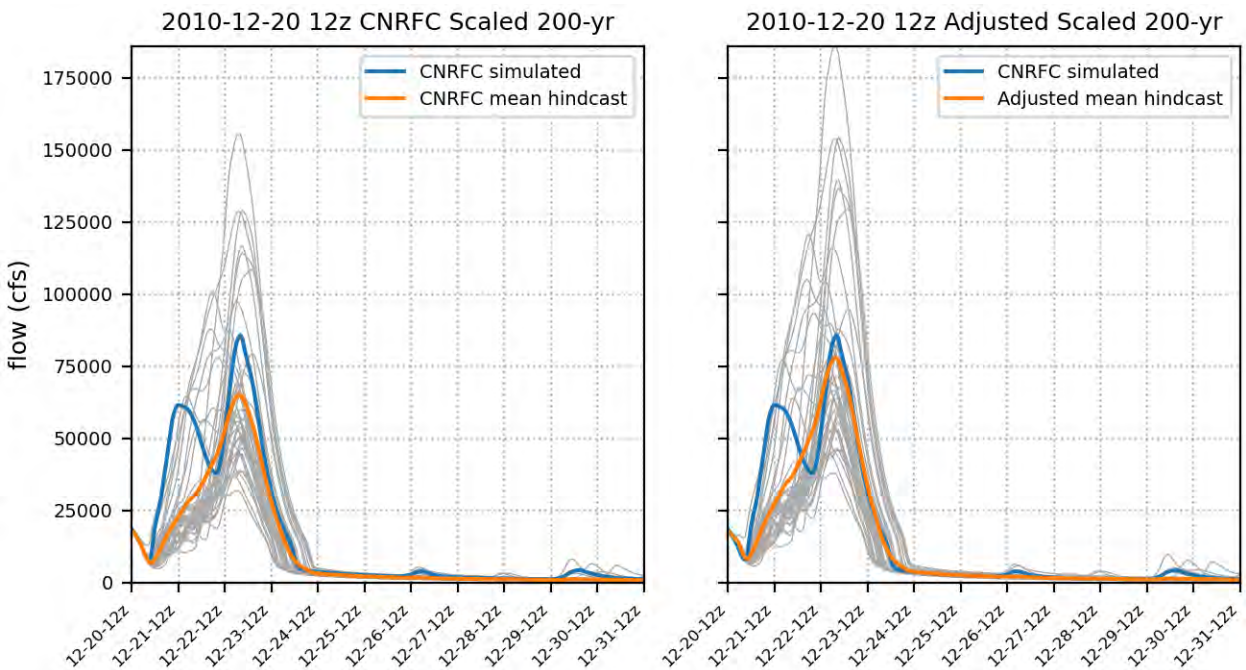

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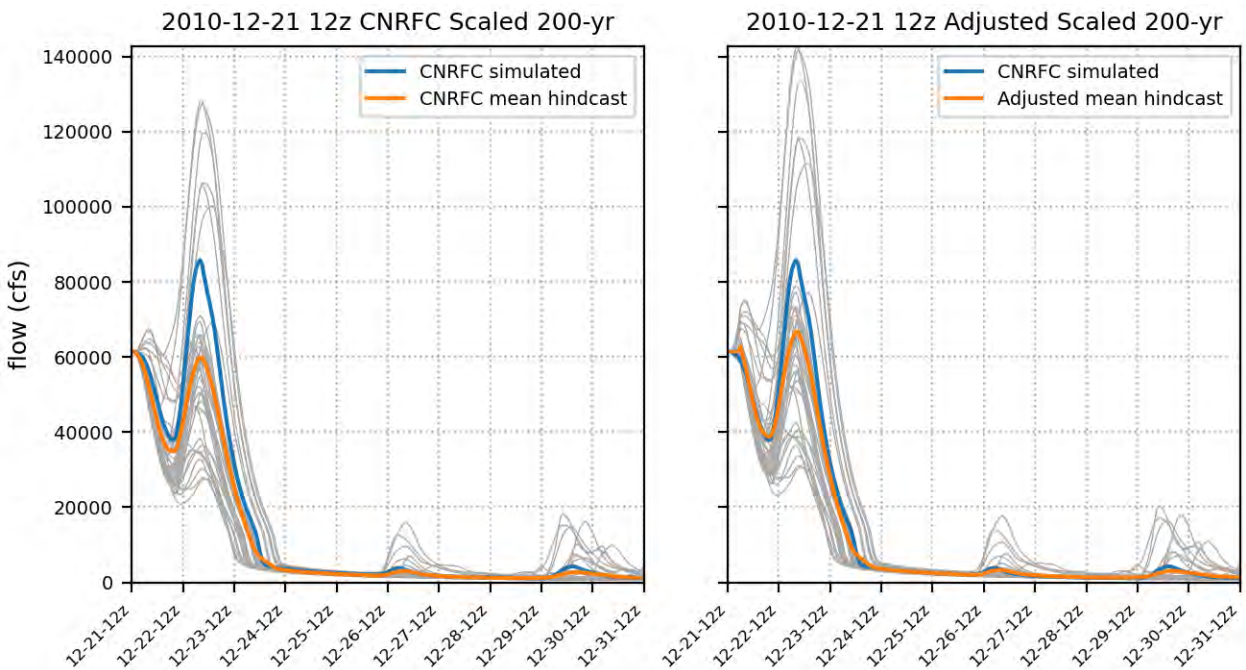

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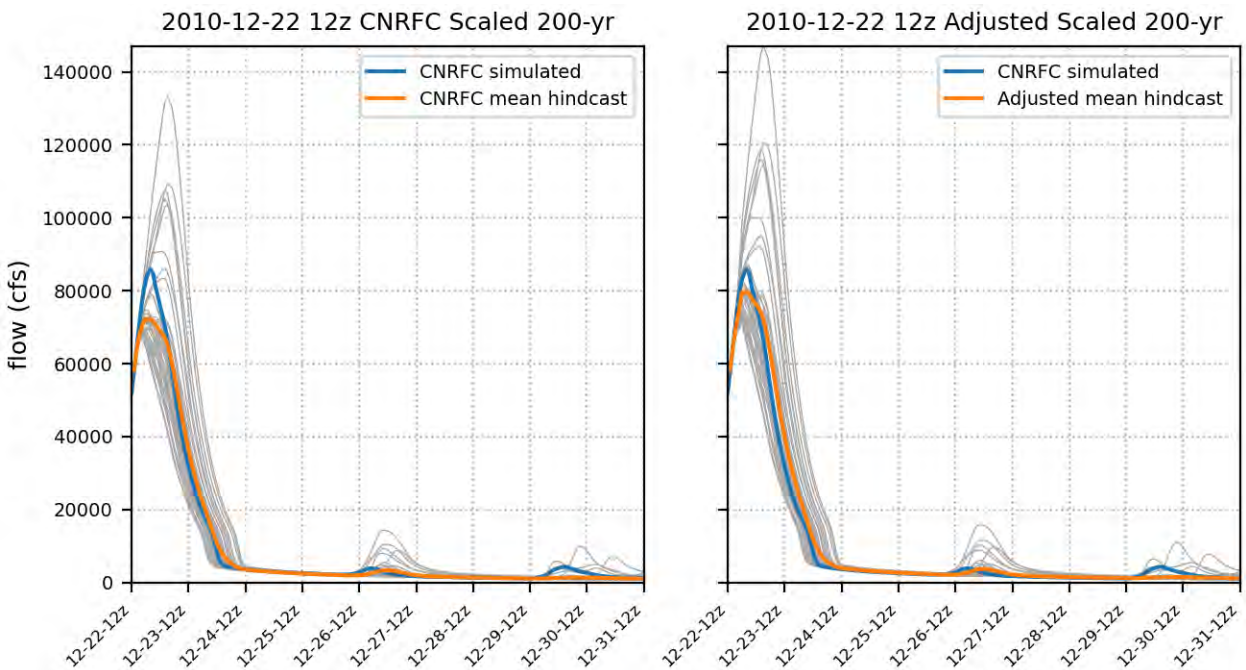

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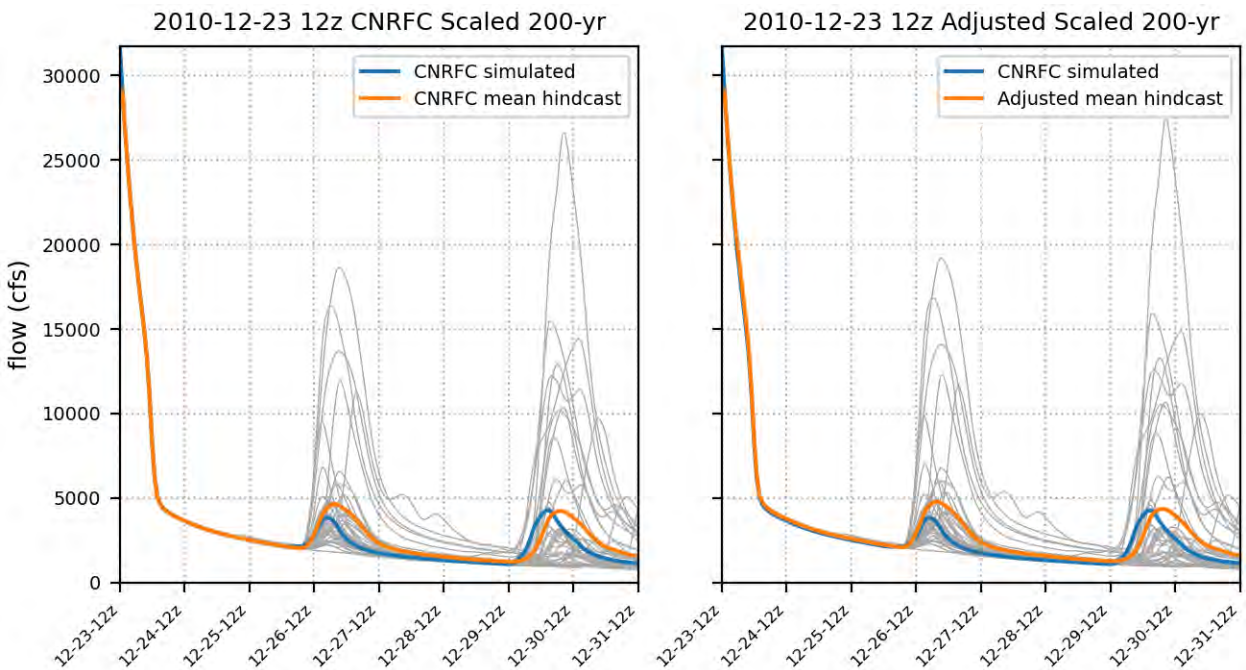

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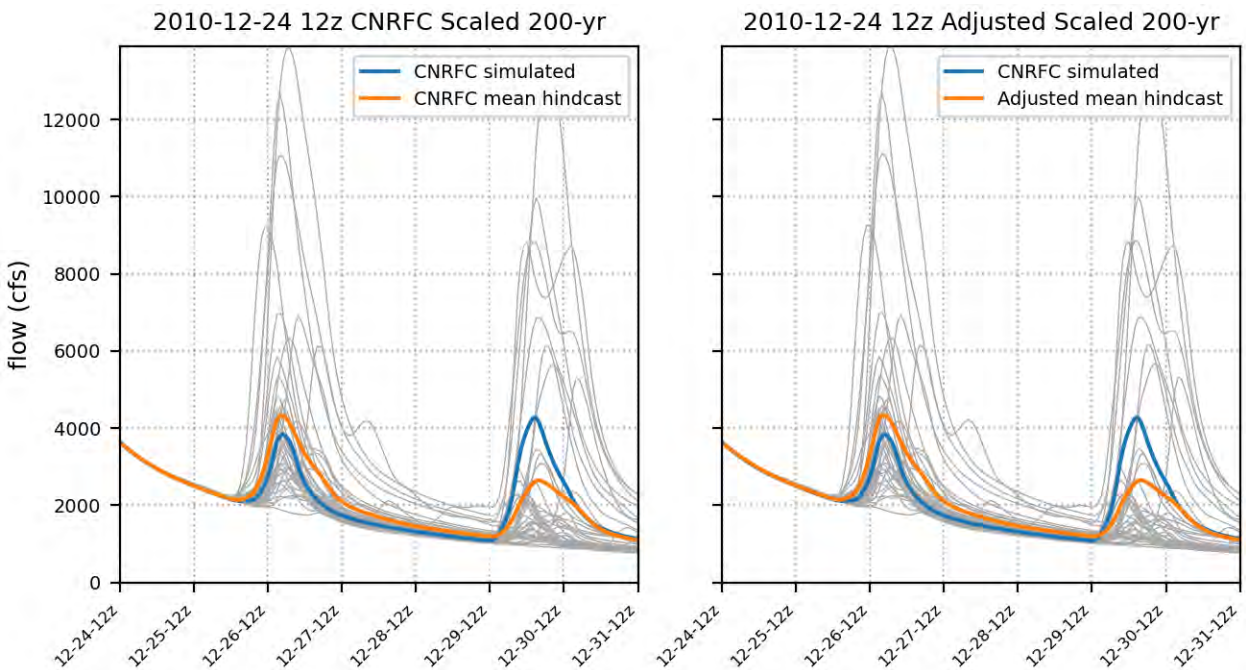

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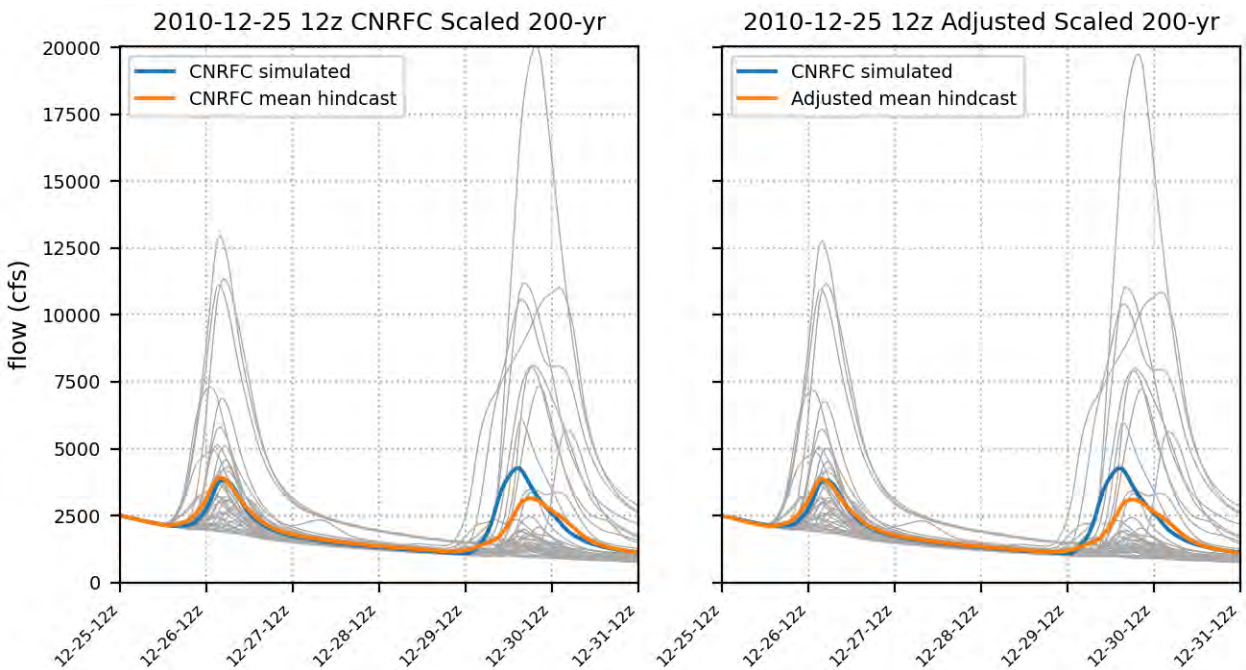

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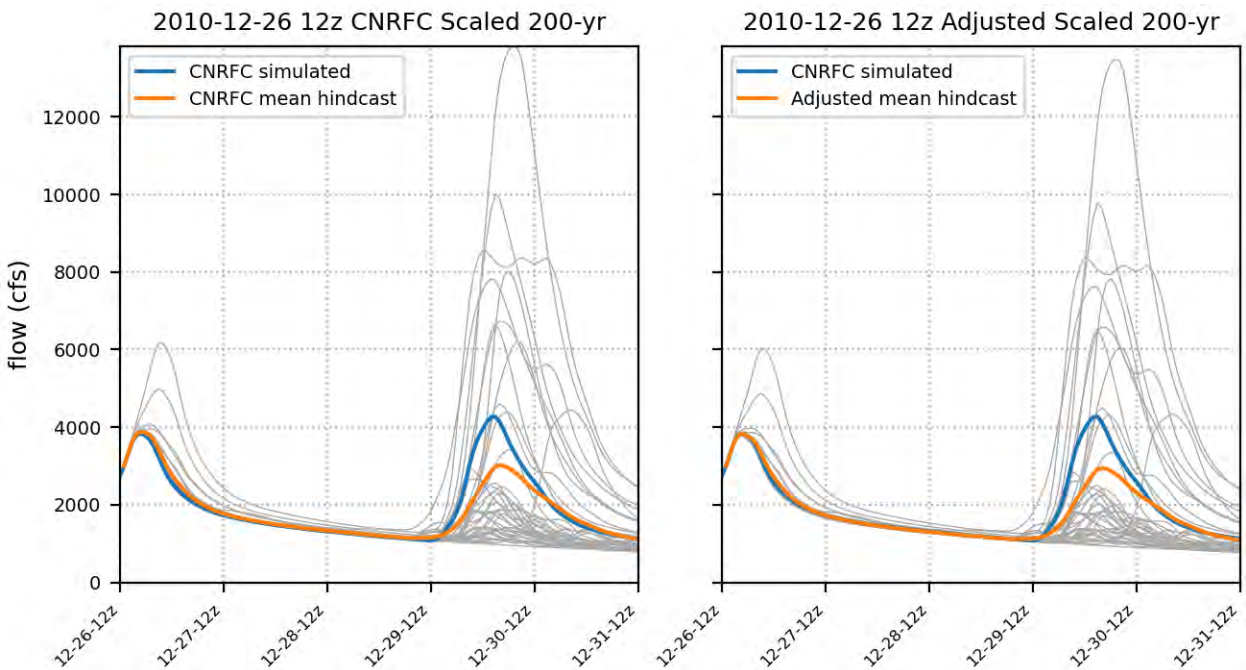

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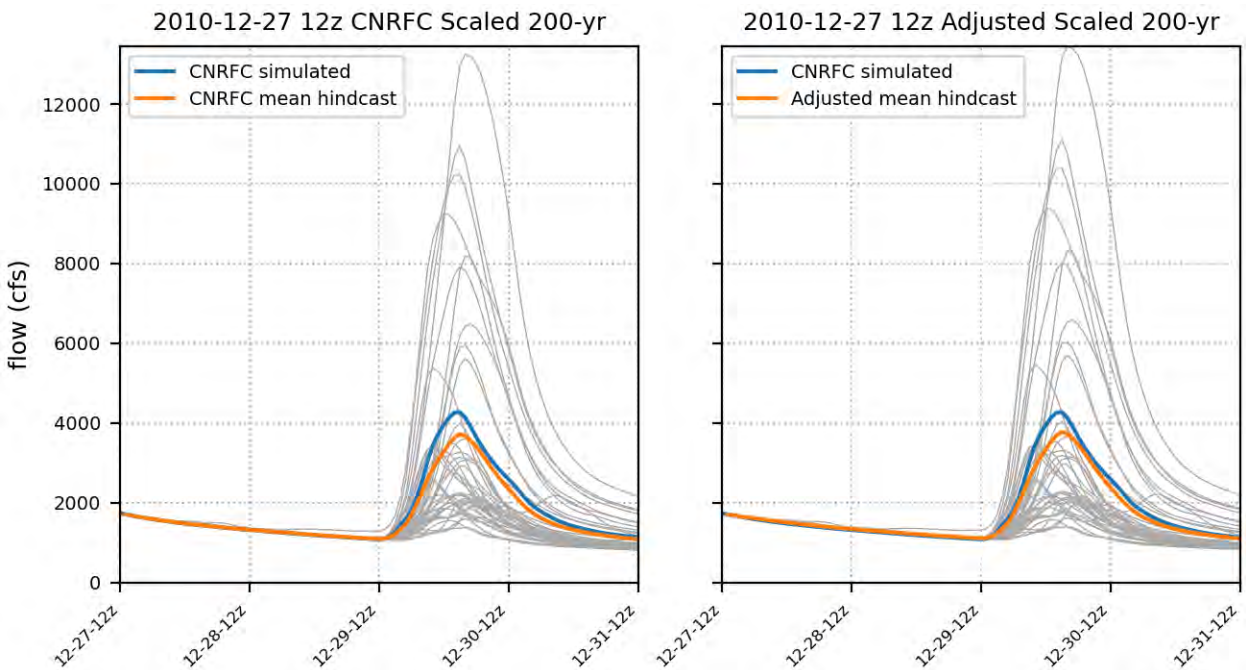

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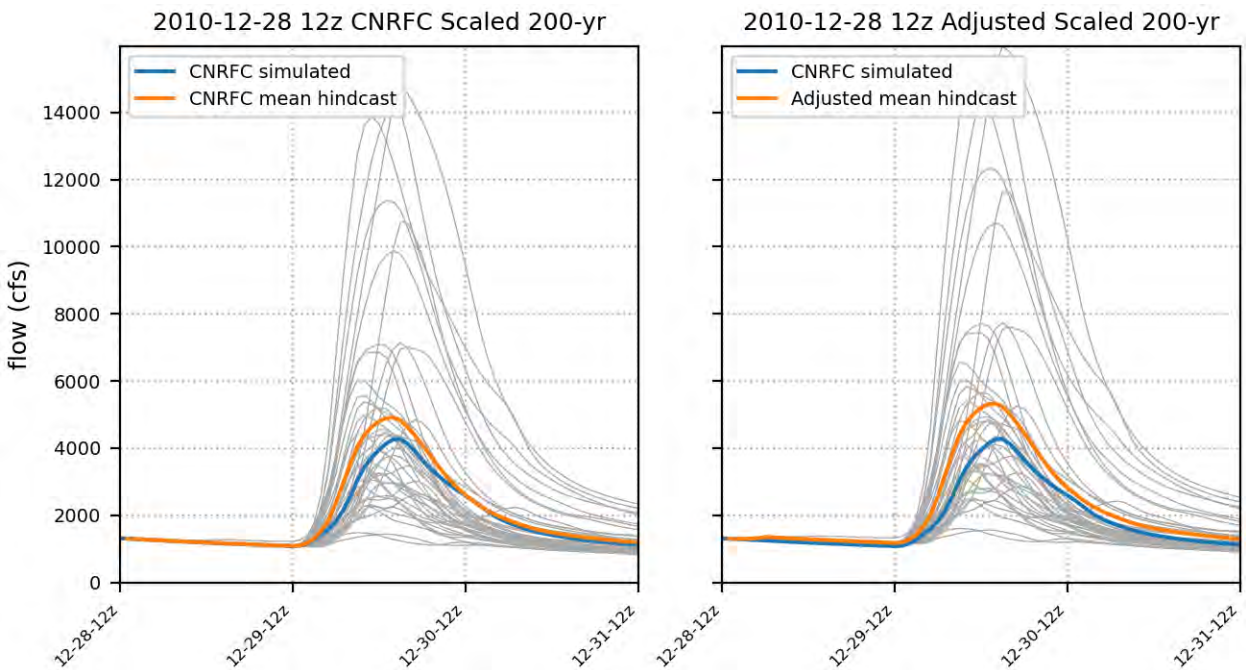

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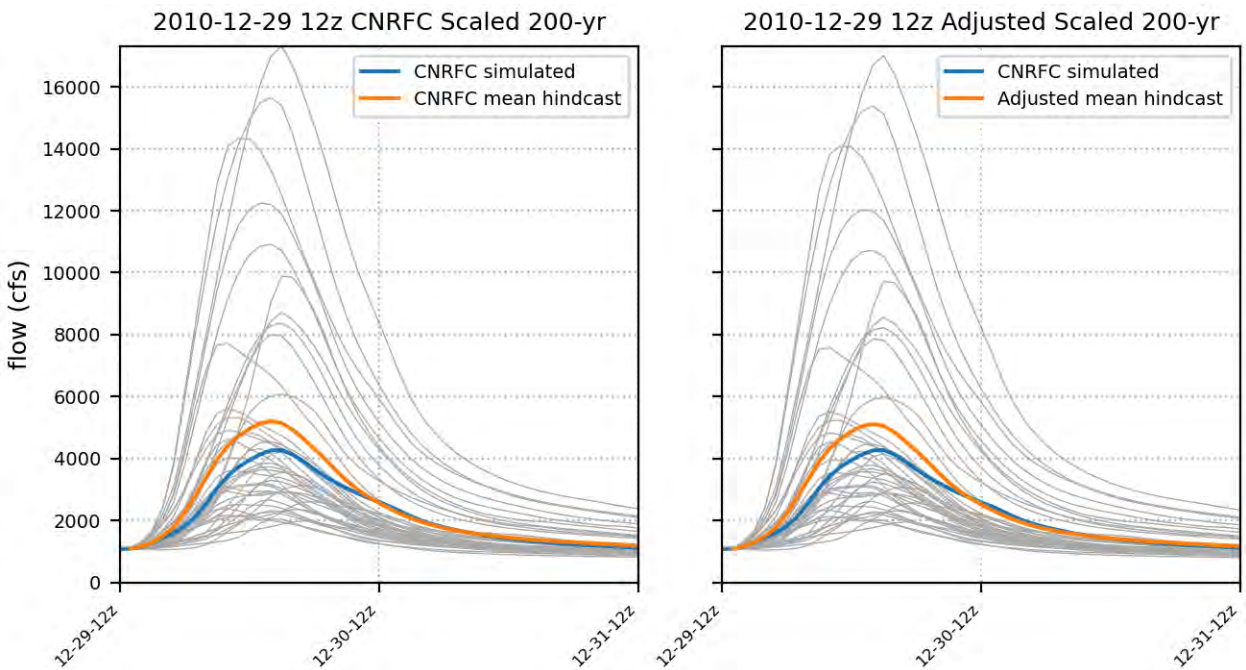
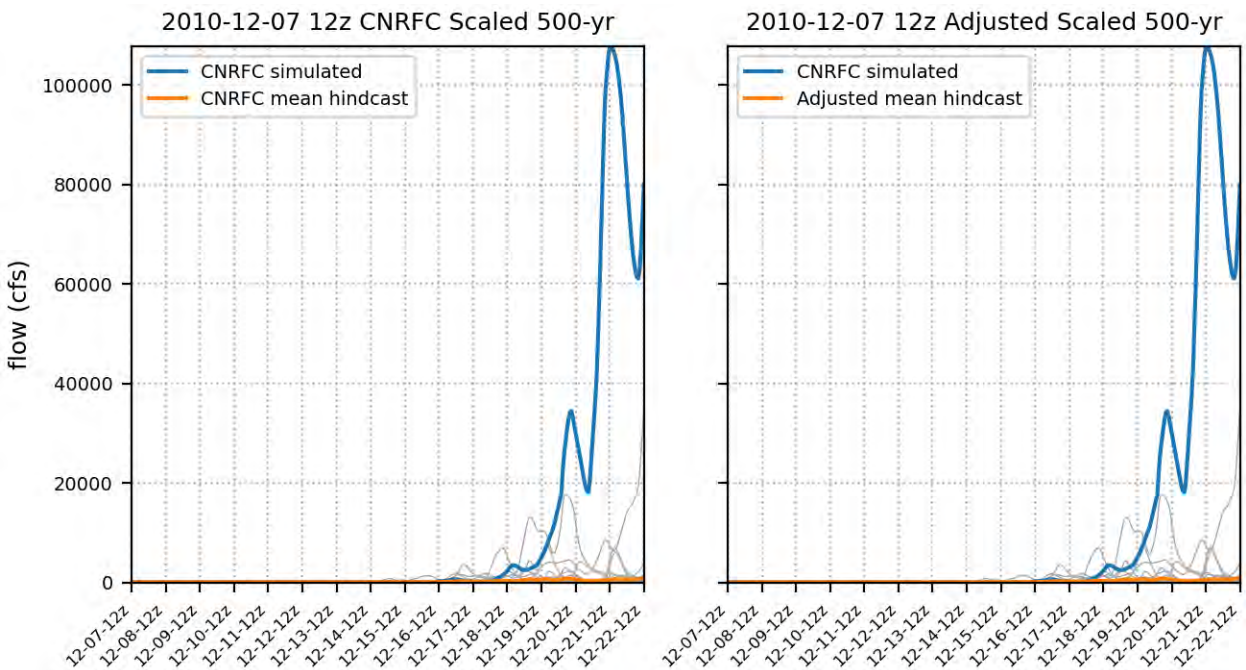


Adjusted Scaled Hindcast 2010 500-yr

2023-03-25

500-yr 12/7/2010



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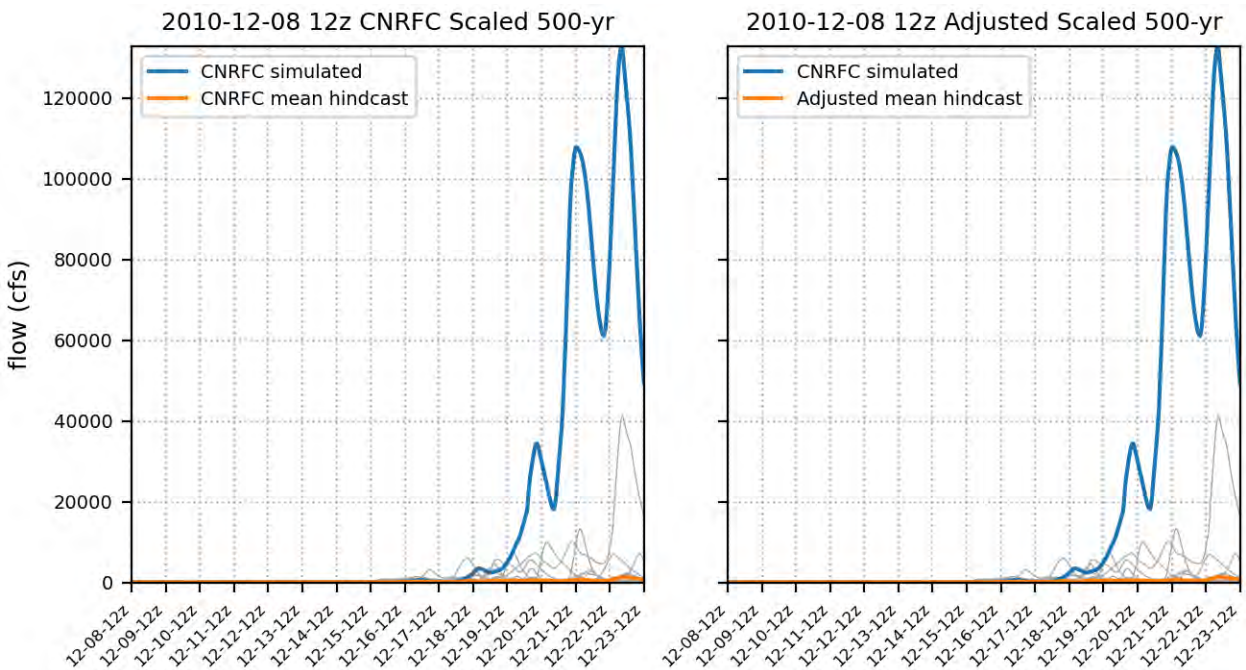

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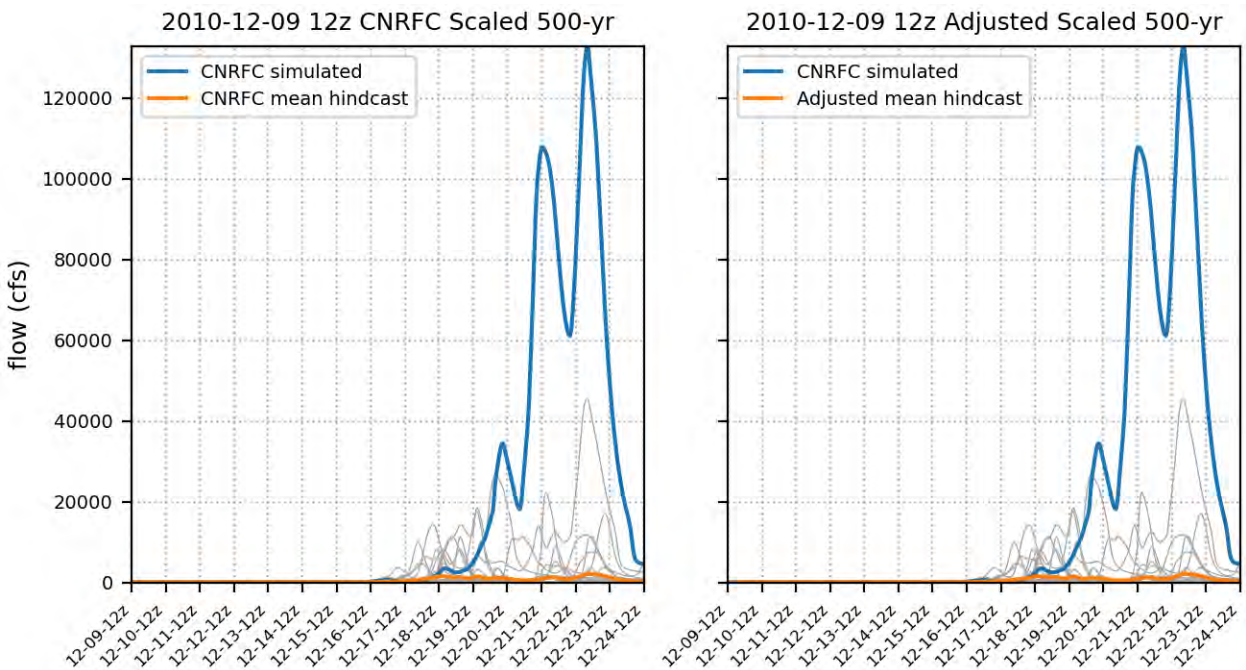

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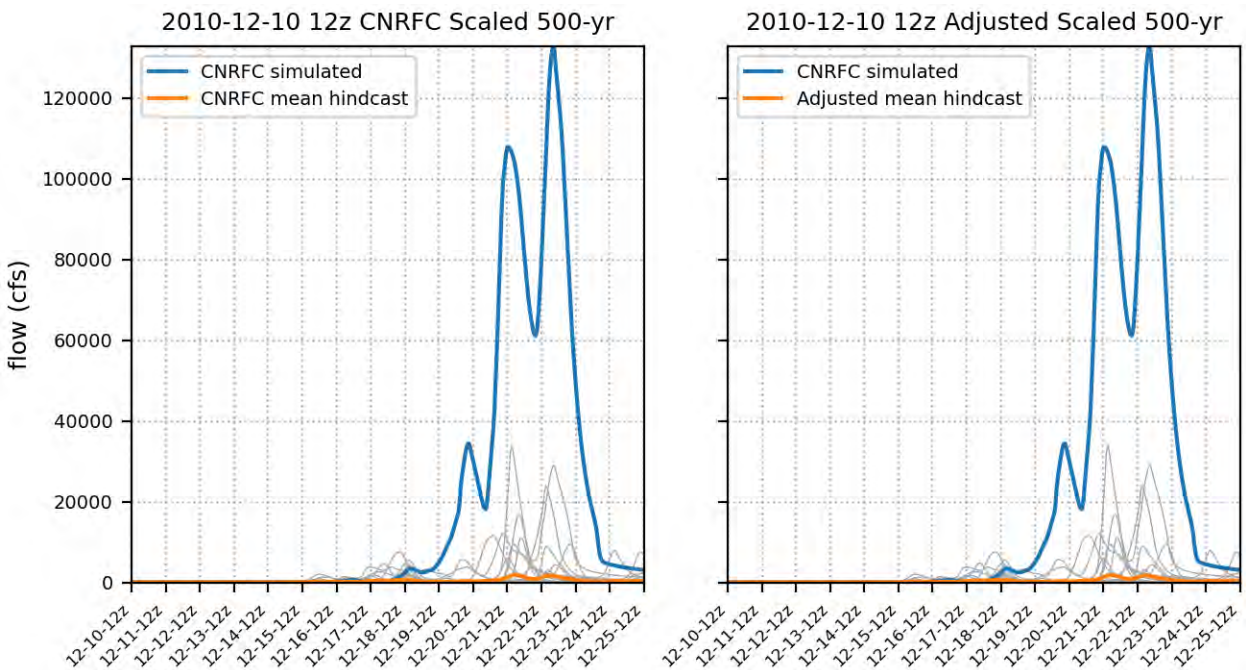

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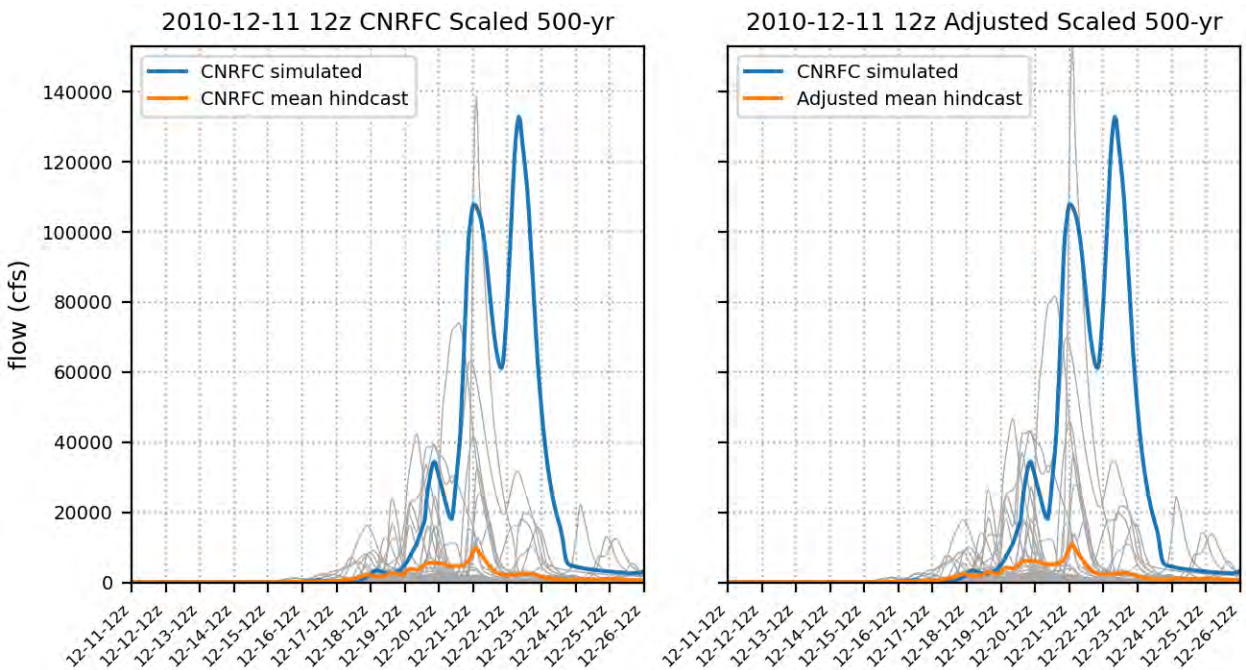

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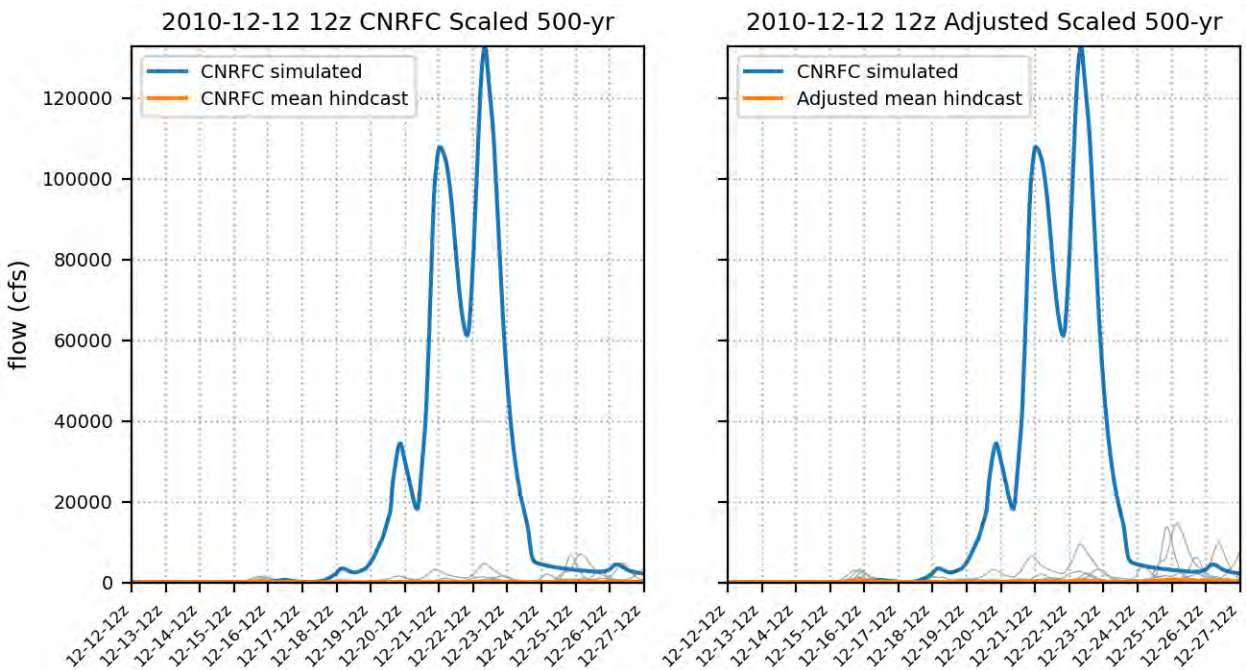

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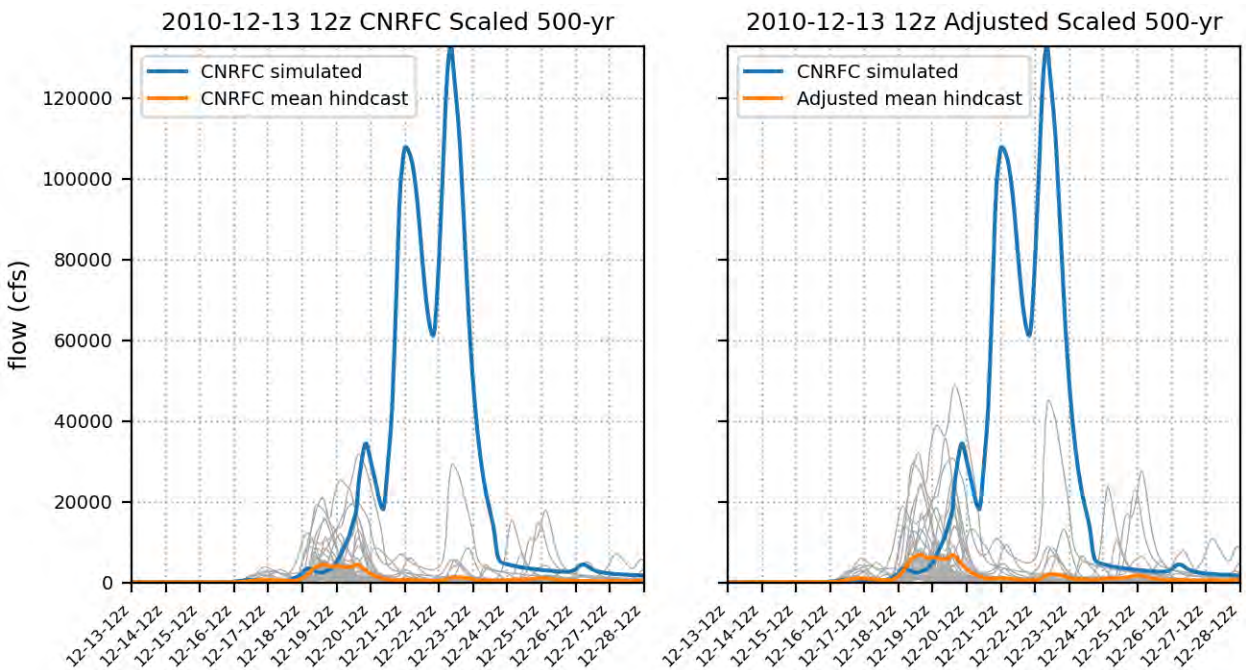

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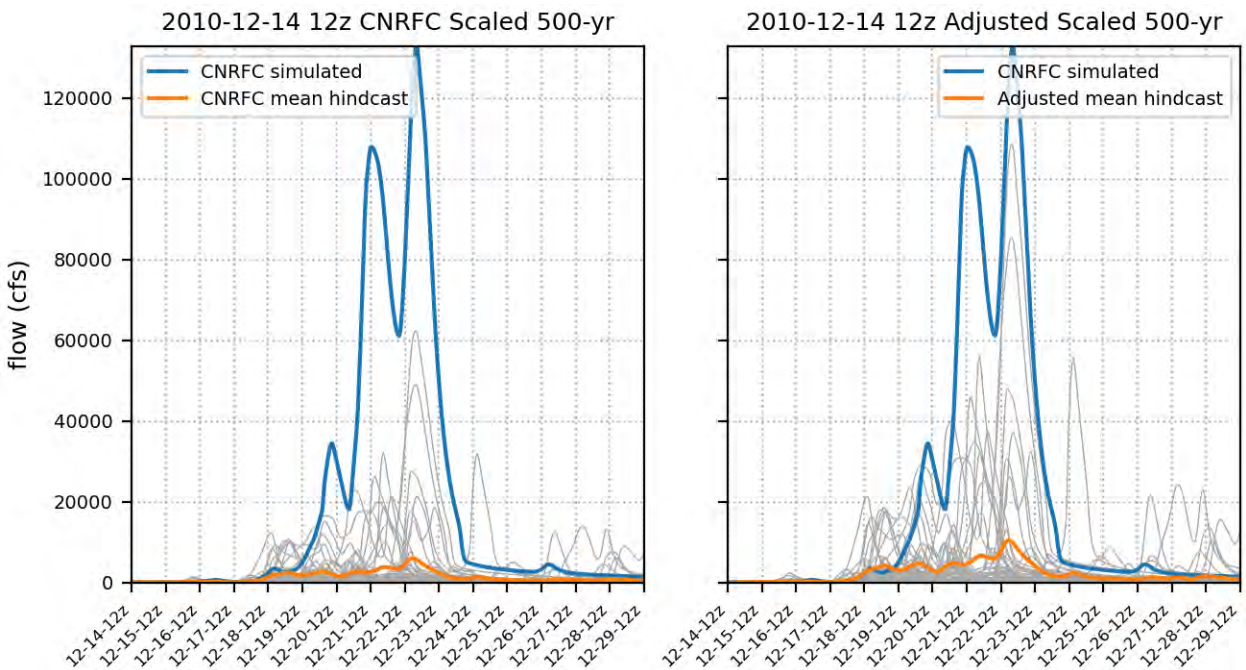

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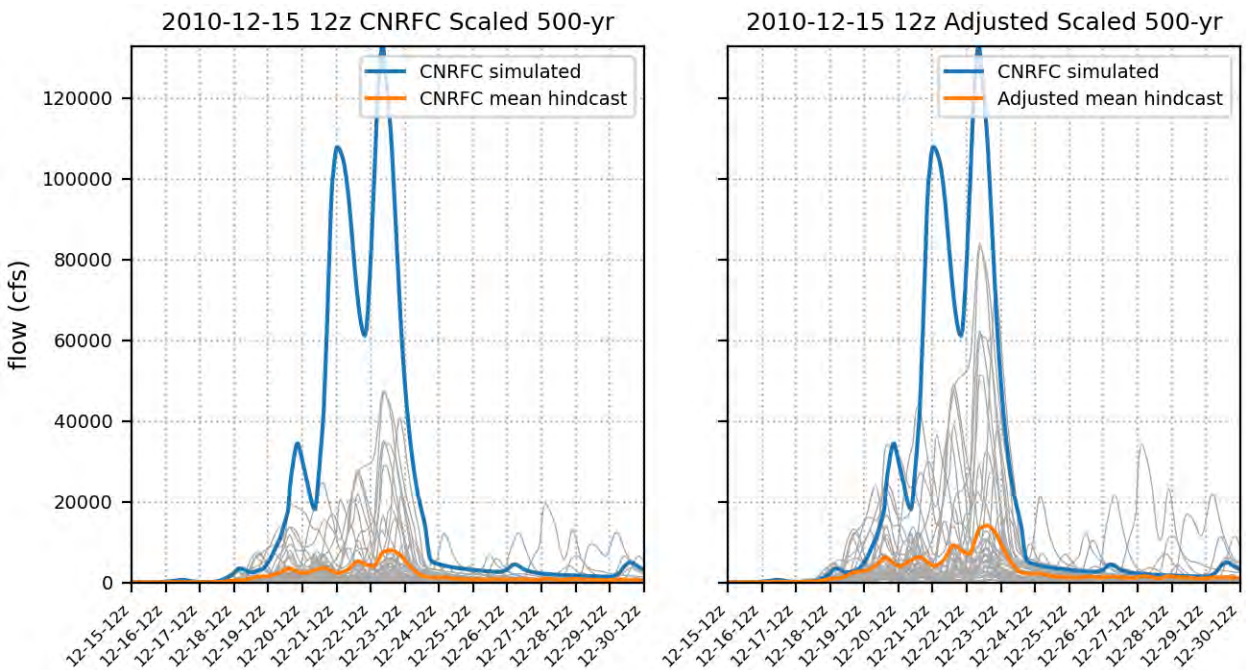

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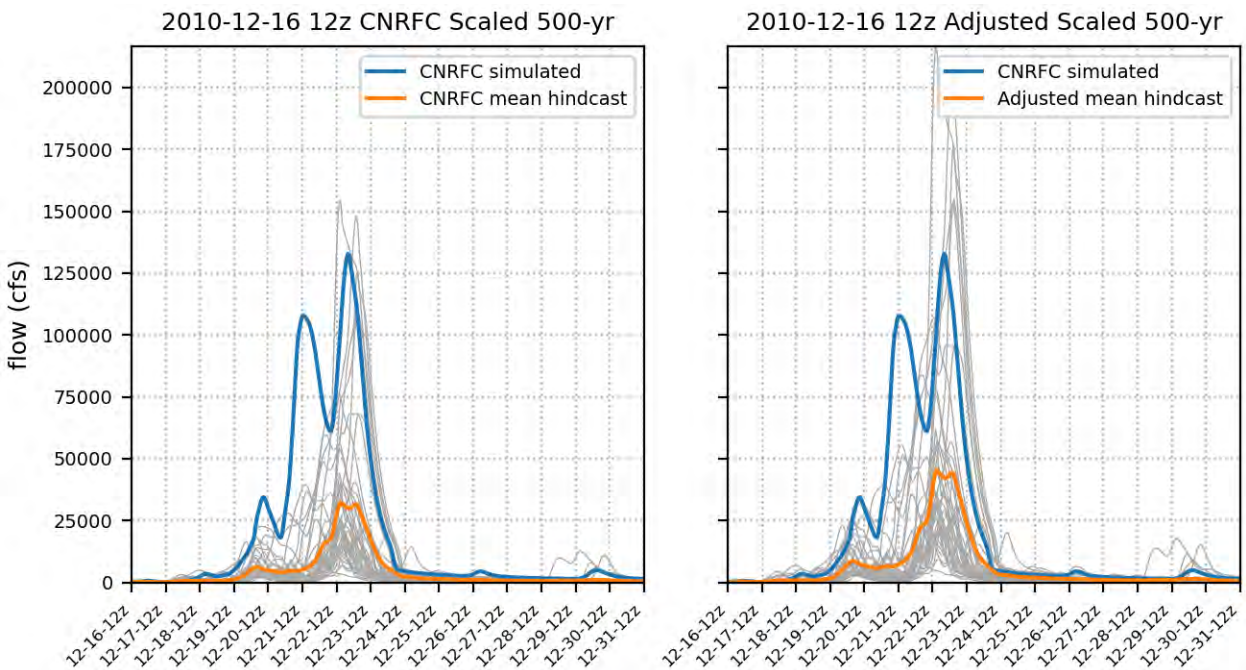

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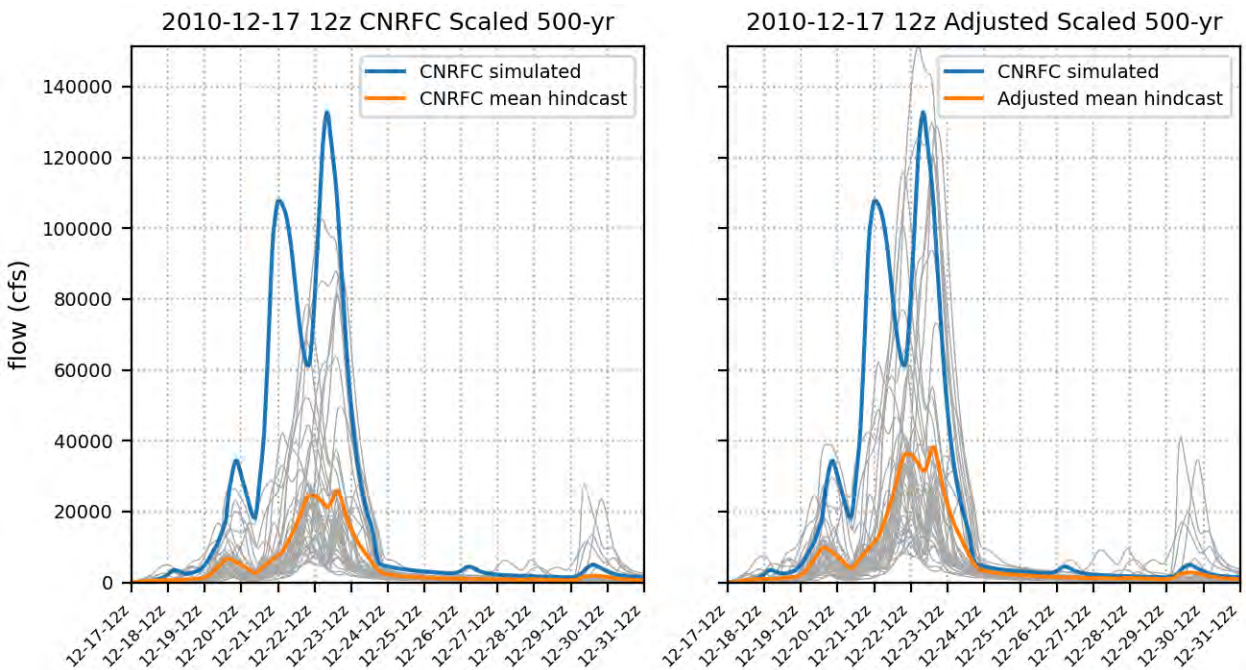

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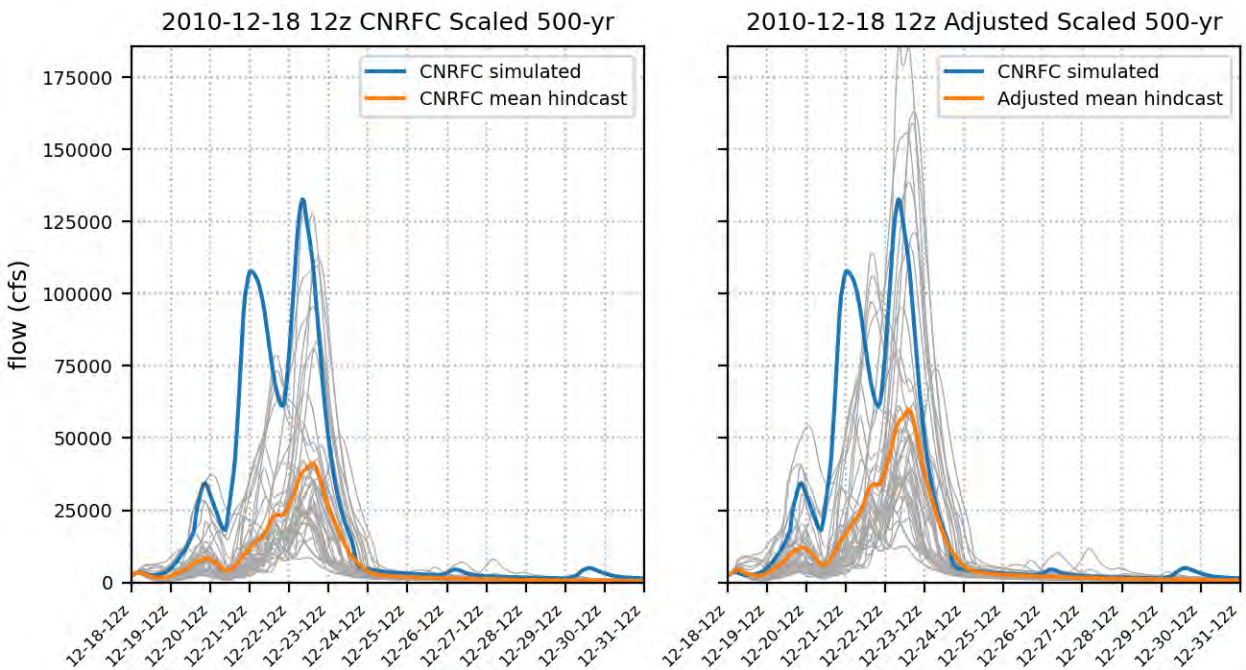

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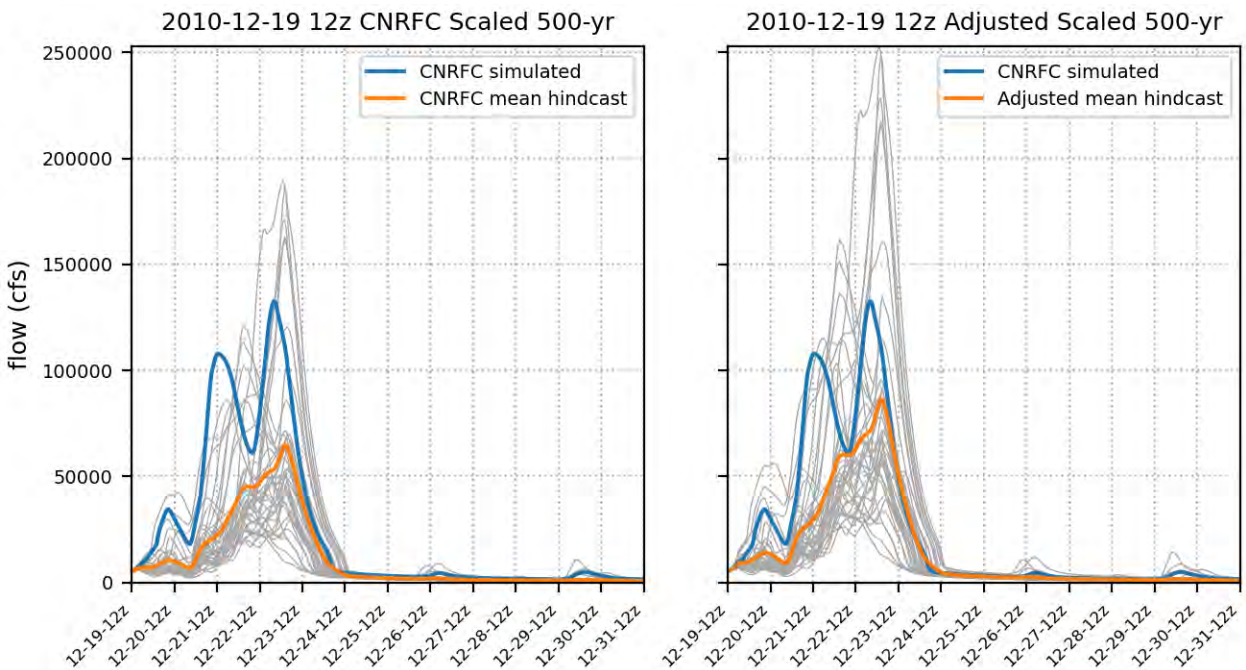

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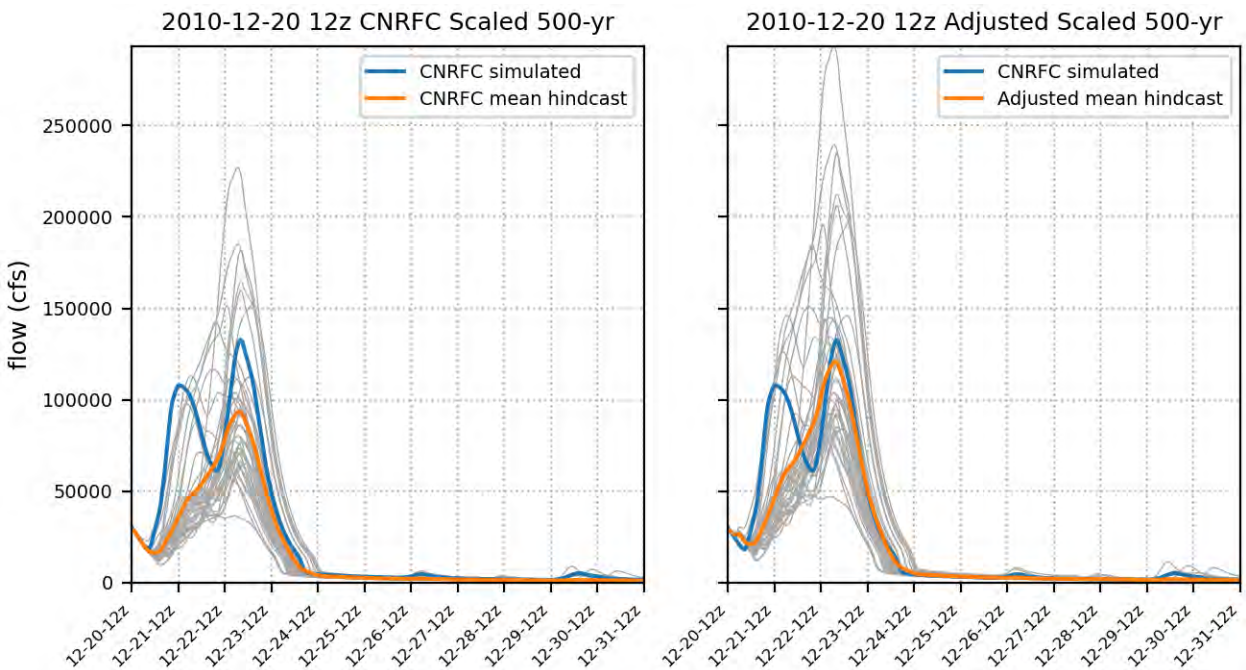

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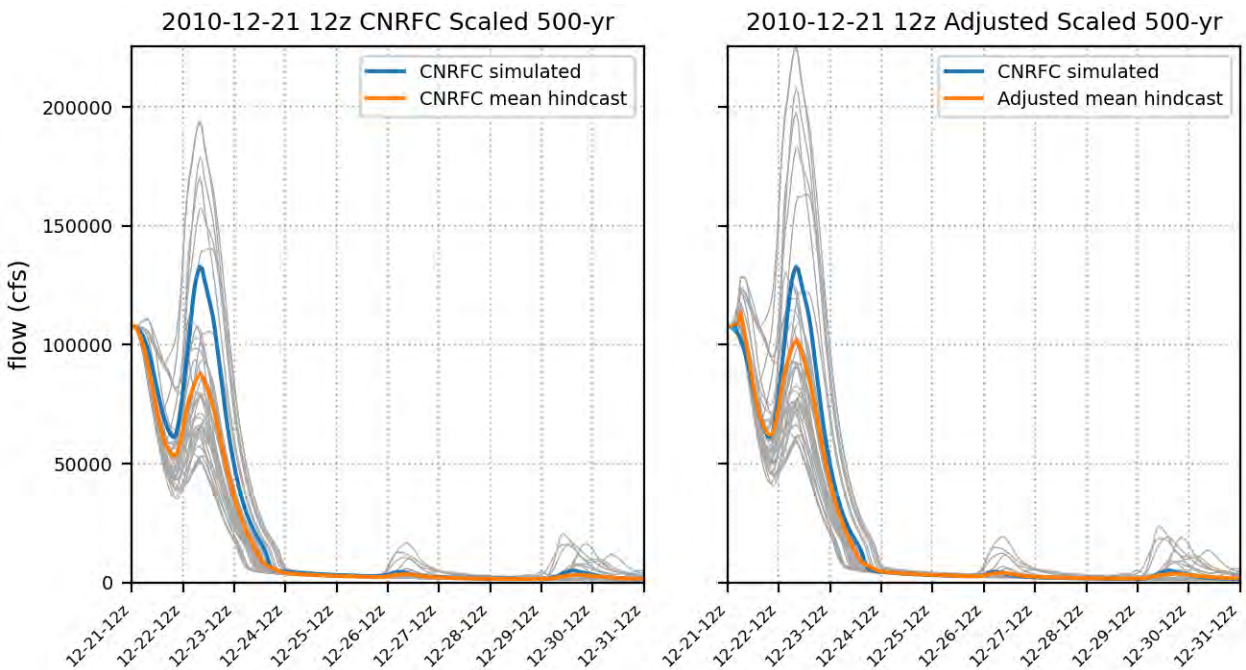

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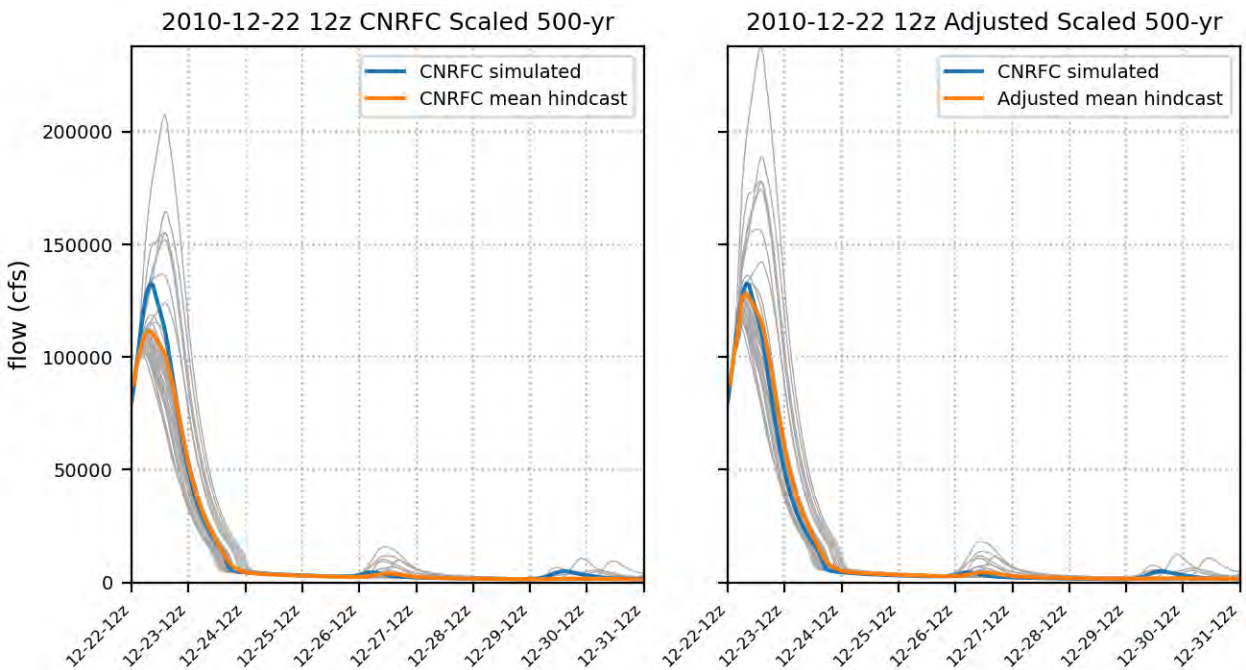

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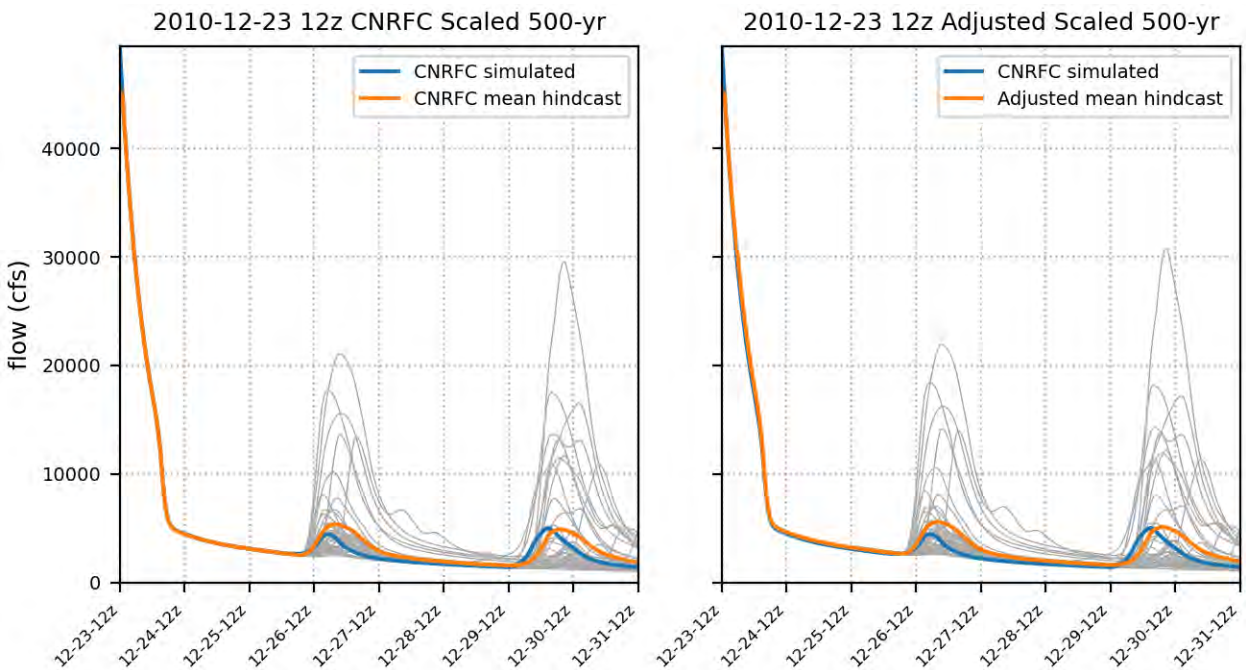

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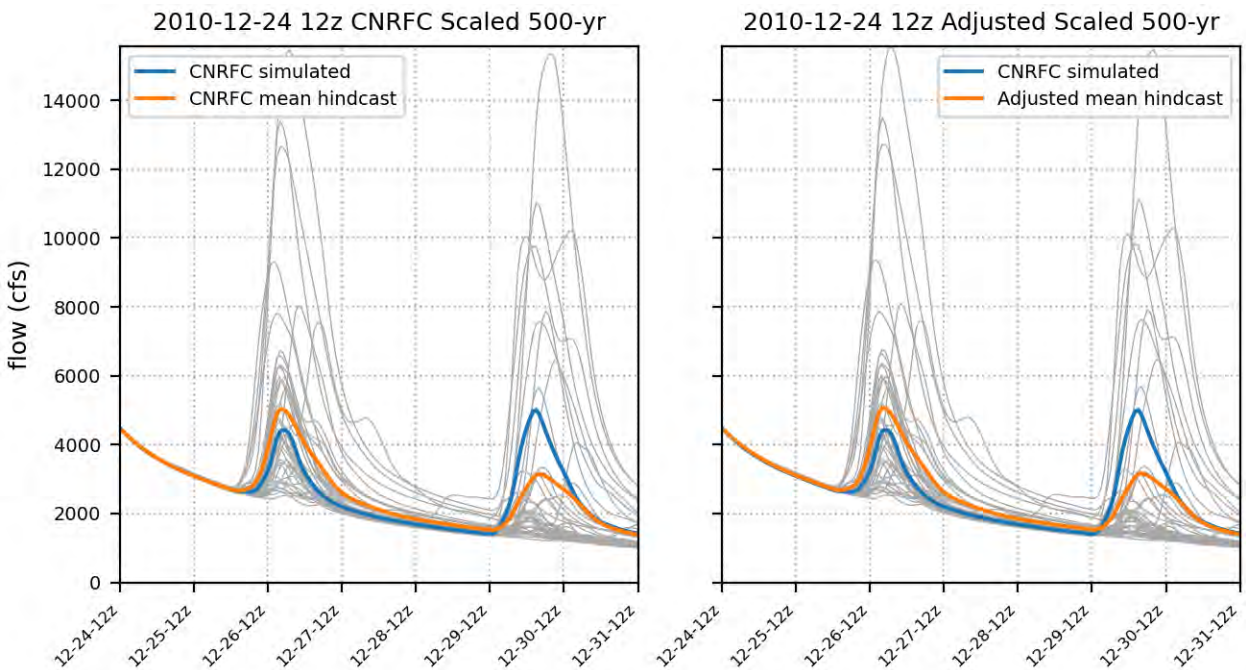

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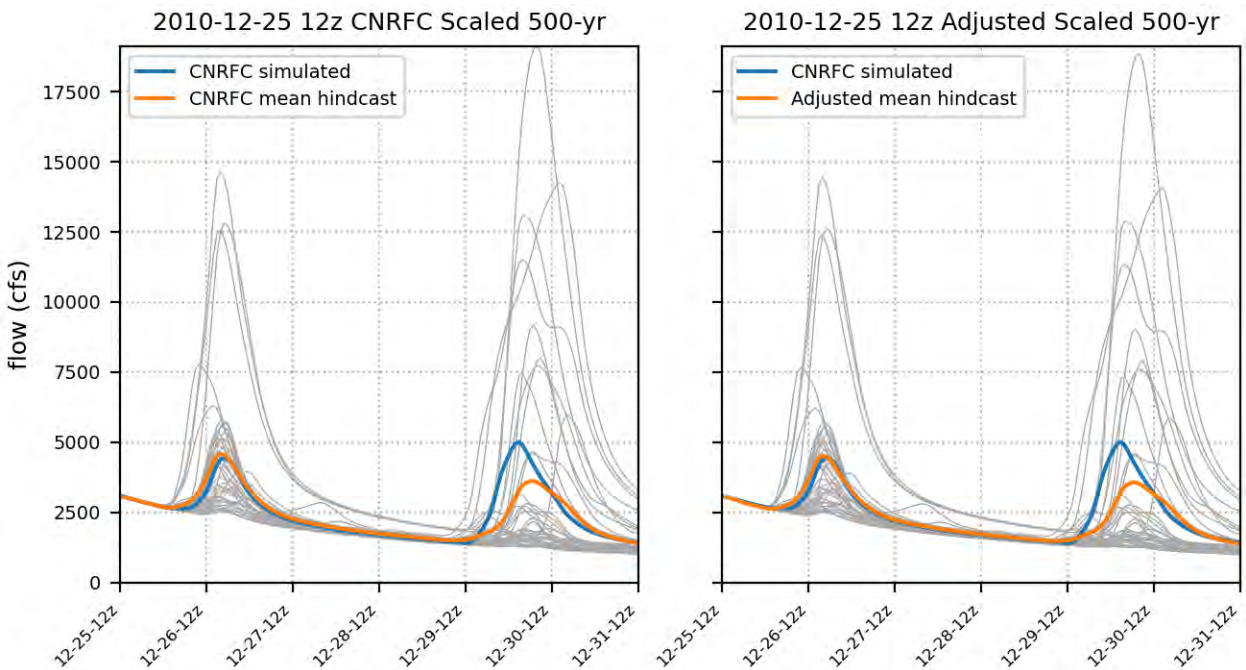

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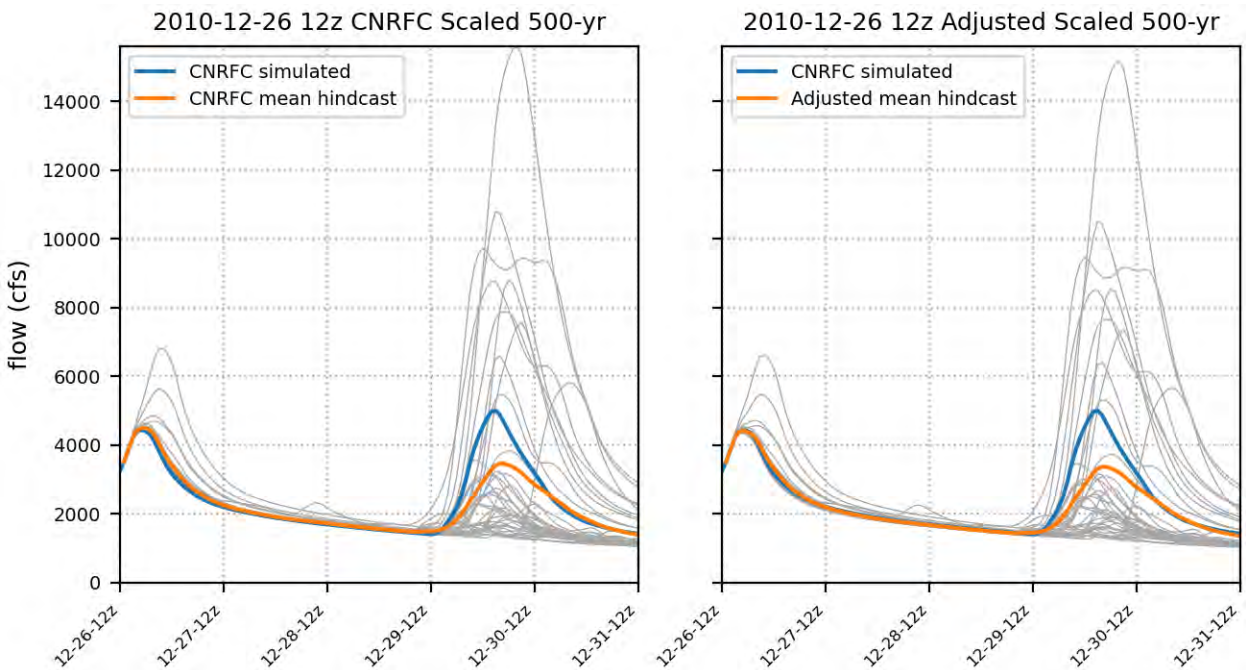

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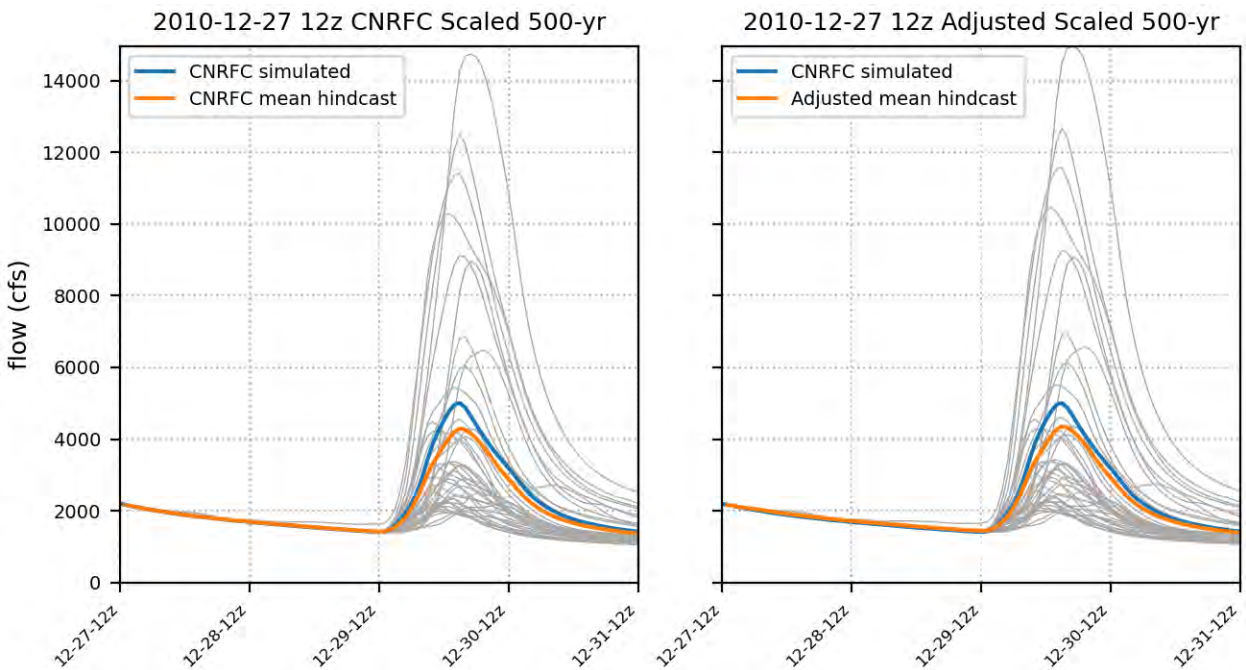

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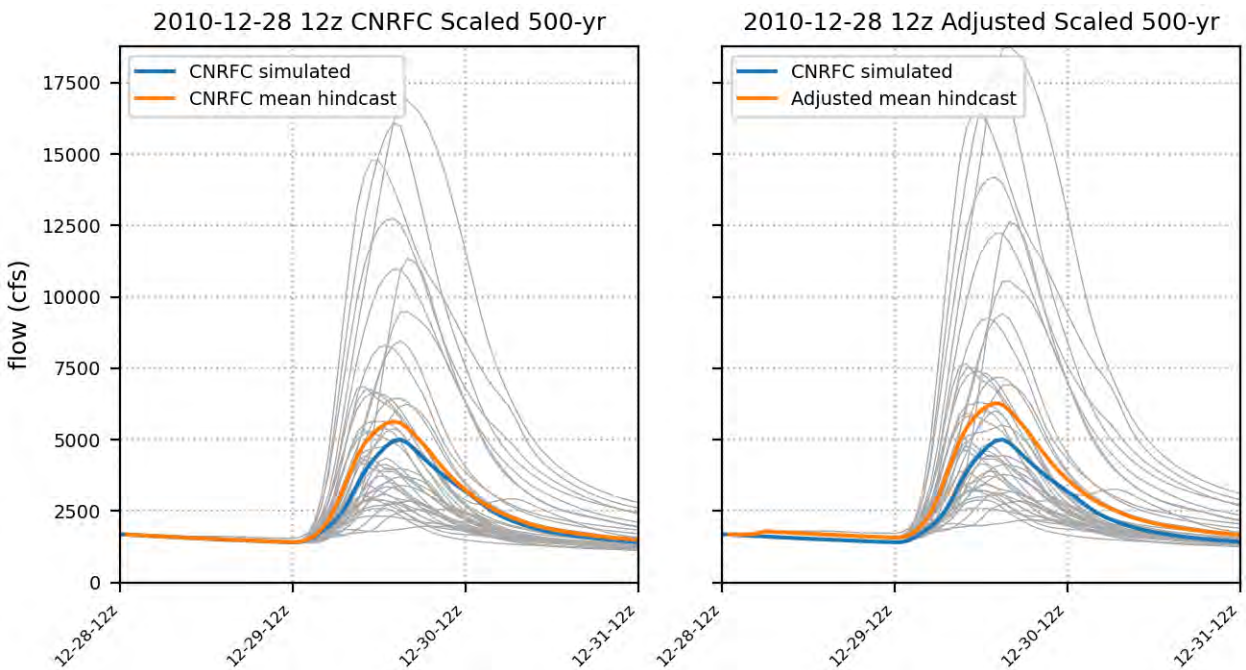

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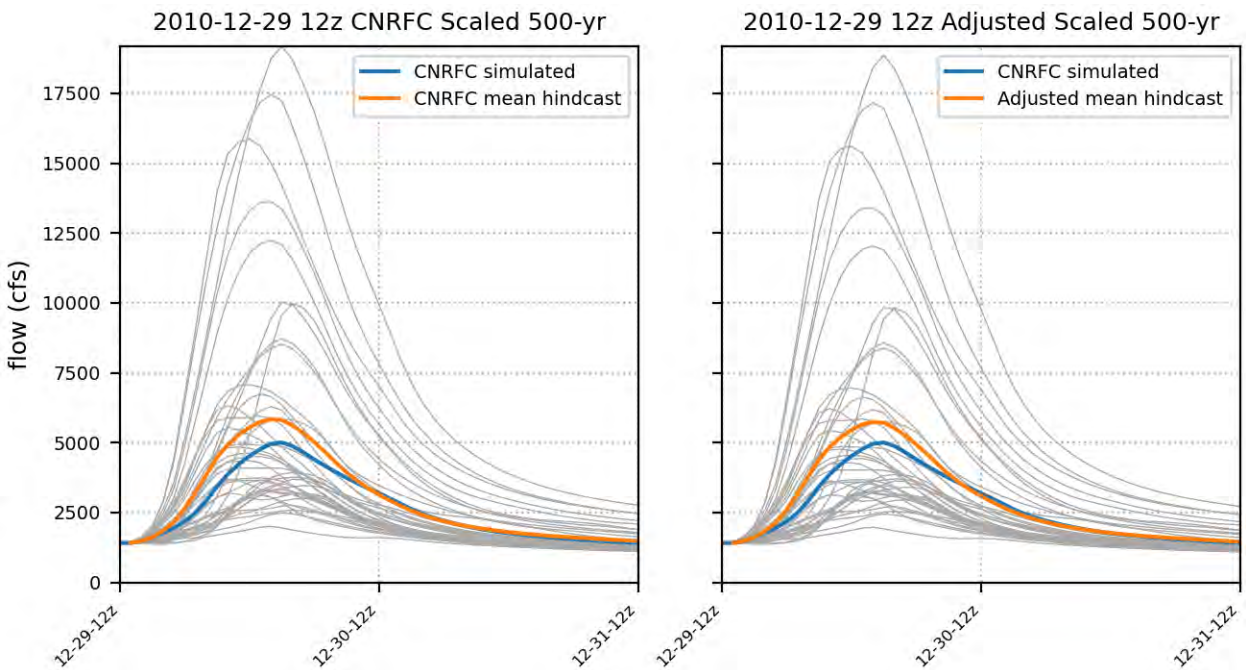
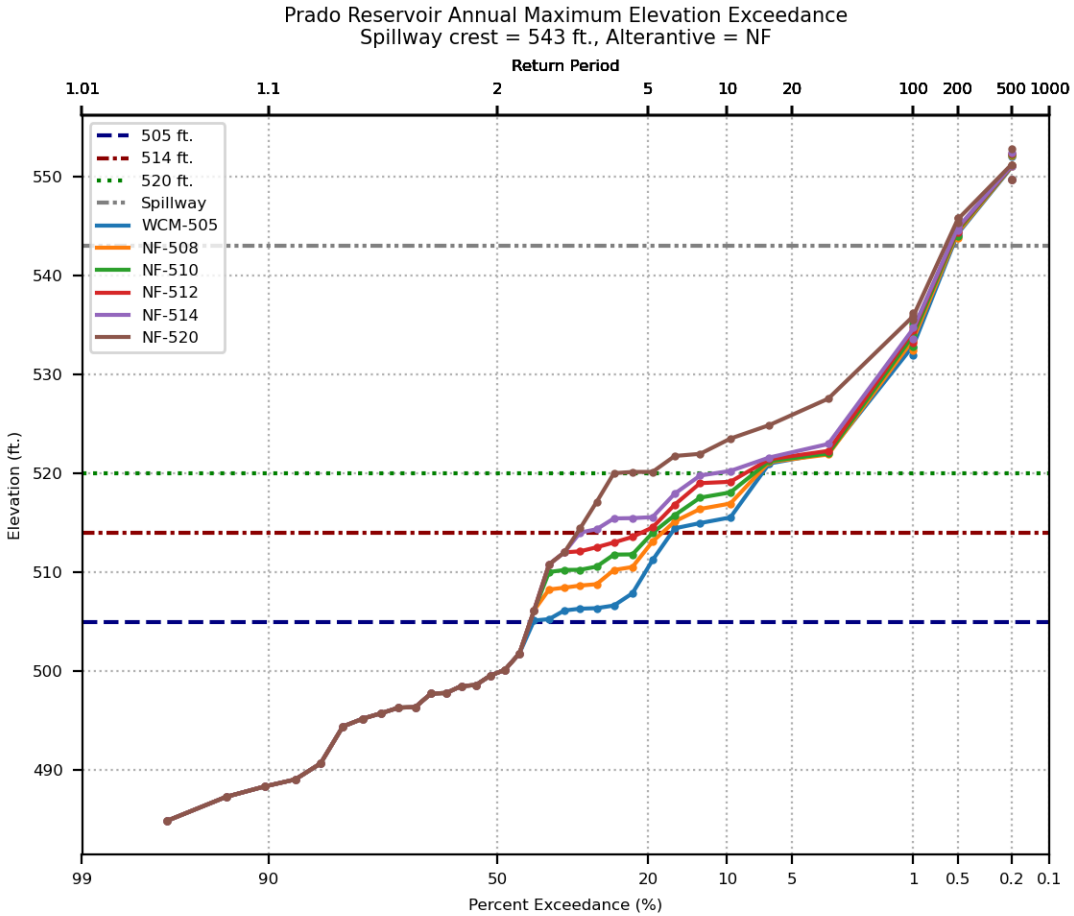
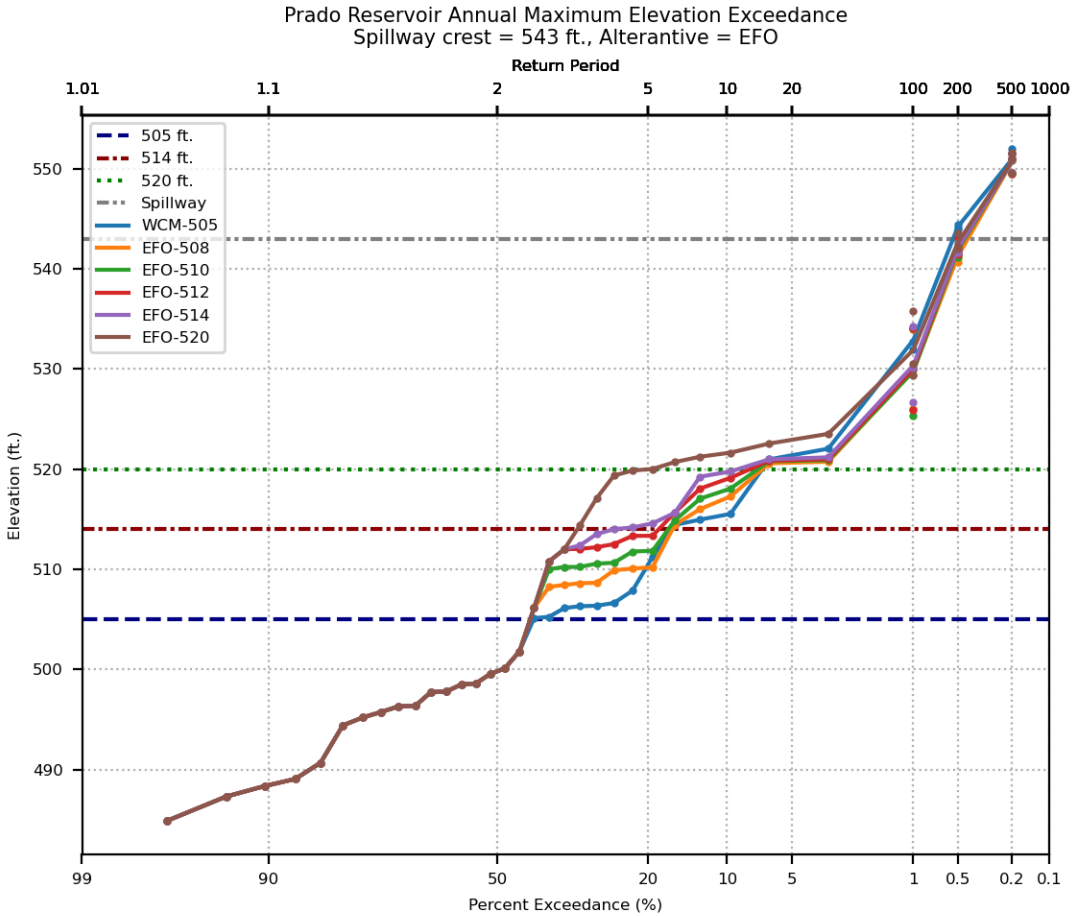


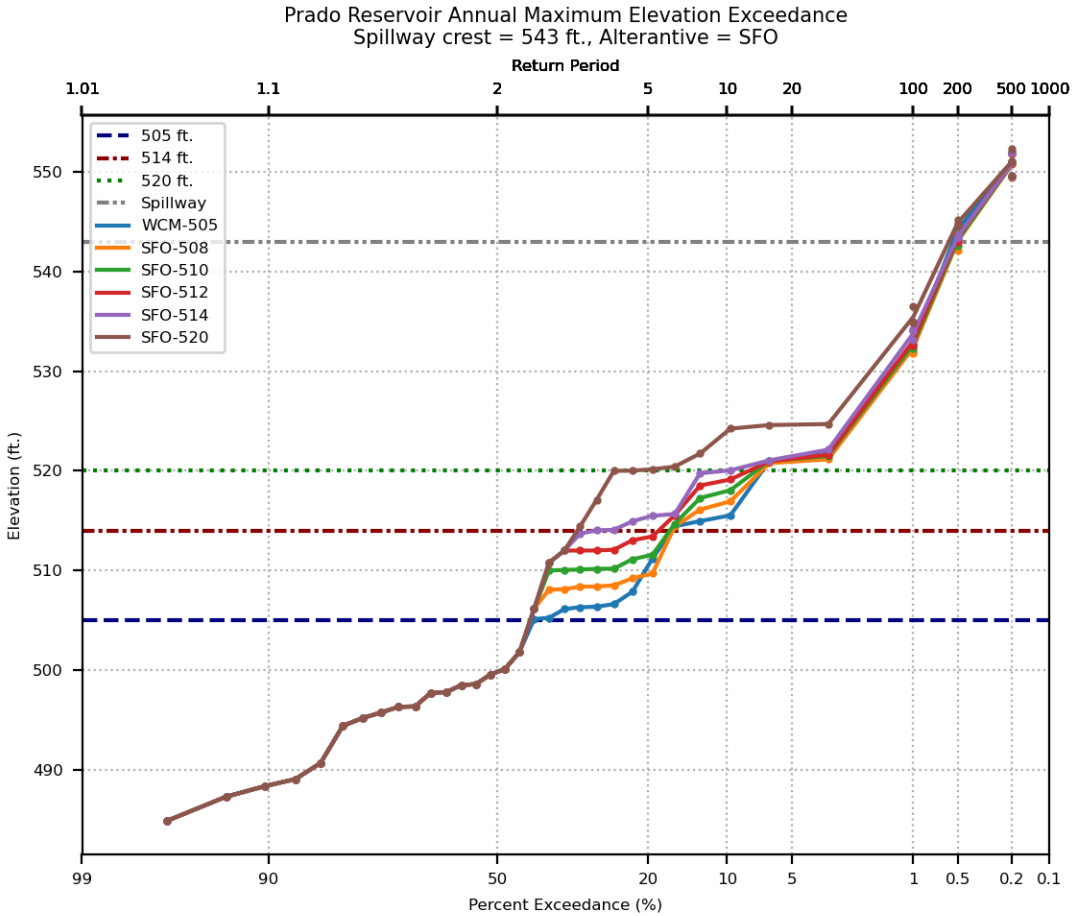
APPENDIX B-2

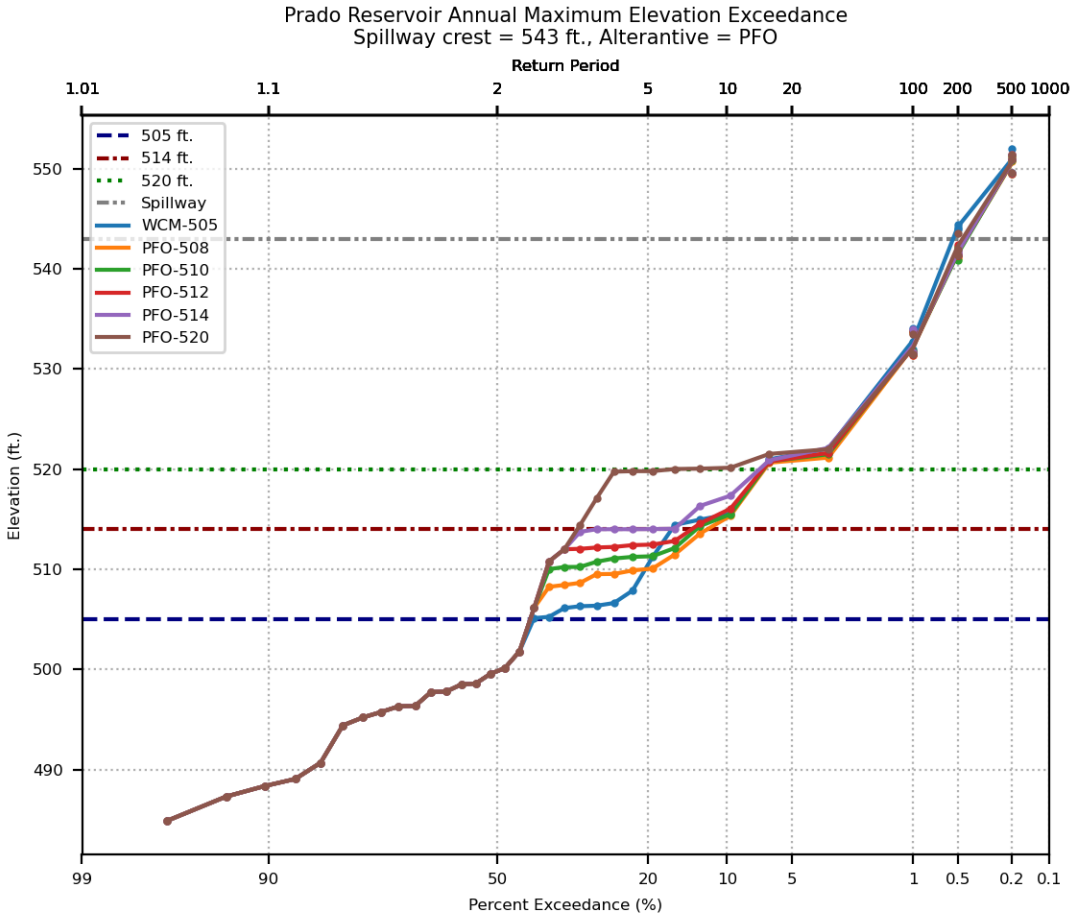
Frequency of Annual Maximum Pool Elevation by *WCP Alternative*

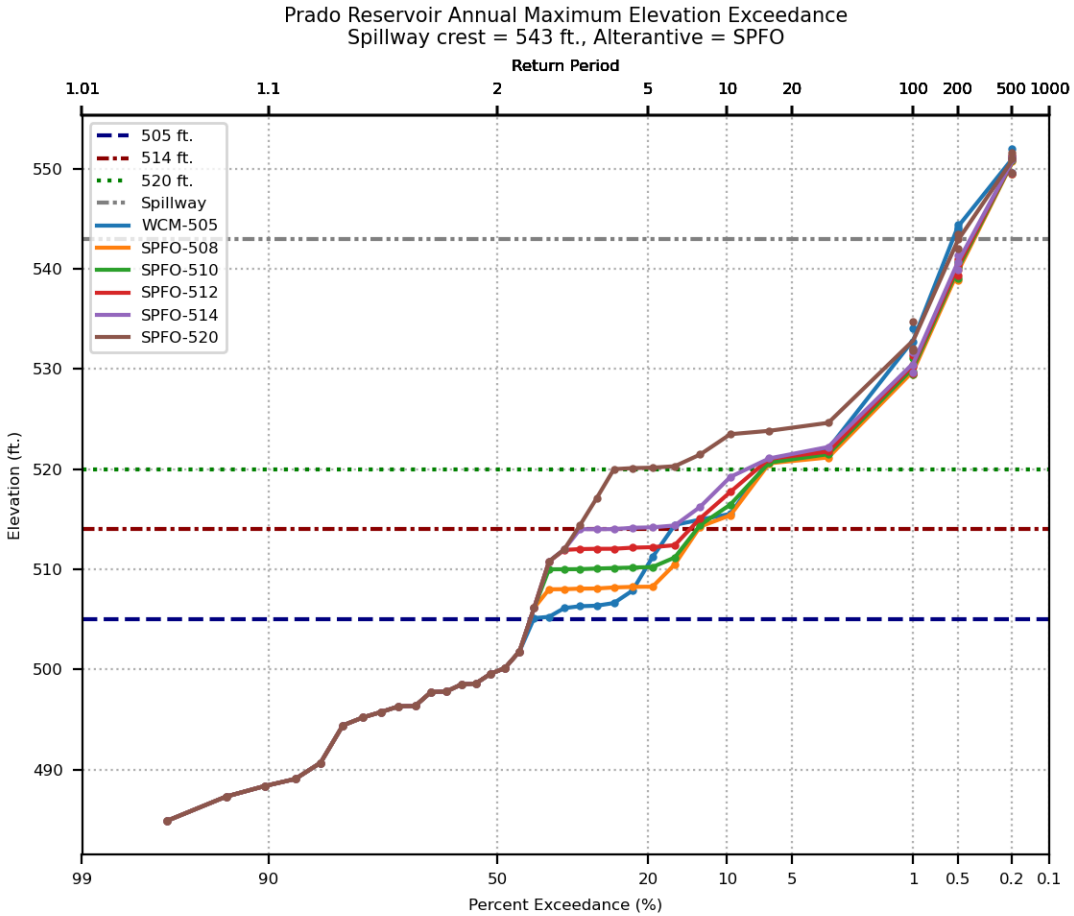
- Spillway elevations of 543’ and 563’
- WCP Alternatives
  - No Forecast (NF)
  - EFO
  - SFO
  - PFO (EFO w/perfect forecasts)
  - SPFO (SFO w/perfect forecasts)
- Maximum buffer pool elevations in legend

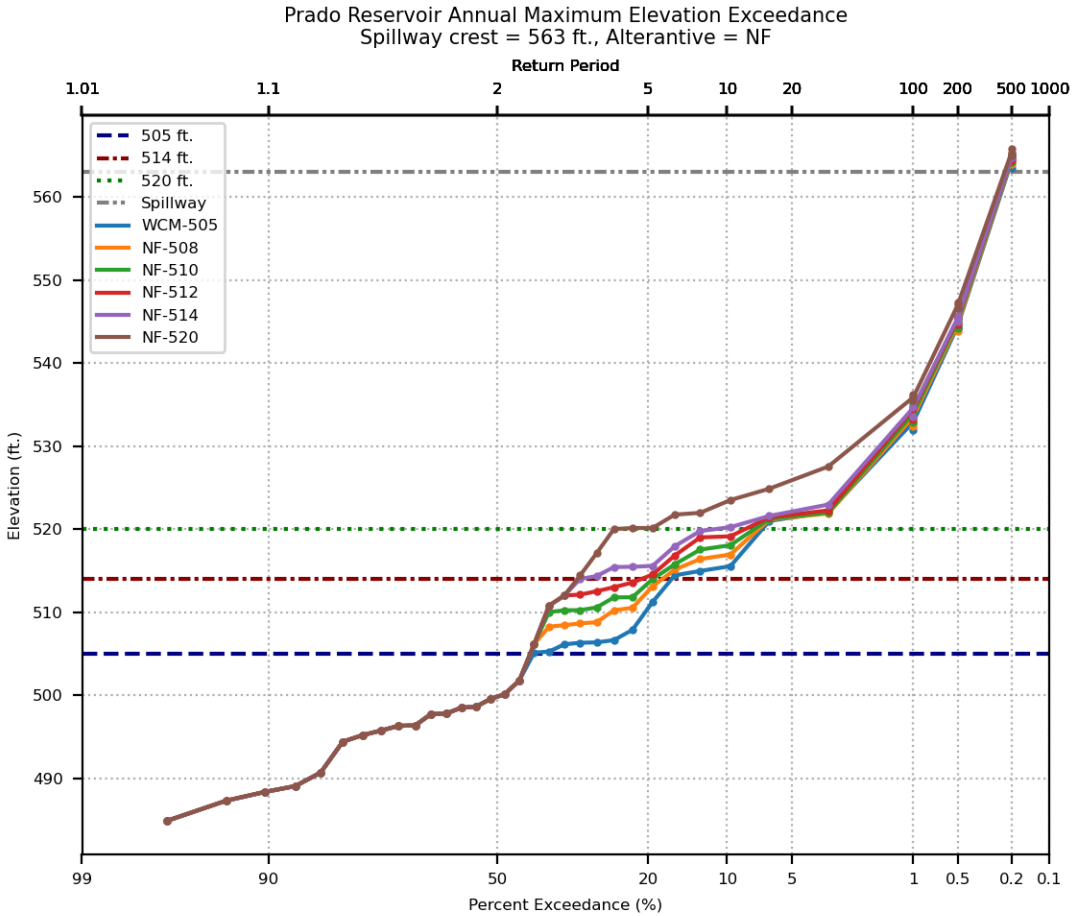

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Alterantive = NF
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

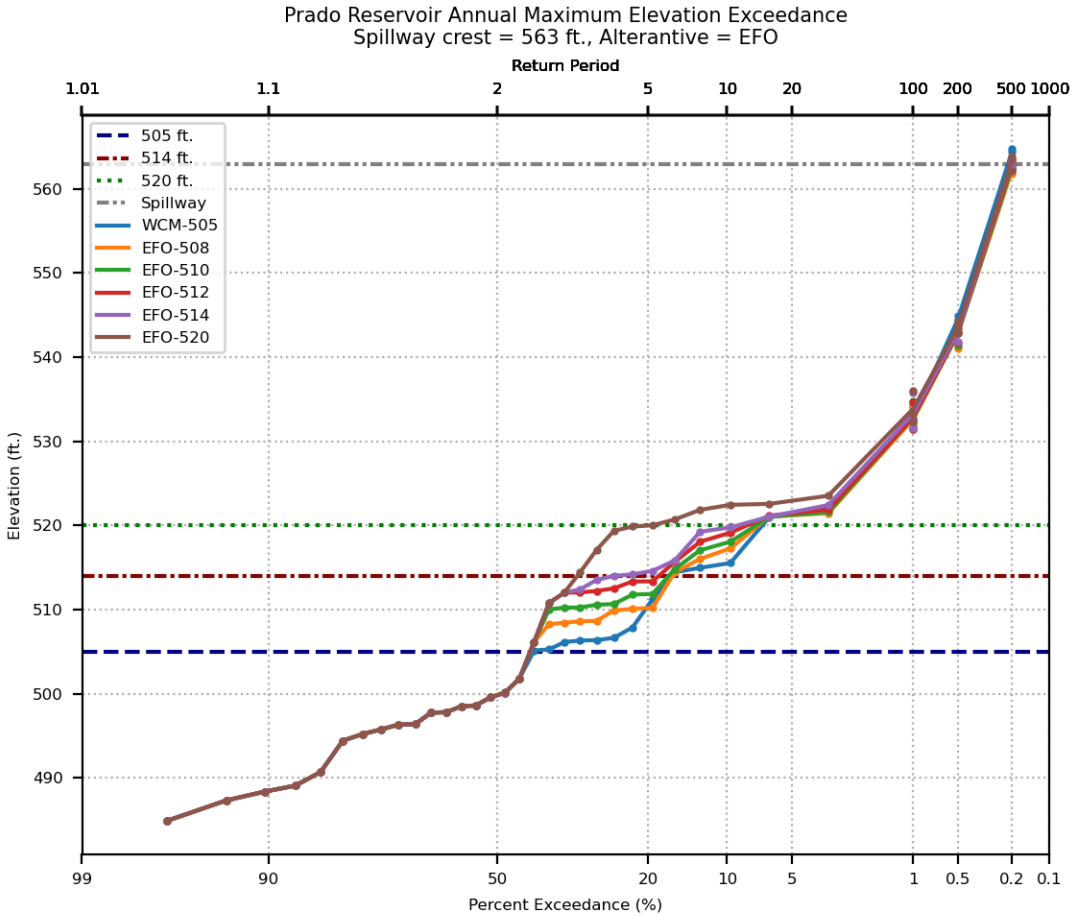

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Alterantive = EFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
EFO-508
EFO-510
EFO-512
EFO-514
EFO-520
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

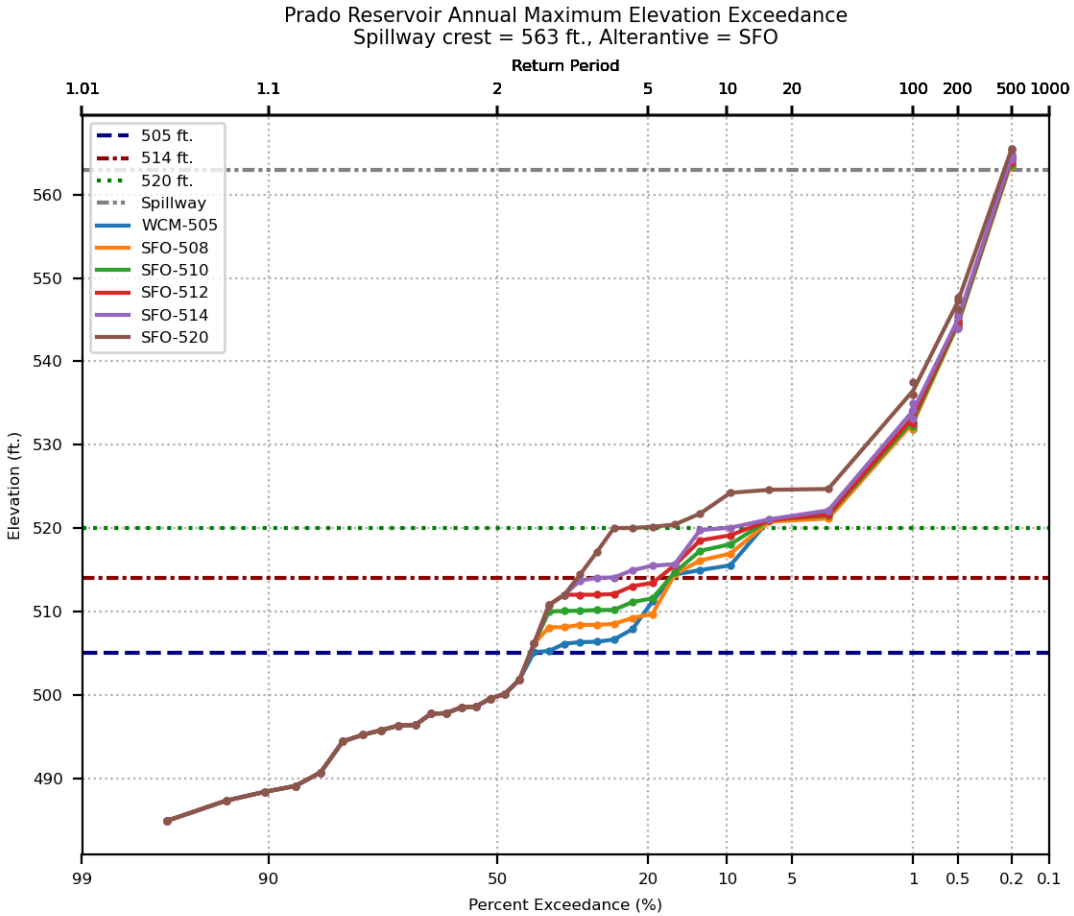

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Alterantive = SFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
SFO-508
SFO-510
SFO-512
SFO-514
SFO-520
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

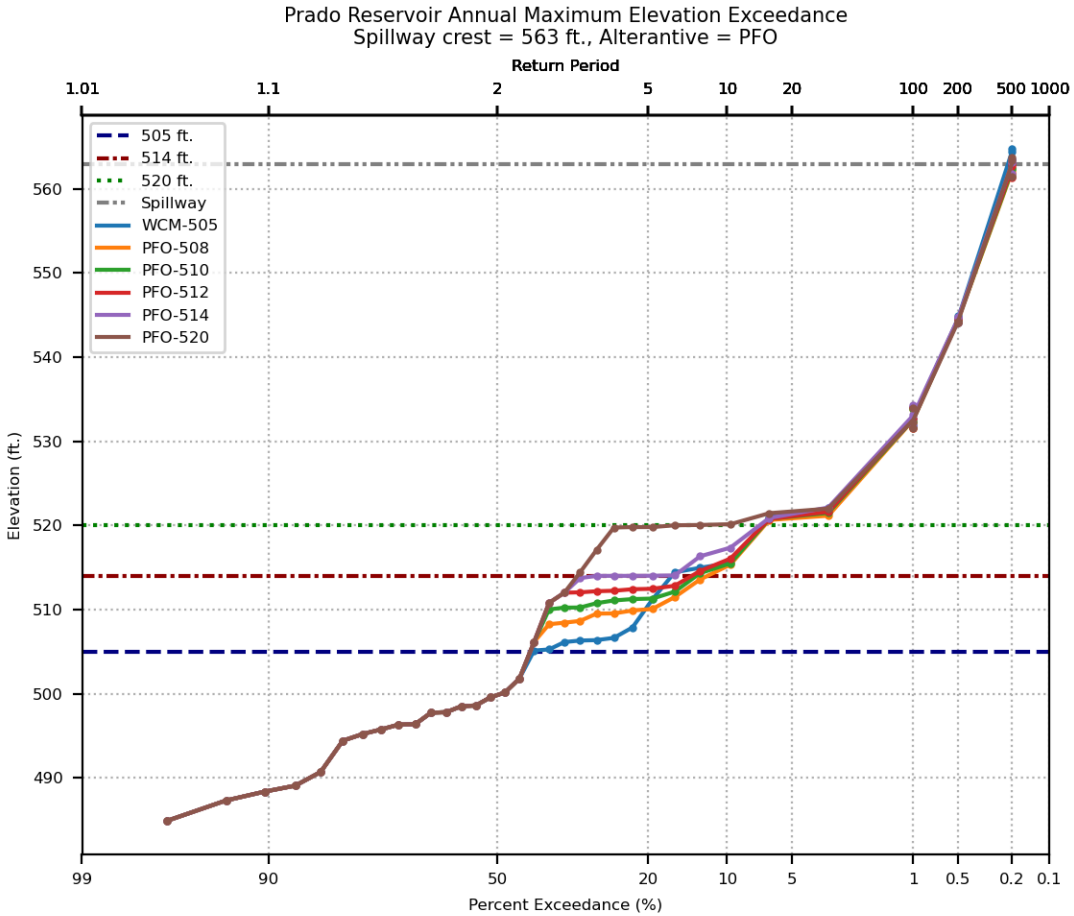

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Alterantive = PFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
PFO-508
PFO-510
PFO-512
PFO-514
PFO-520
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

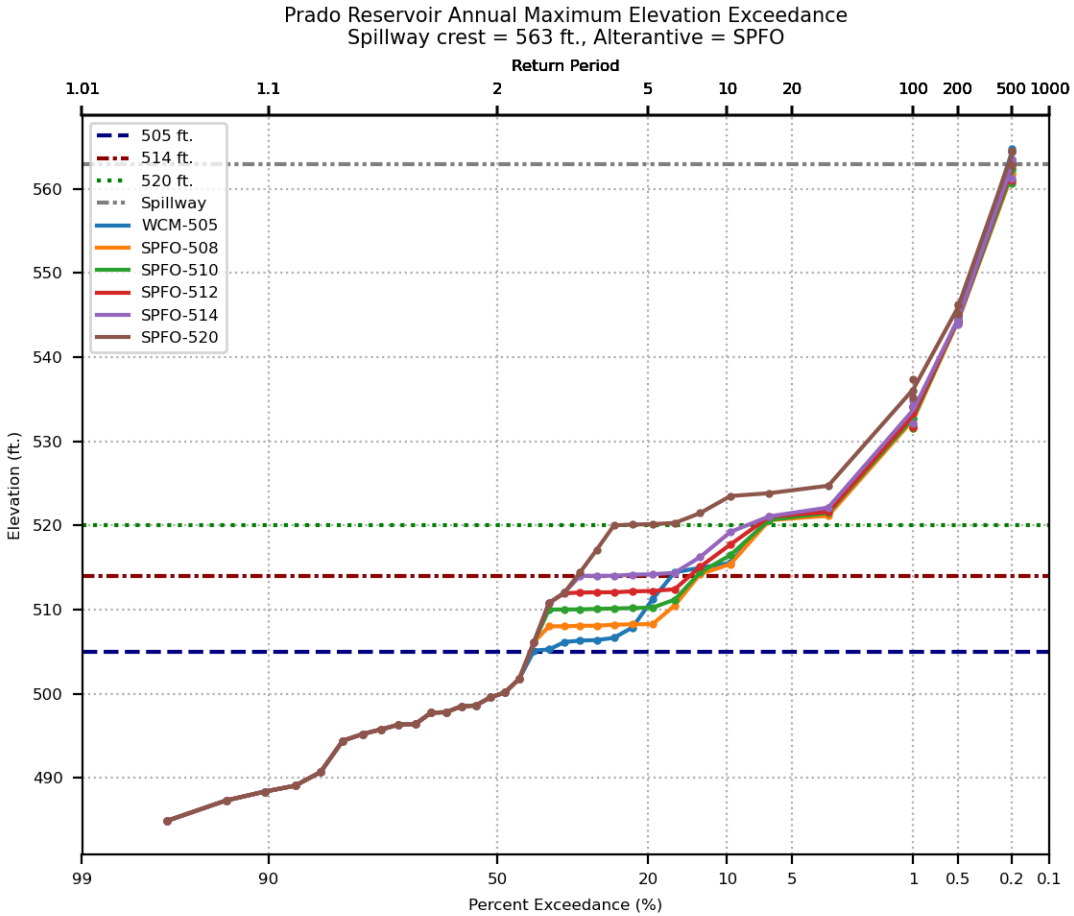

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Alterantive = SPFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

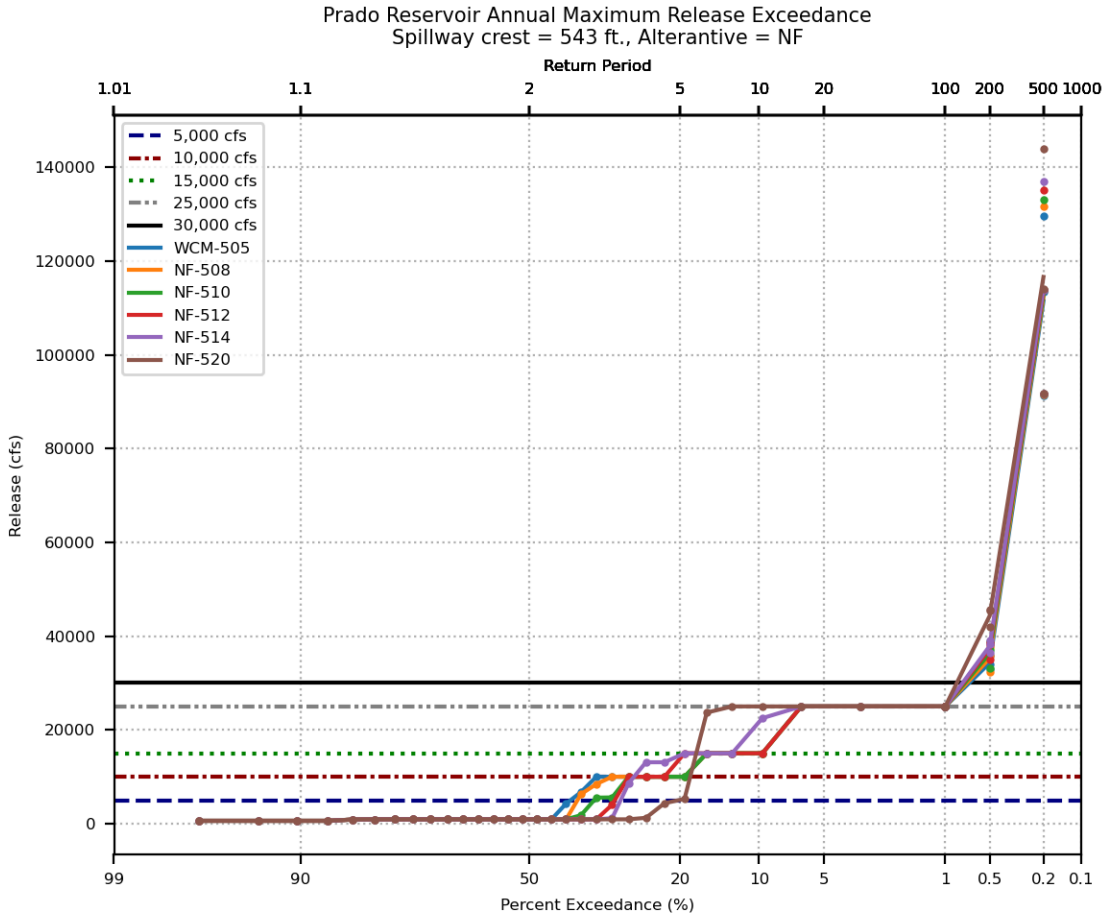

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Alterantive = NF
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Elevation (ft.)
560
550
540
530
520
510
500
490
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

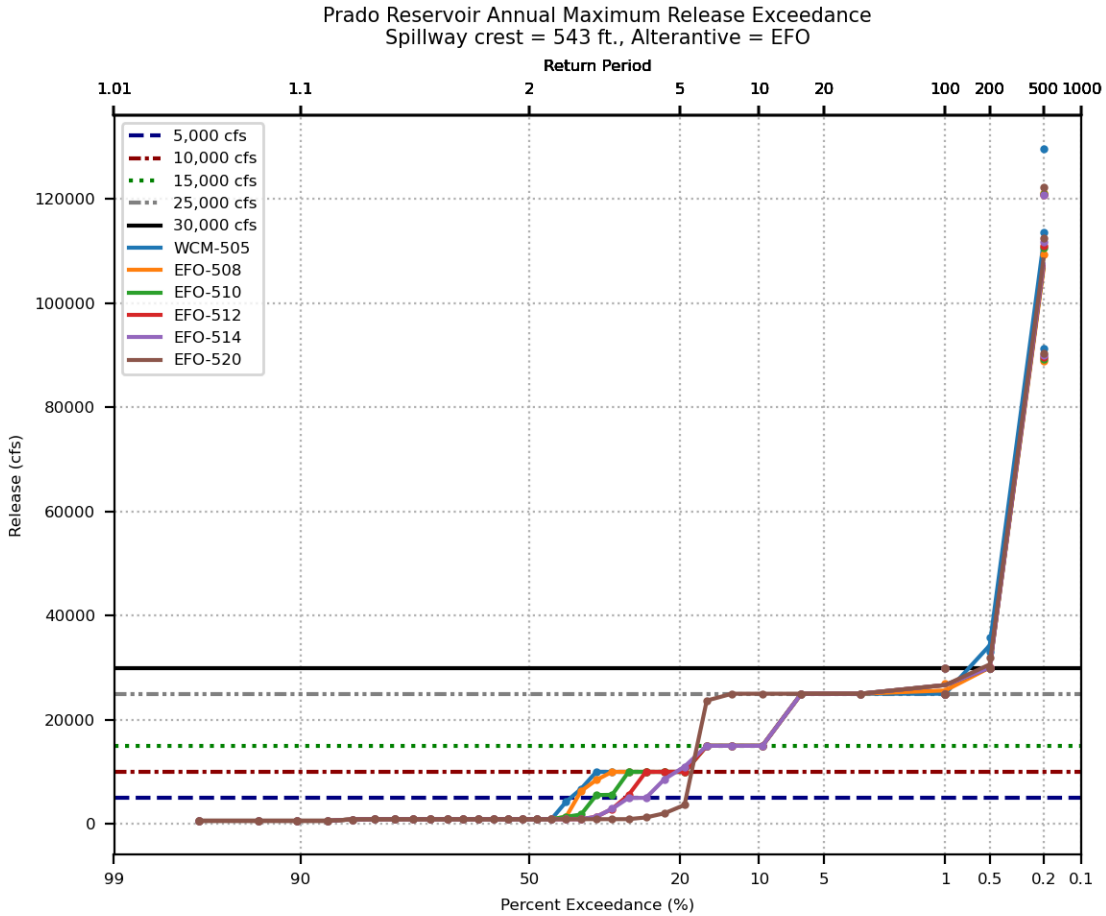

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Alterantive = EFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
EFO-508
EFO-510
EFO-512
EFO-514
EFO-520
Elevation (ft.)
560
550
540
530
520
510
500
490
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

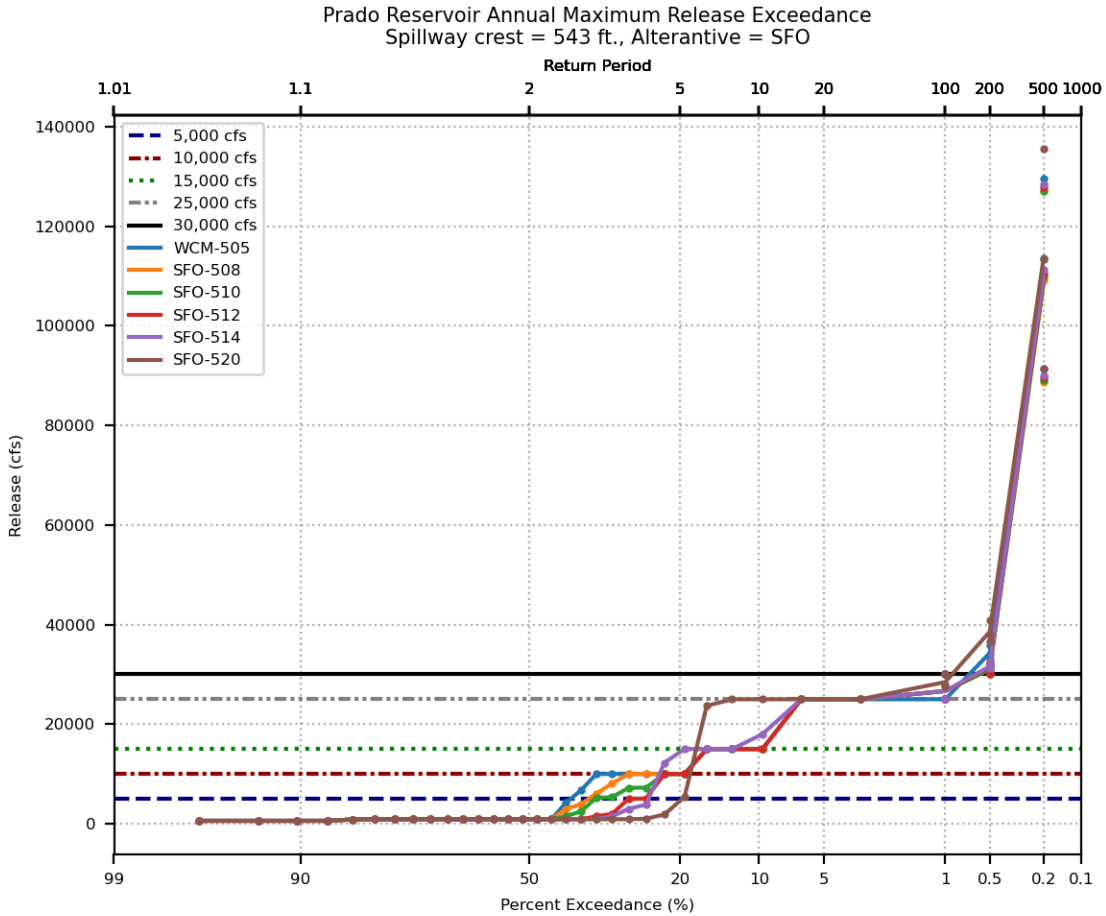

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Alterantive = SFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
SFO-508
SFO-510
SFO-512
SFO-514
SFO-520
560
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

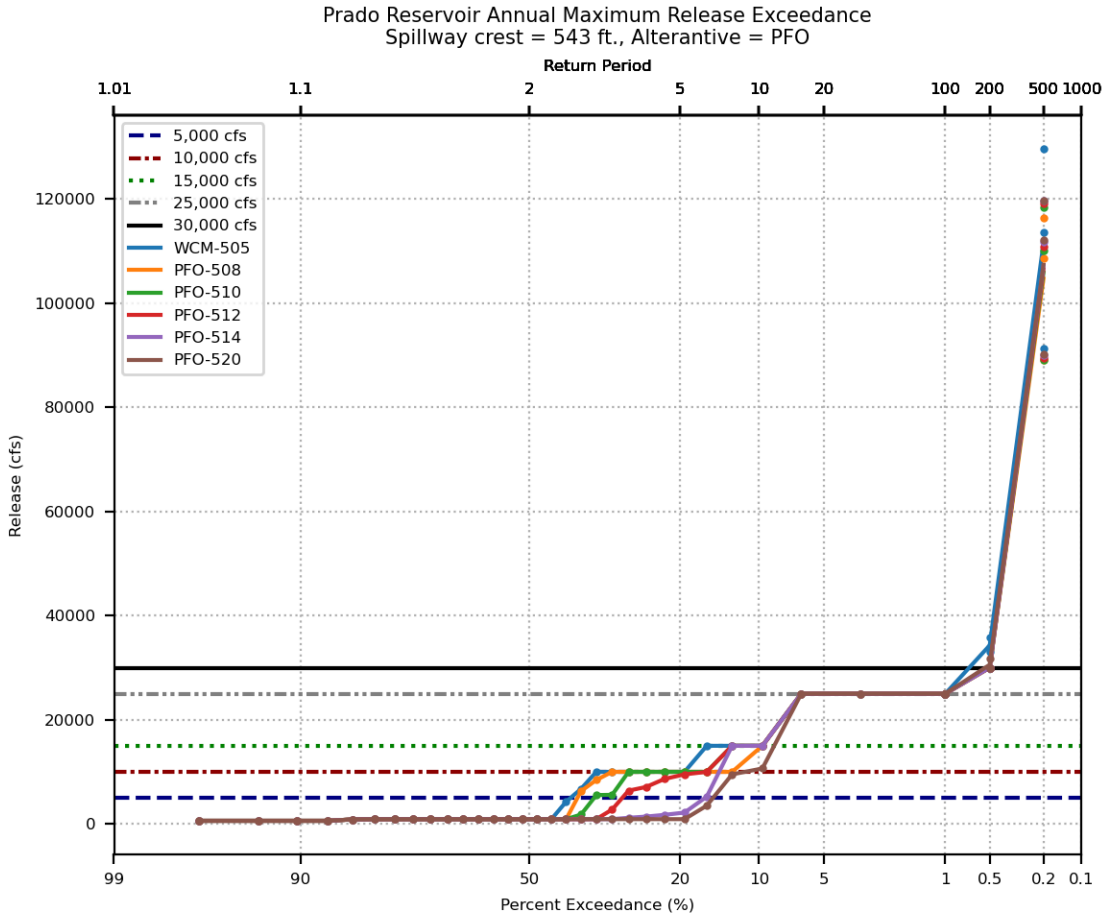

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Alterantive = PFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
PFO-508
PFO-510
PFO-512
PFO-514
PFO-520
Elevation (ft.)
560
550
540
530
520
510
500
490
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

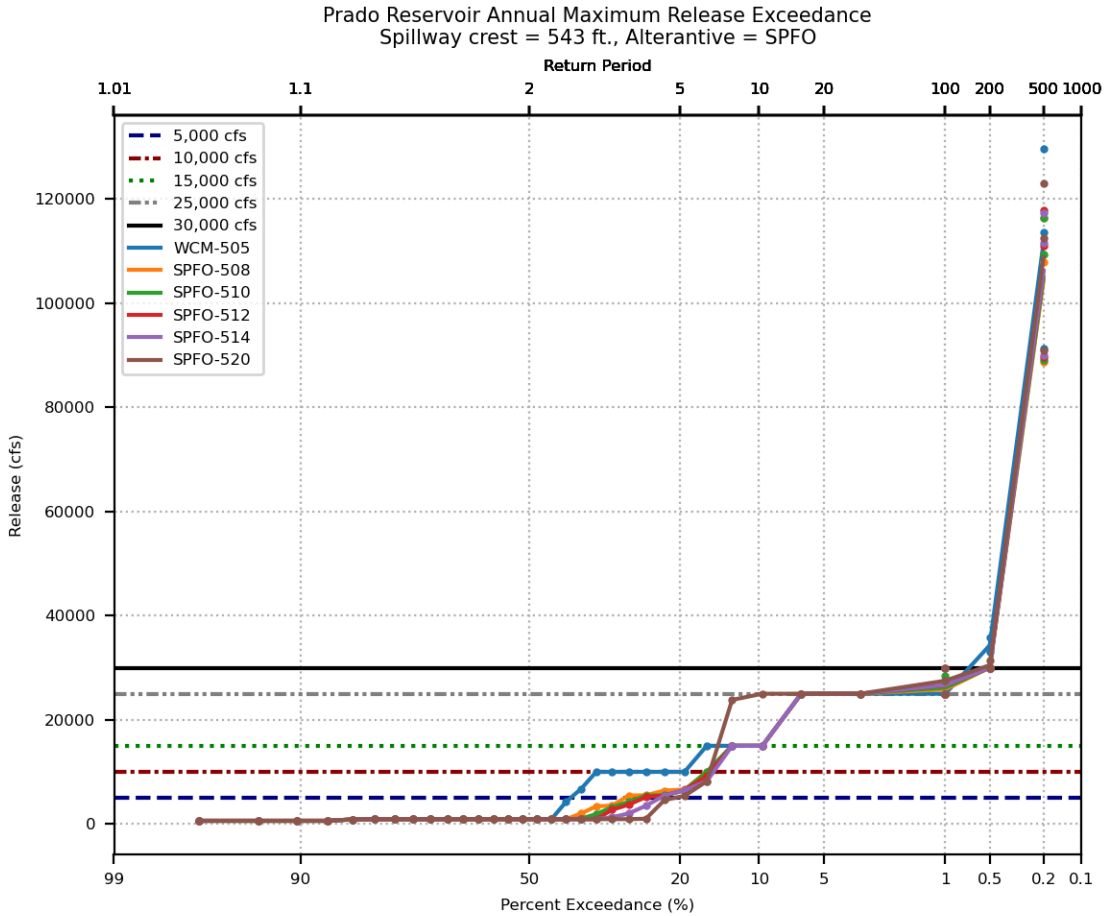

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Alterantive = SPFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
Elevation (ft.)
560
550
540
530
520
510
500
490
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

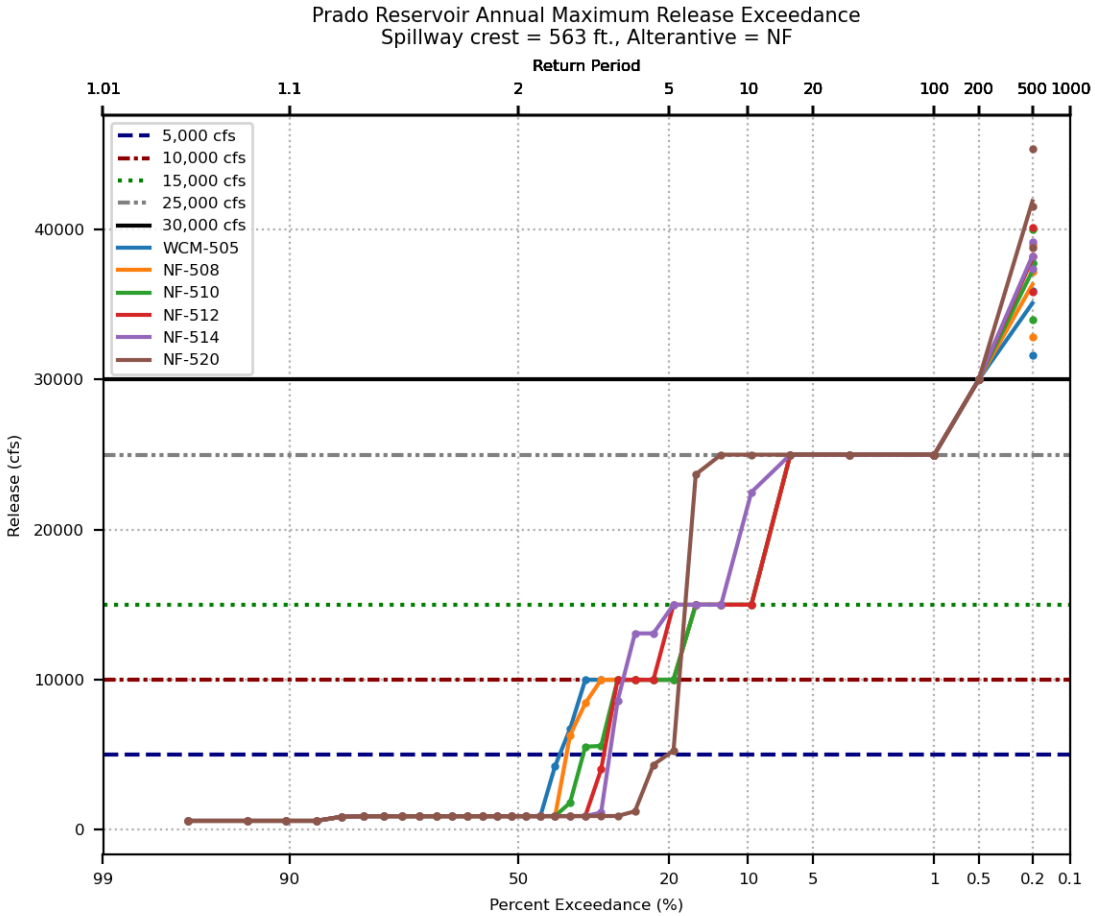

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Alterantive = NF
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Release (cfs)
140000
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

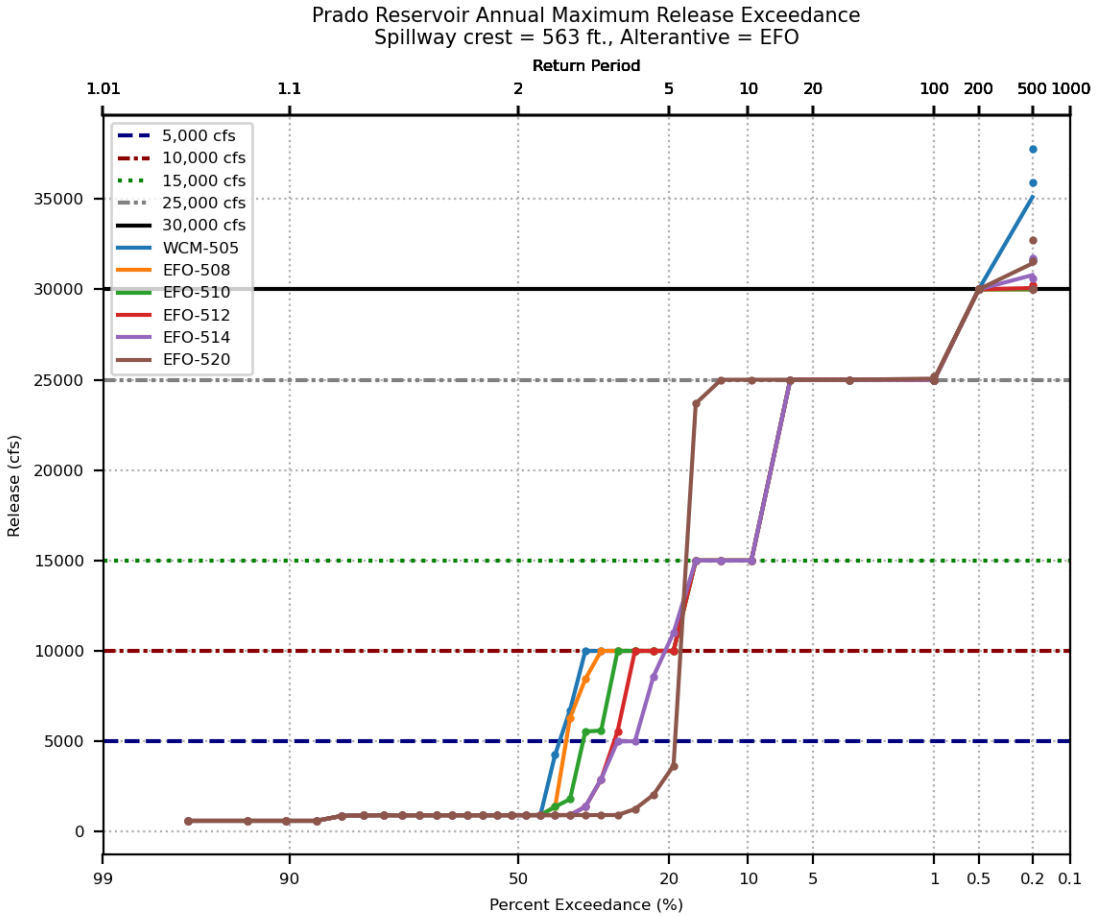

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Alterantive = EFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM-505
EFO-508
EFO-510
EFO-512
EFO-514
EFO-520
Release (cfs)
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

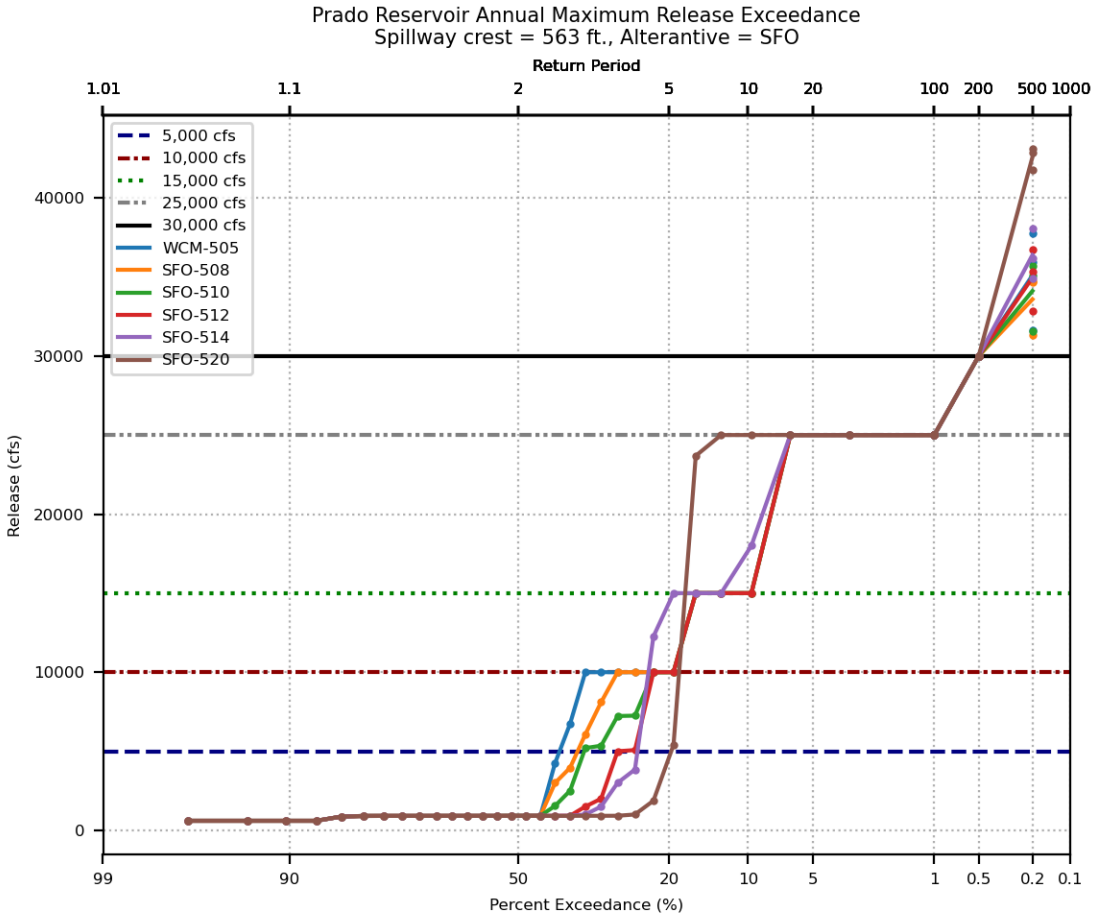

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Alterantive = SFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
140000
120000
100000
80000
60000
40000
20000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM-505
SFO-508
SFO-510
SFO-512
SFO-514
SFO-520
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

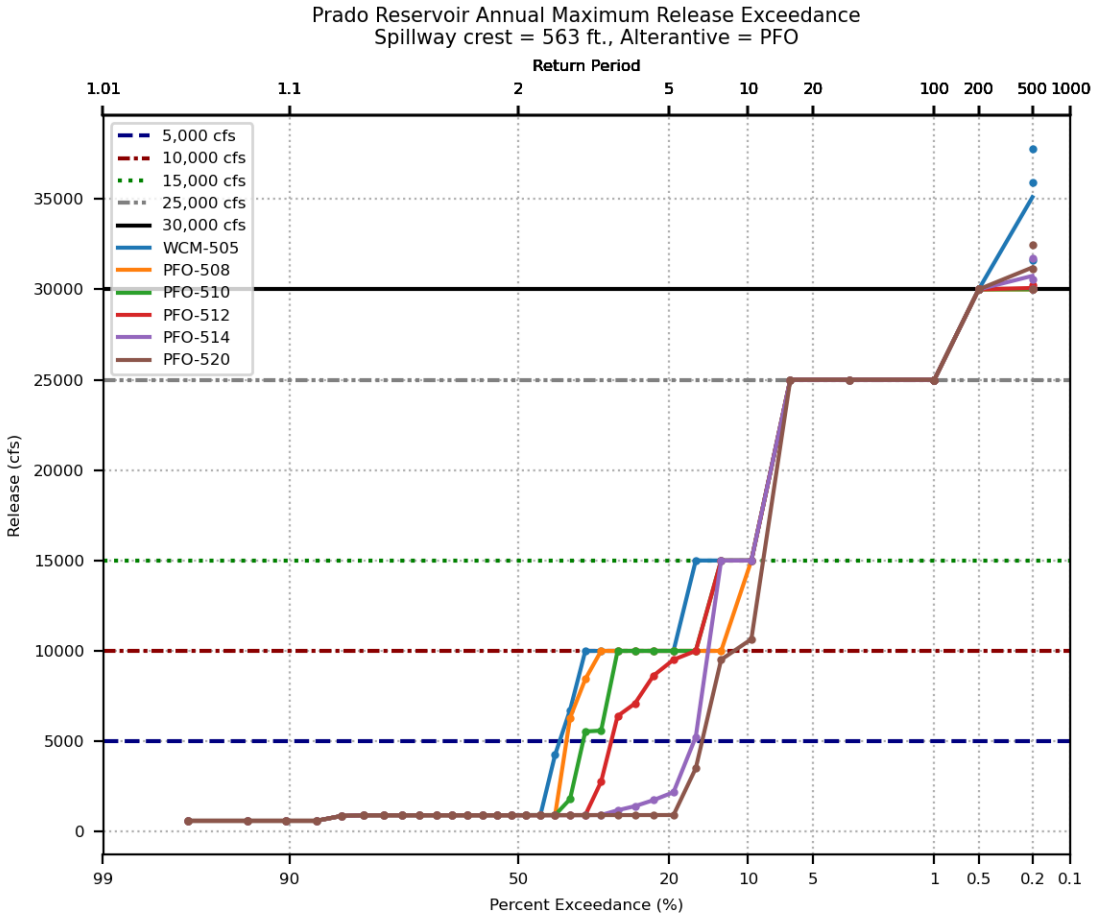

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Alterantive = PFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM-505
PFO-508
PFO-510
PFO-512
PFO-514
PFO-520
Release (cfs)
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

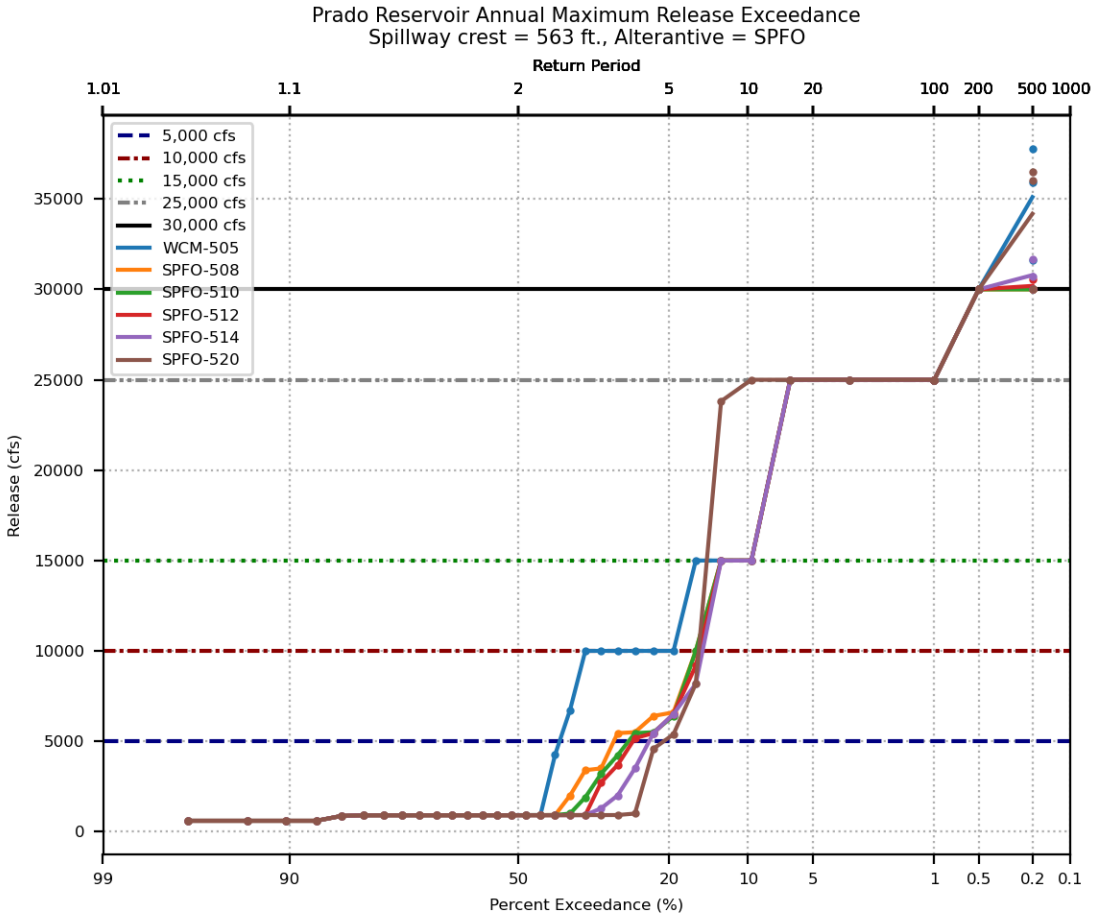

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Alterantive = SPFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM-505
SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
Release (cfs)
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Alterantive = NF
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Release (cfs)
40000
30000
20000
10000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Alterantive = EFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM-505
EFO-508
EFO-510
EFO-512
EFO-514
EFO-520
35000
30000
25000
20000
15000
10000
5000
0
Release (cfs)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

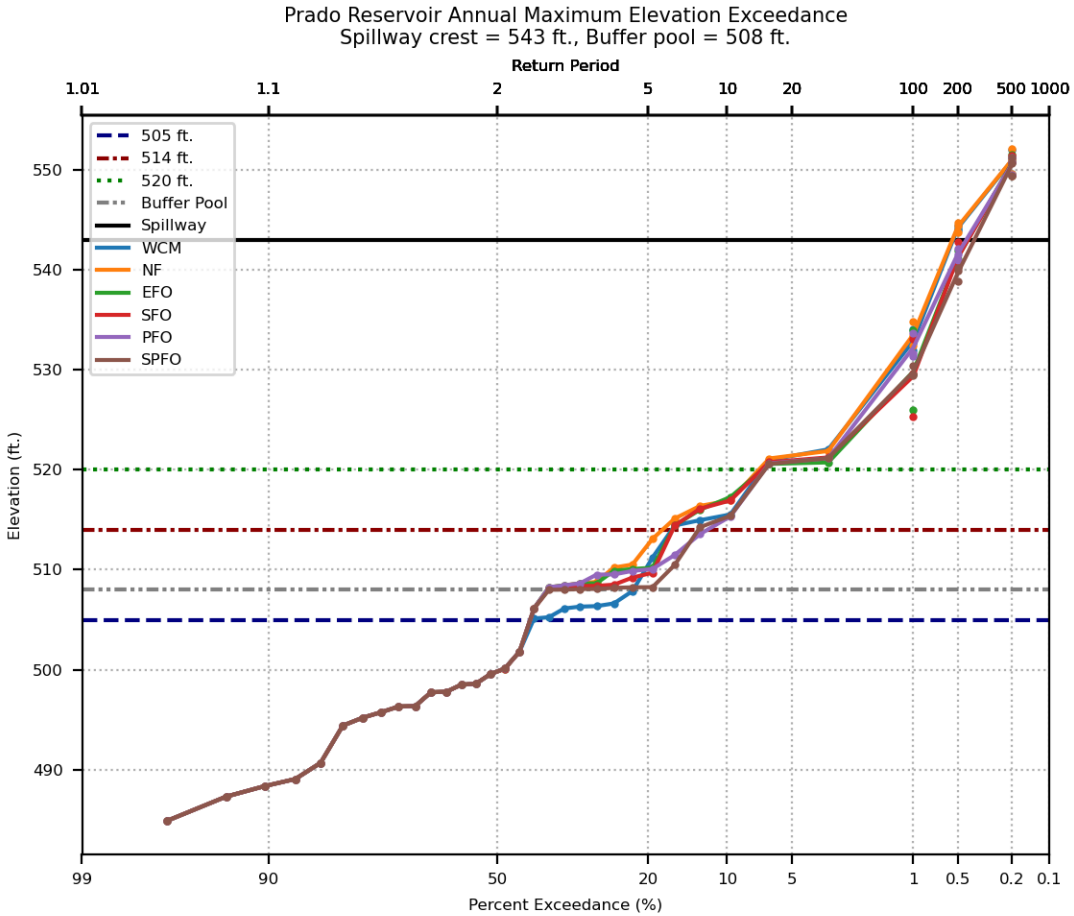

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Alterantive = SFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM-505
SFO-508
SFO-510
SFO-512
SFO-514
SFO-520
Release (cfs)
40000
30000
20000
10000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

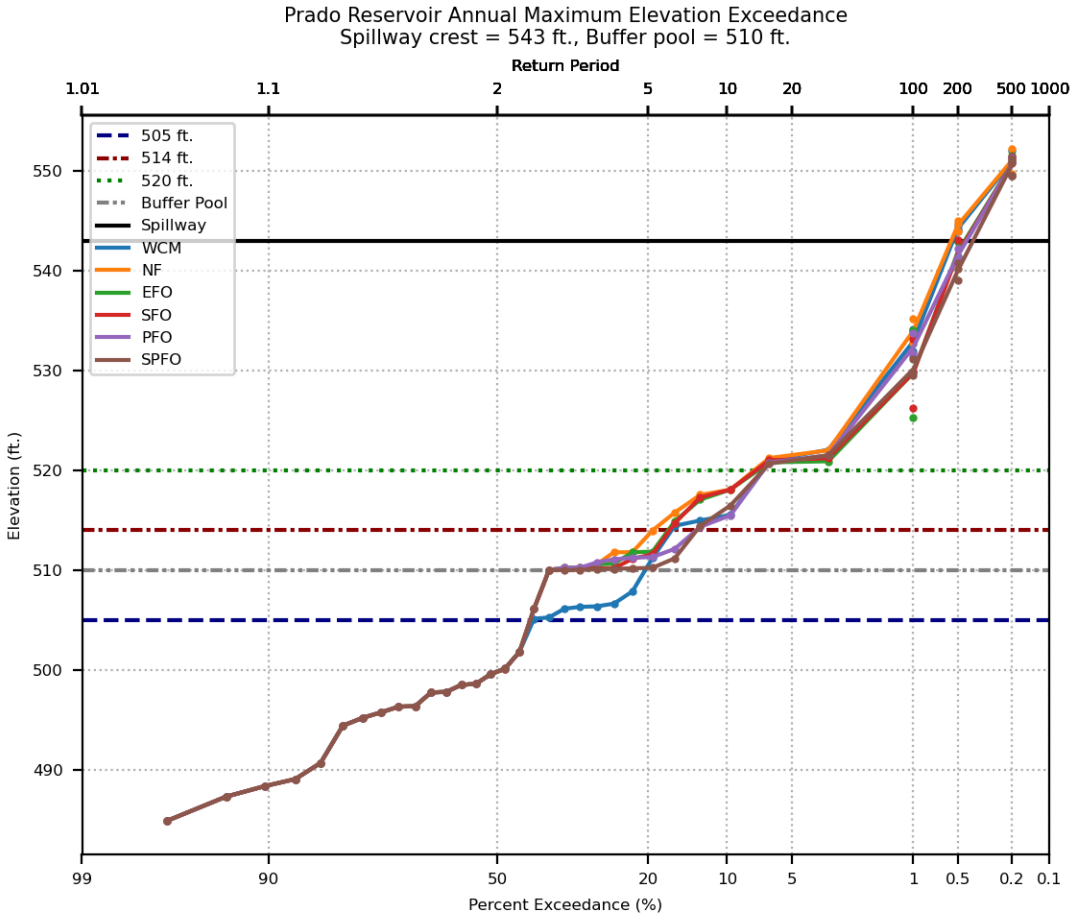

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Alterantive = PFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM-505
PFO-508
PFO-510
PFO-512
PFO-514
PFO-520
Release (cfs)
35000
30000
25000
20000
15000
10000
5000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

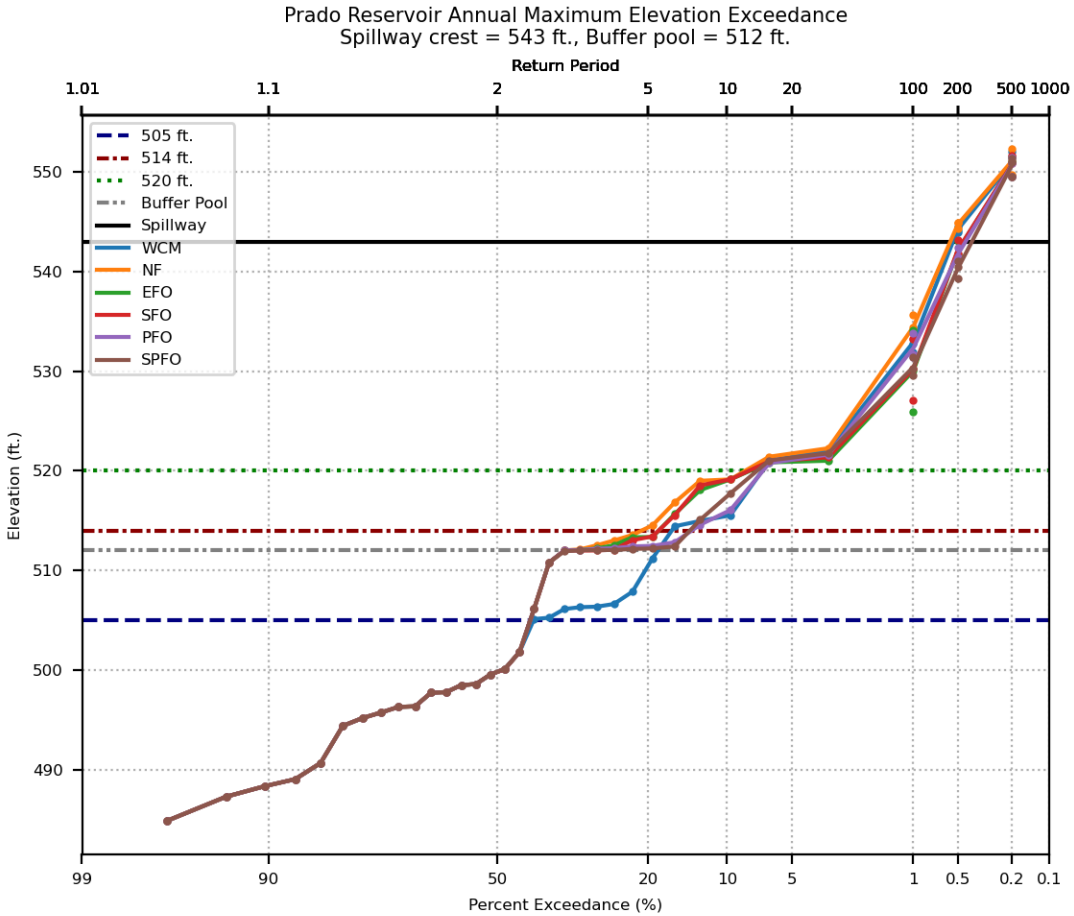

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Alterantive = SPFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM-505
SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
Release (cfs)
35000
30000
25000
20000
15000
10000
5000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

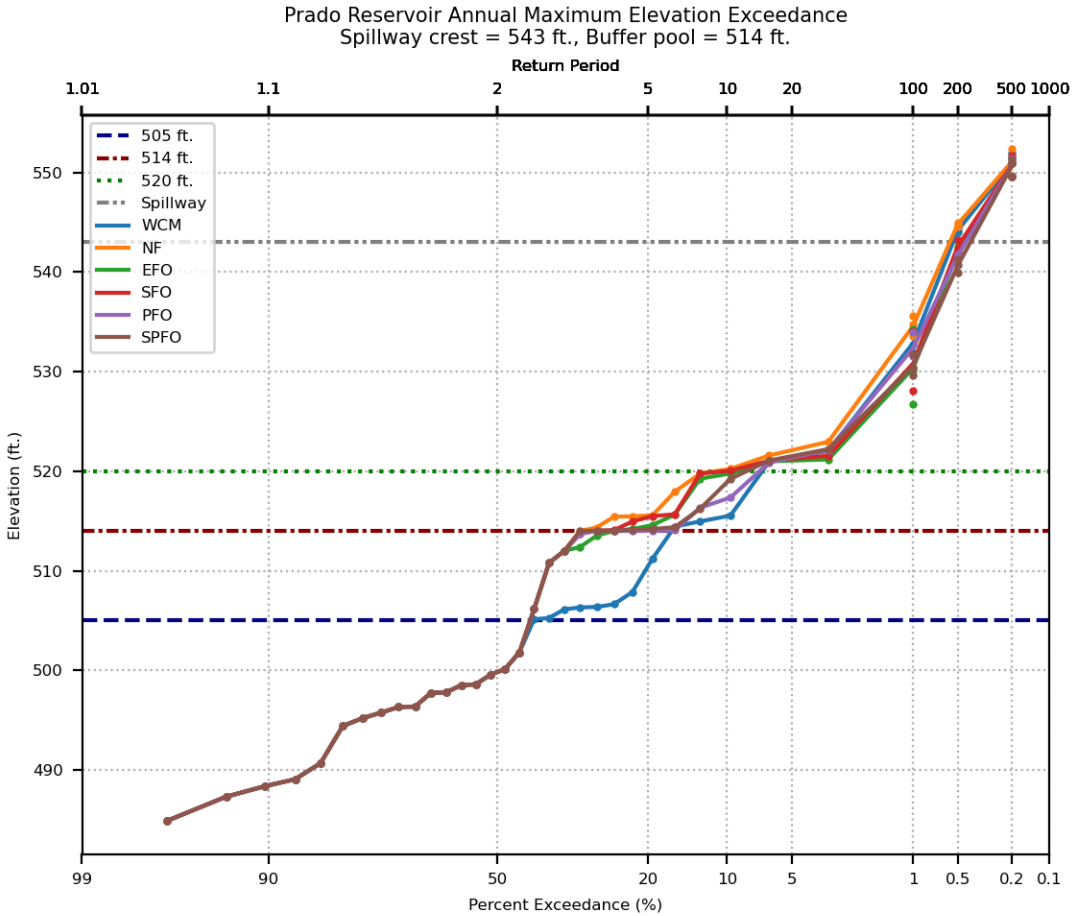
Frequency of Annual Maximum Pool Elevation *by Buffer Pool*

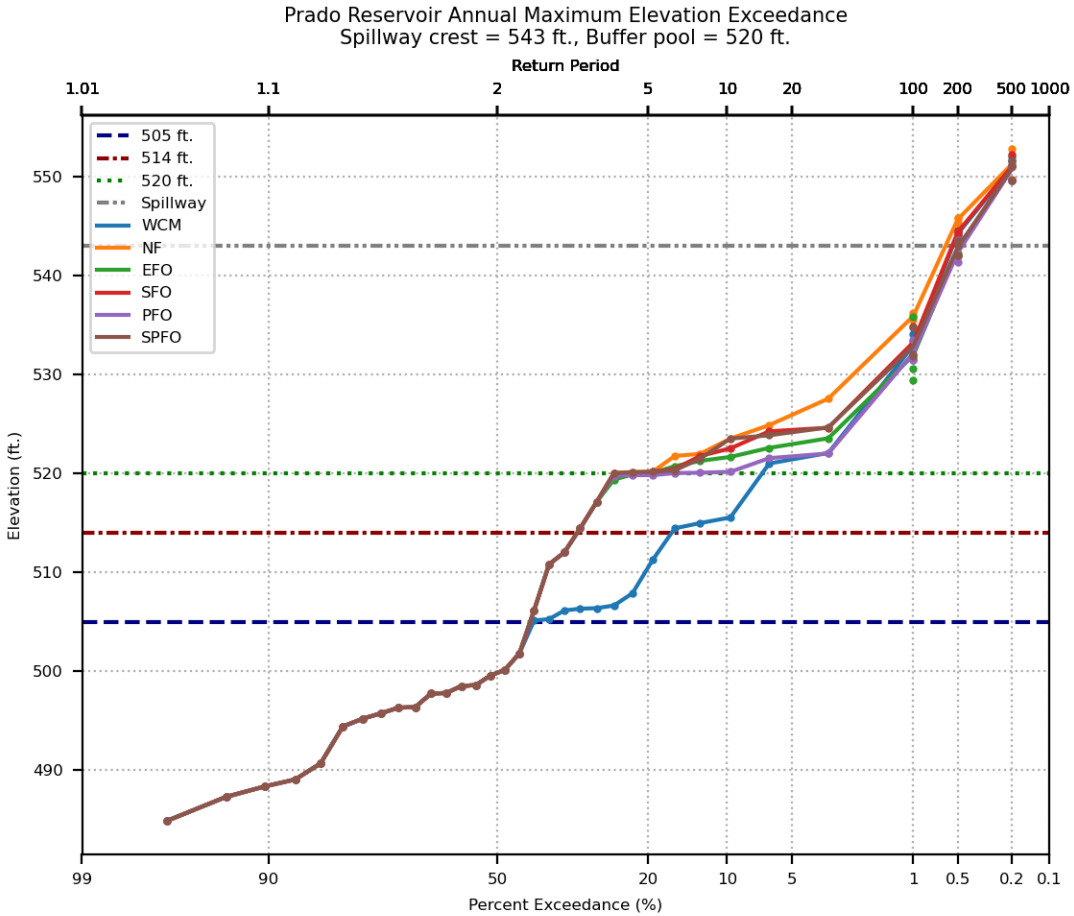
- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’
  - 510’
  - 512’
  - 514’
  - 520’
- WCP alternatives in legend

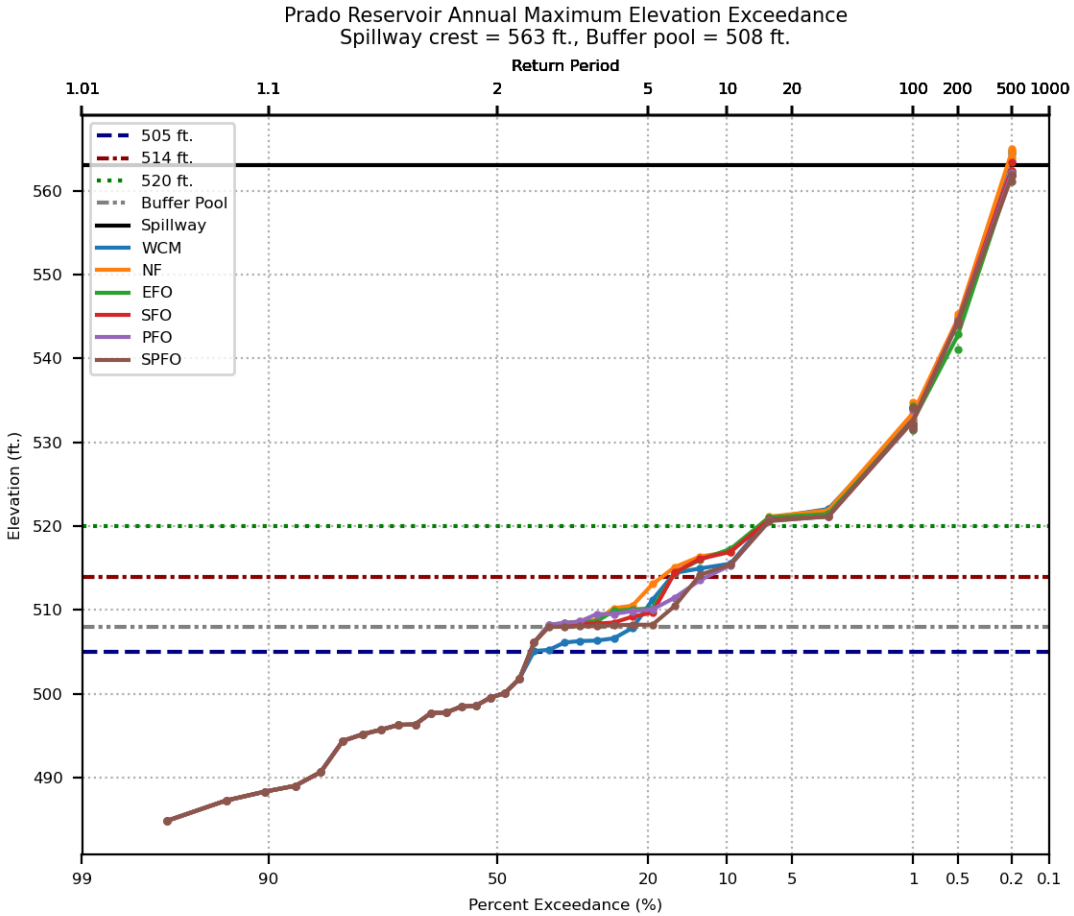

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 508 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO
PFO
SPFO
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

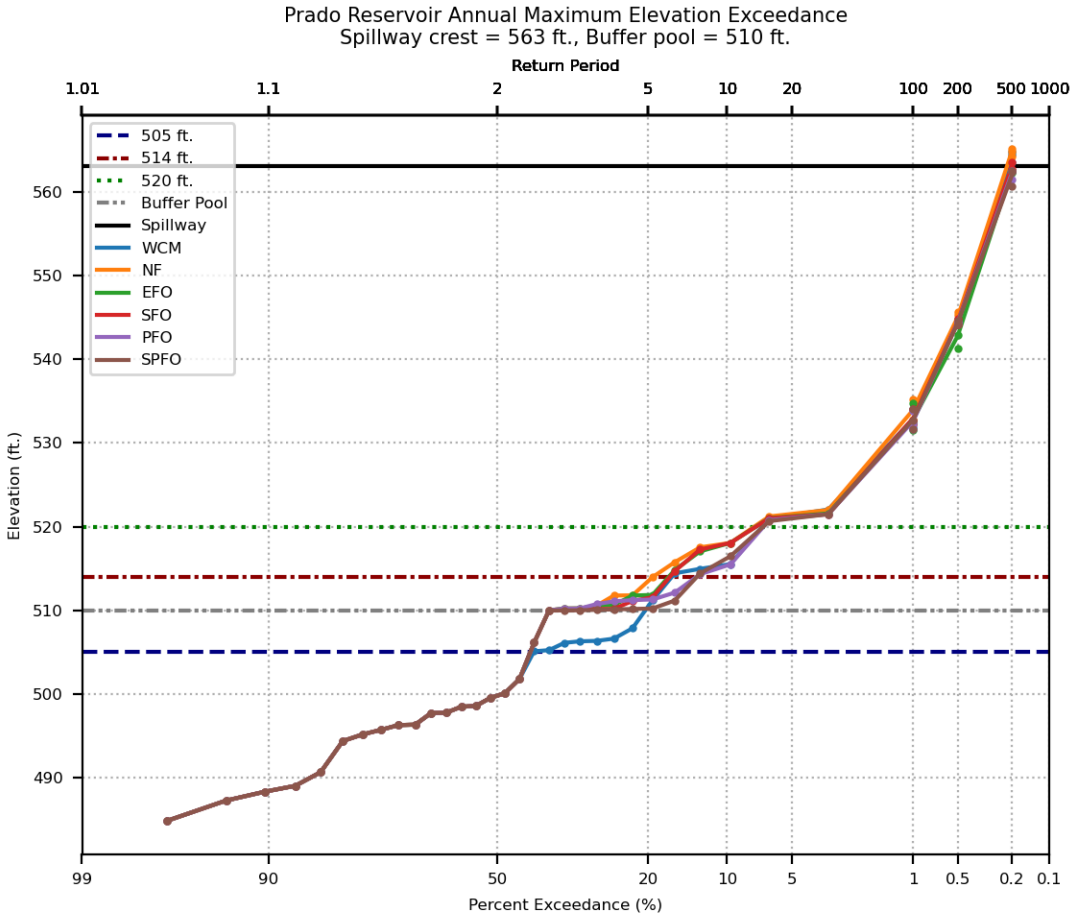

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 510 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO
PFO
SPFO
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

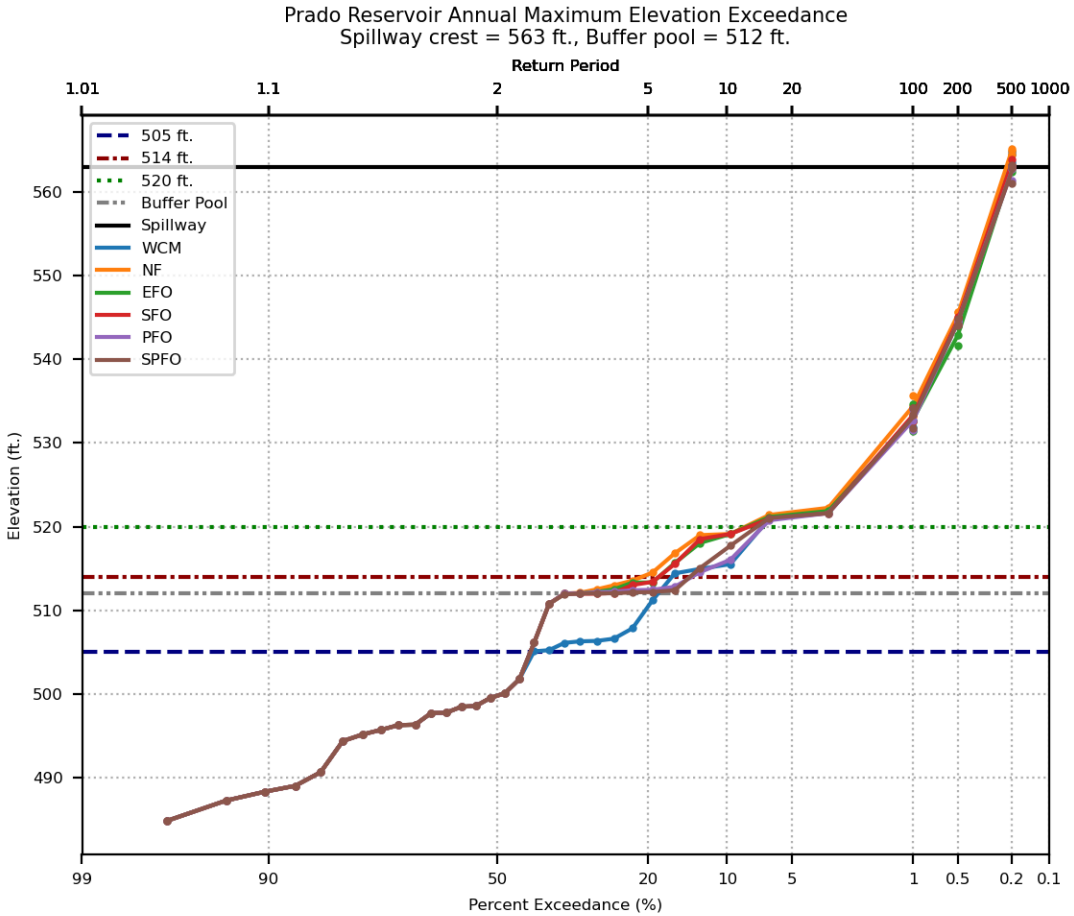

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 512 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO
PFO
SPFO
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

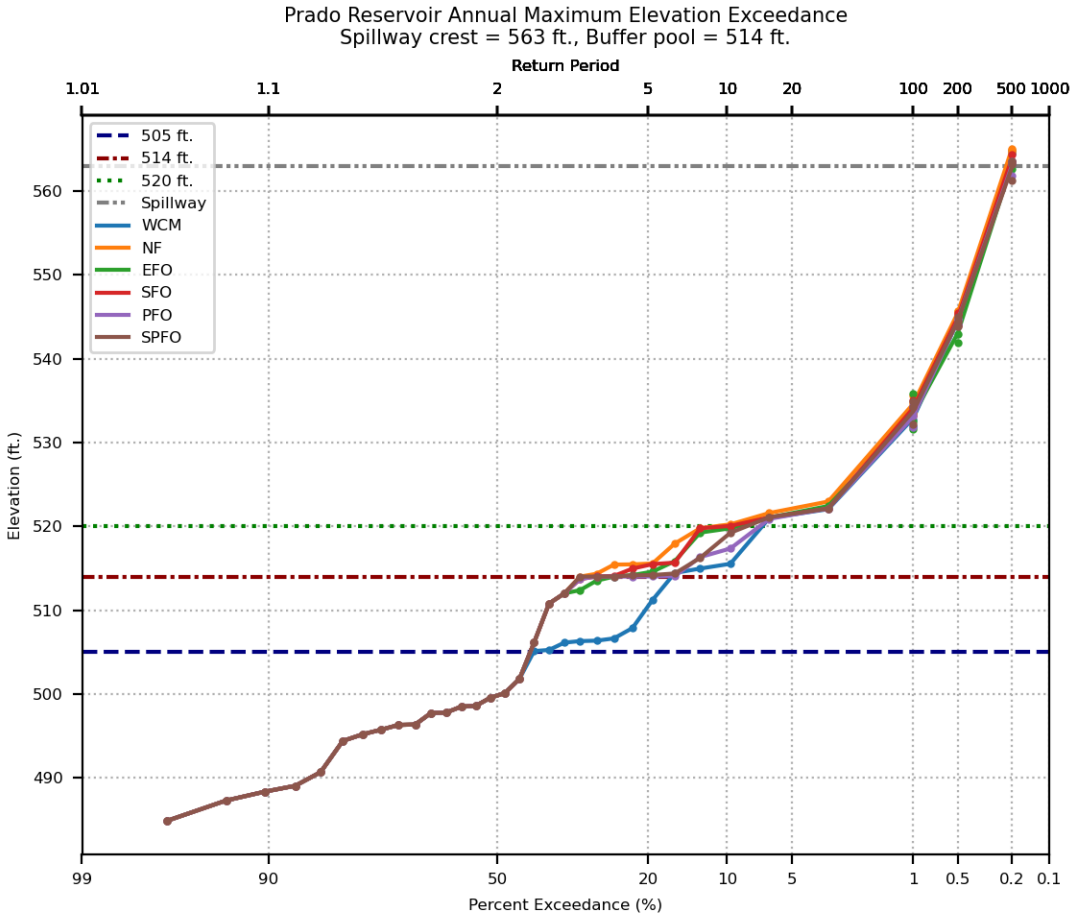

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 514 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
PFO
SPFO
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

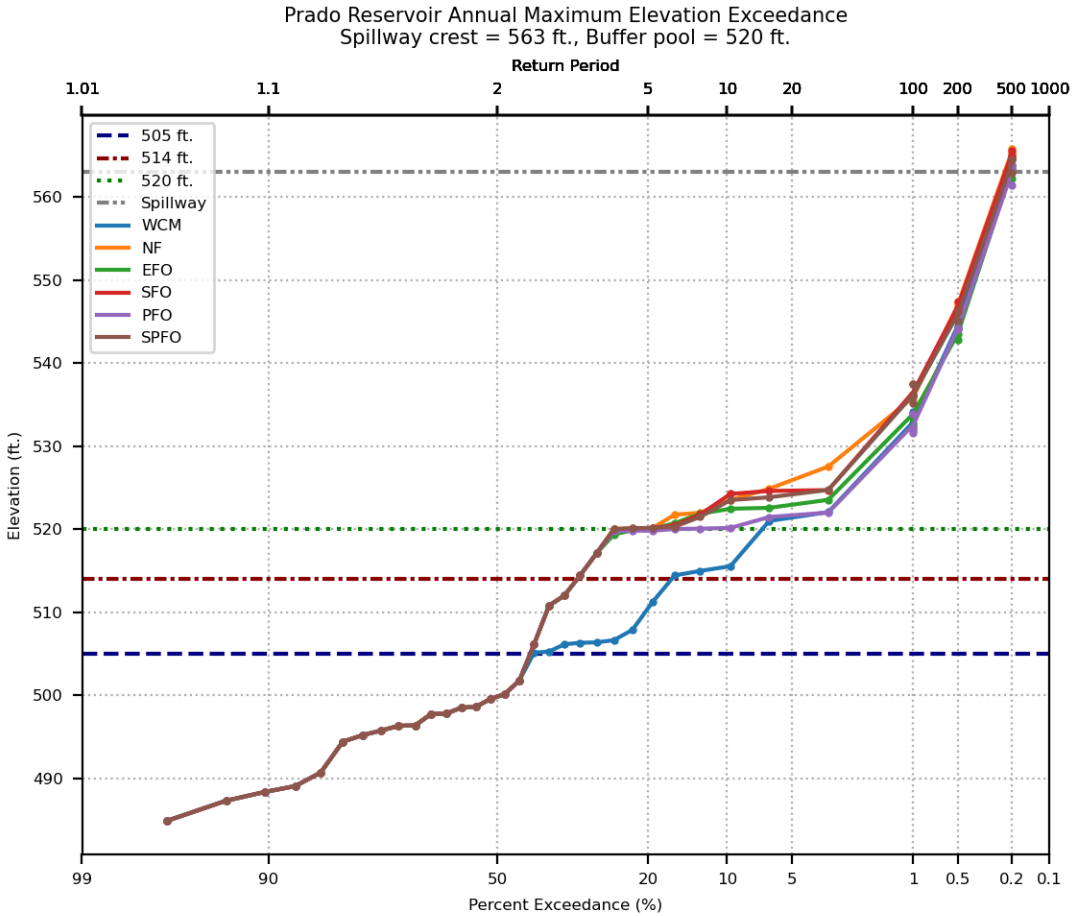

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 520 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
PFO
SPFO
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

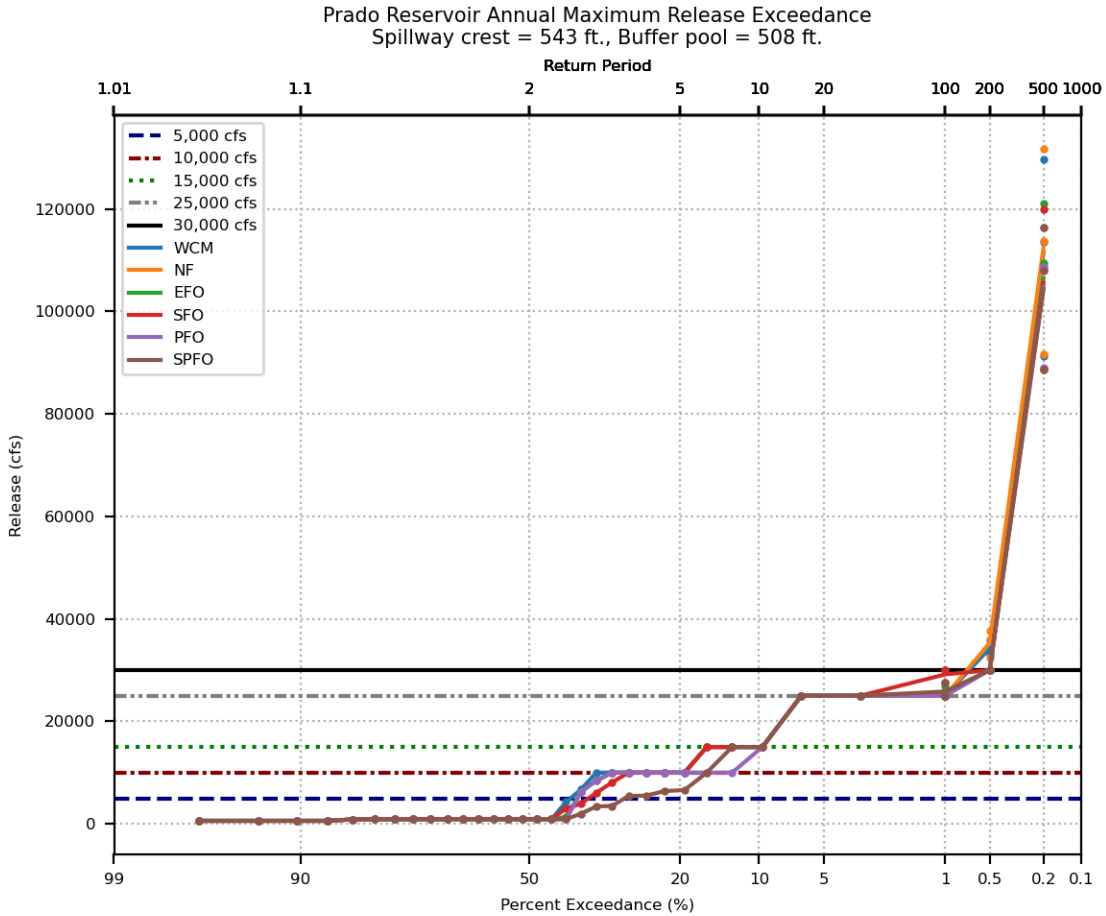

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 508 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO
PFO
SPFO
560
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

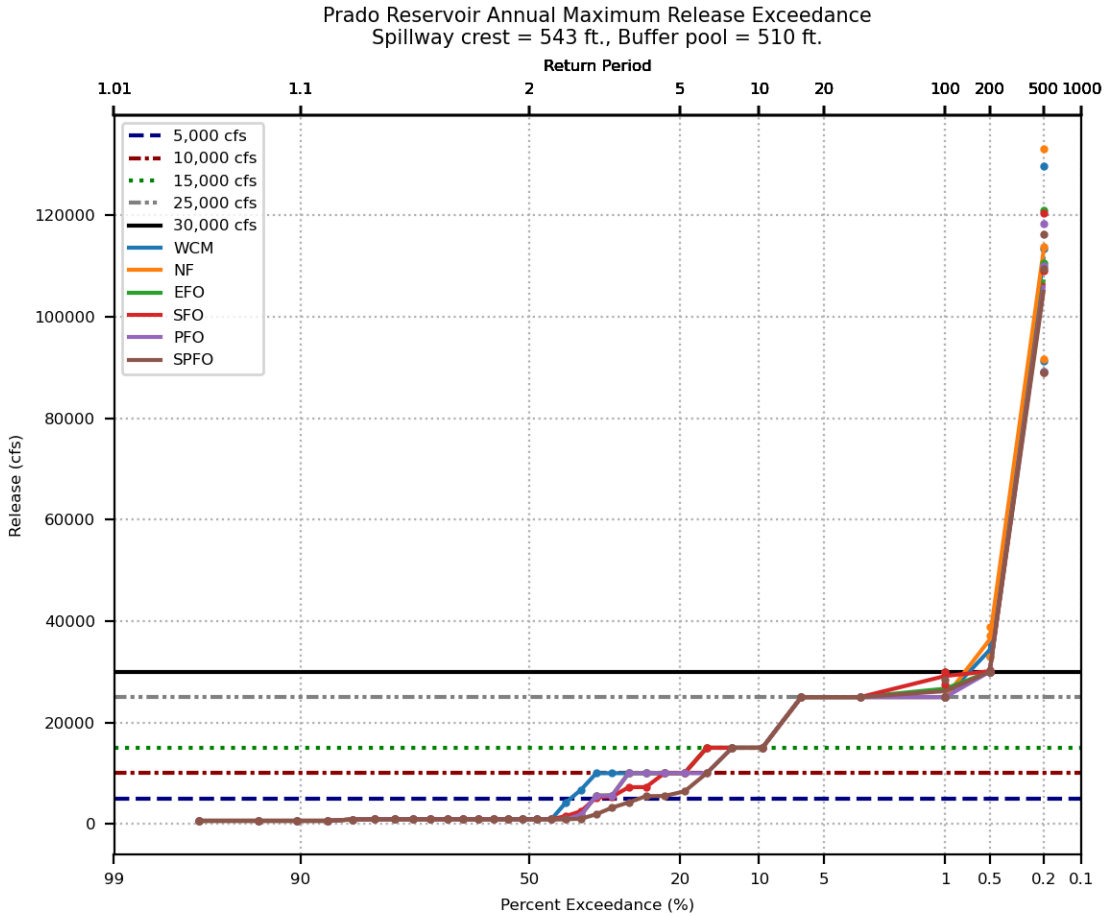

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 510 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO
PFO
SPFO
560
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

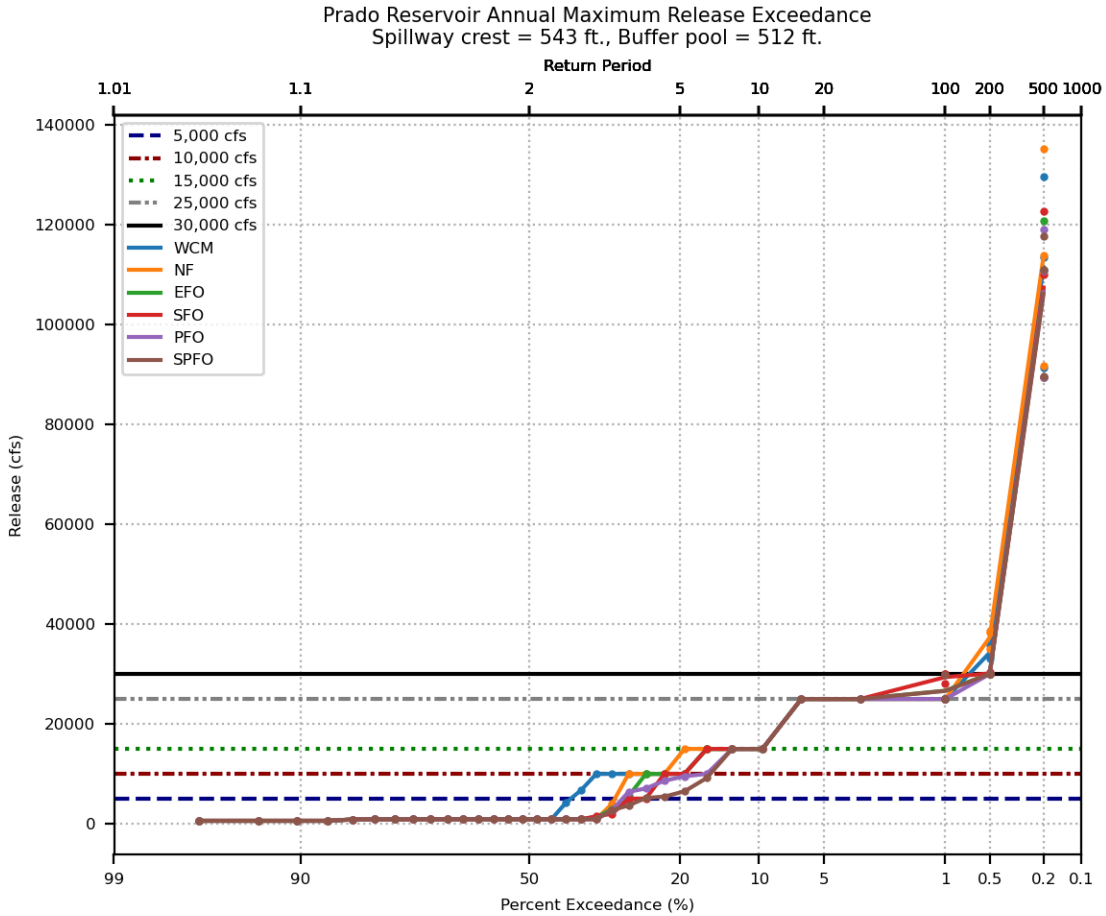

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 512 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO
PFO
SPFO
560
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

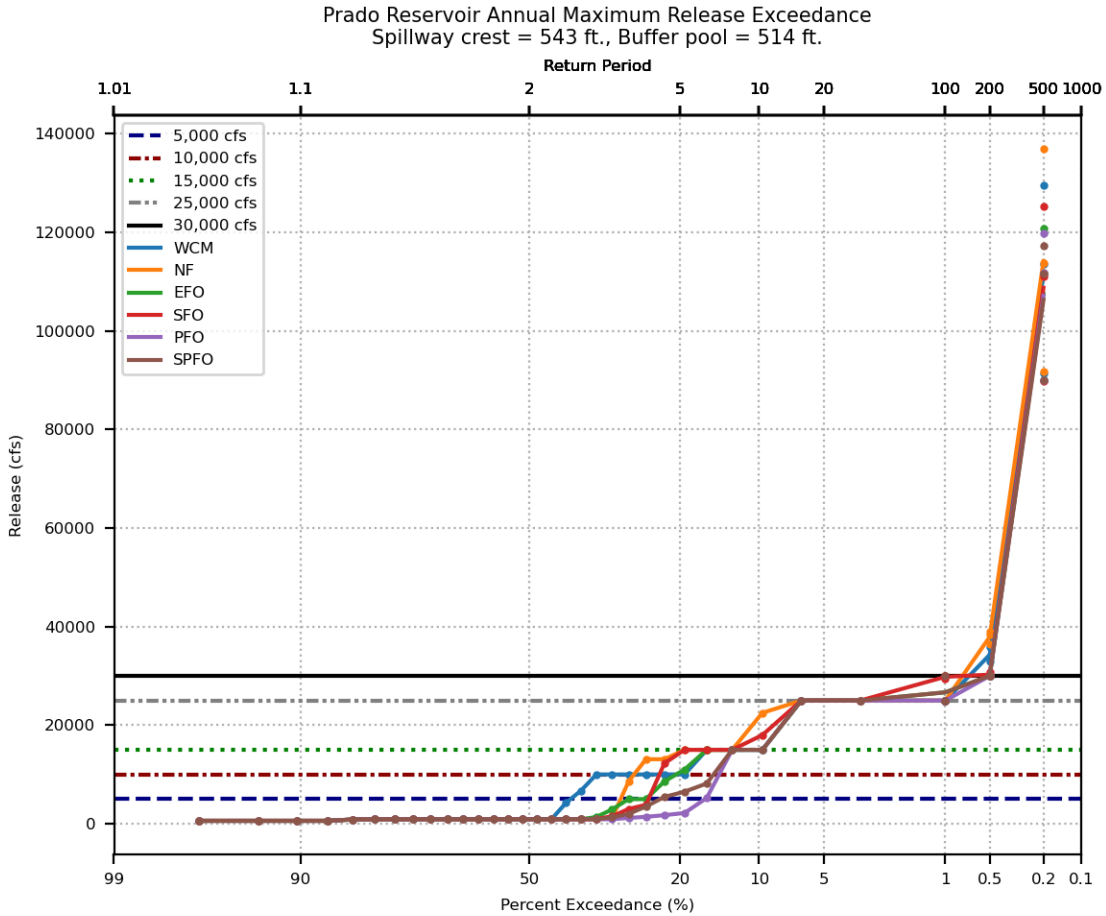

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 514 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
PFO
SPFO
Elevation (ft.)
560
550
540
530
520
510
500
490
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

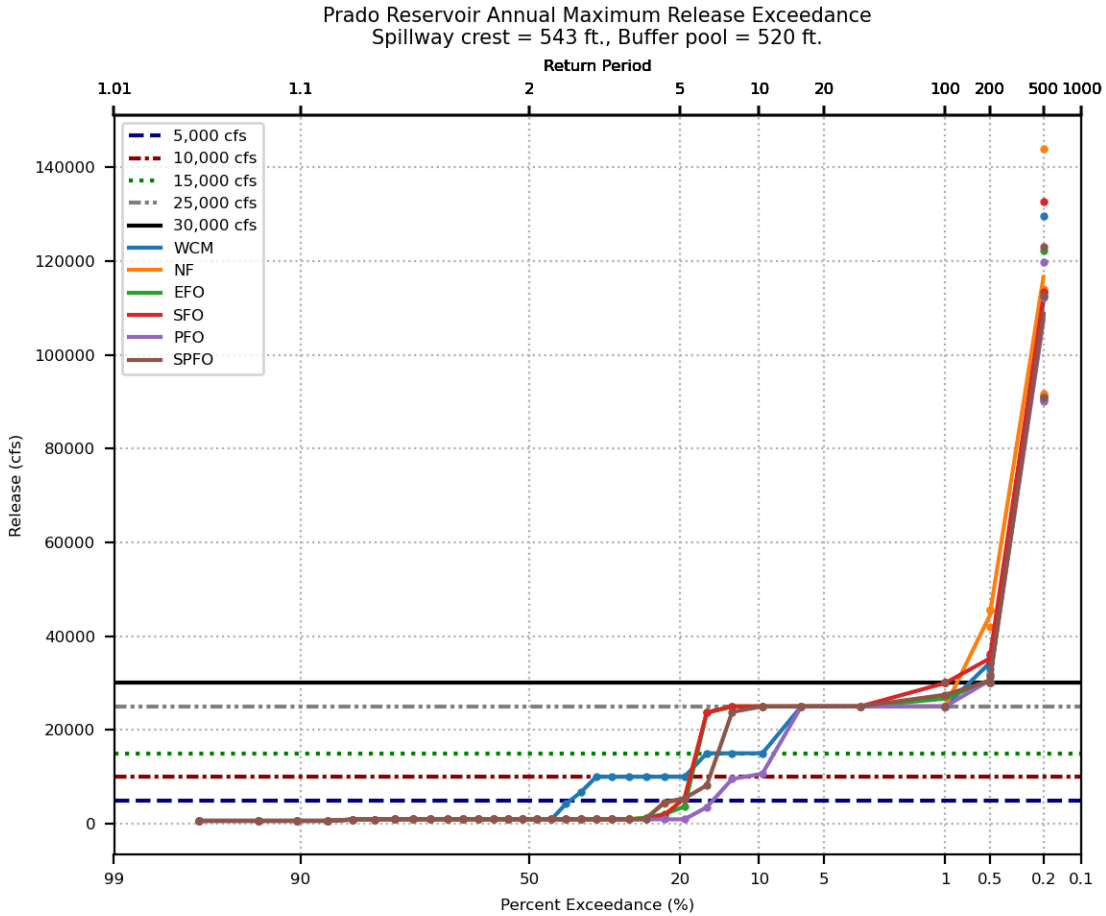

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 520 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
PFO
SPFO
560
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

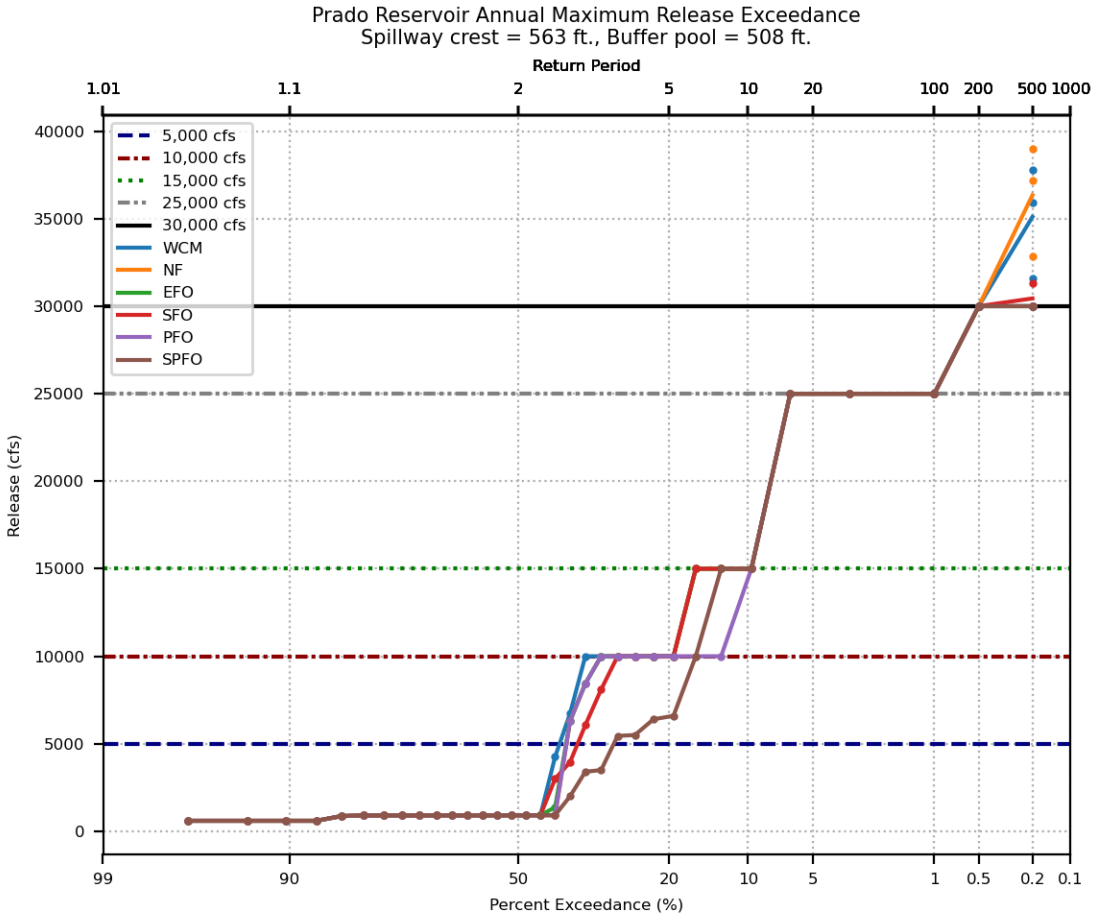

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 508 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
Release (cfs)
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

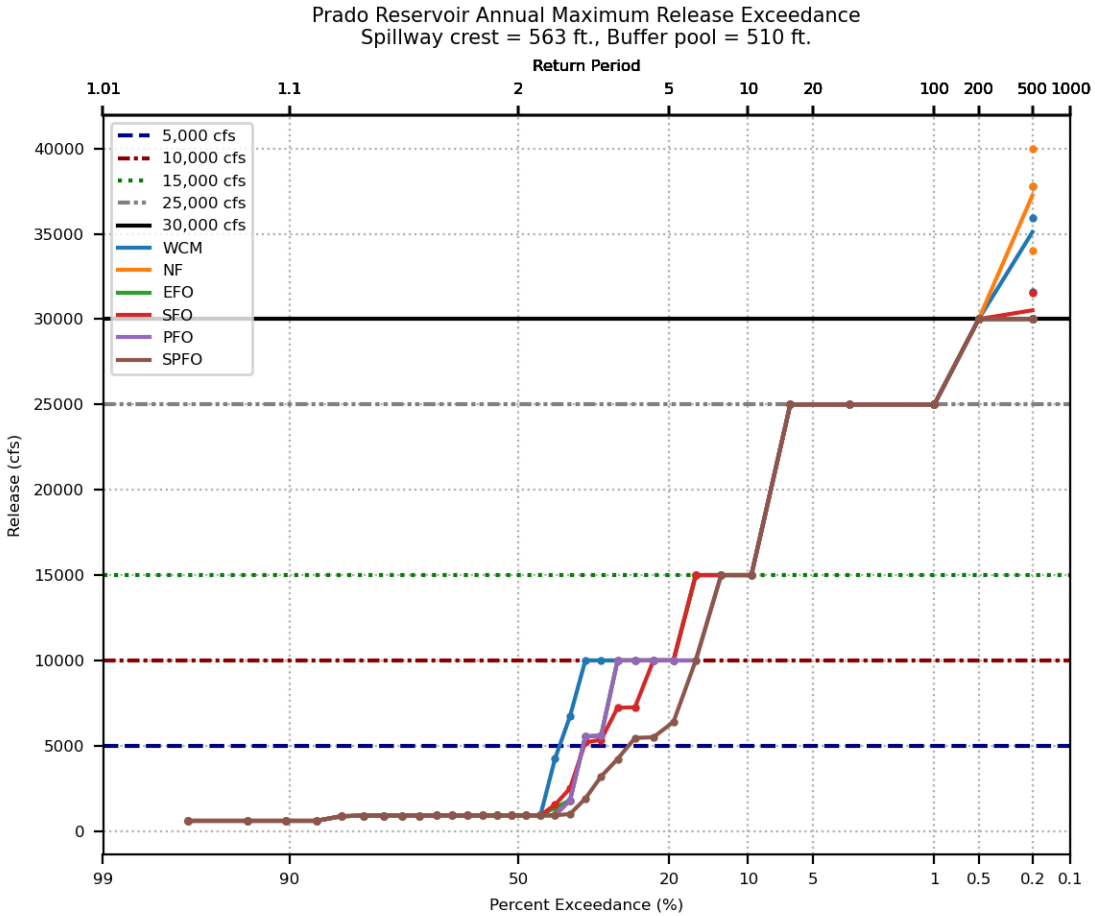

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 510 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
Release (cfs)
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

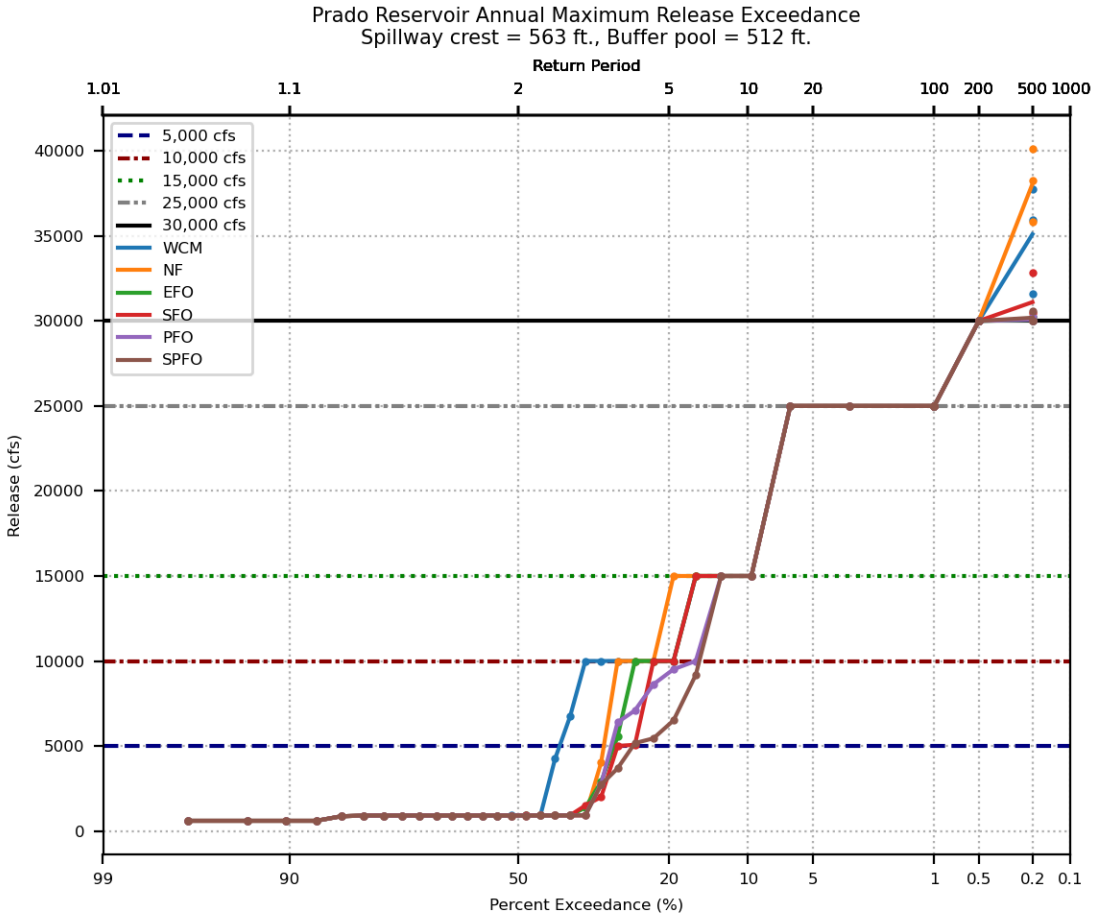

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 512 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
140000
120000
100000
80000
60000
40000
20000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

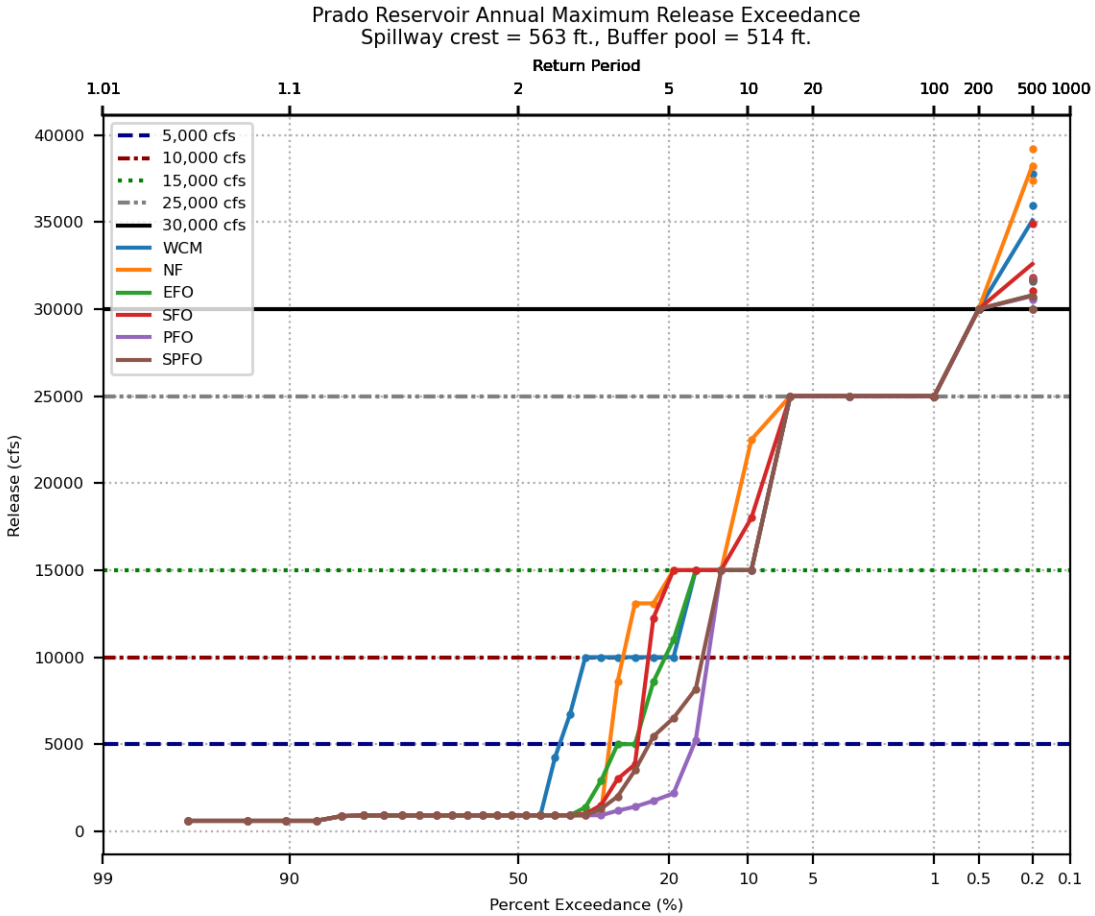

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 514 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
Release (cfs)
140000
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

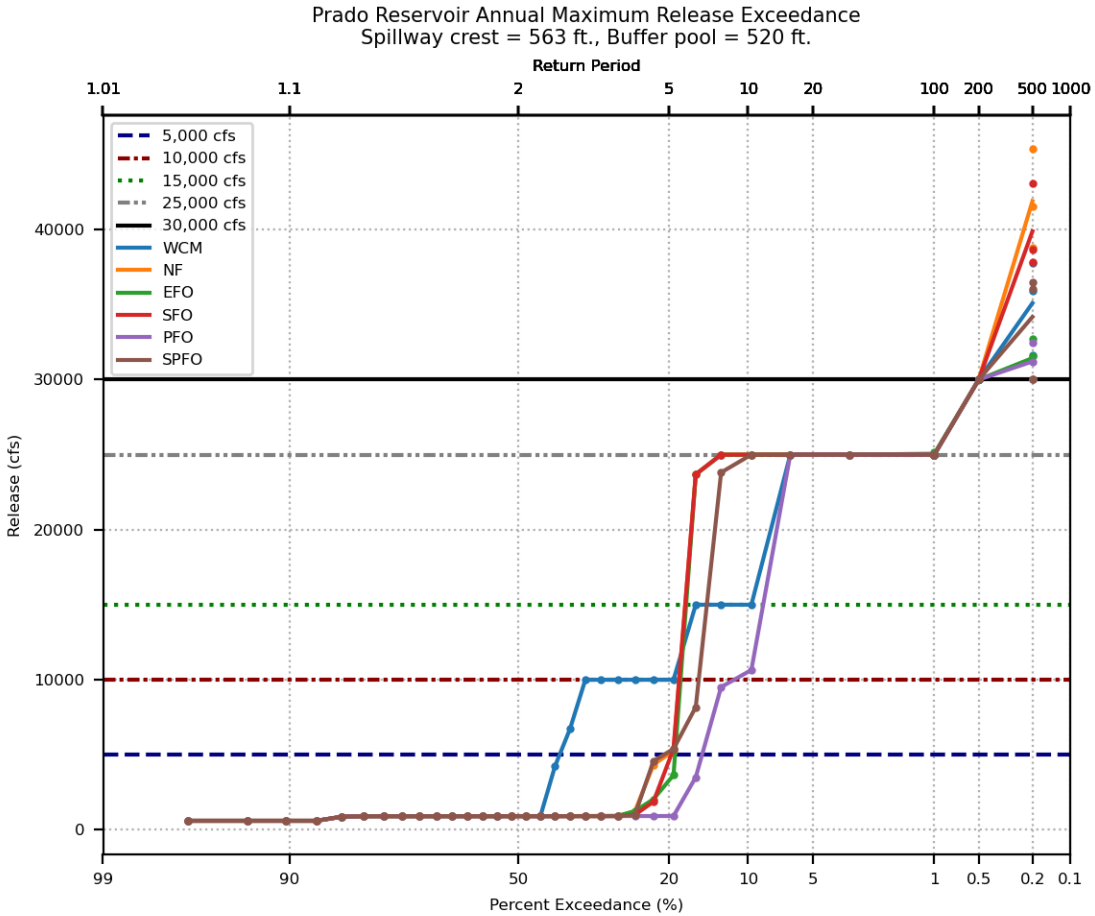

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 520 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
Release (cfs)
140000
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 508 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
Release (cfs)
40000
35000
30000
25000
20000
15000
10000
5000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 510 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
Release (cfs)
40000
35000
30000
25000
20000
15000
10000
5000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

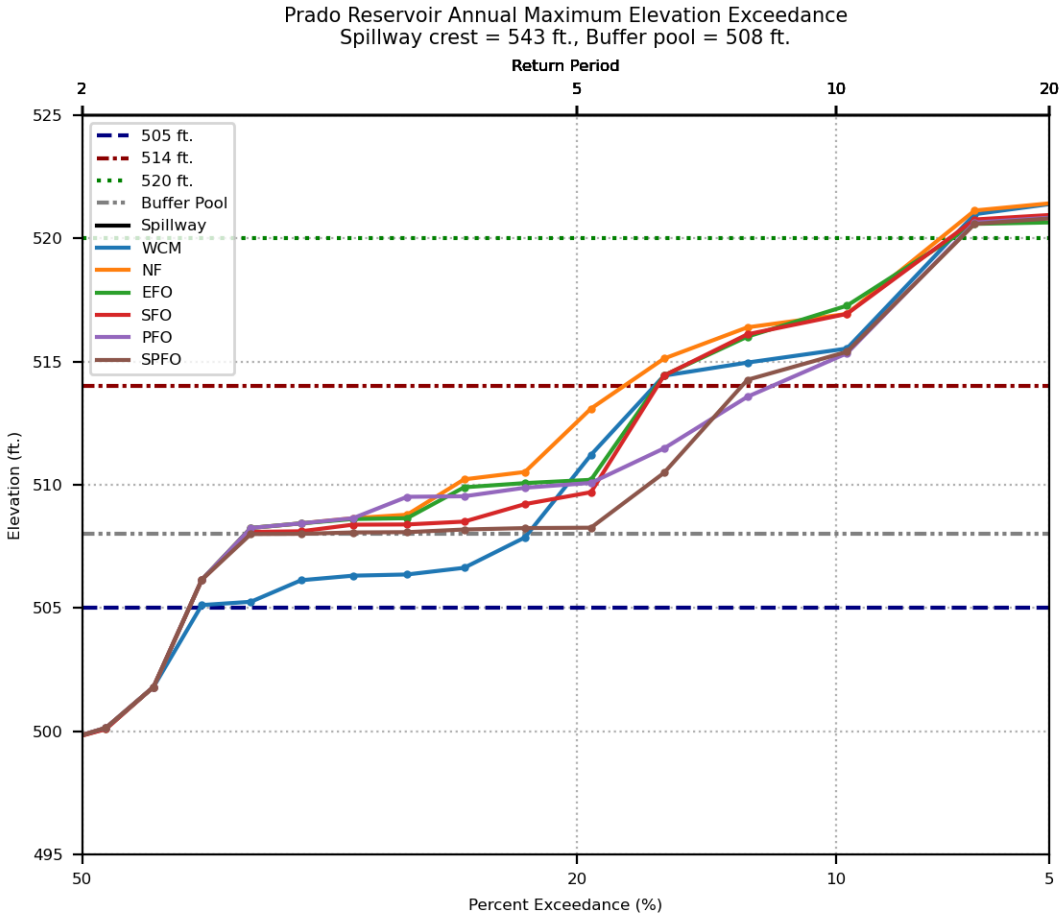

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 512 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
Release (cfs)
40000
35000
30000
25000
20000
15000
10000
5000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

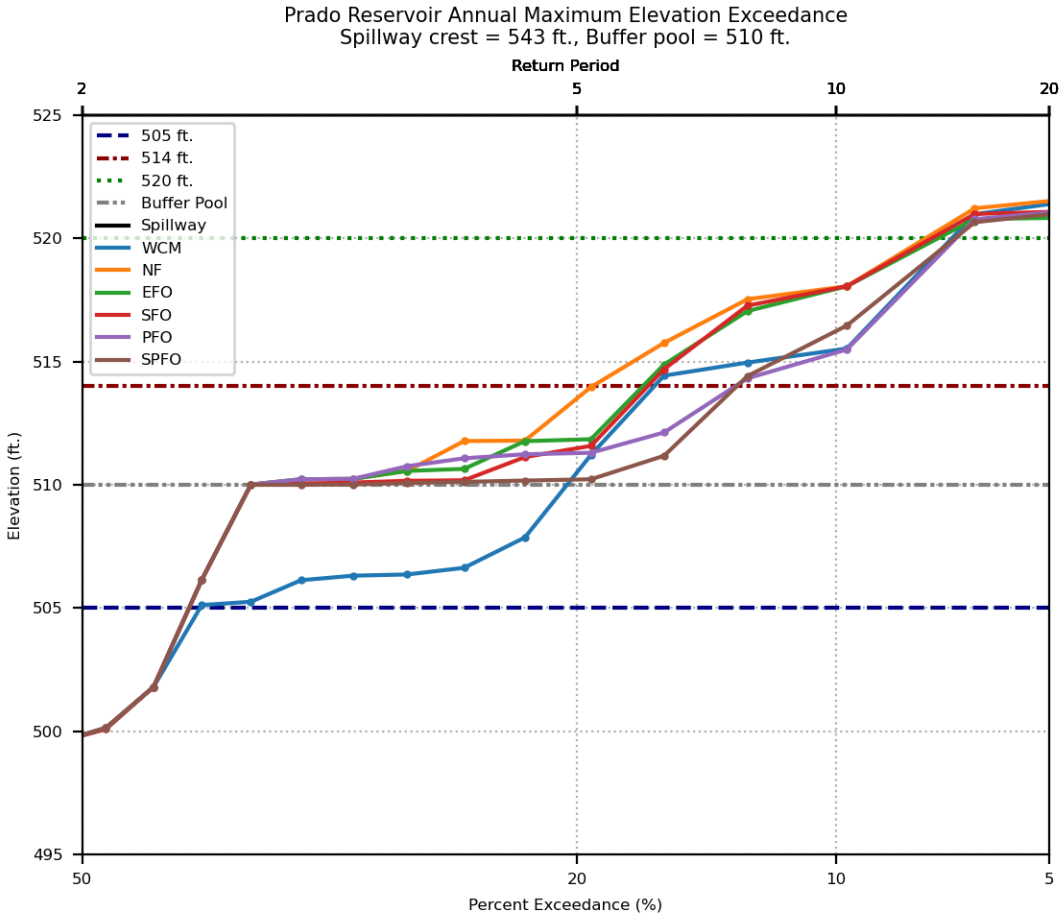

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 514 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
Release (cfs)
40000
35000
30000
25000
20000
15000
10000
5000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

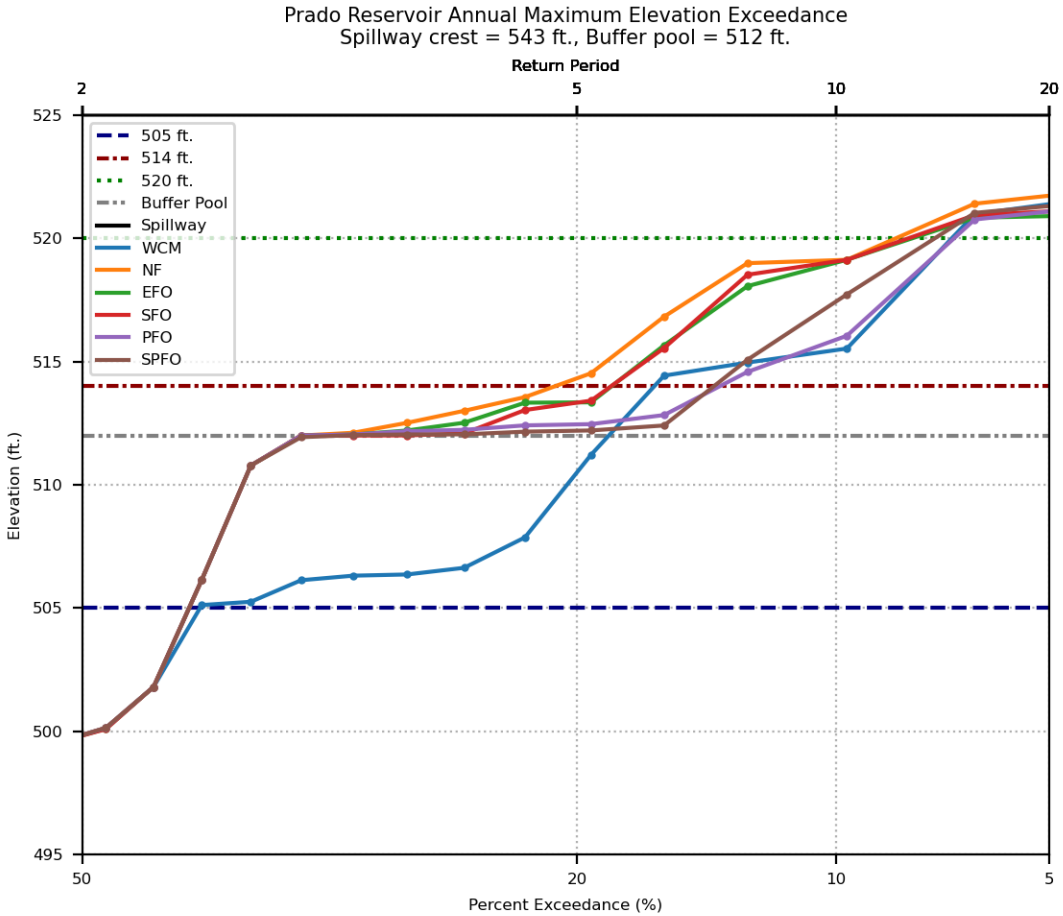

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 520 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
40000
30000
20000
10000
0
Release (cfs)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

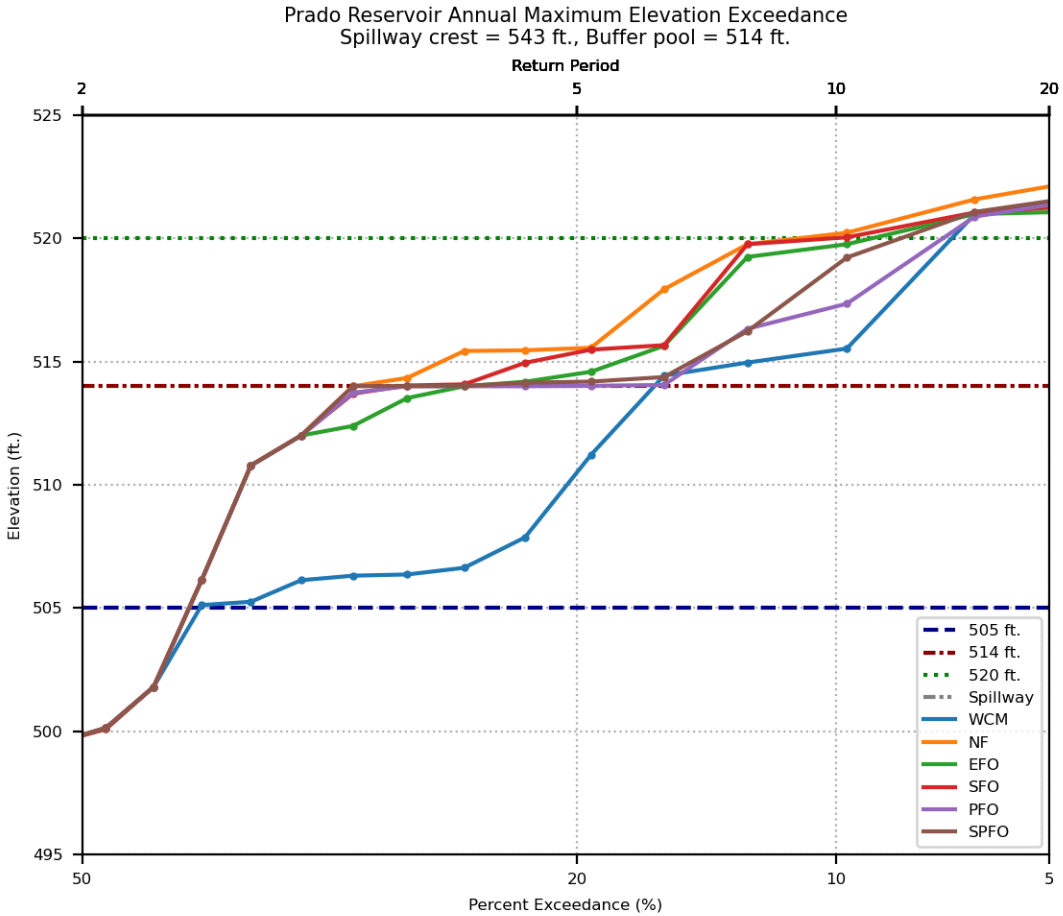
Frequency of Annual Maximum Pool Elevation *by Buffer Pool* - Zoomed

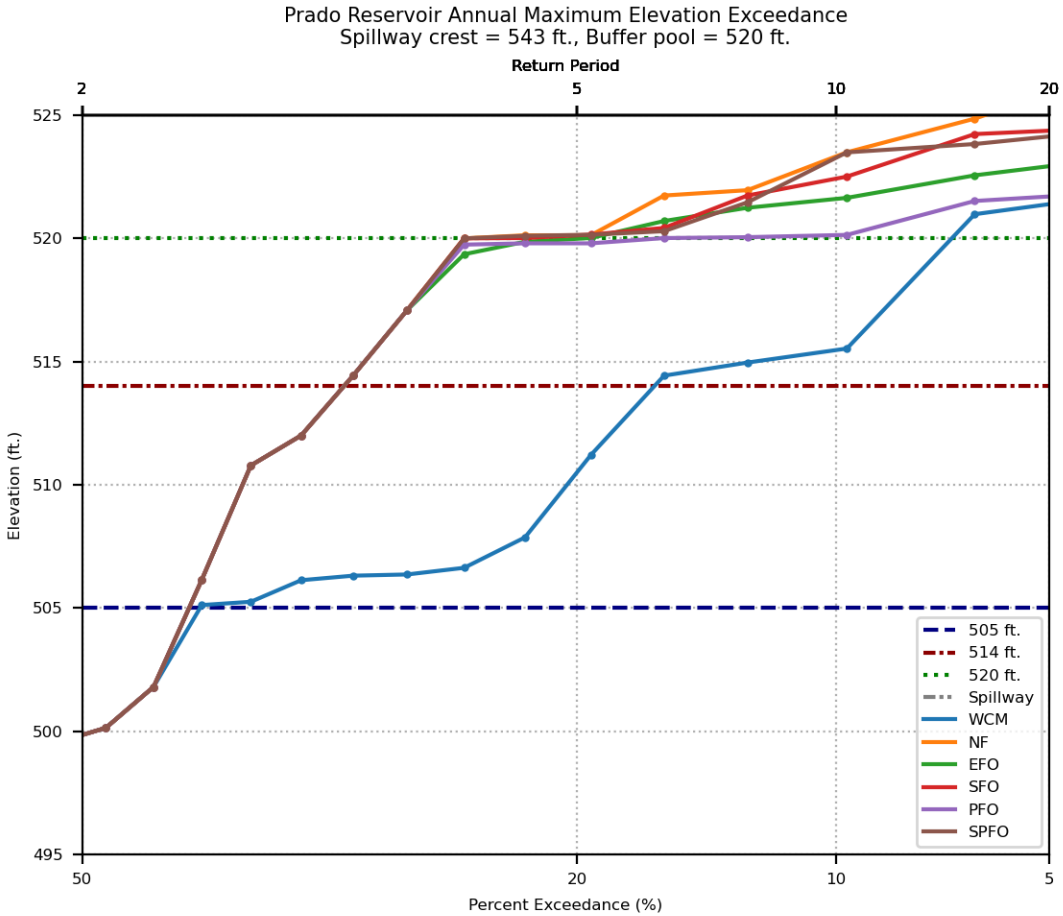
- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’
  - 510’
  - 512’
  - 514’
  - 520’
- WCP alternatives in legend

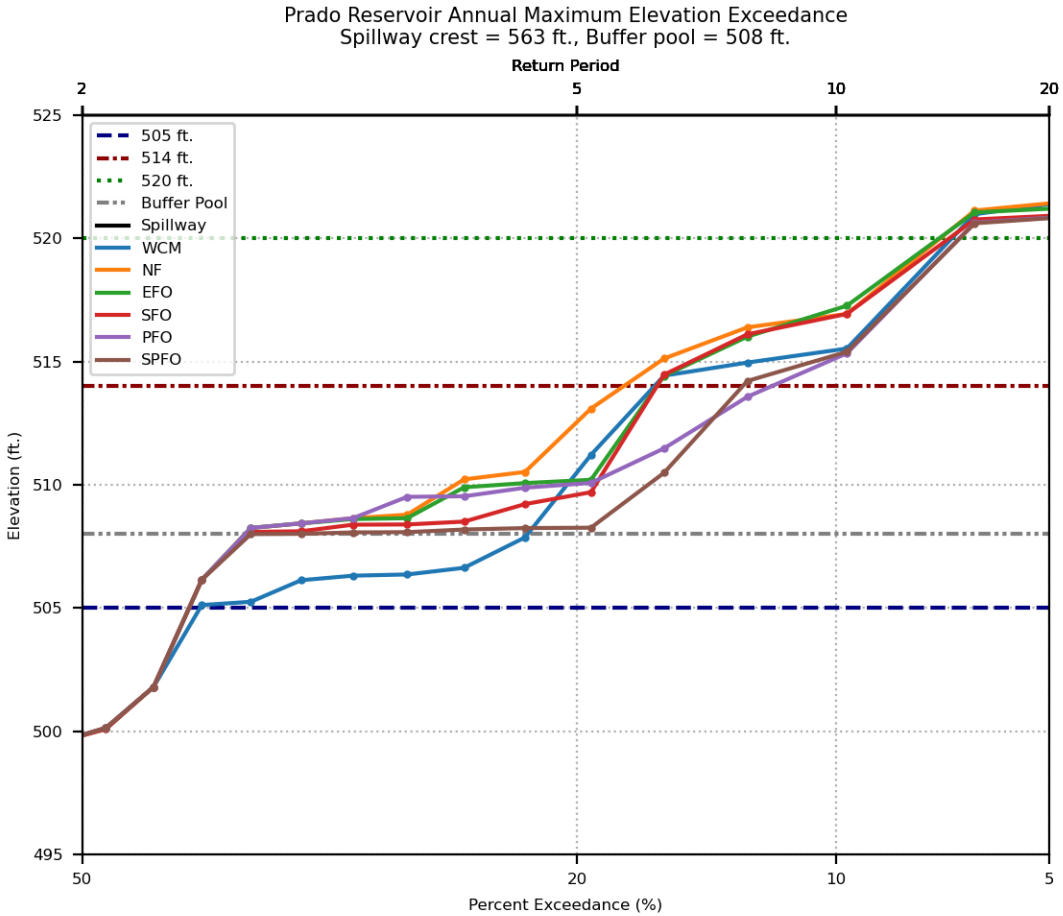

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 508 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)

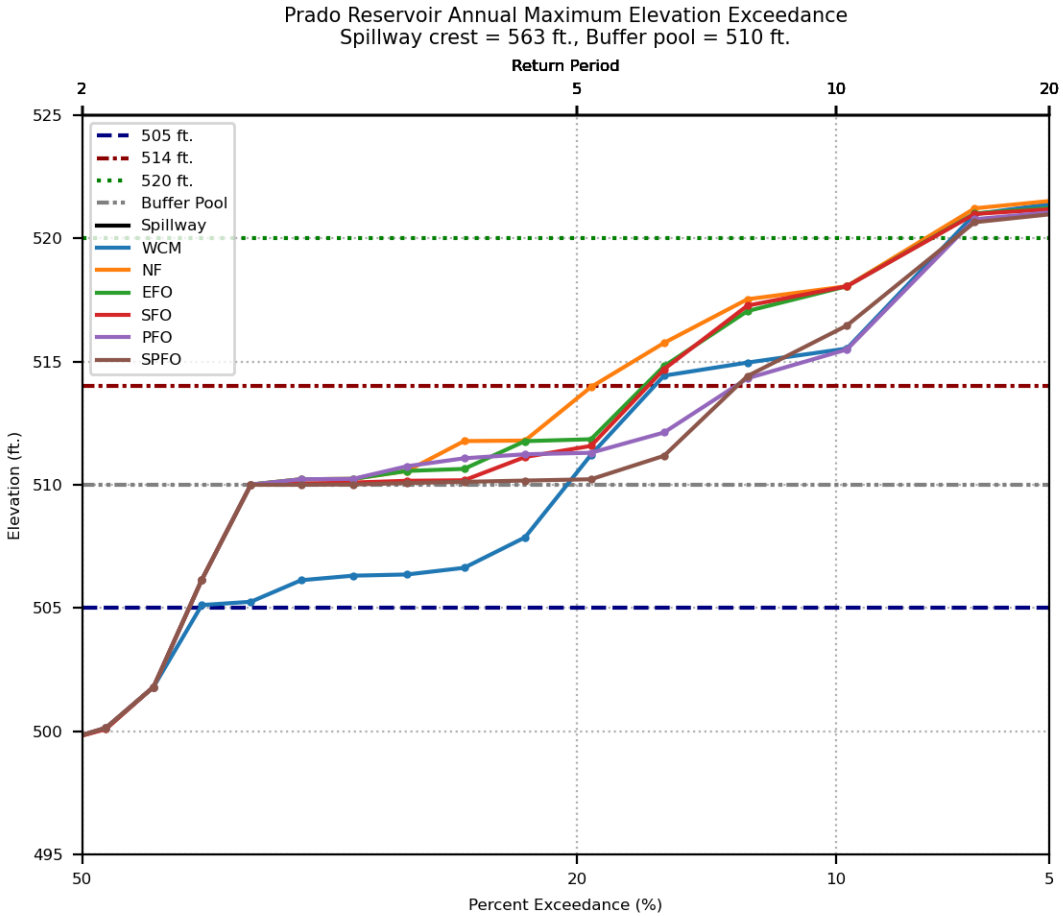

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 510 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)

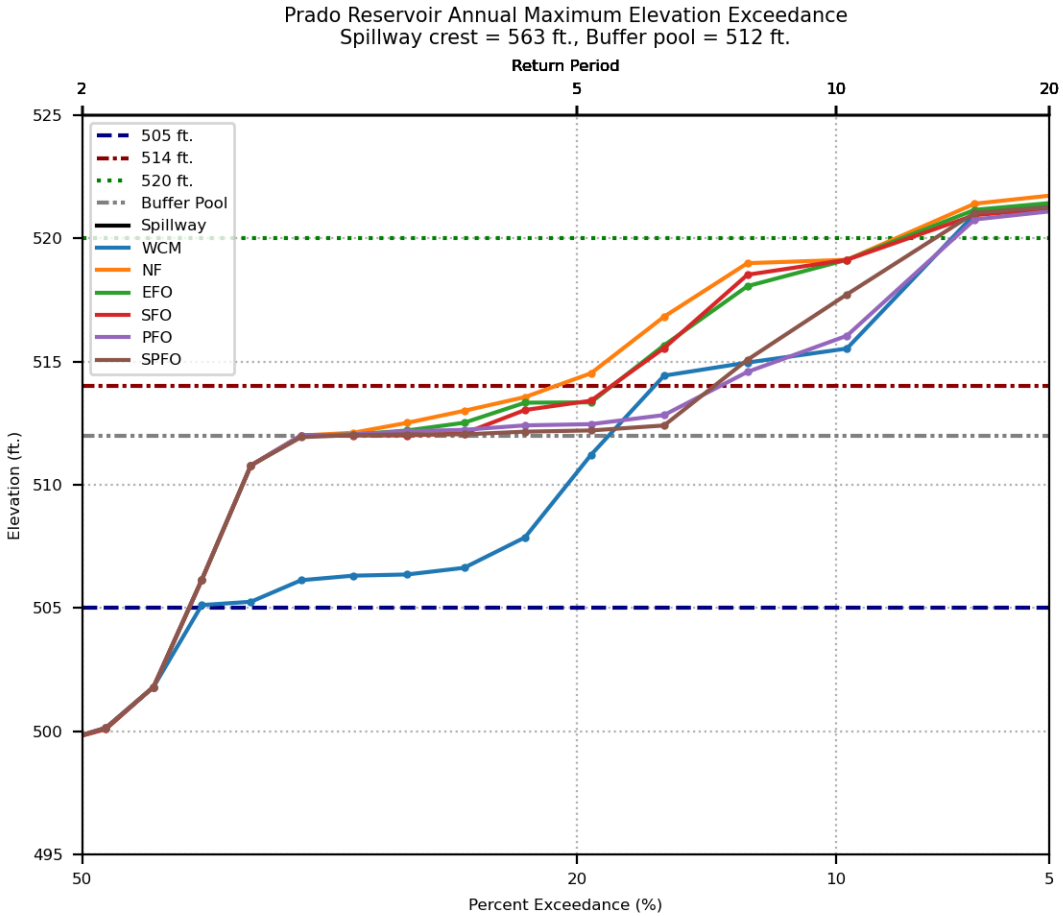

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 512 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)

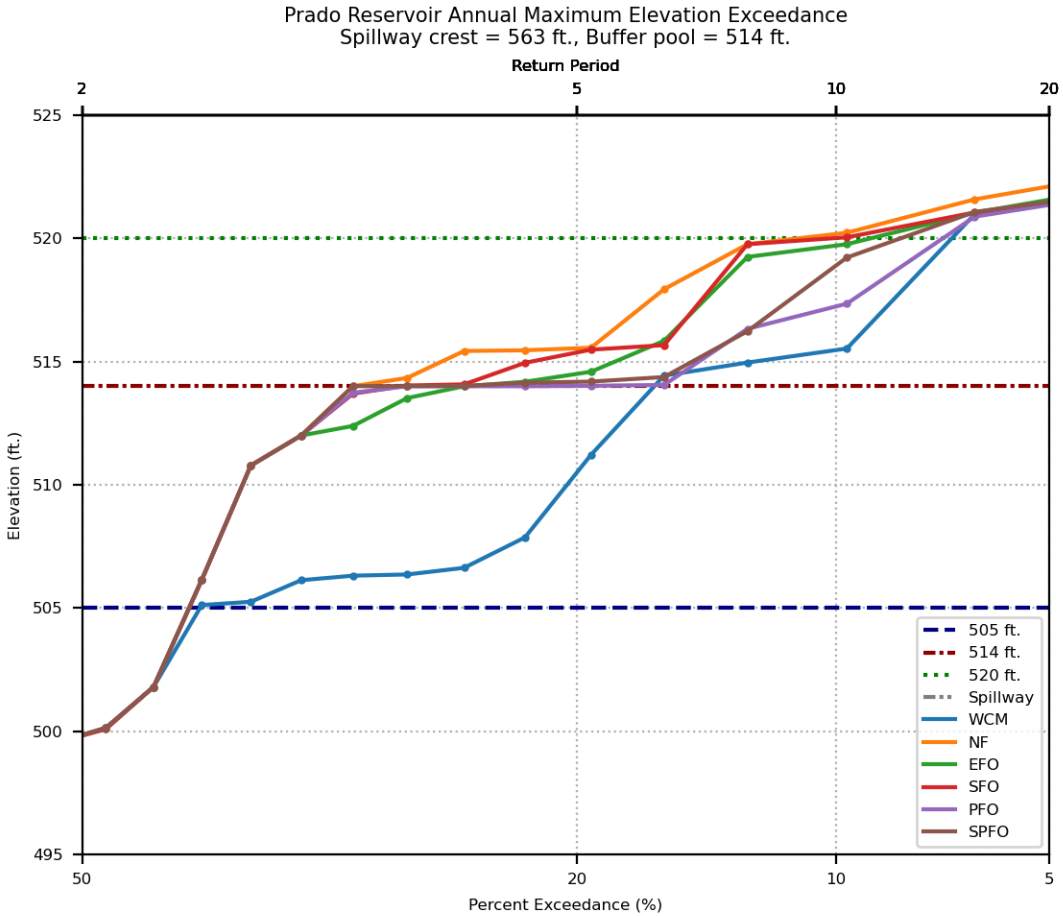

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 514 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
PFO
SPFO

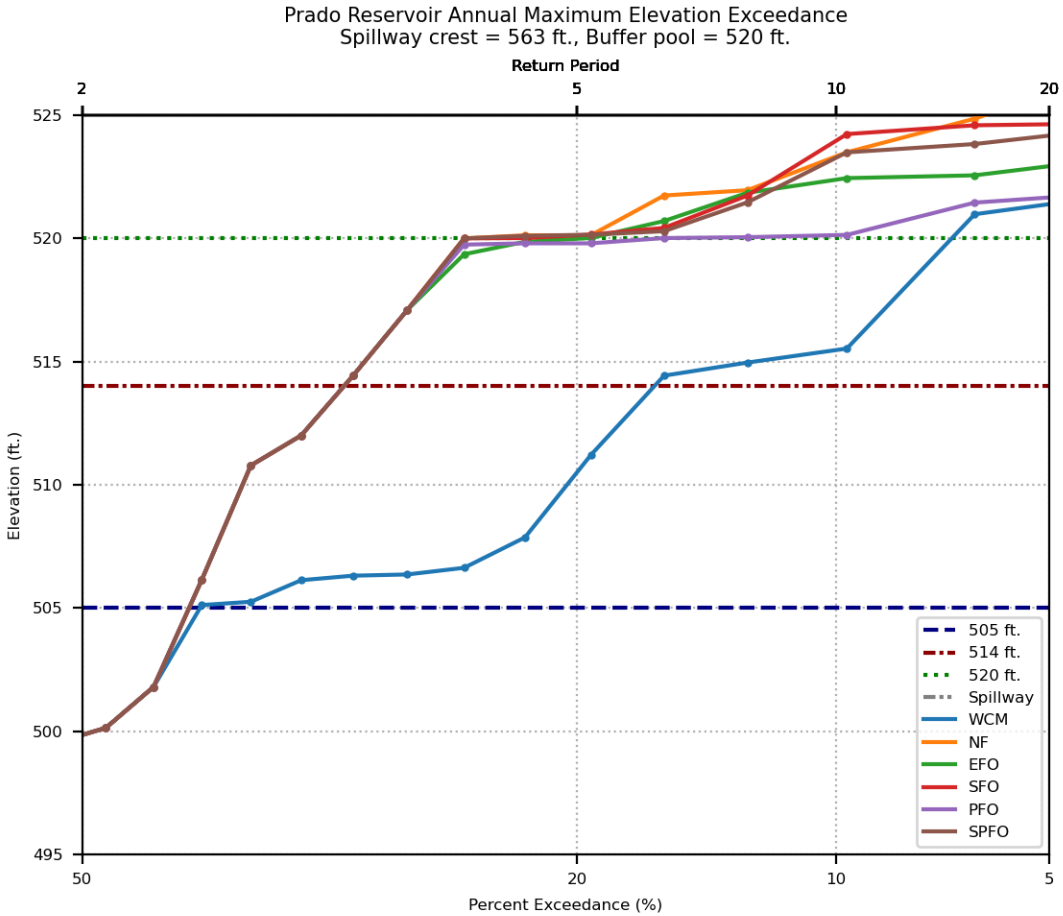

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 520 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
PFO
SPFO

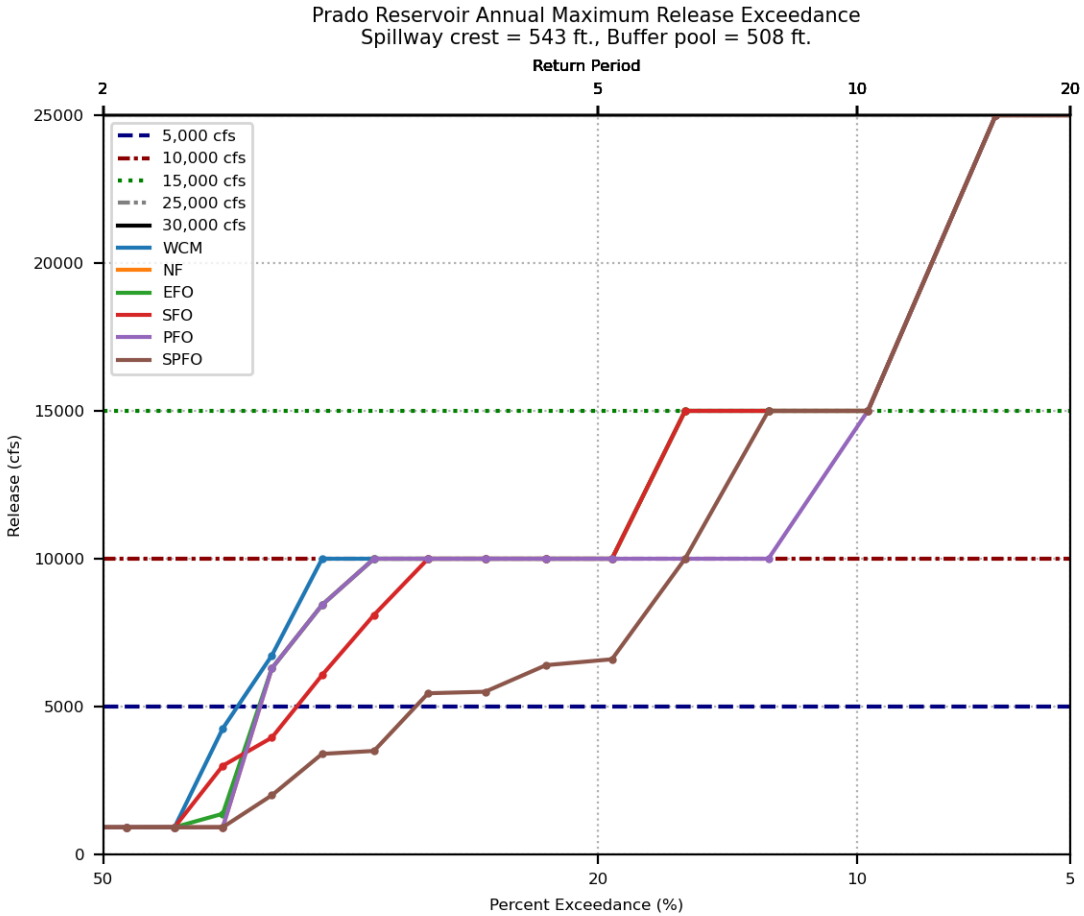

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 508 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)

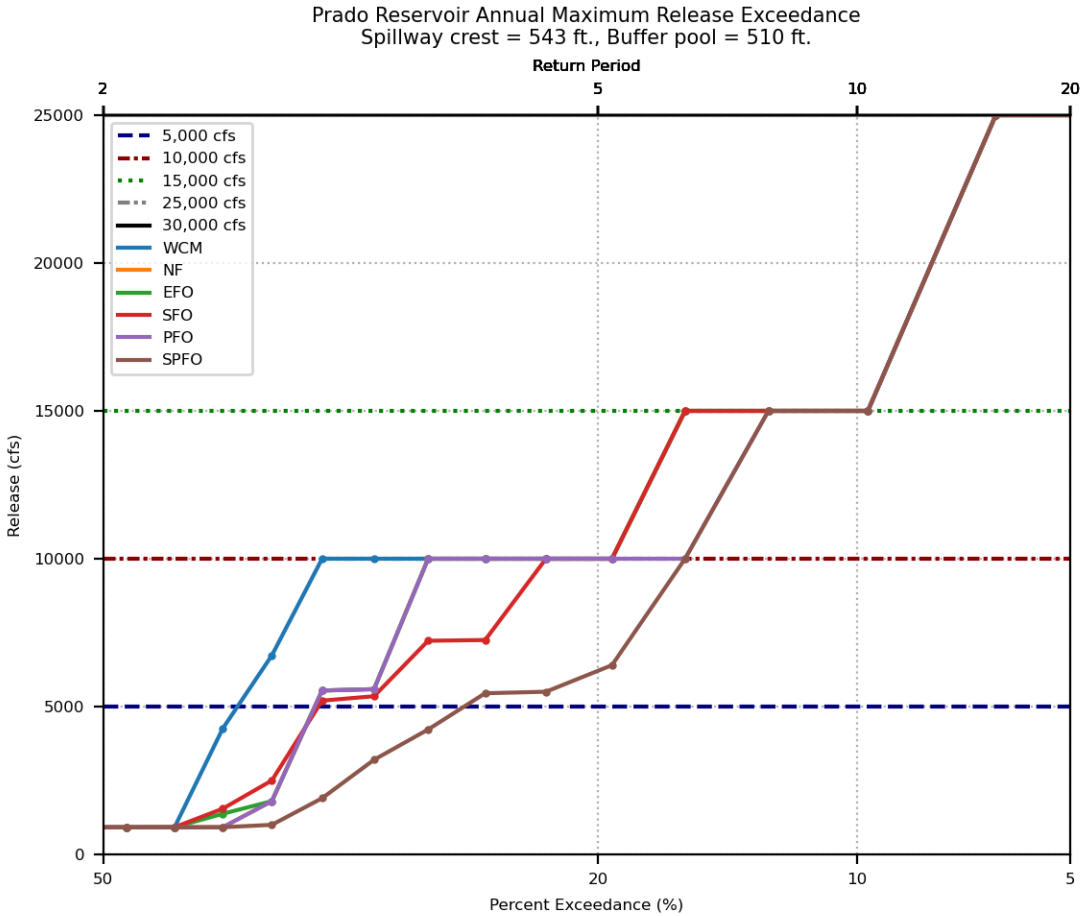

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 510 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)

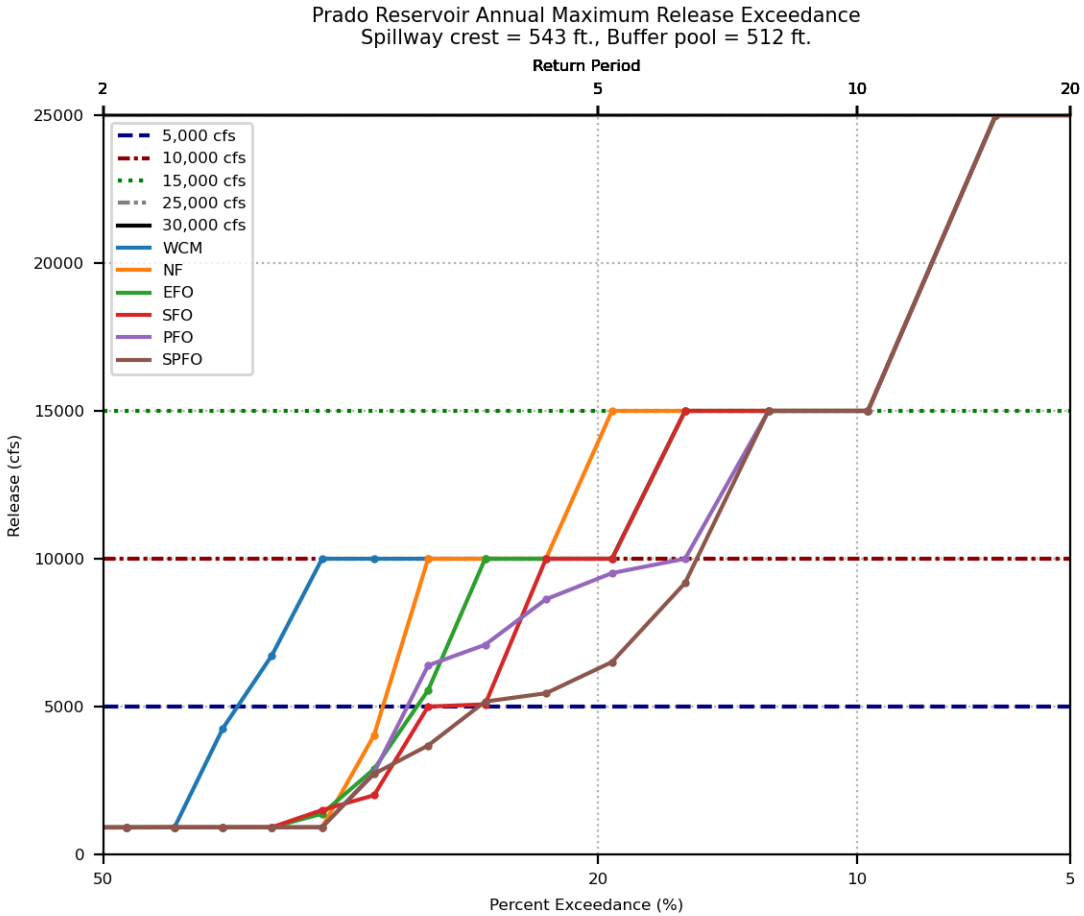

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 512 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)

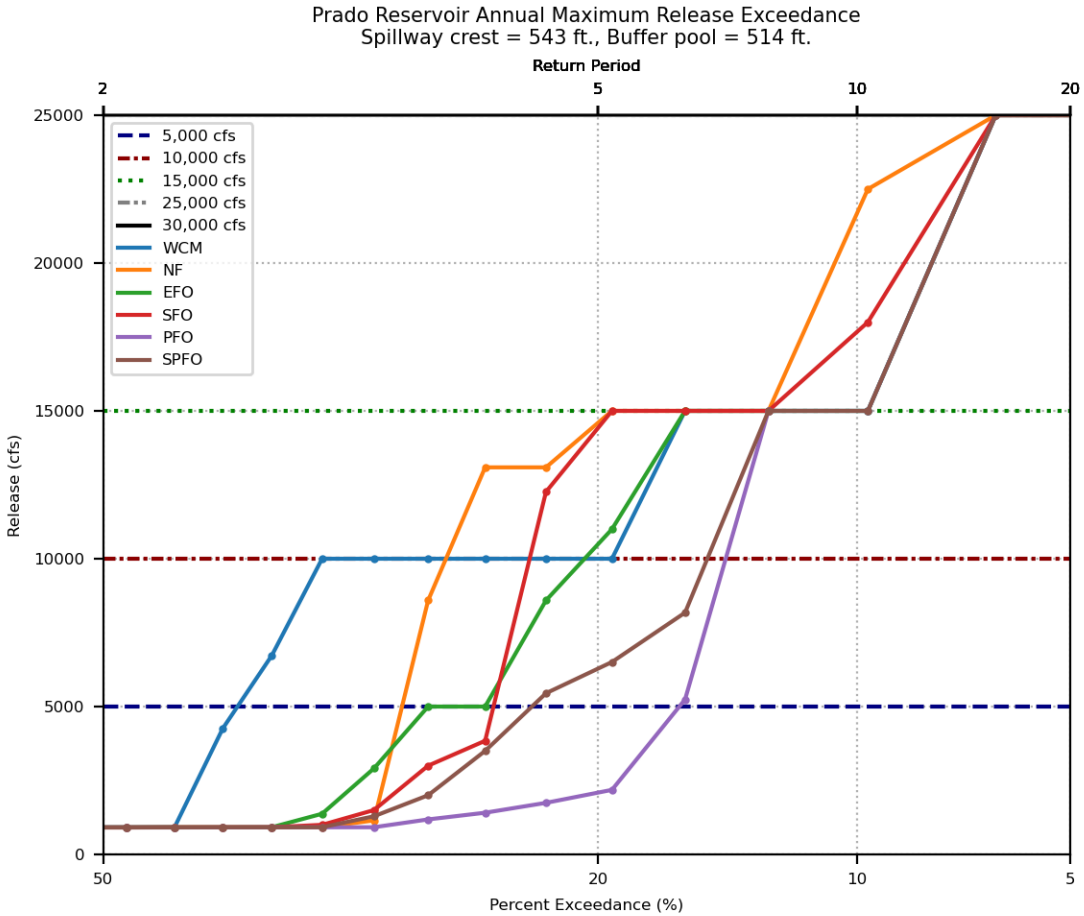

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 514 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
PFO
SPFO

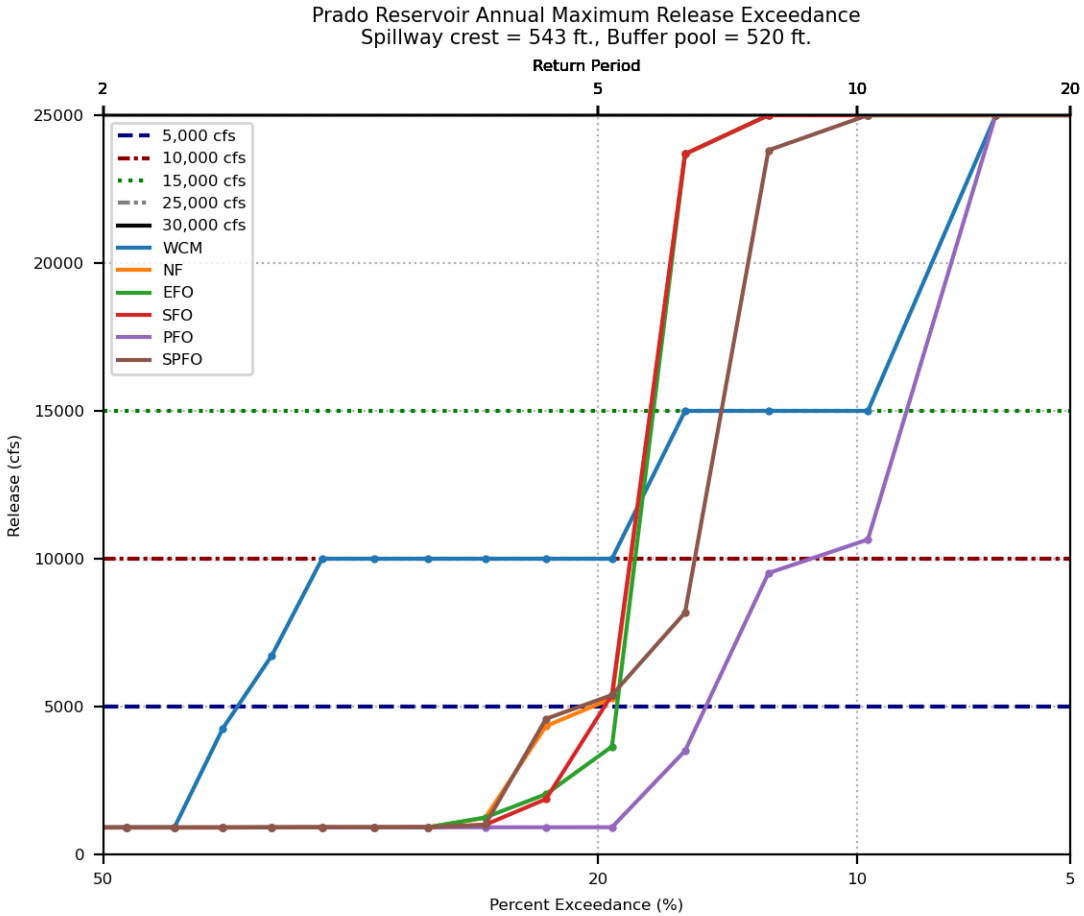

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 520 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
PFO
SPFO

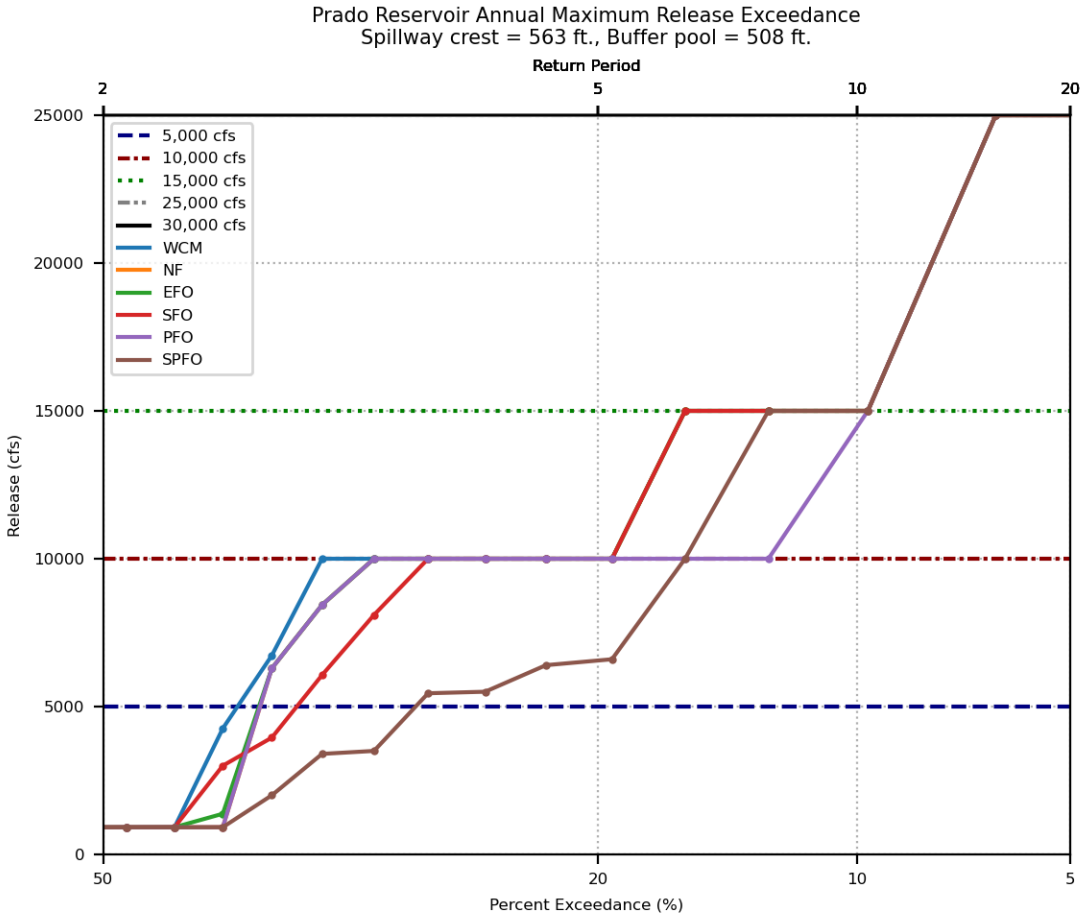

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 508 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)

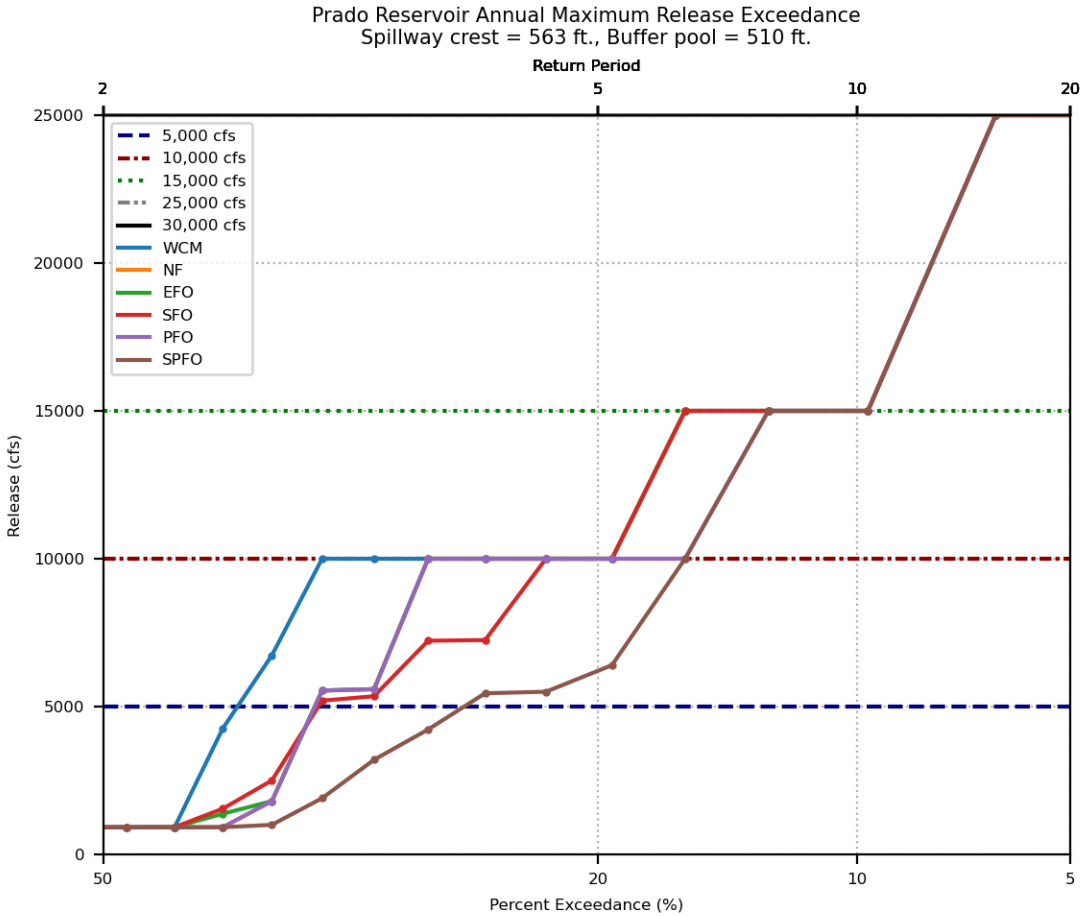

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 510 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)

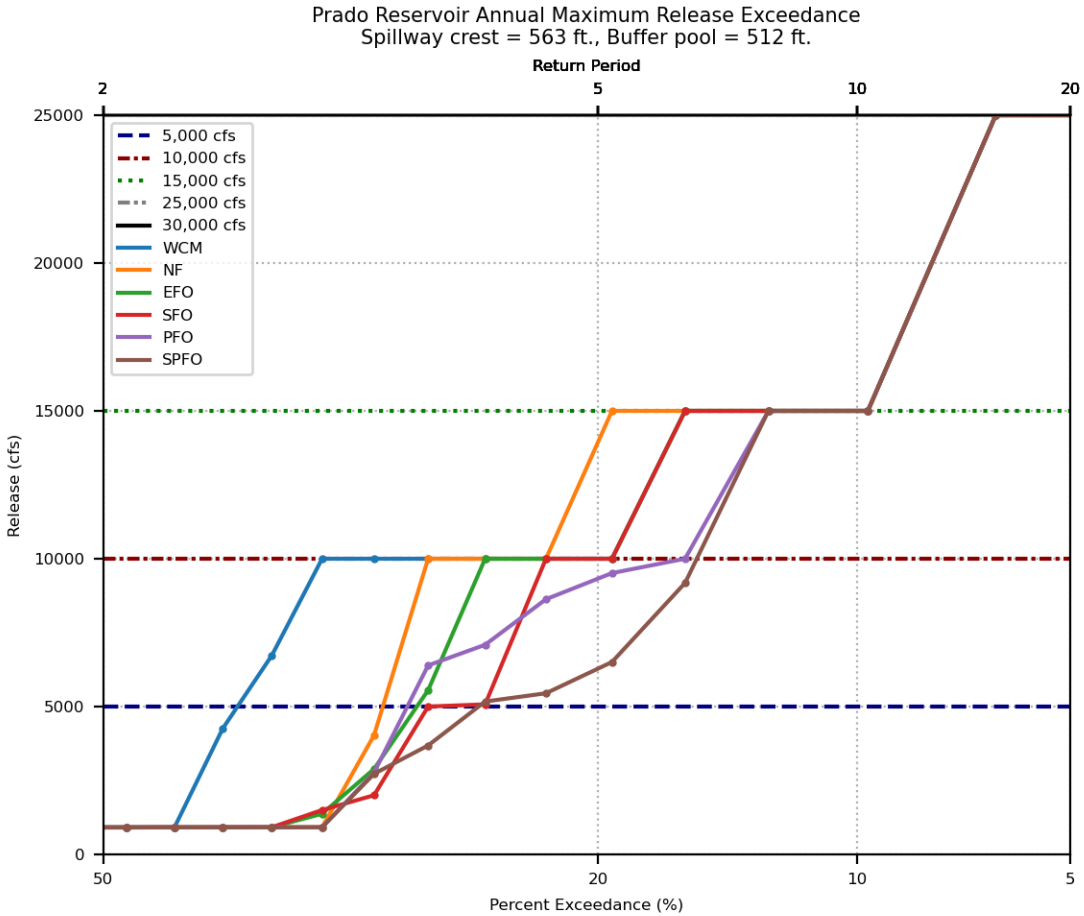

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 512 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)

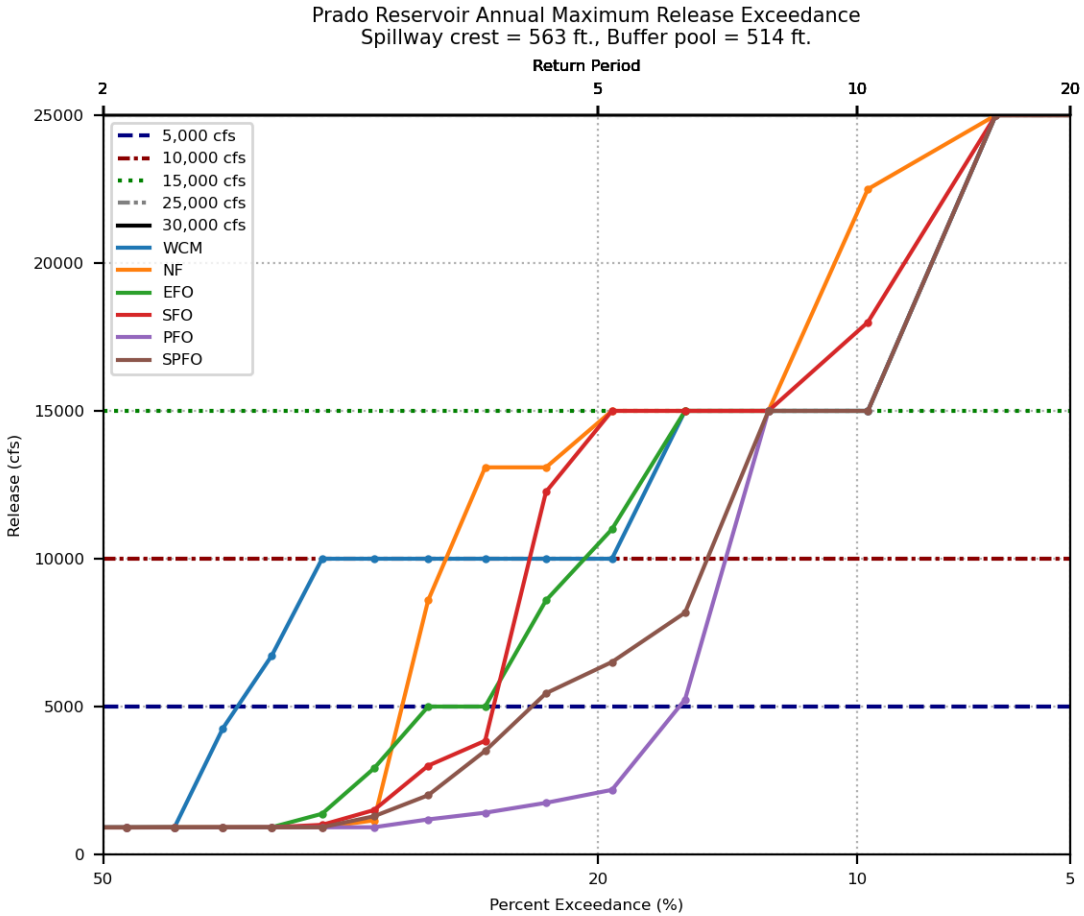

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 514 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)

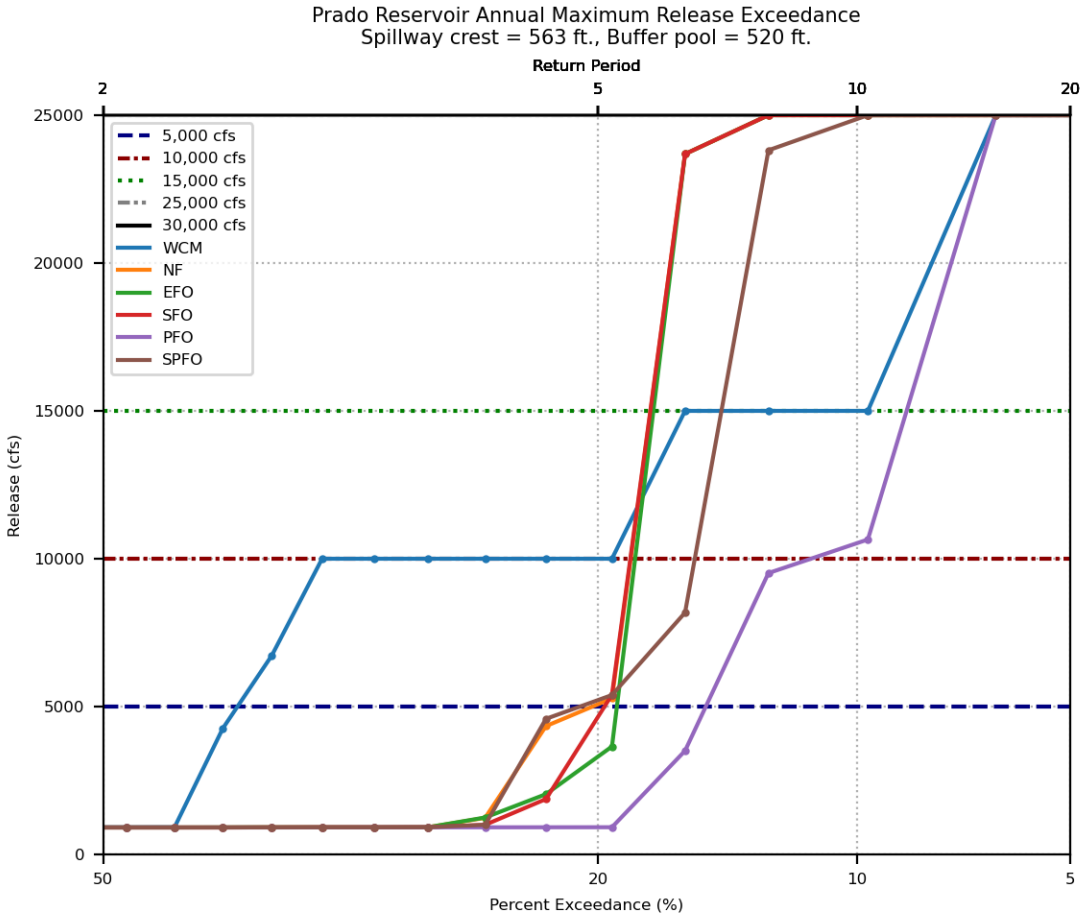

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 520 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 508 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 510 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)

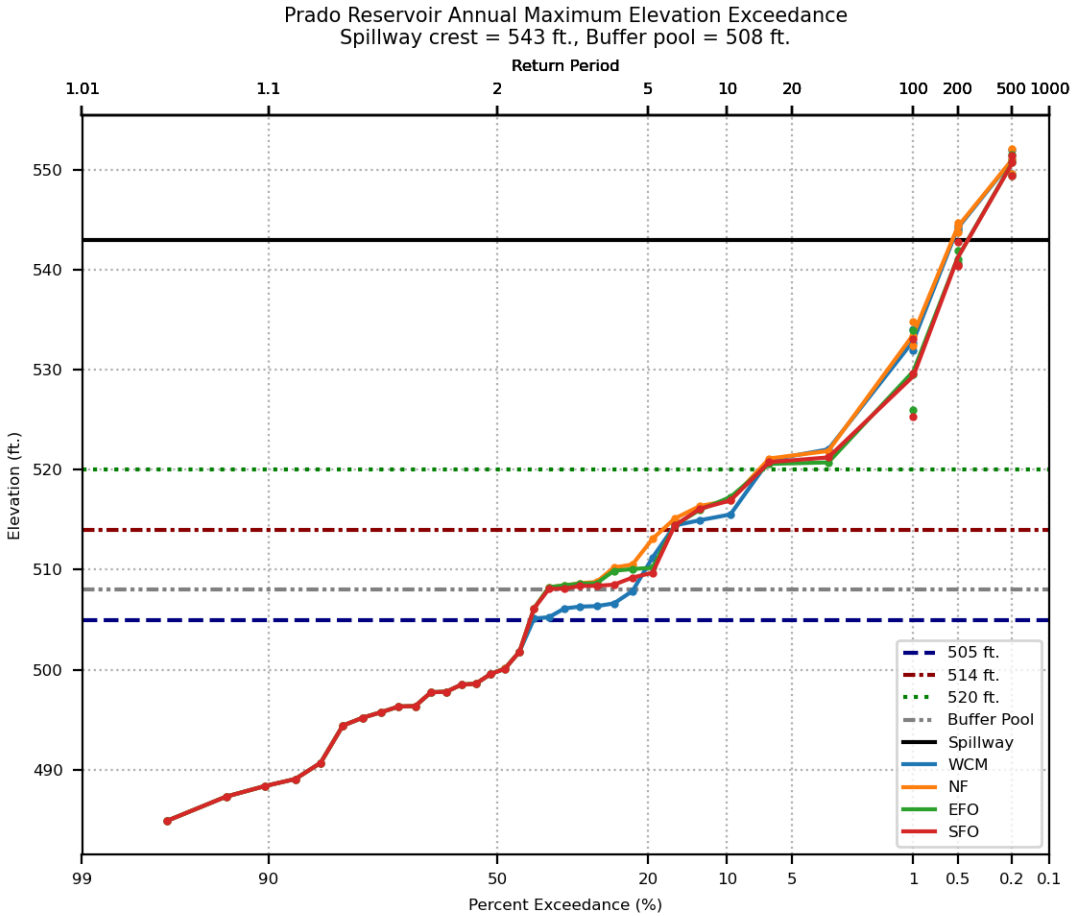

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 512 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)

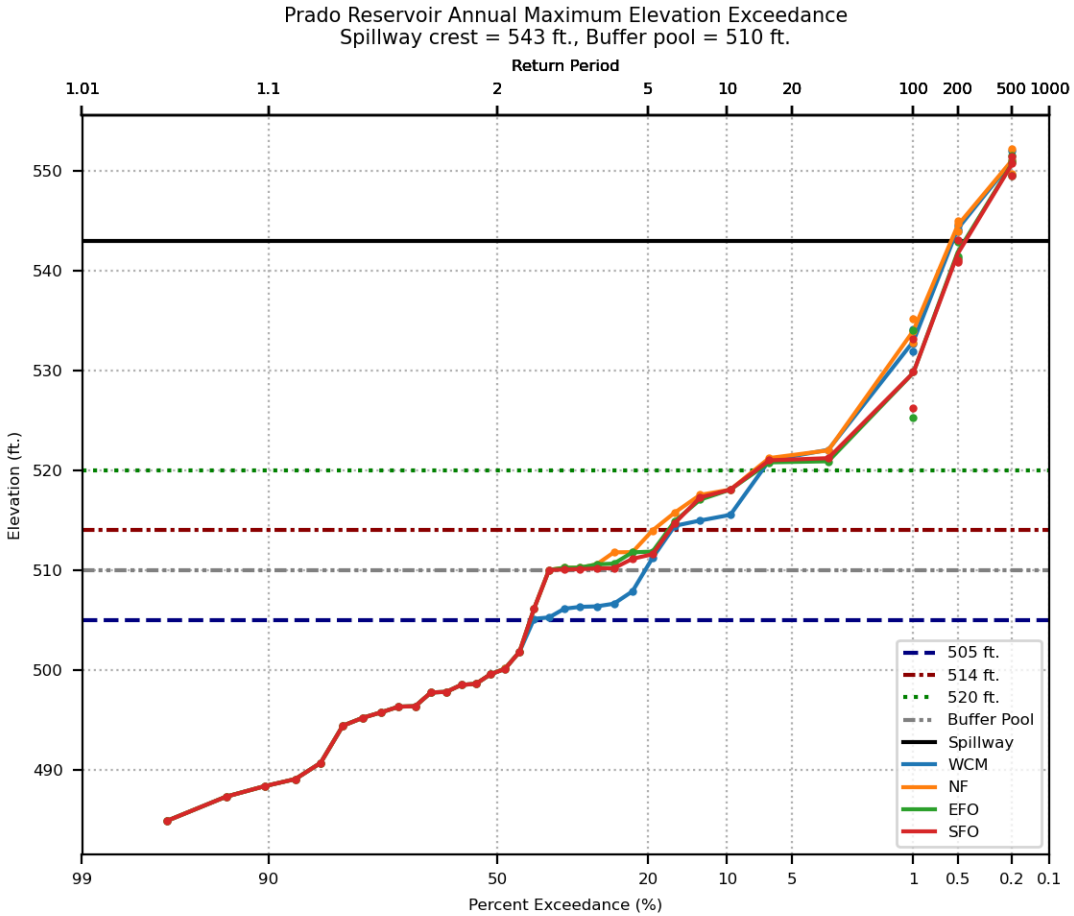

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 514 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)

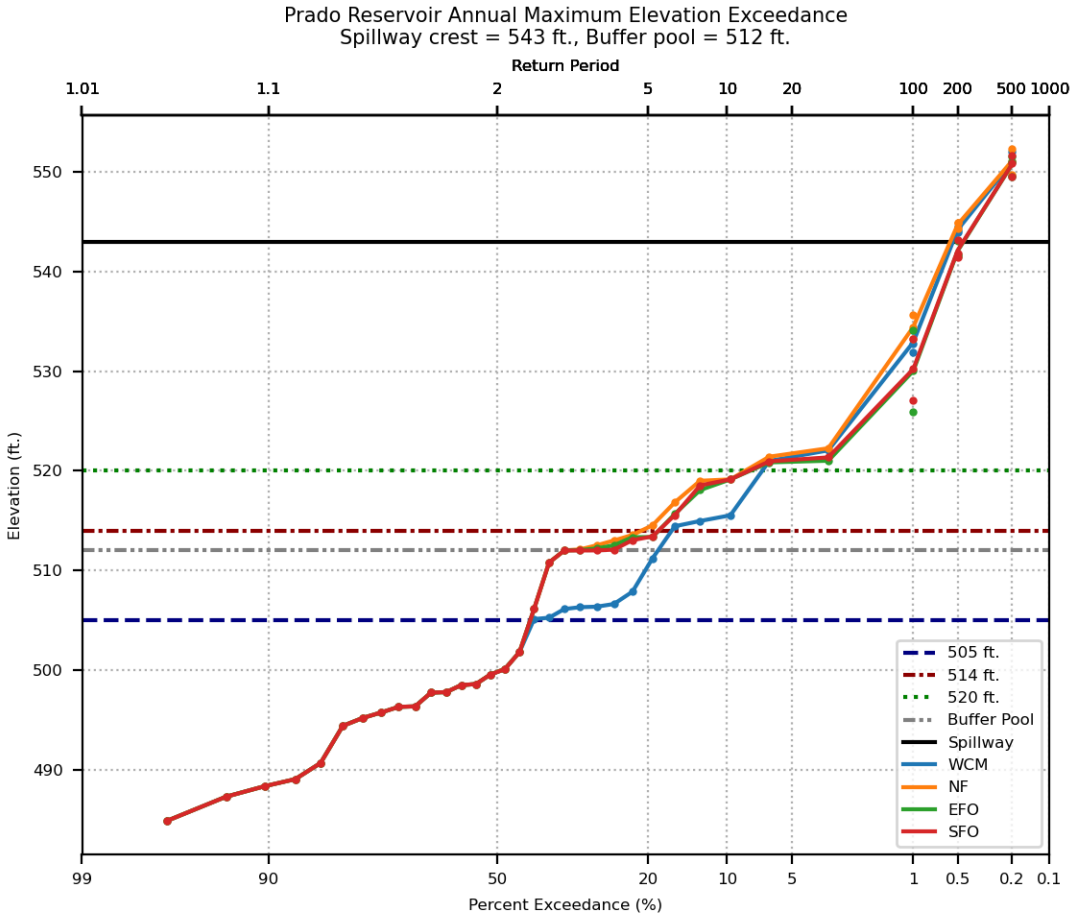

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 520 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)

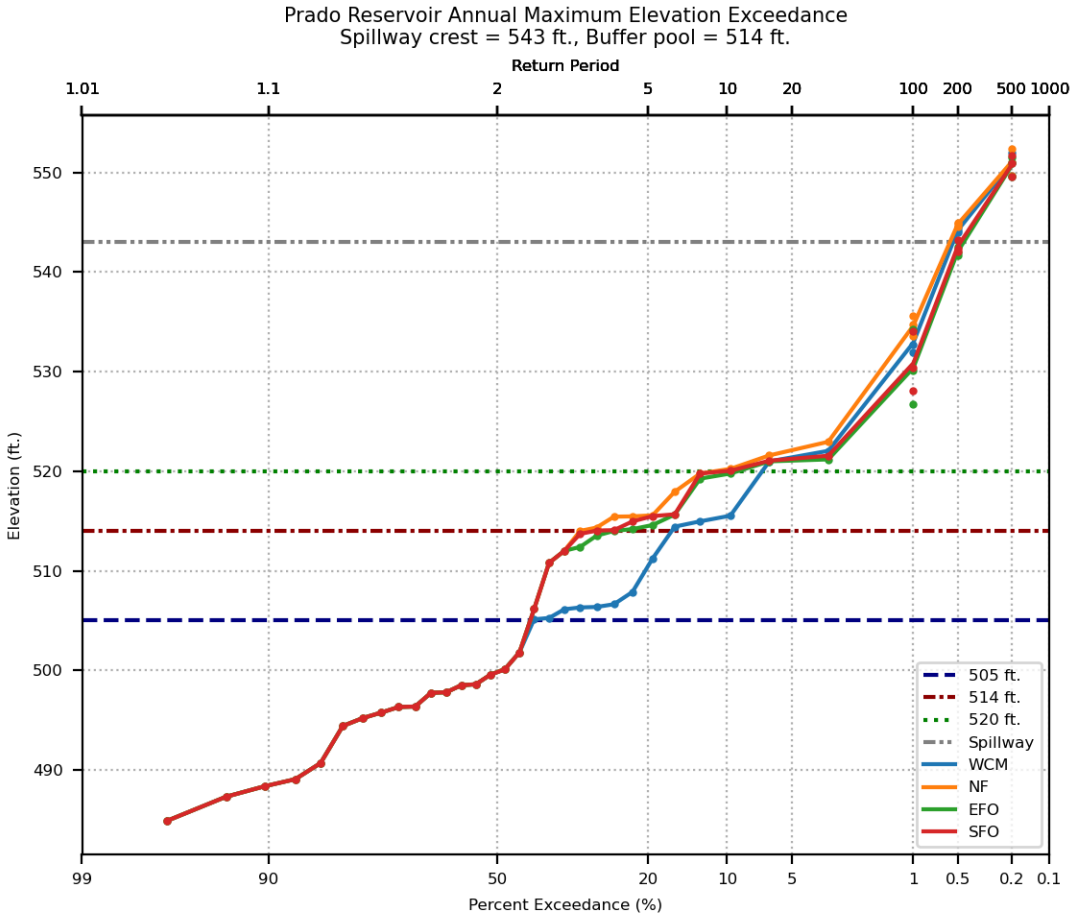
Frequency of Annual Maximum Pool Elevation *by Buffer Pool (NP)*

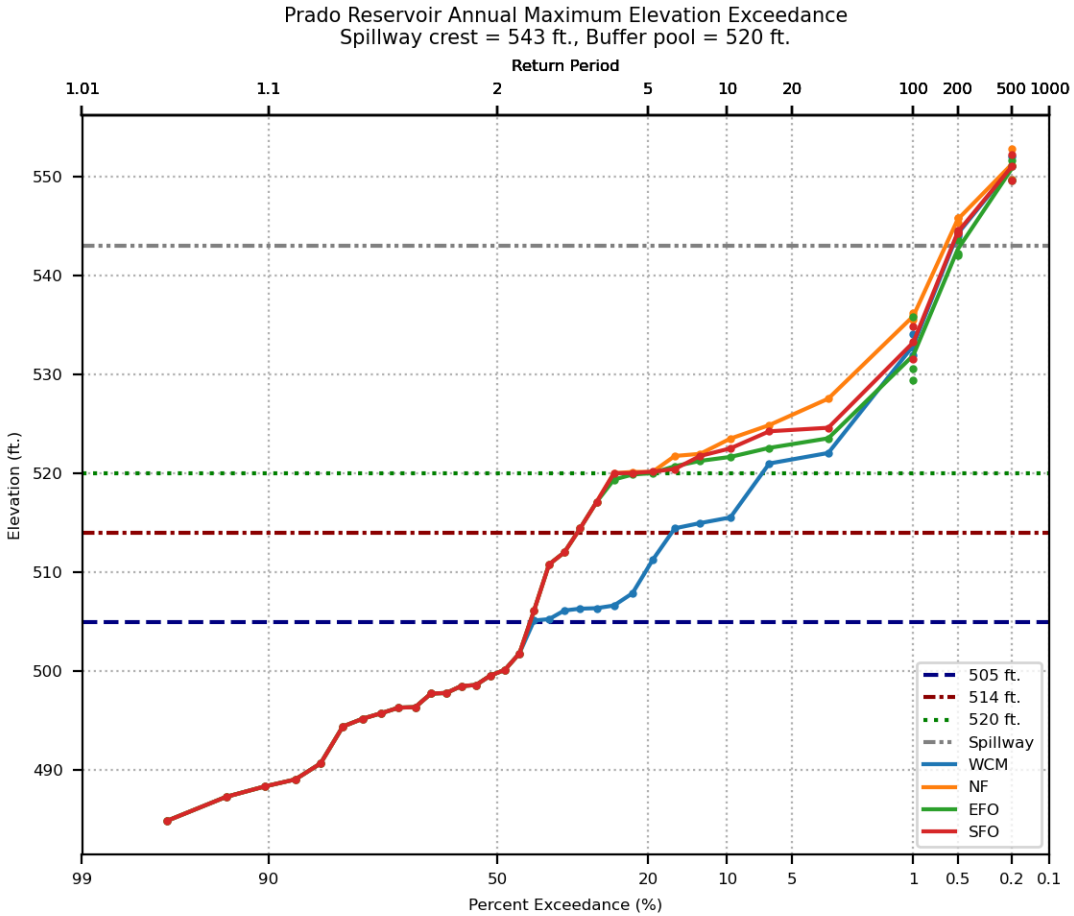
- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’
  - 510’
  - 512’
  - 514’
  - 520’
- WCP alternatives in legend
  - No perfect forecast results

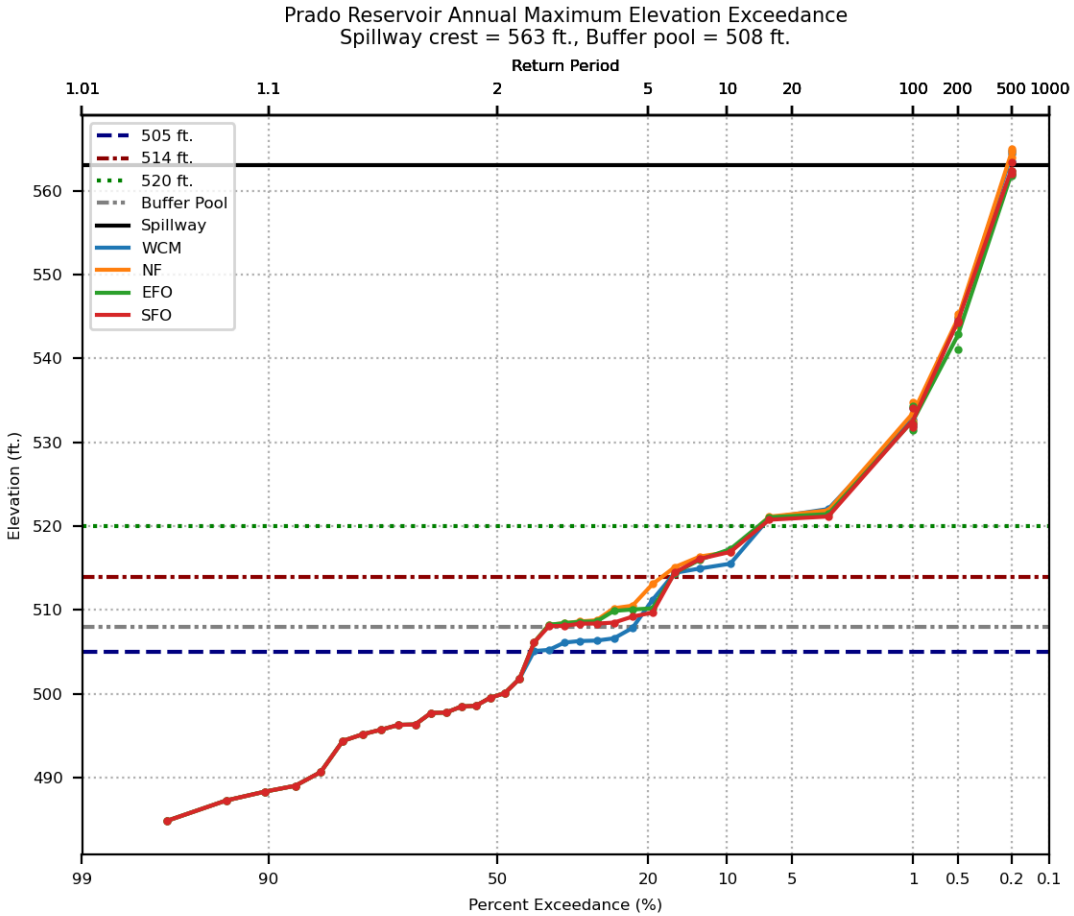

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 508 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO

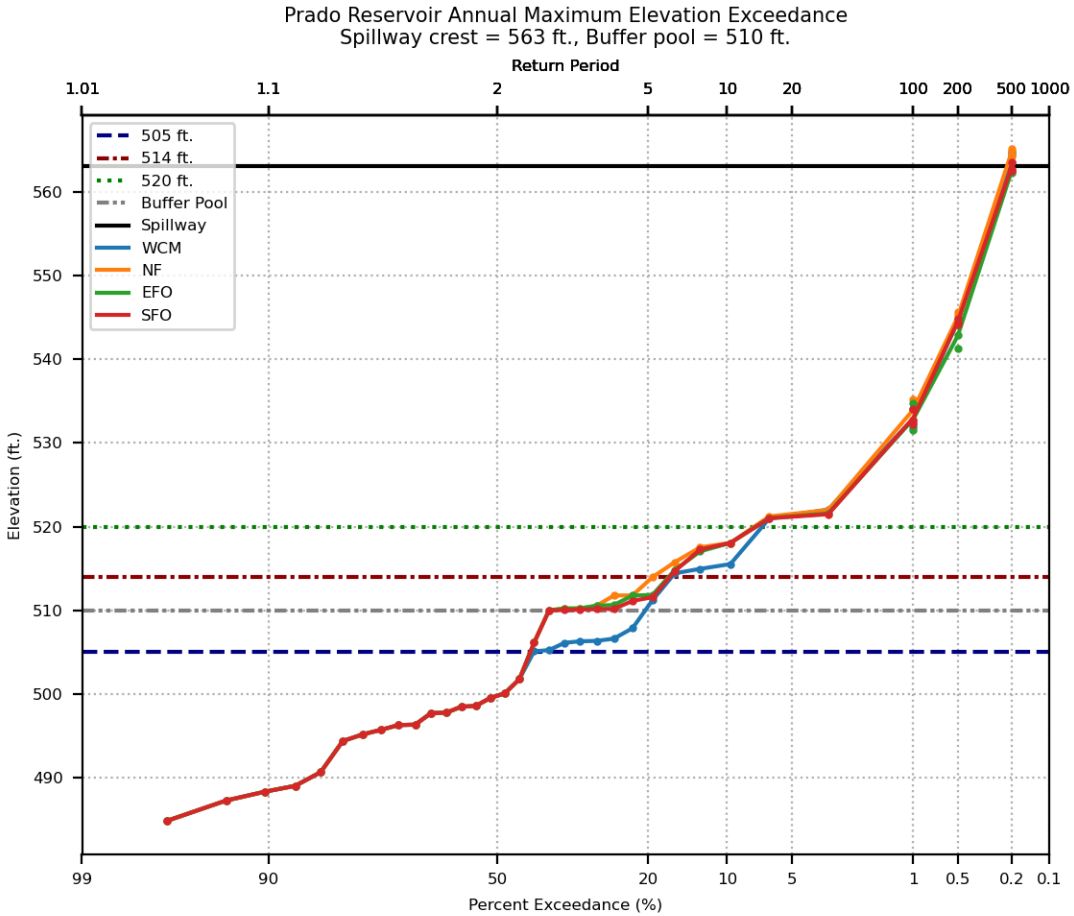

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 510 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO

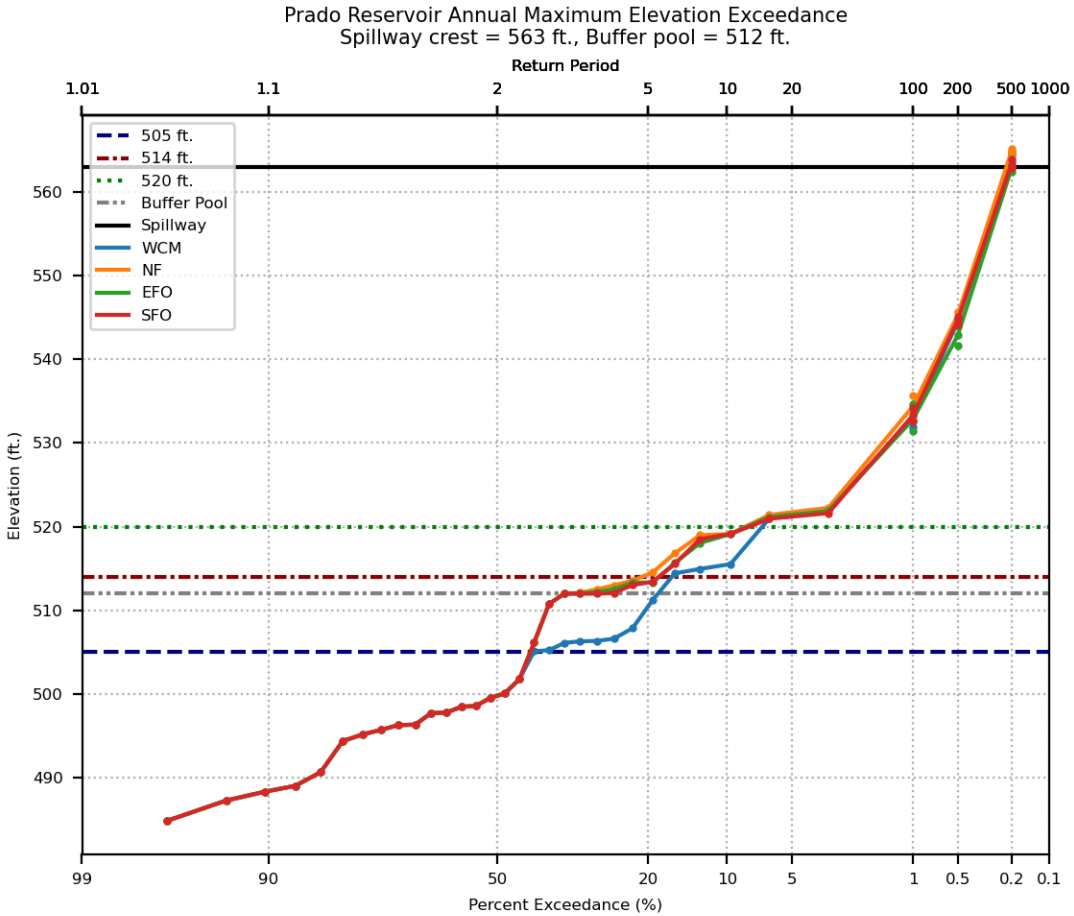

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 512 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO

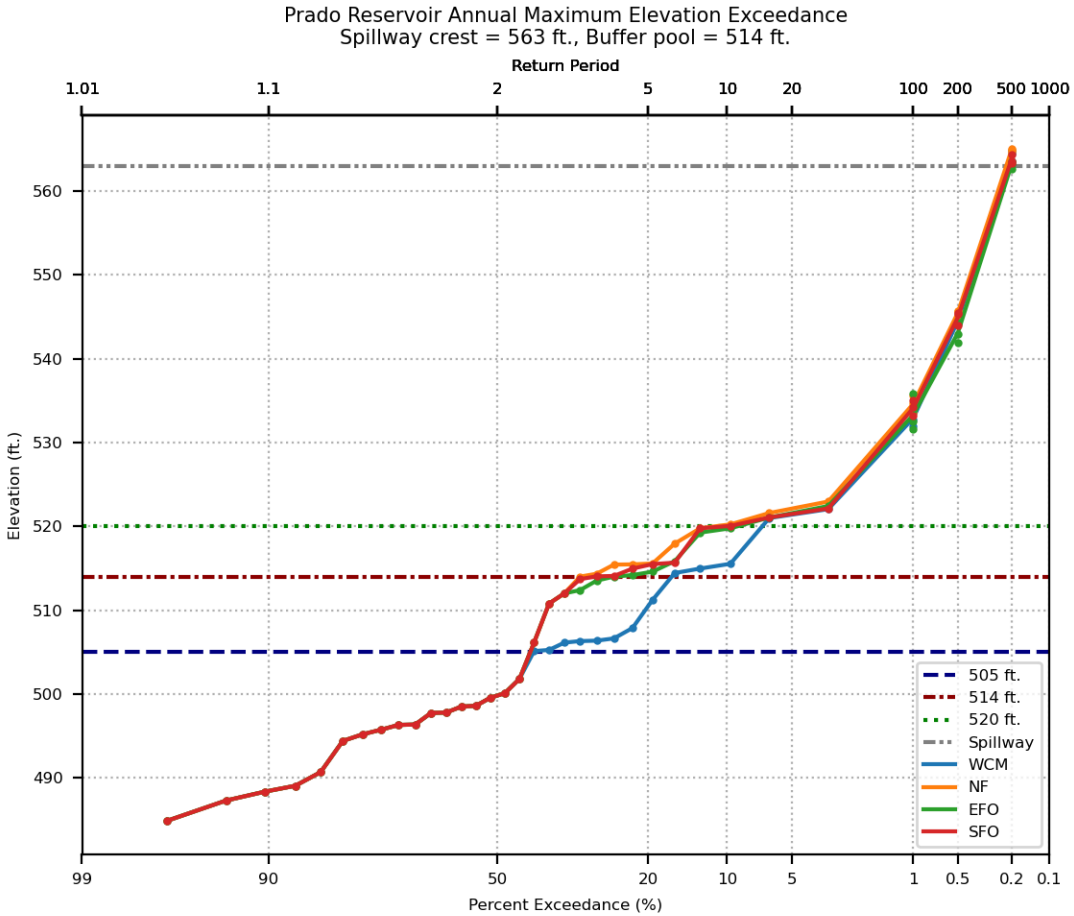

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 514 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
Elevation (ft.)
550
540
530
520
510
500
490
Percent Exceedance (%)
99
90
50
20
10
5
1
0.5
0.2
0.1
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO

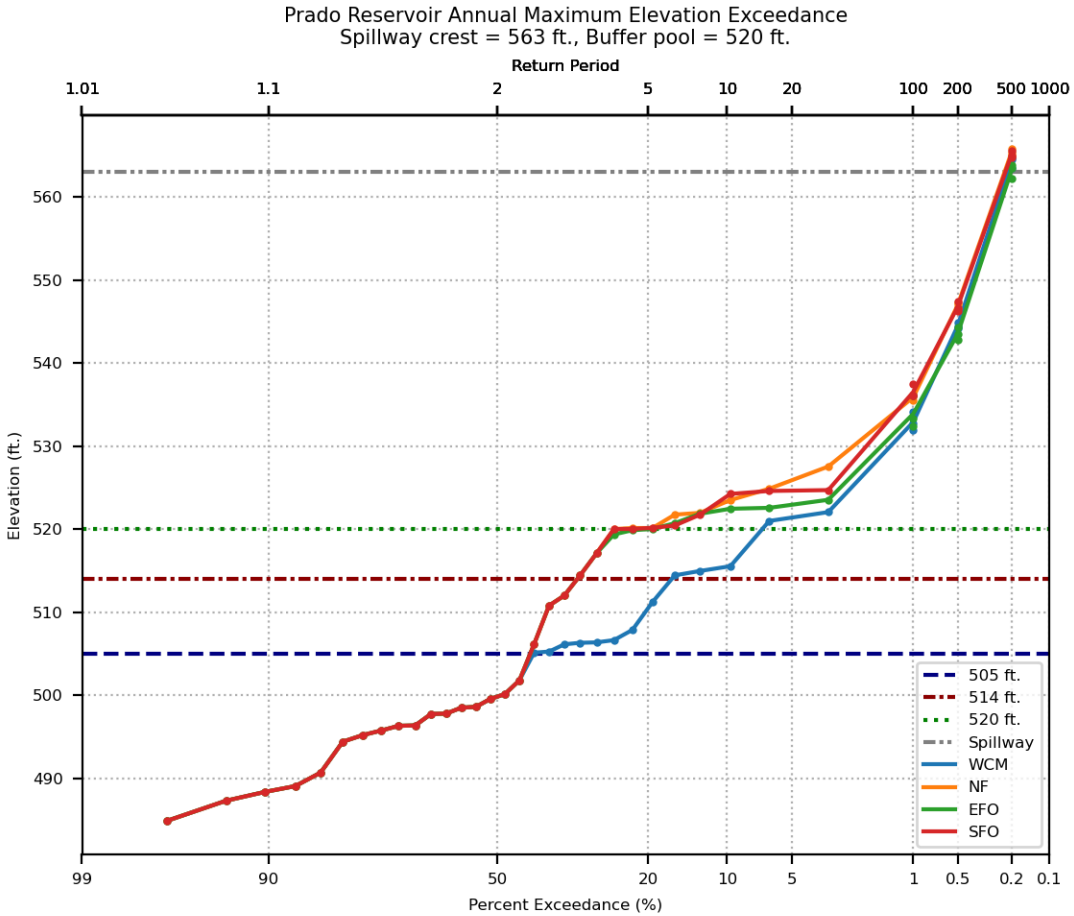

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 520 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
Elevation (ft.)
550
540
530
520
510
500
490
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO

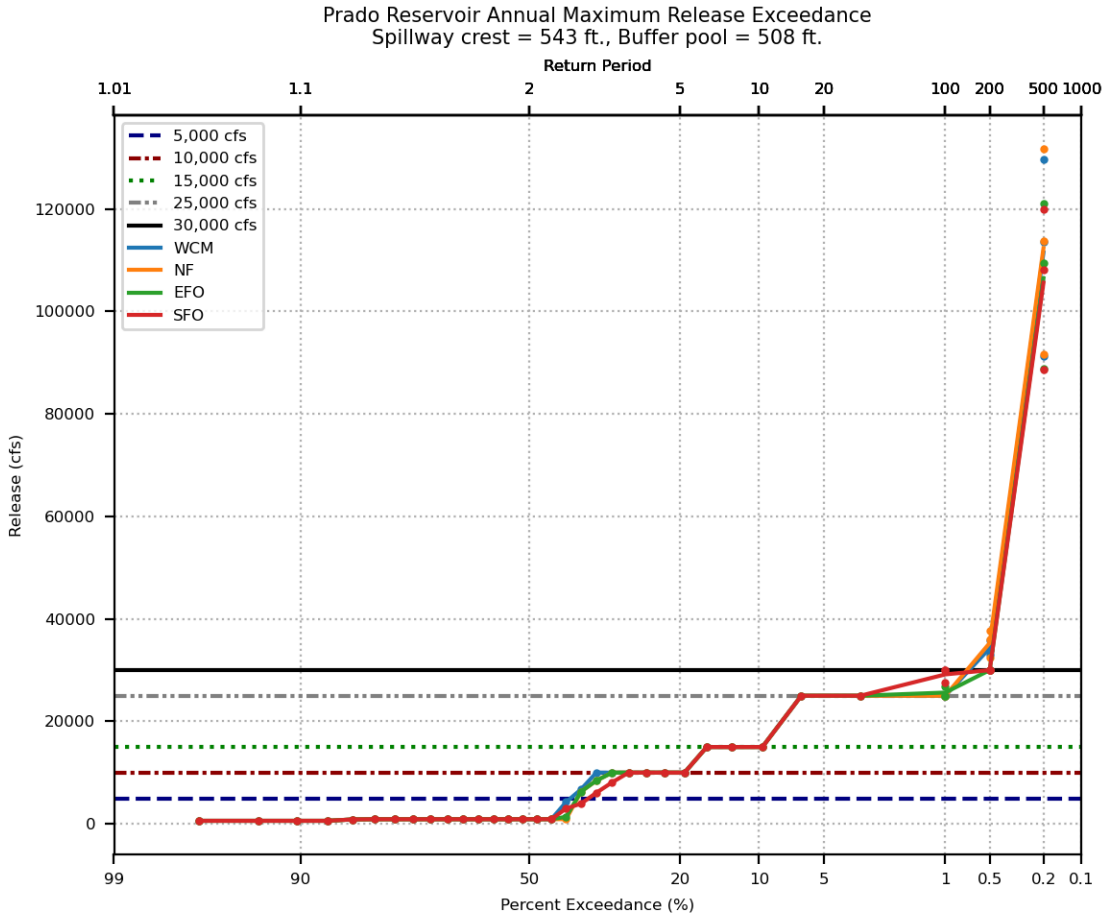

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 508 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO
560
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

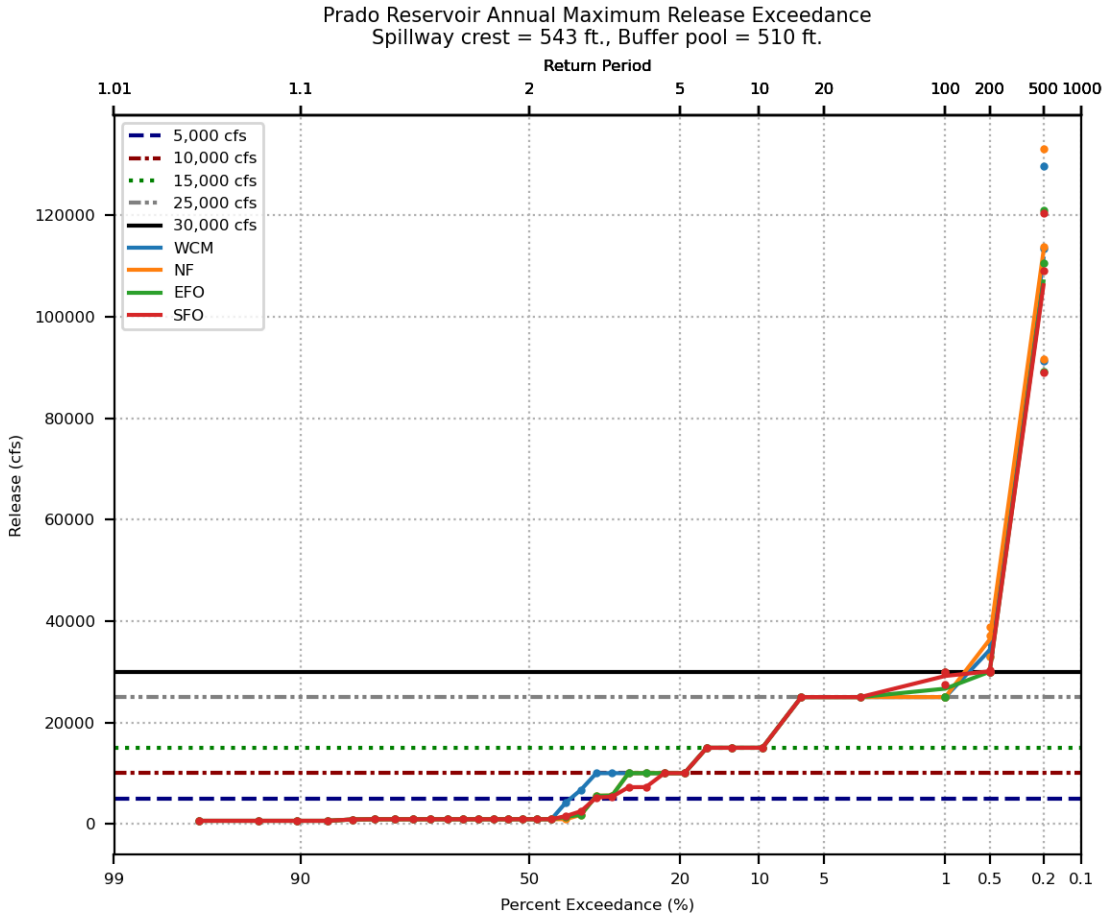

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 510 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO
560
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

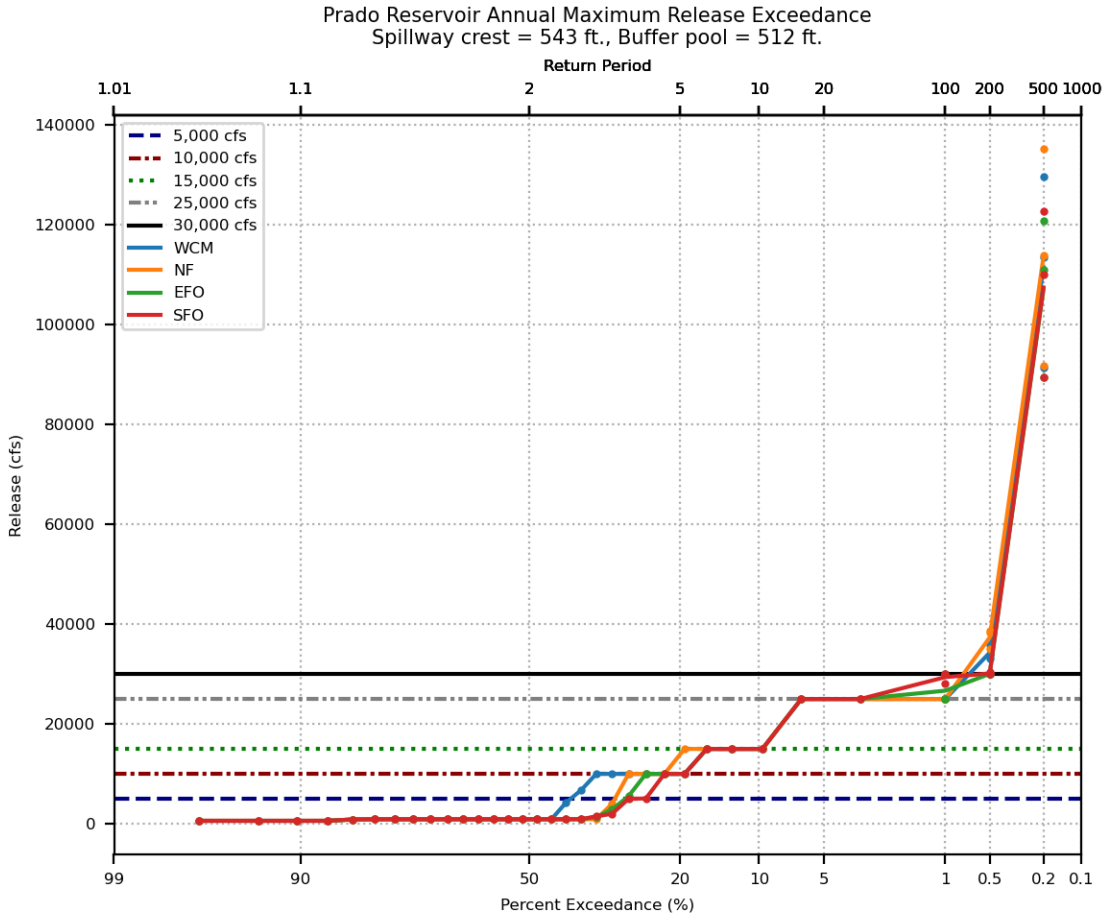

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 512 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO
560
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

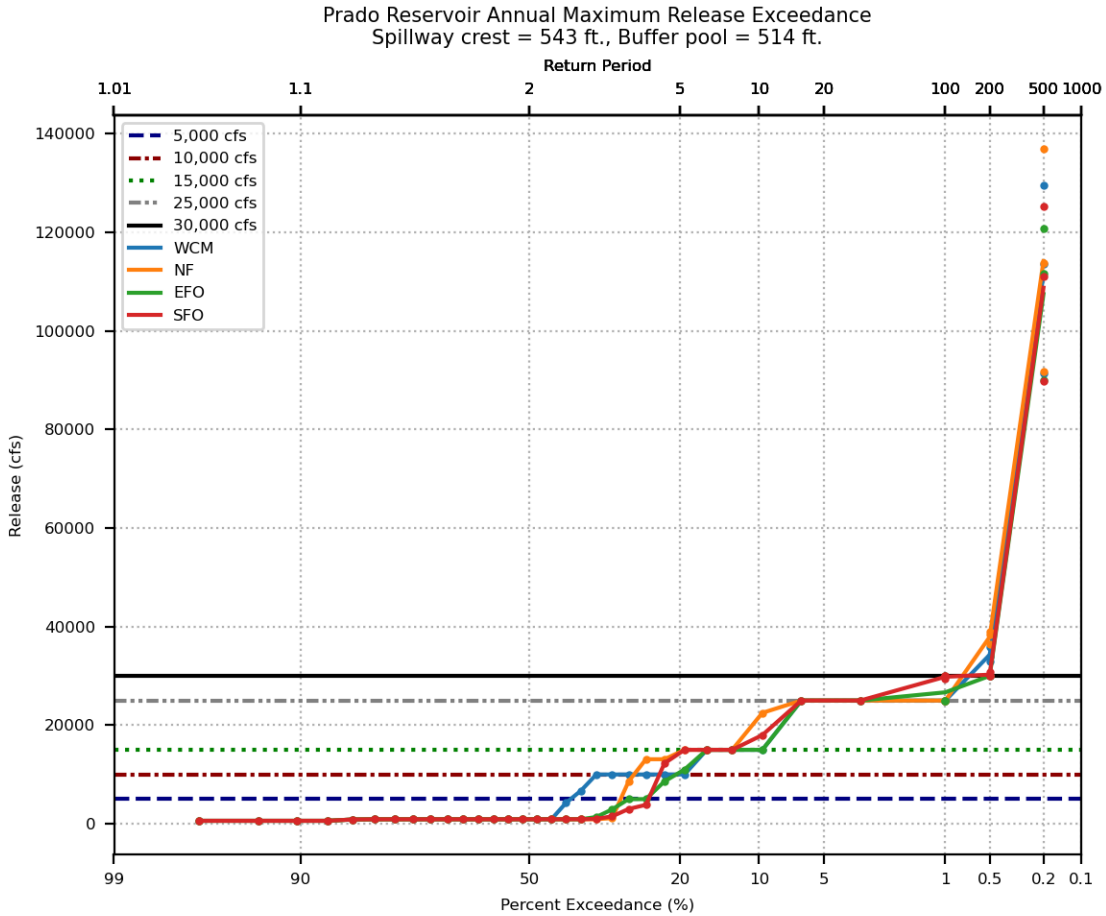

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 514 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
Elevation (ft.)
560
550
540
530
520
510
500
490
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO

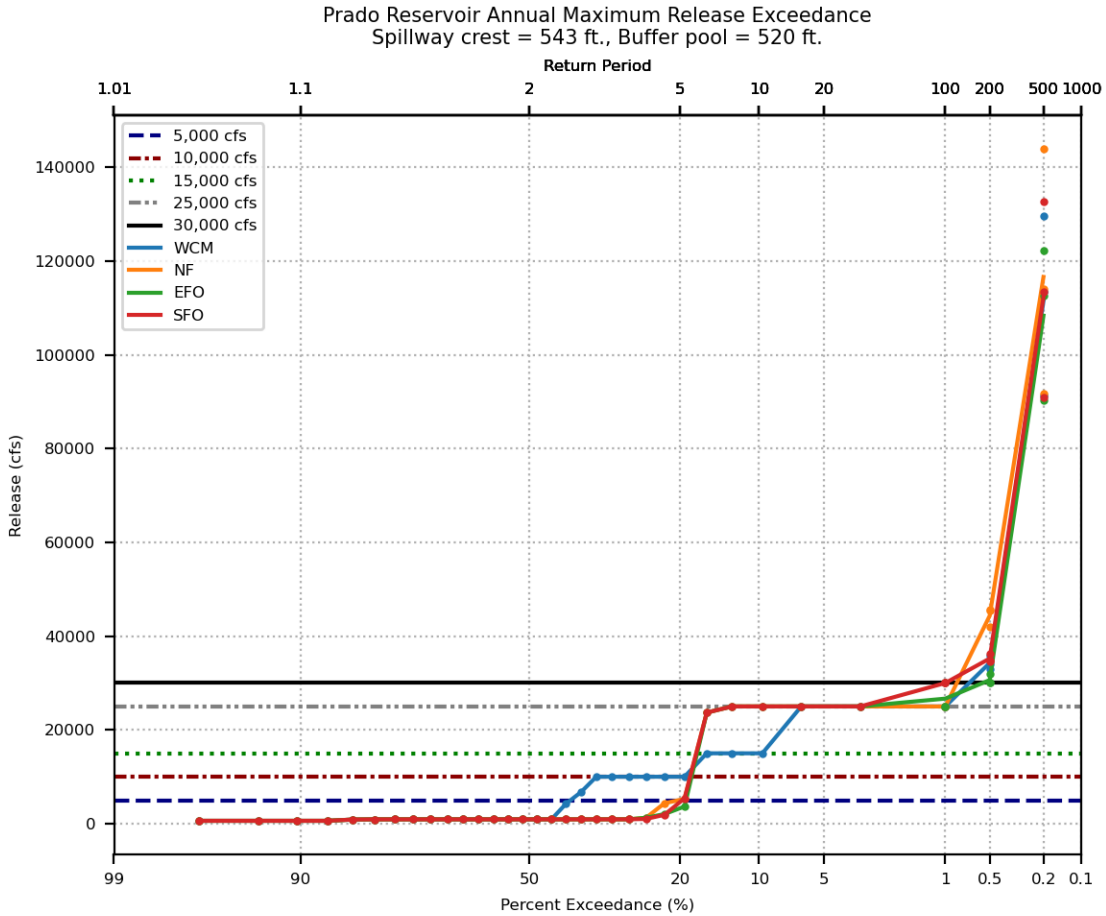

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 520 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
Elevation (ft.)
560
550
540
530
520
510
500
490
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO

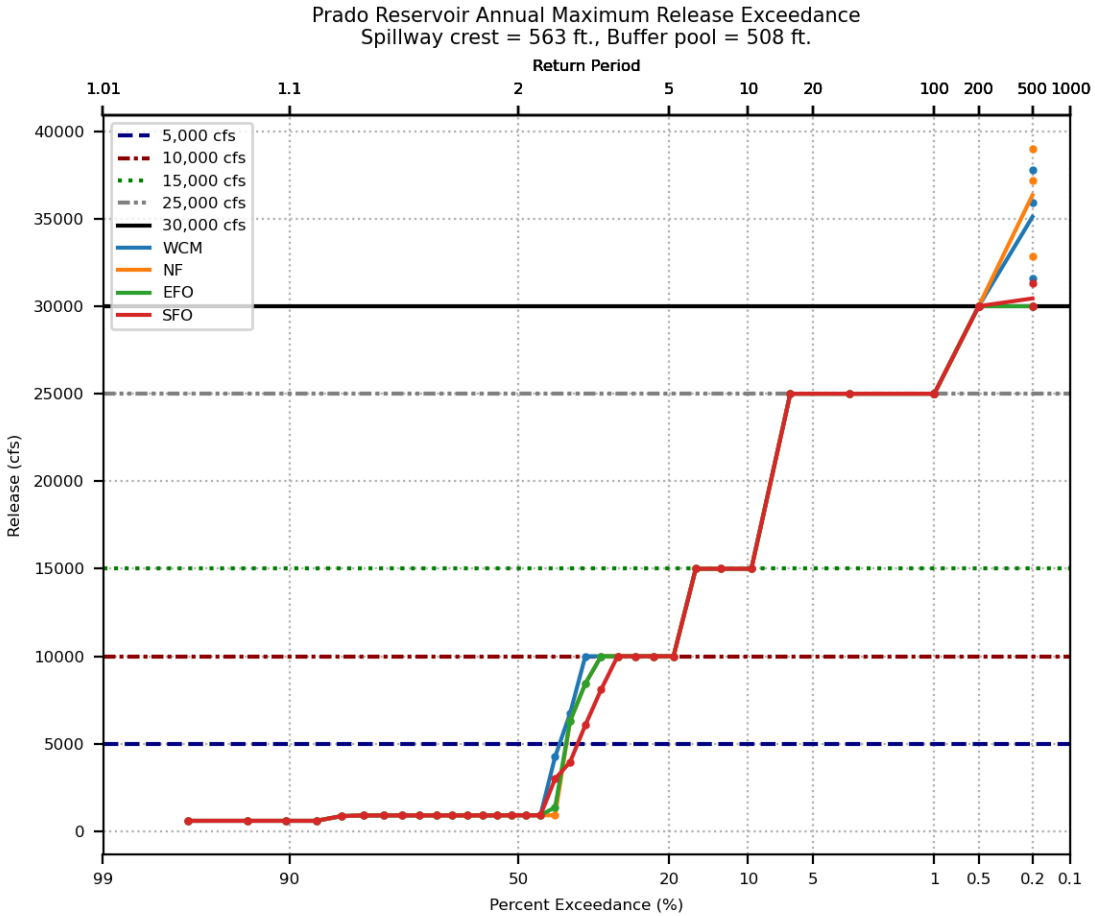

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 508 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
Release (cfs)
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

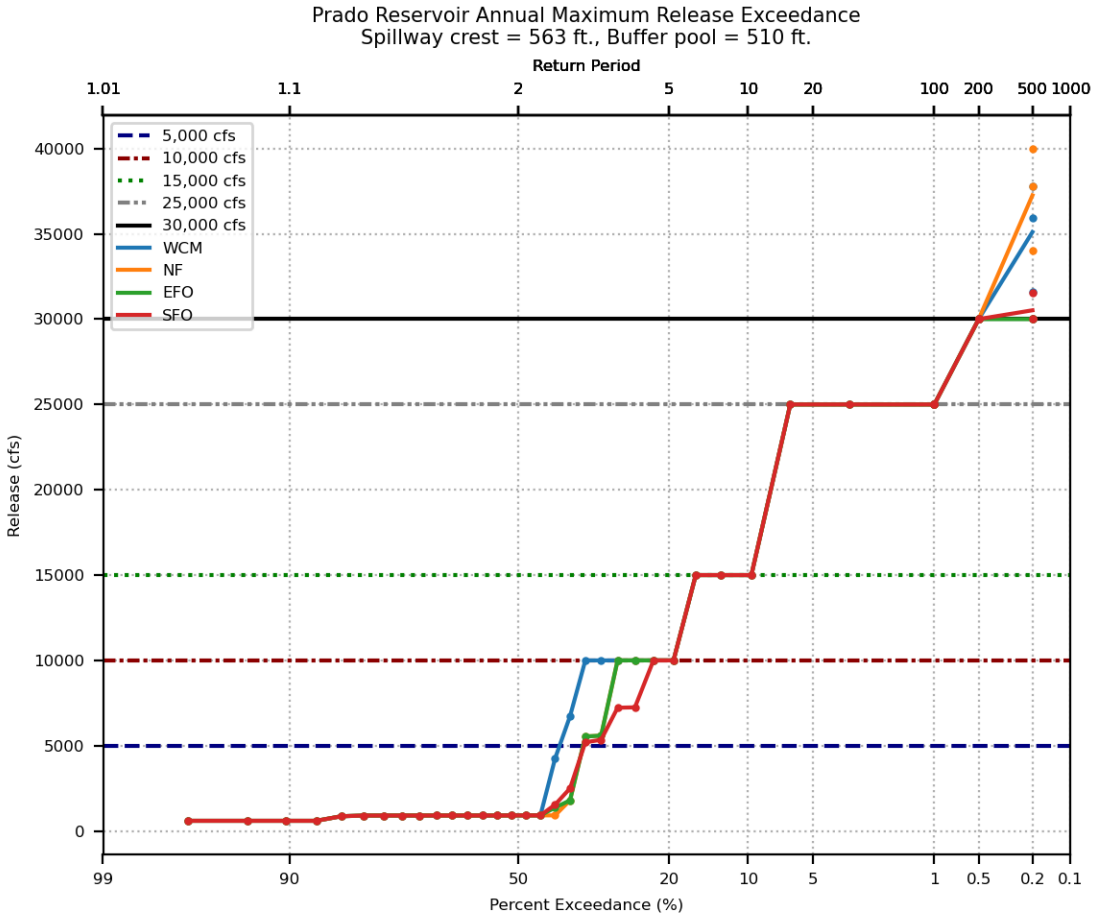

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 510 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
Release (cfs)
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

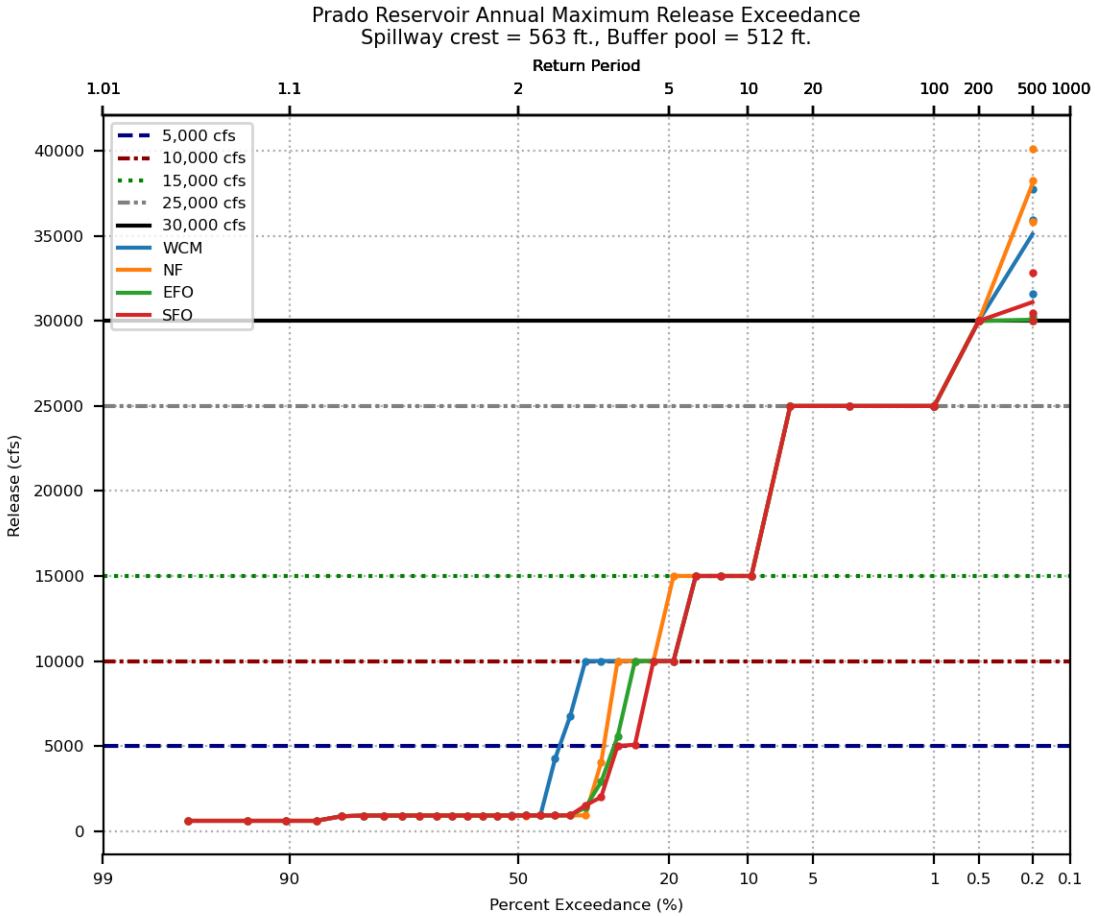

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 512 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
140000
120000
100000
80000
60000
40000
20000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

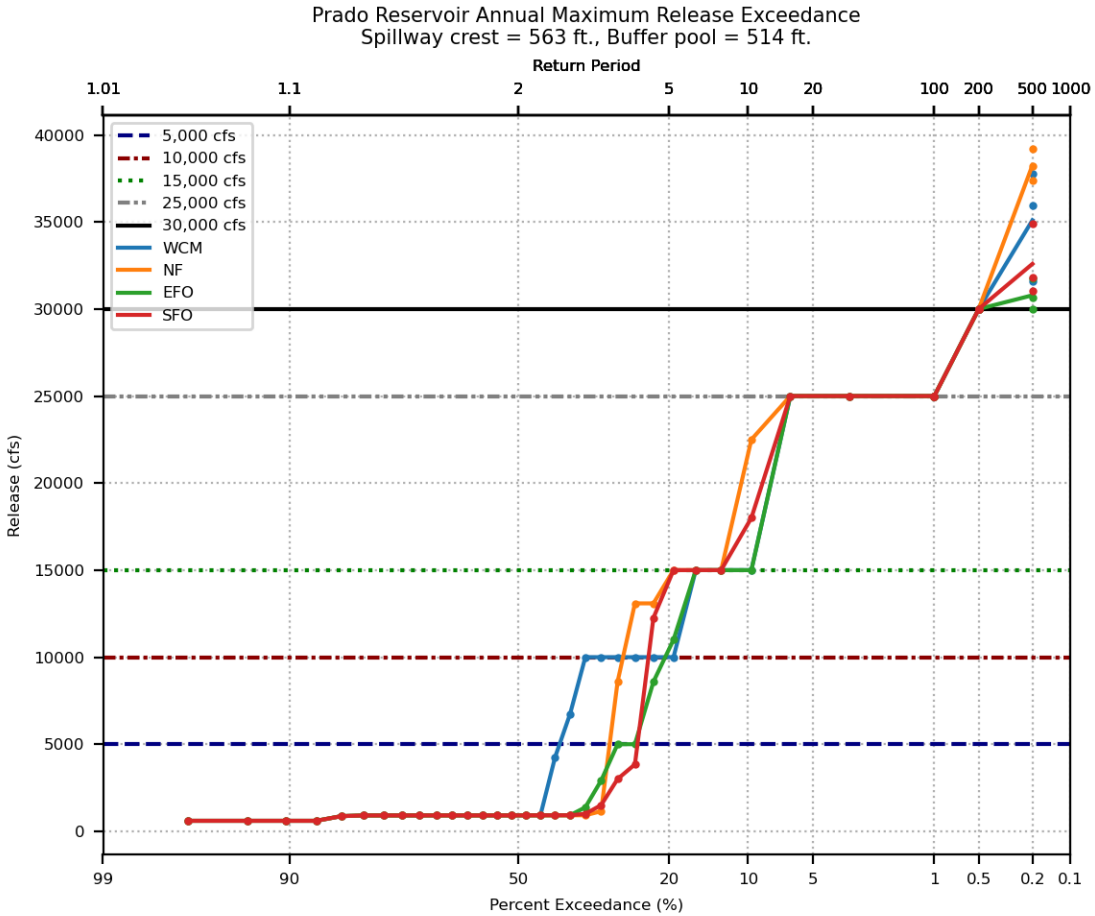

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 514 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
Release (cfs)
140000
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

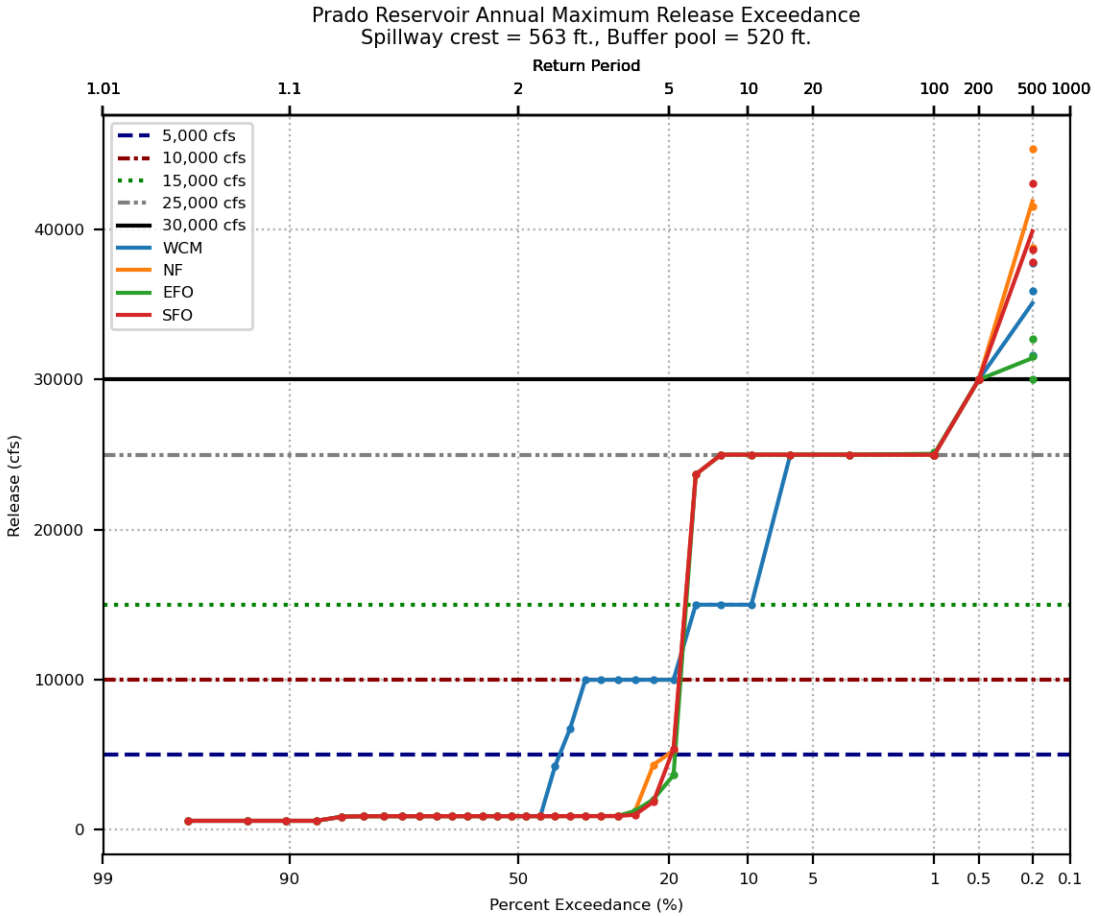

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 520 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
Release (cfs)
140000
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 508 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
Release (cfs)
40000
35000
30000
25000
20000
15000
10000
5000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 510 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
Release (cfs)
40000
35000
30000
25000
20000
15000
10000
5000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

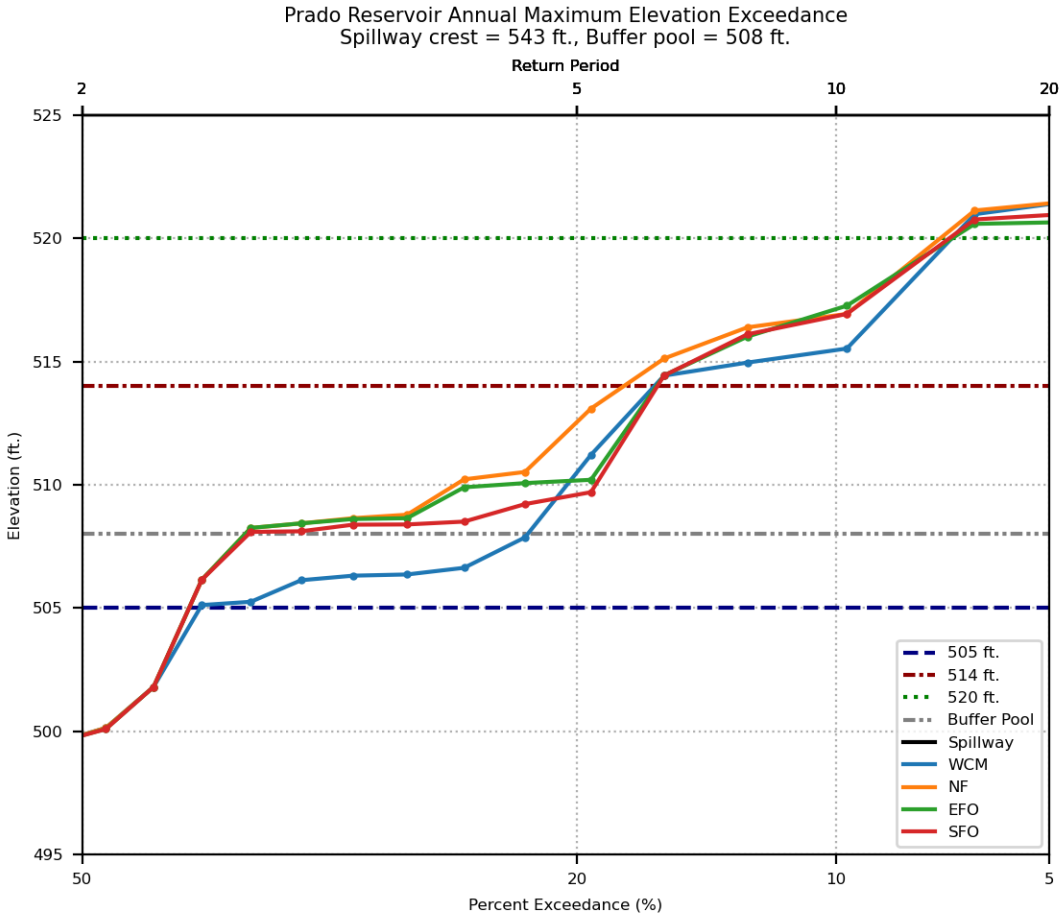

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 512 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
Release (cfs)
40000
35000
30000
25000
20000
15000
10000
5000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

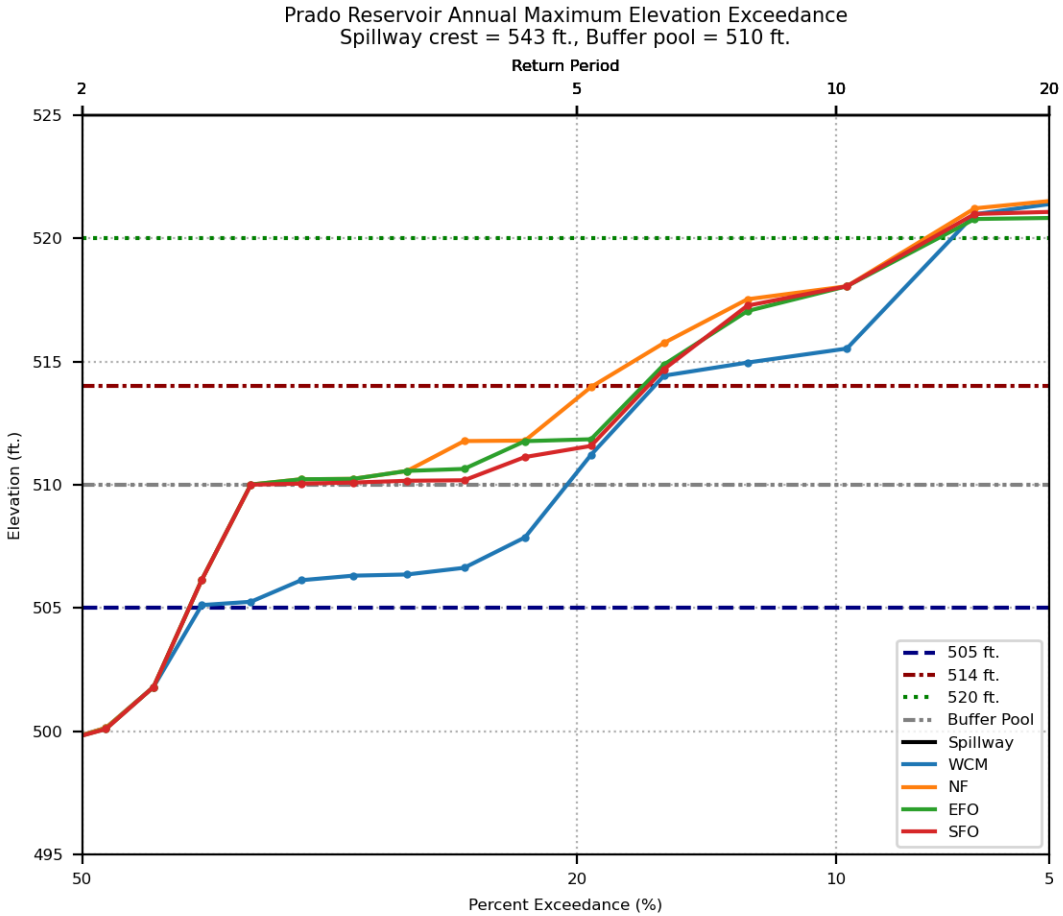

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 514 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
Release (cfs)
40000
35000
30000
25000
20000
15000
10000
5000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

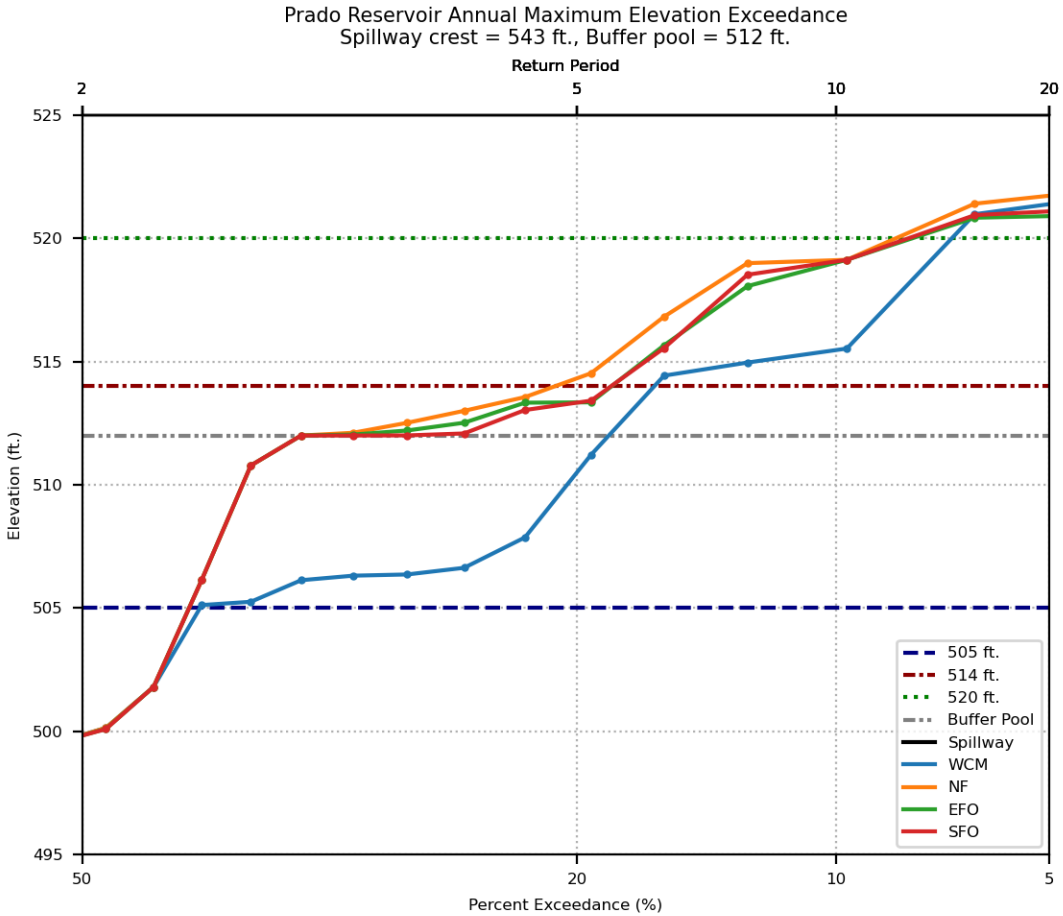

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 520 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
40000
30000
20000
10000
0
Release (cfs)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

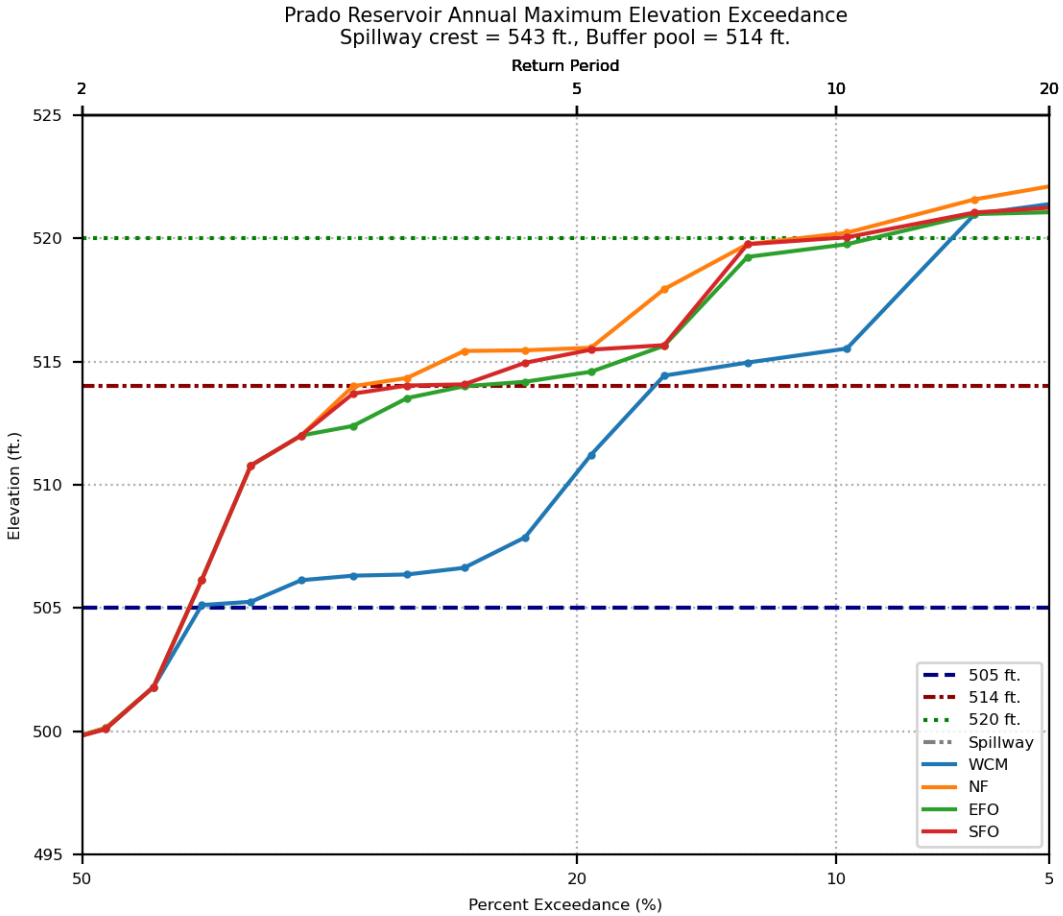
Frequency of Annual Maximum Pool Elevation *by Buffer Pool (NP)* – Zoomed

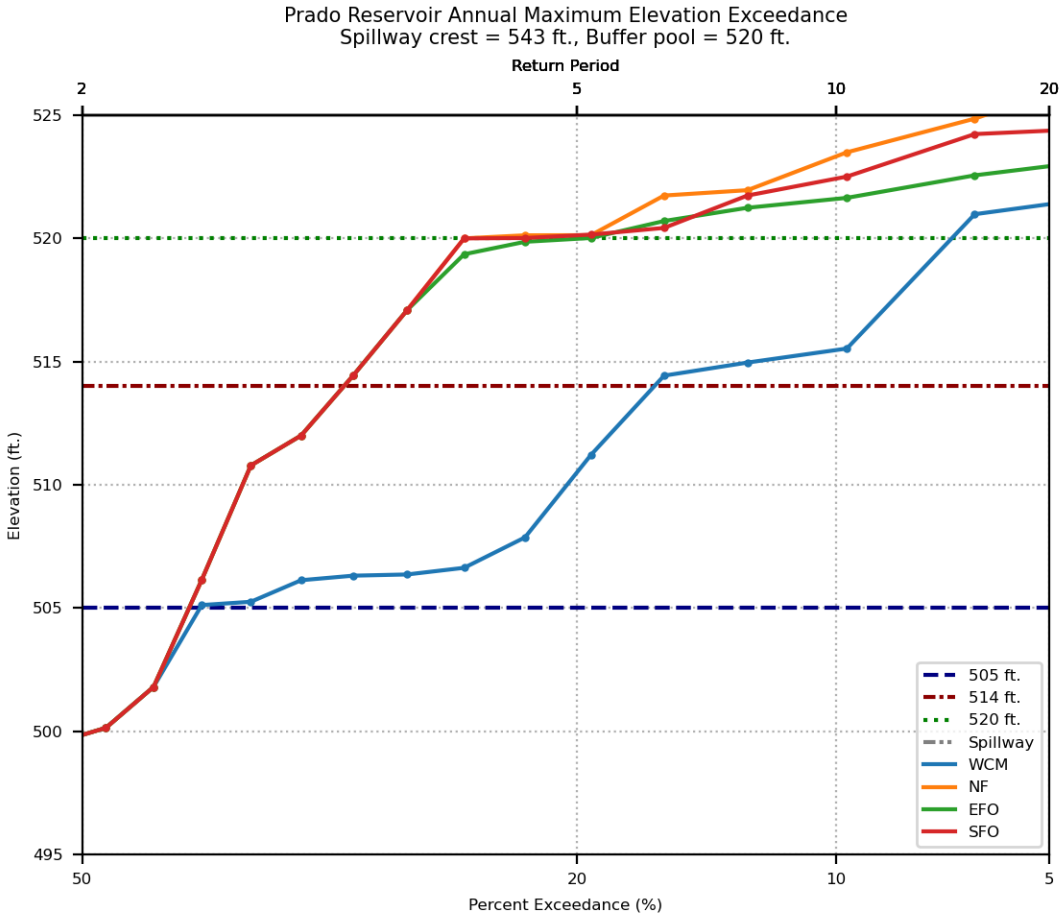
- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’
  - 510’
  - 512’
  - 514’
  - 520’
- WCP alternatives in legend
  - No perfect forecast results

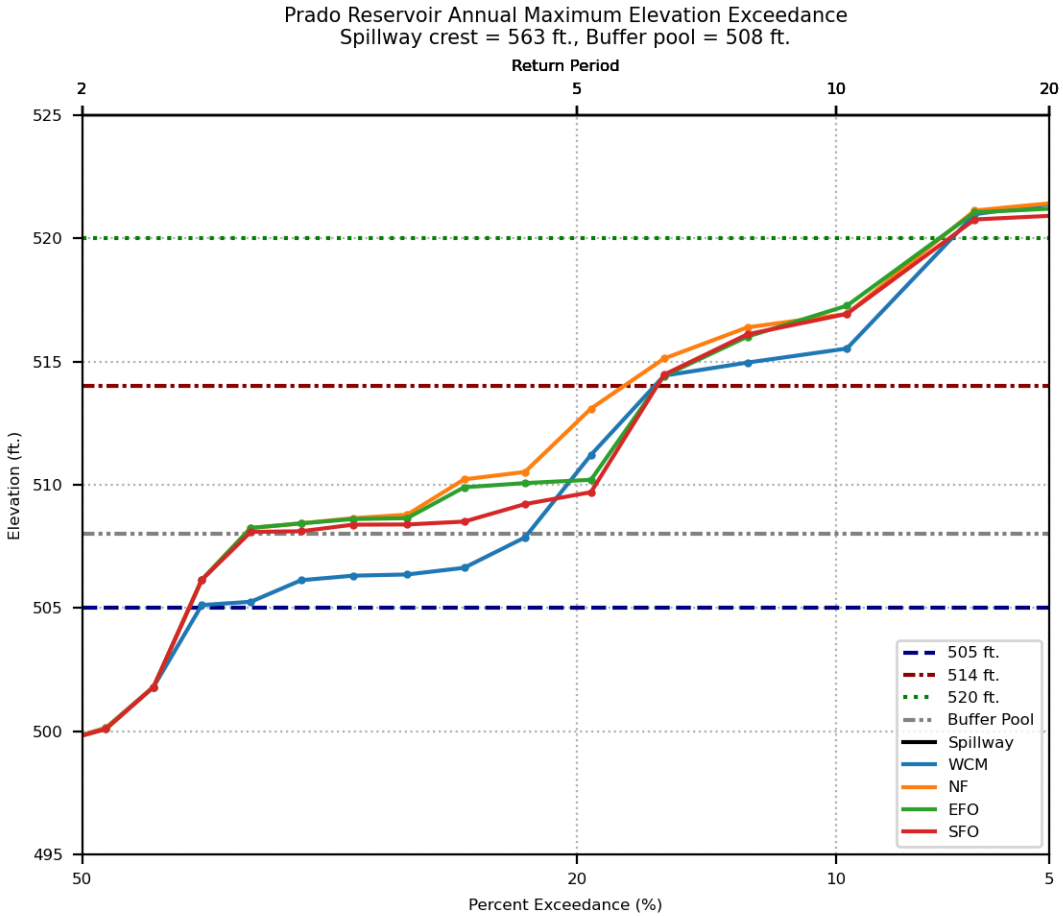

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 508 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO

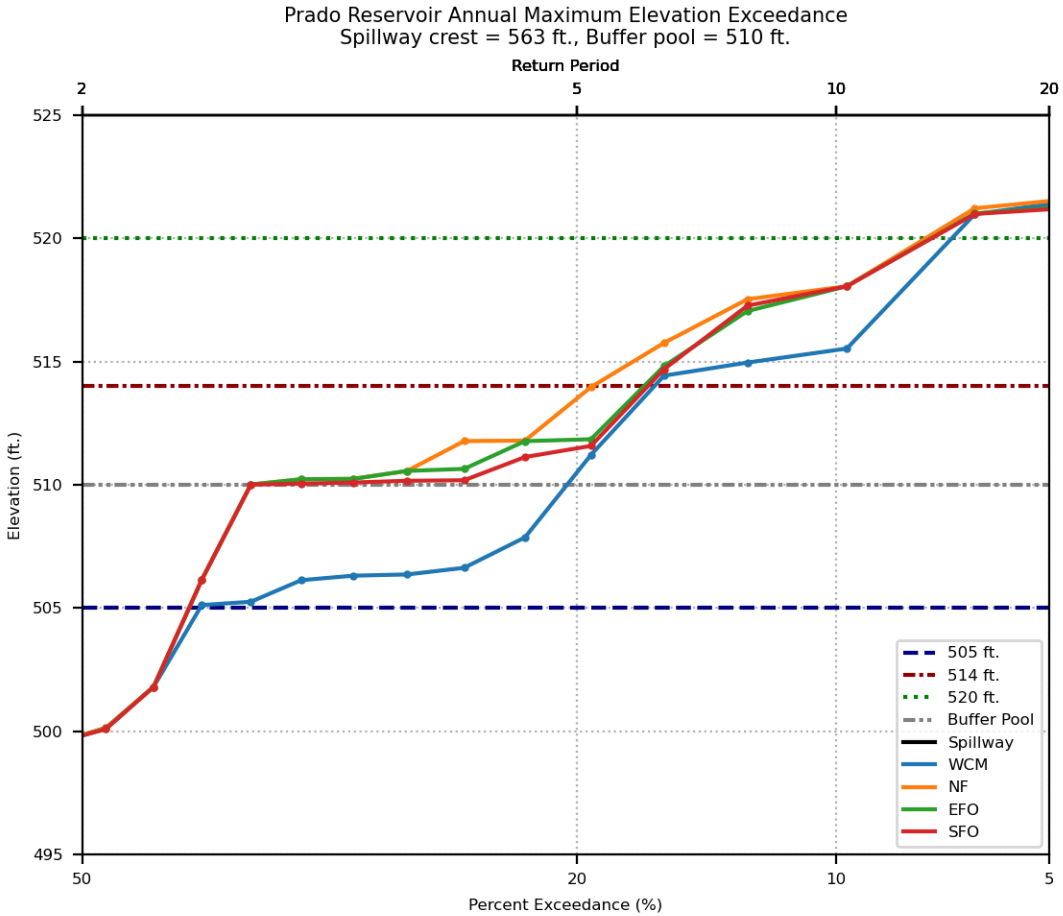

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 510 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO

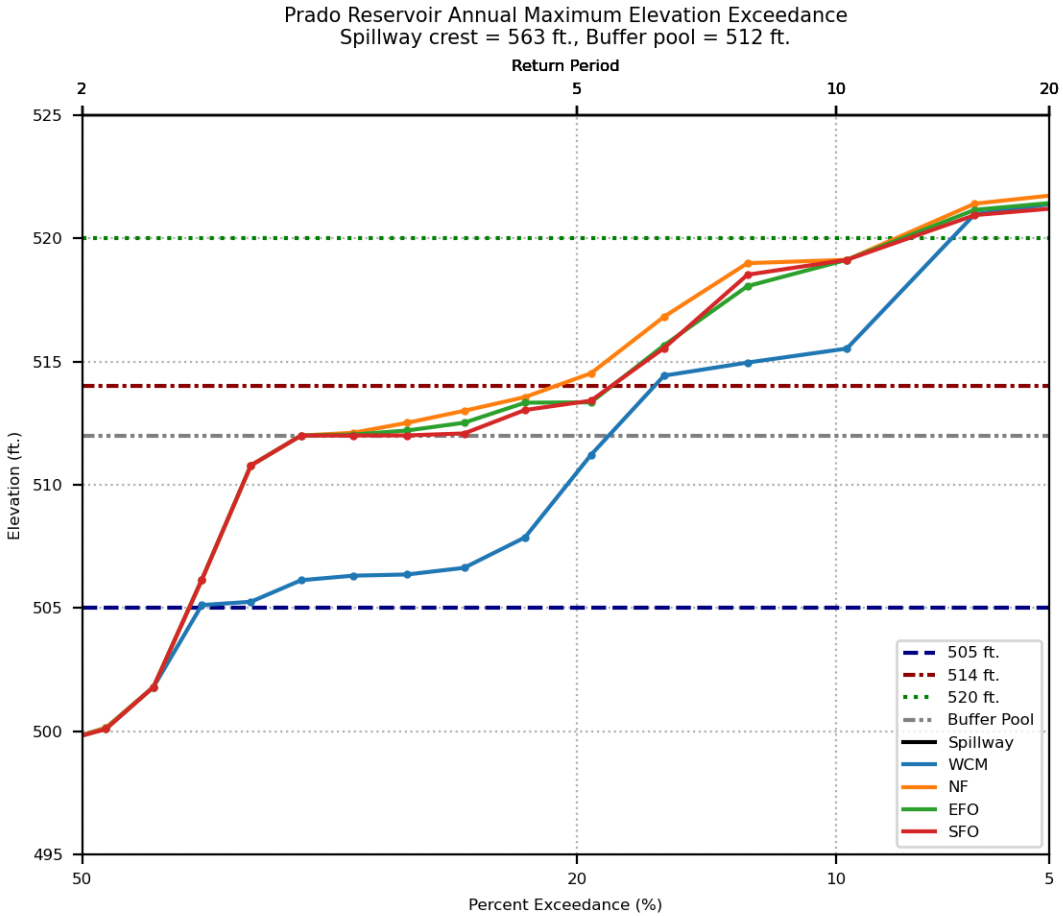

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 512 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO

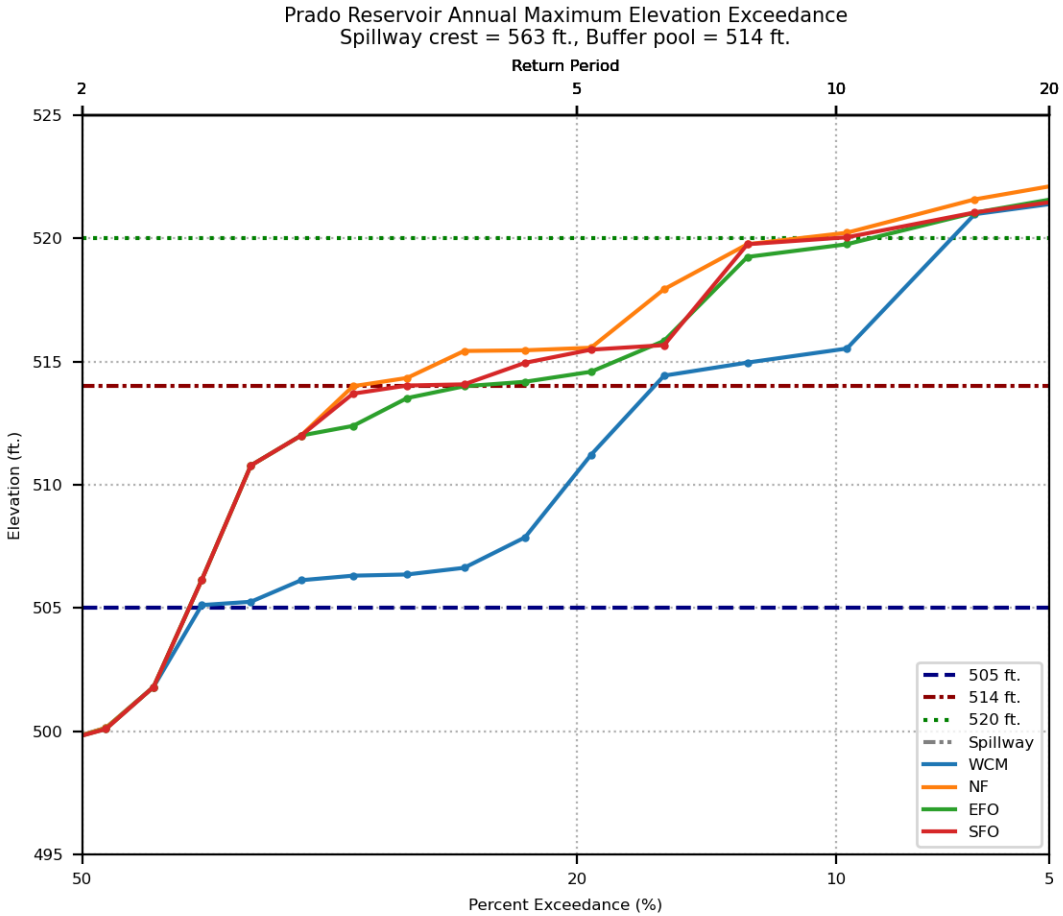

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 514 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO

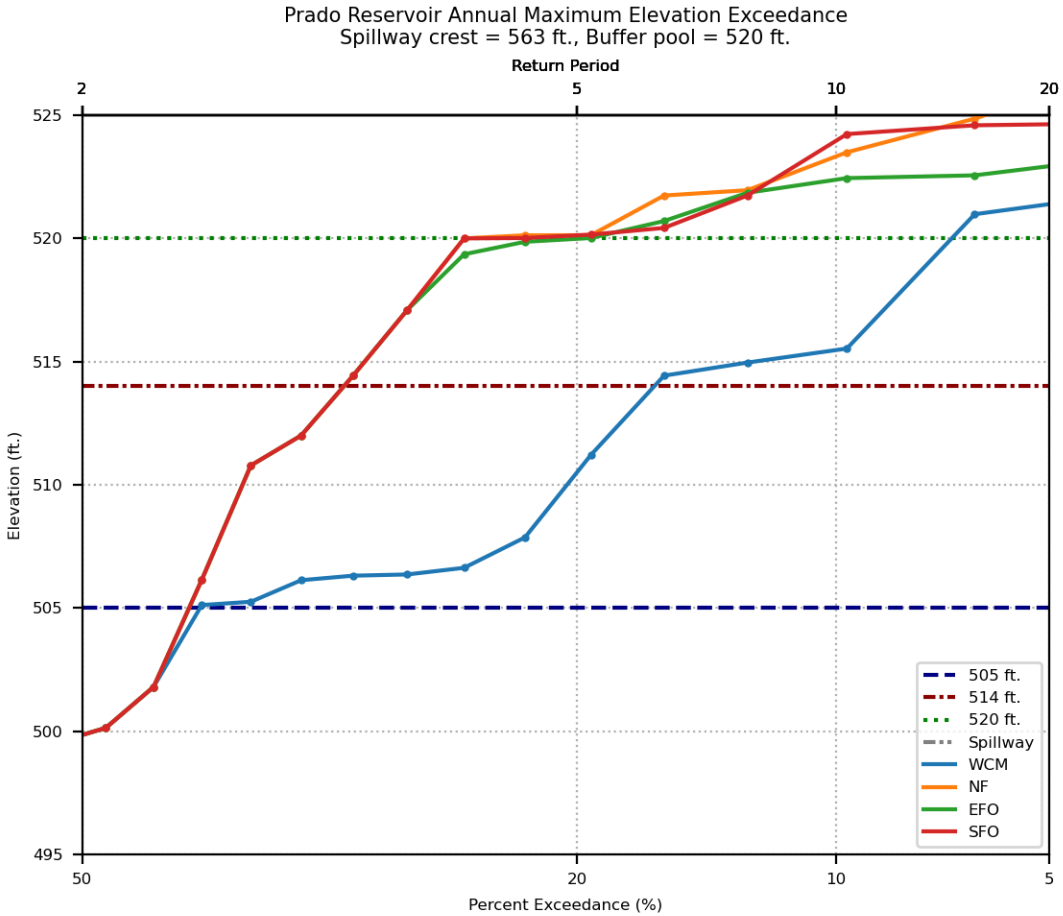

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 520 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO

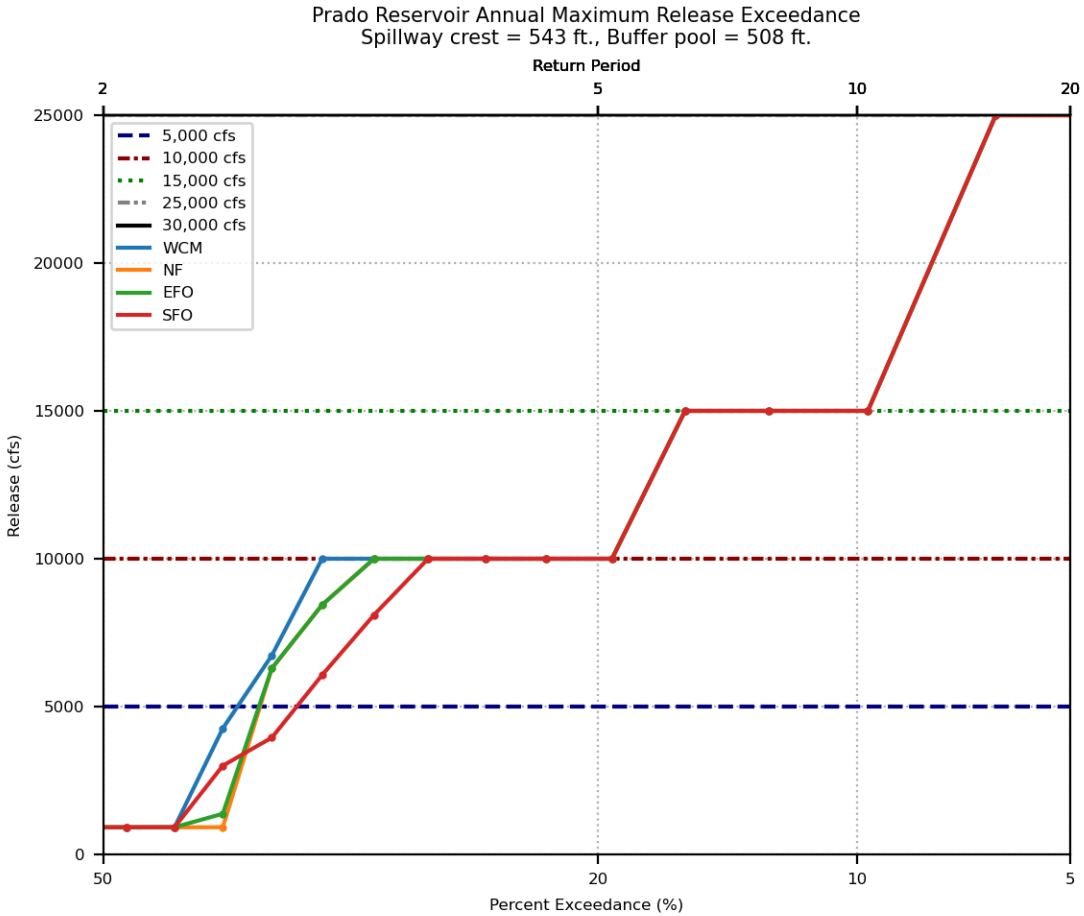

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 508 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO

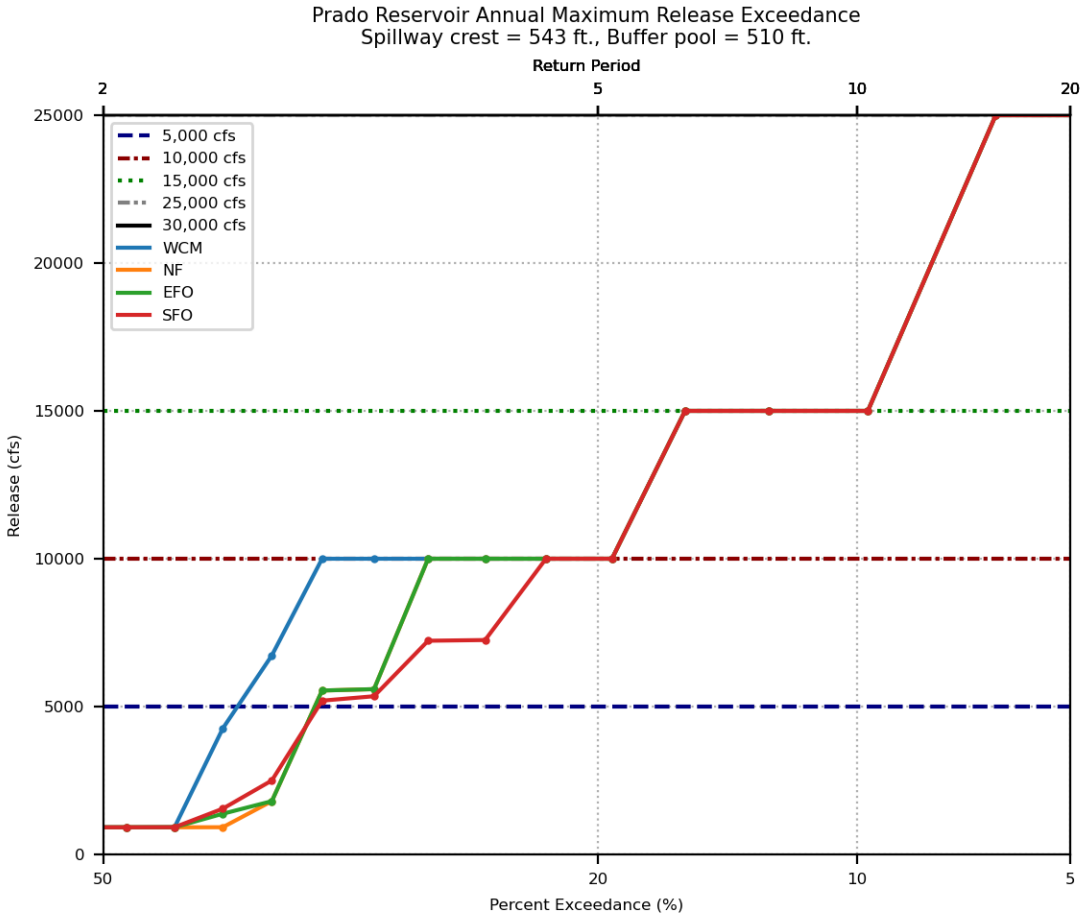

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 510 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO

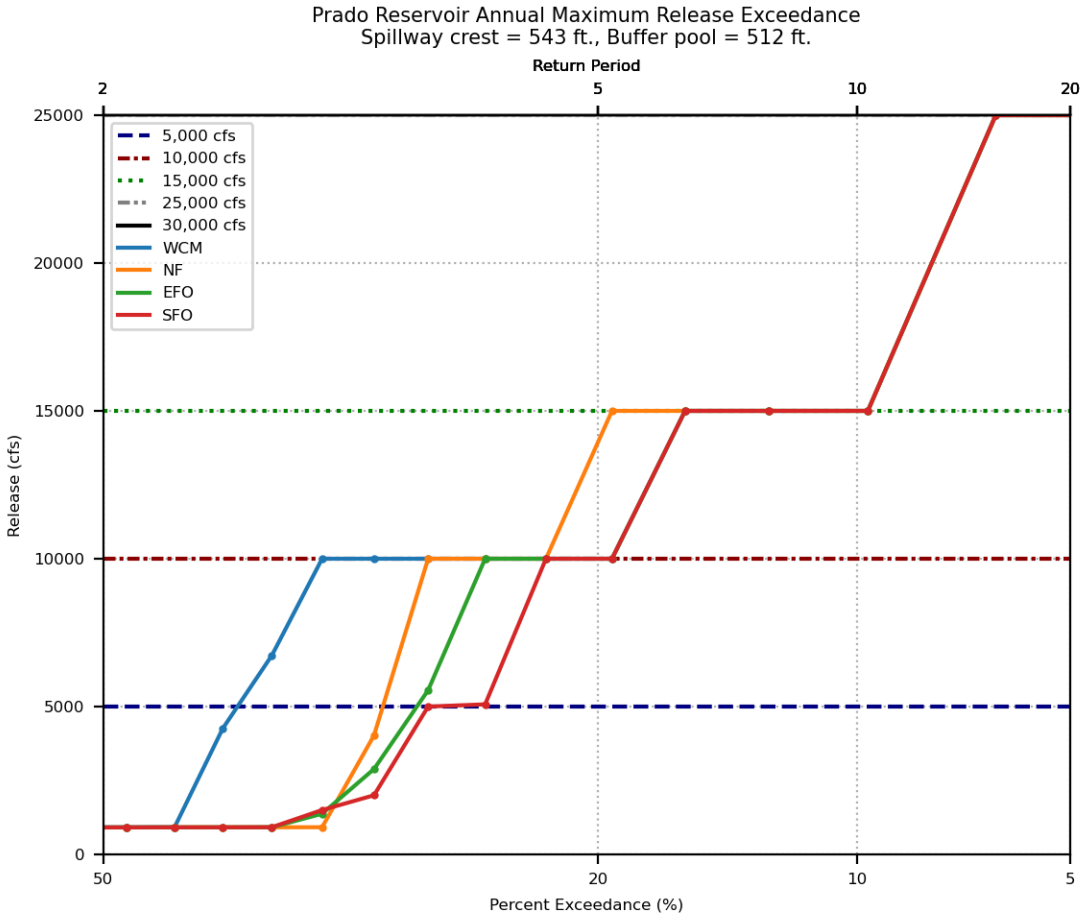

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 512 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
NF
EFO
SFO

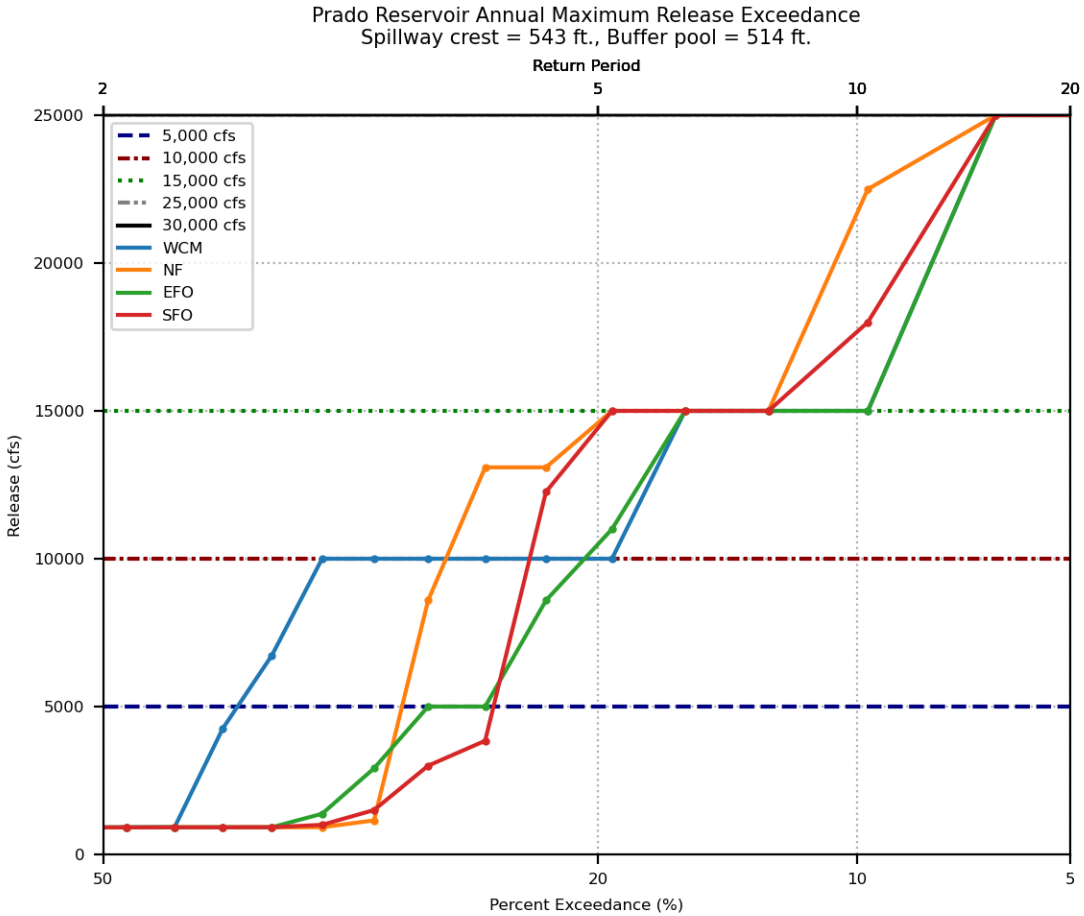

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 514 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO

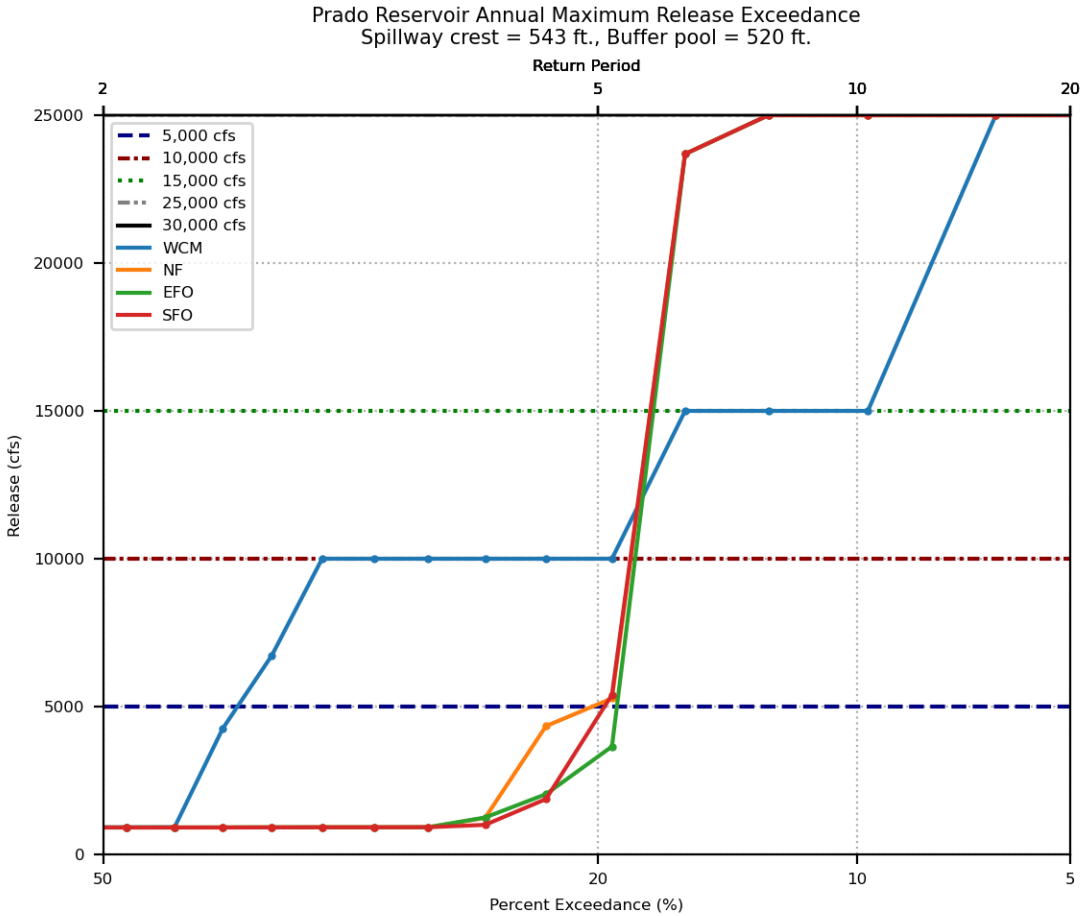

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 520 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO

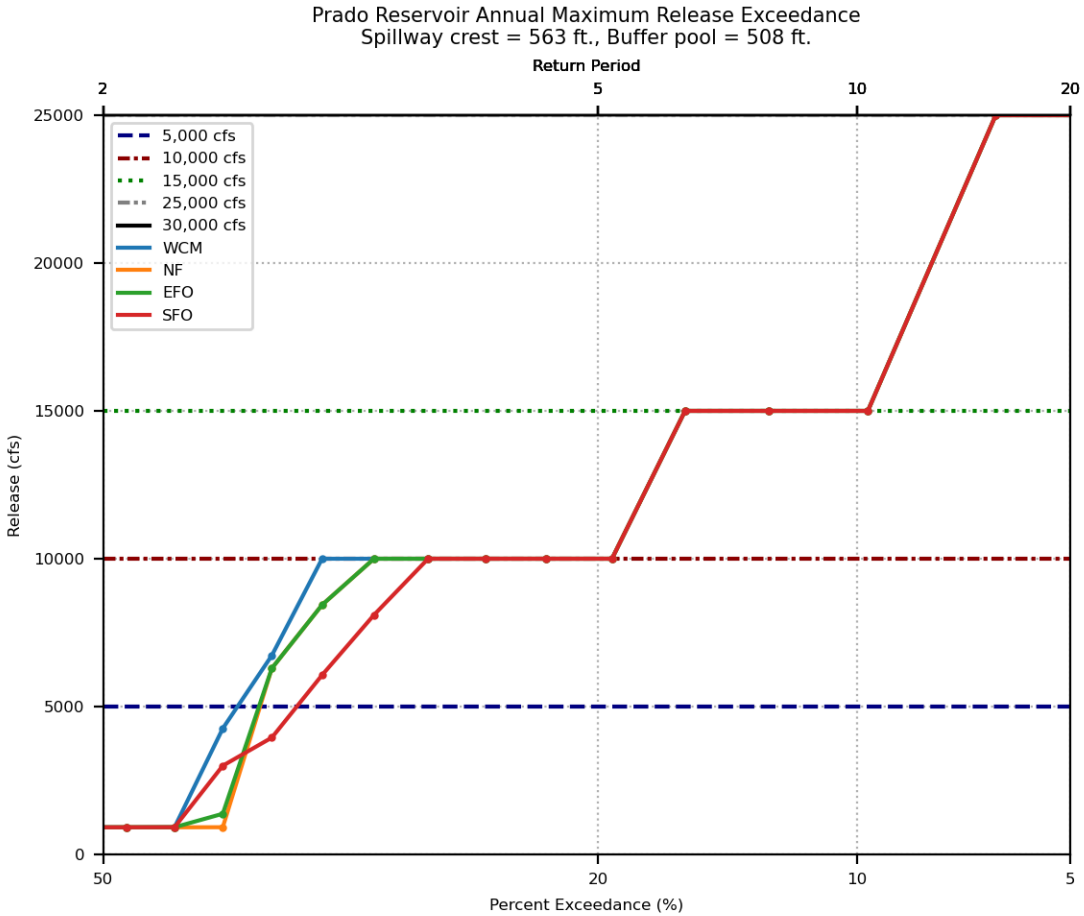

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 508 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
50
20
10
5
Percent Exceedance (%)

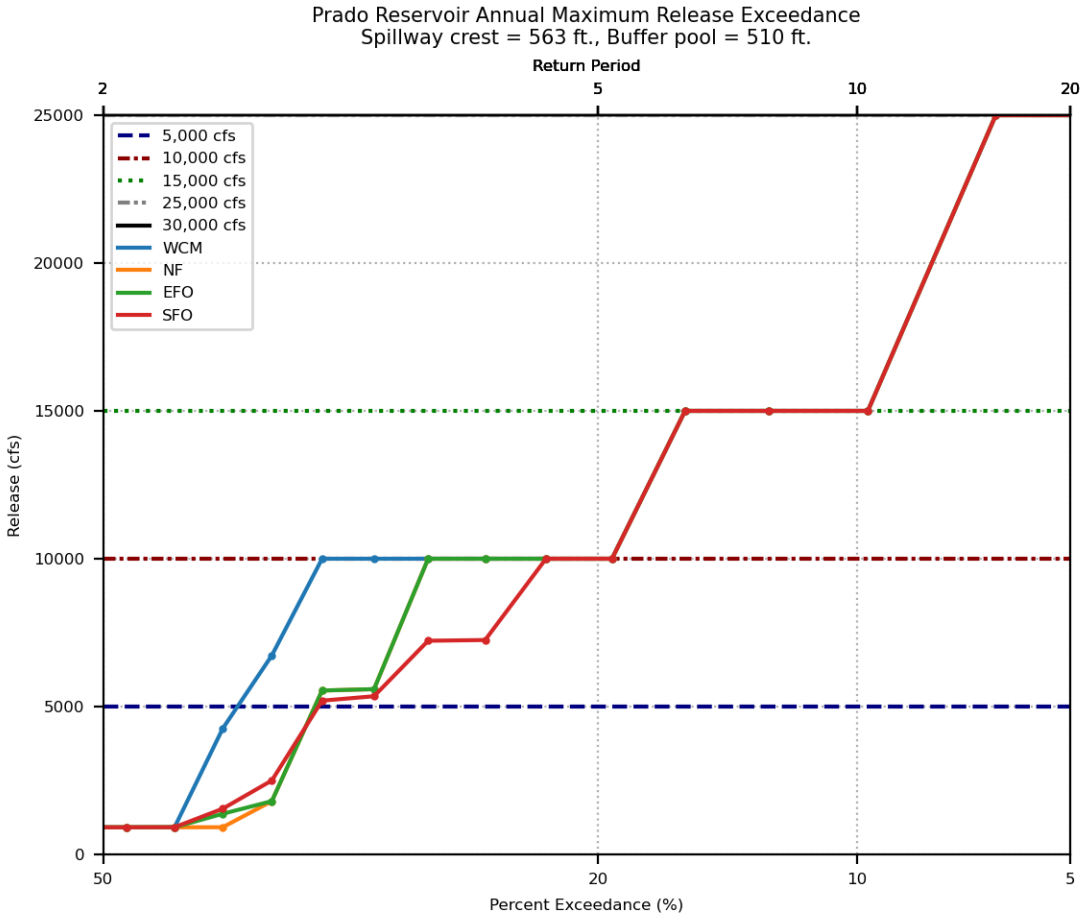

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 510 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
50
20
10
5
Percent Exceedance (%)

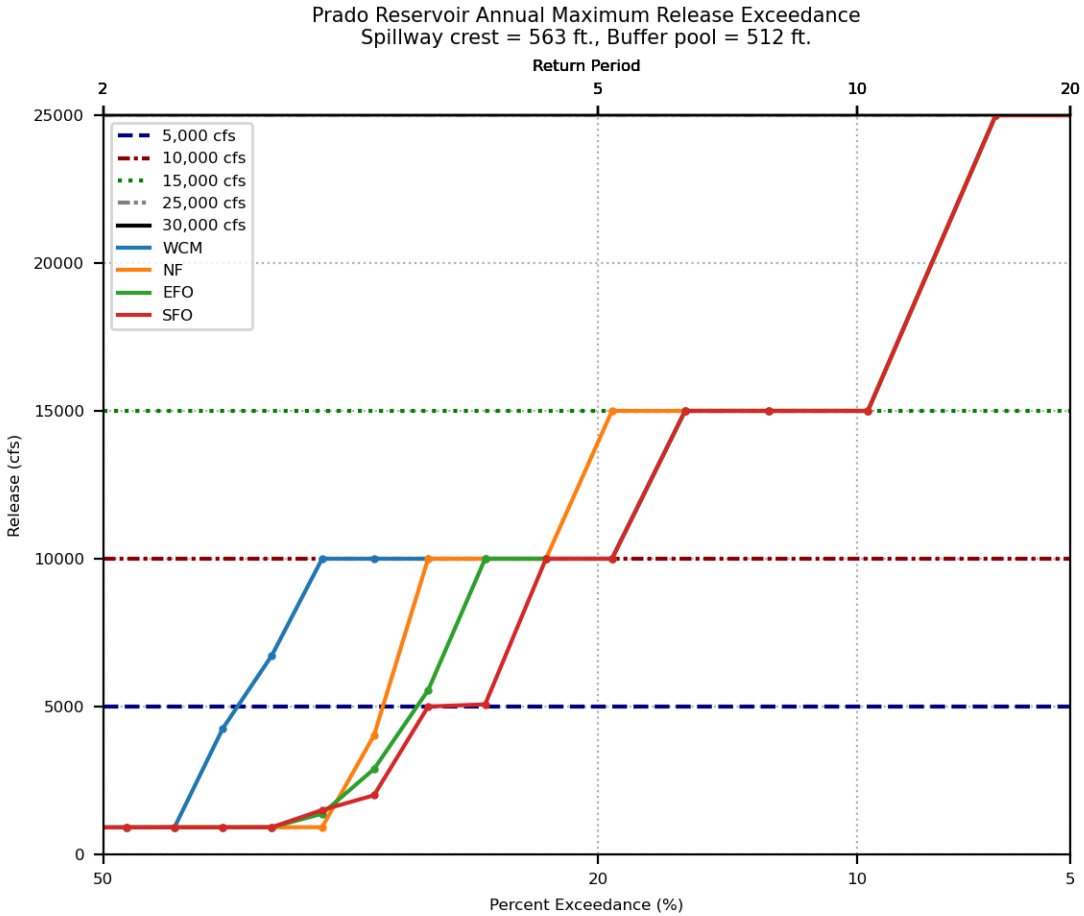

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 512 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
50
20
10
5
Percent Exceedance (%)

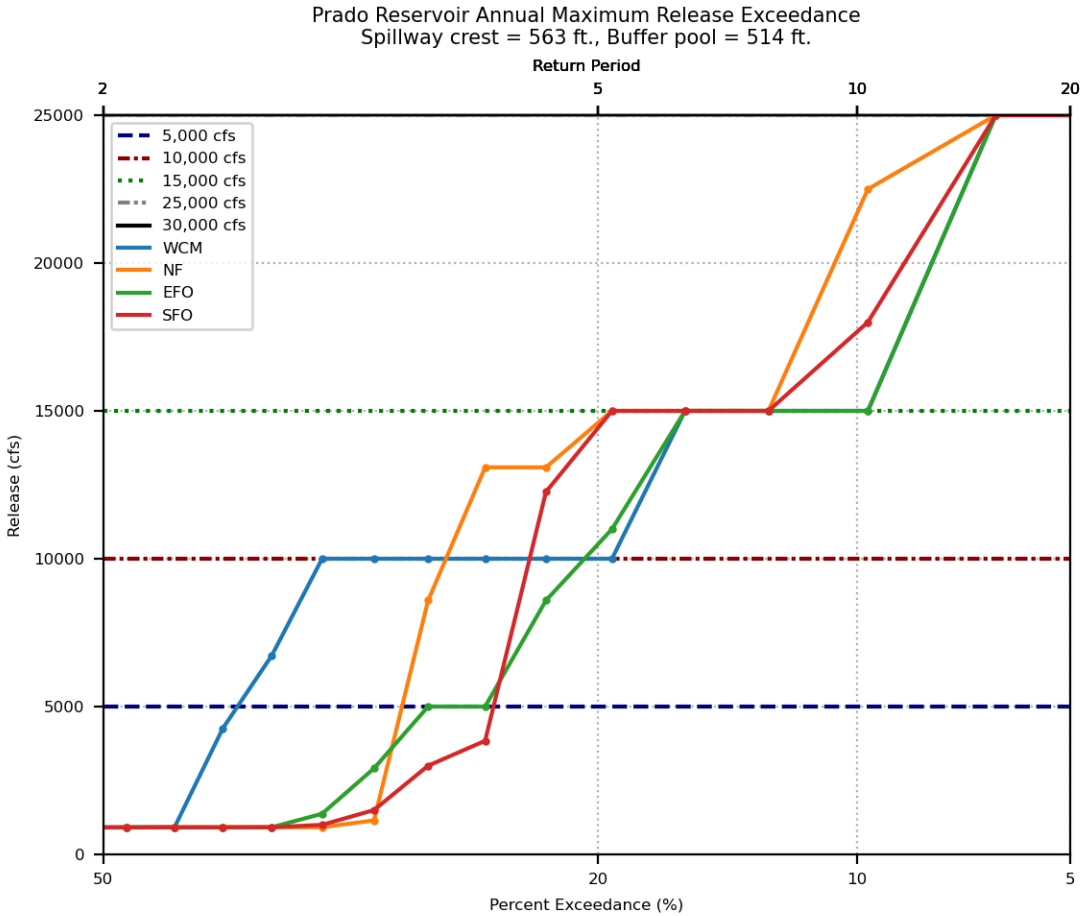

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 514 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
50
20
10
5
Percent Exceedance (%)

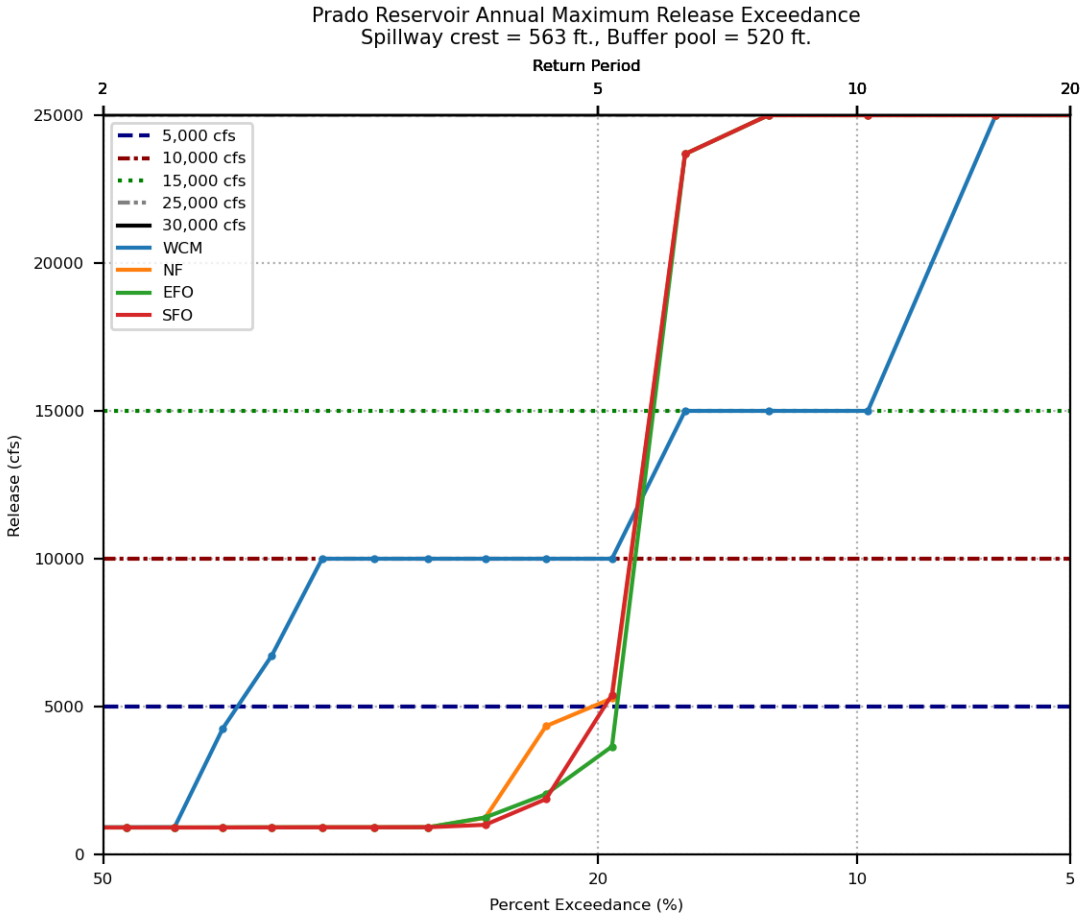

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 520 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
50
20
10
5
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 508 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
50
20
10
5
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 510 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
50
20
10
5
Percent Exceedance (%)

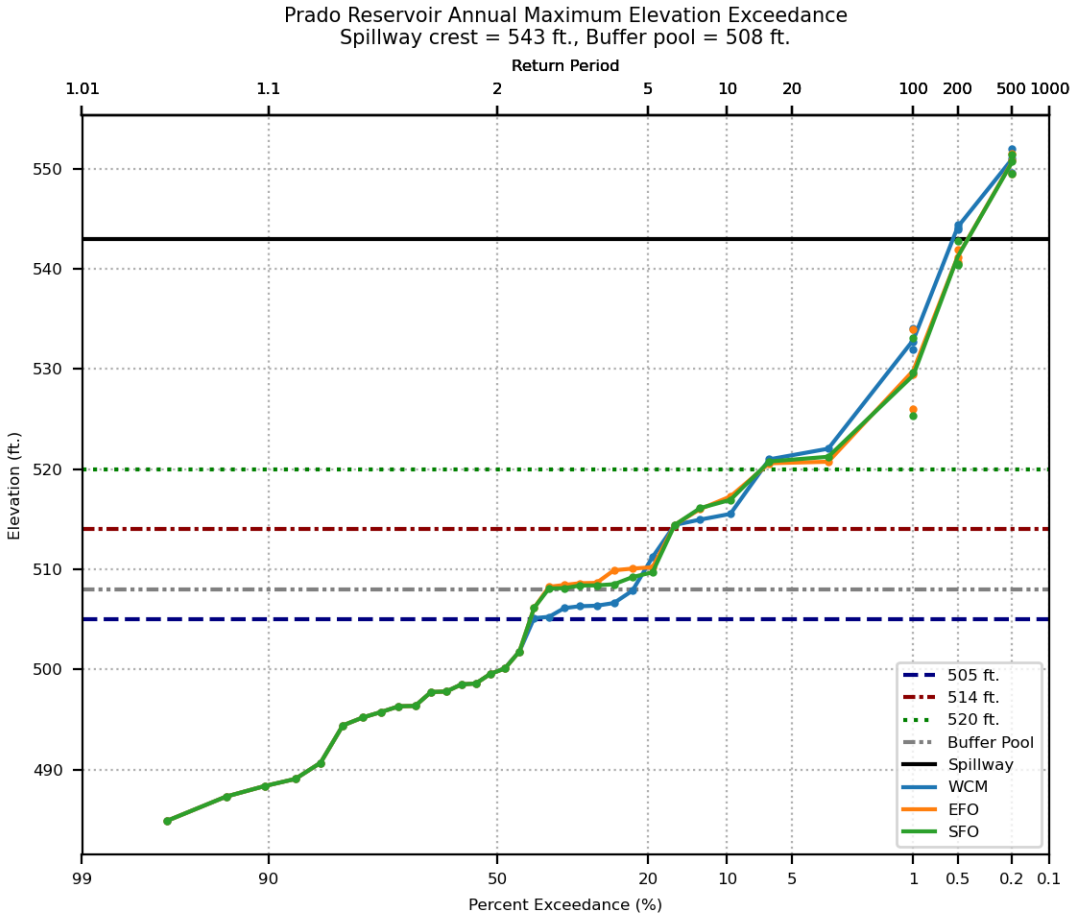

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 512 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
50
20
10
5
Percent Exceedance (%)

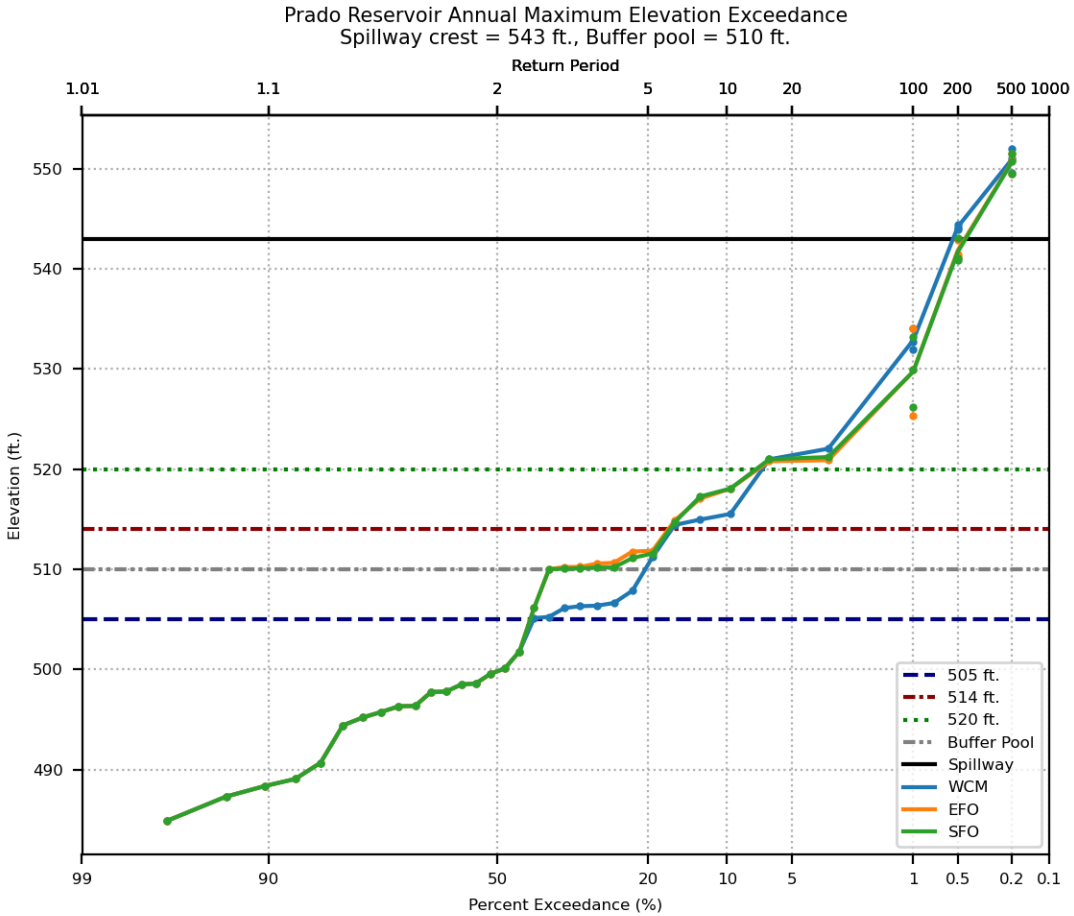

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 514 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
50
20
10
5
Percent Exceedance (%)

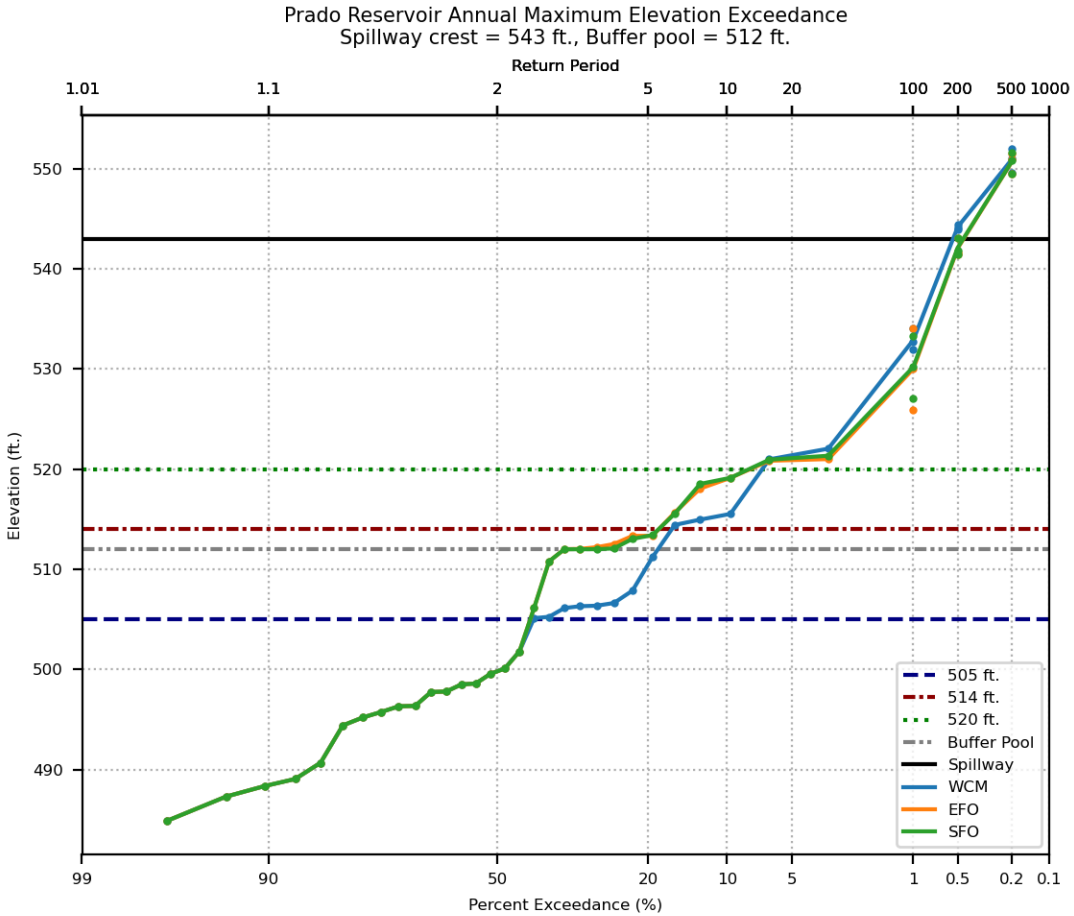

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 520 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
50
20
10
5
Percent Exceedance (%)

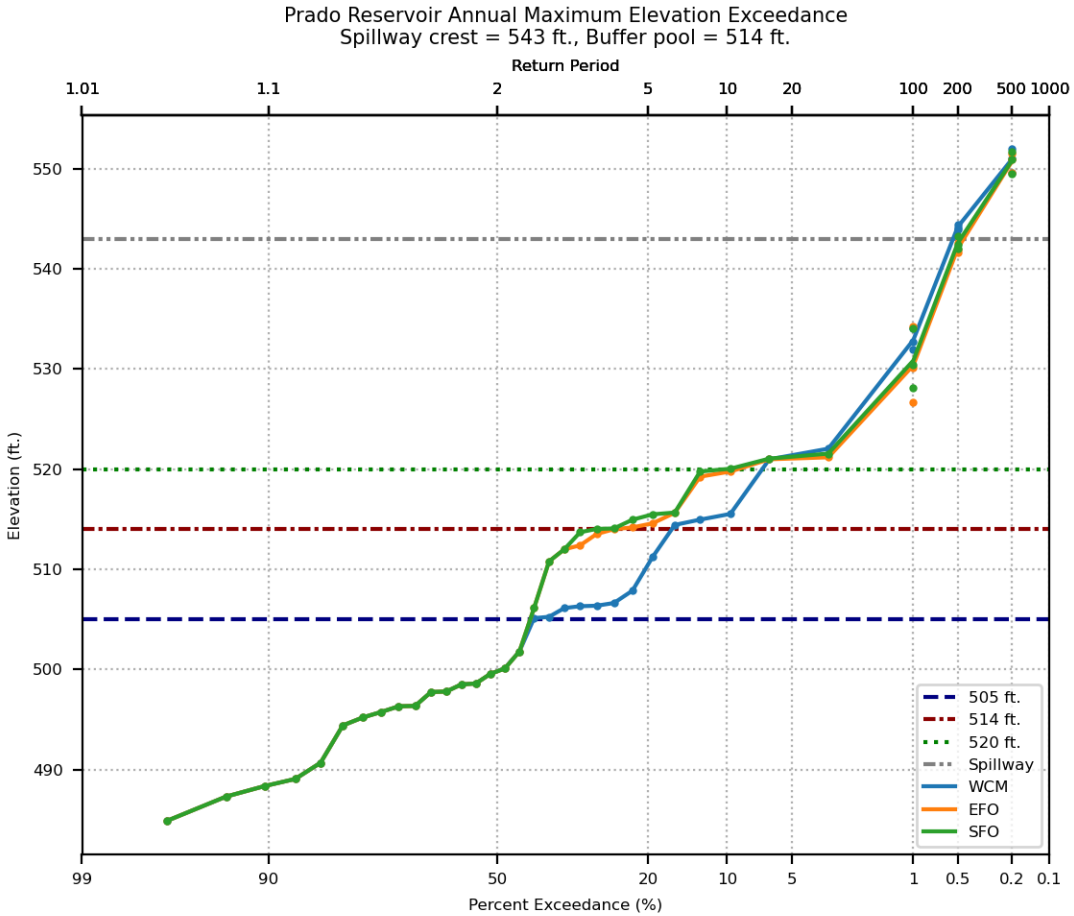
Frequency of Annual Maximum Pool Elevation *by Buffer Pool (NP/NF)*

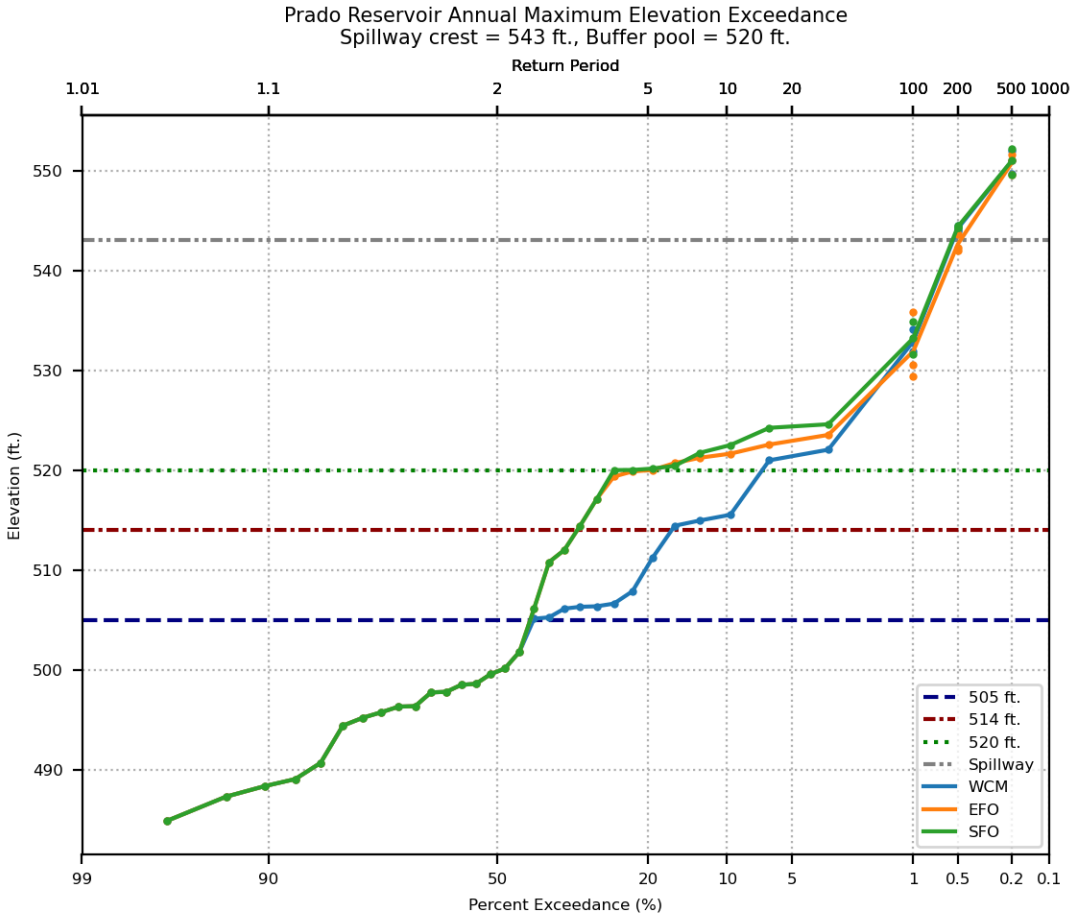
- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’
  - 510’
  - 512’
  - 514’
  - 520’
- WCP alternatives in legend
  - Perfect Forecast results omitted
  - No Forecast results omitted

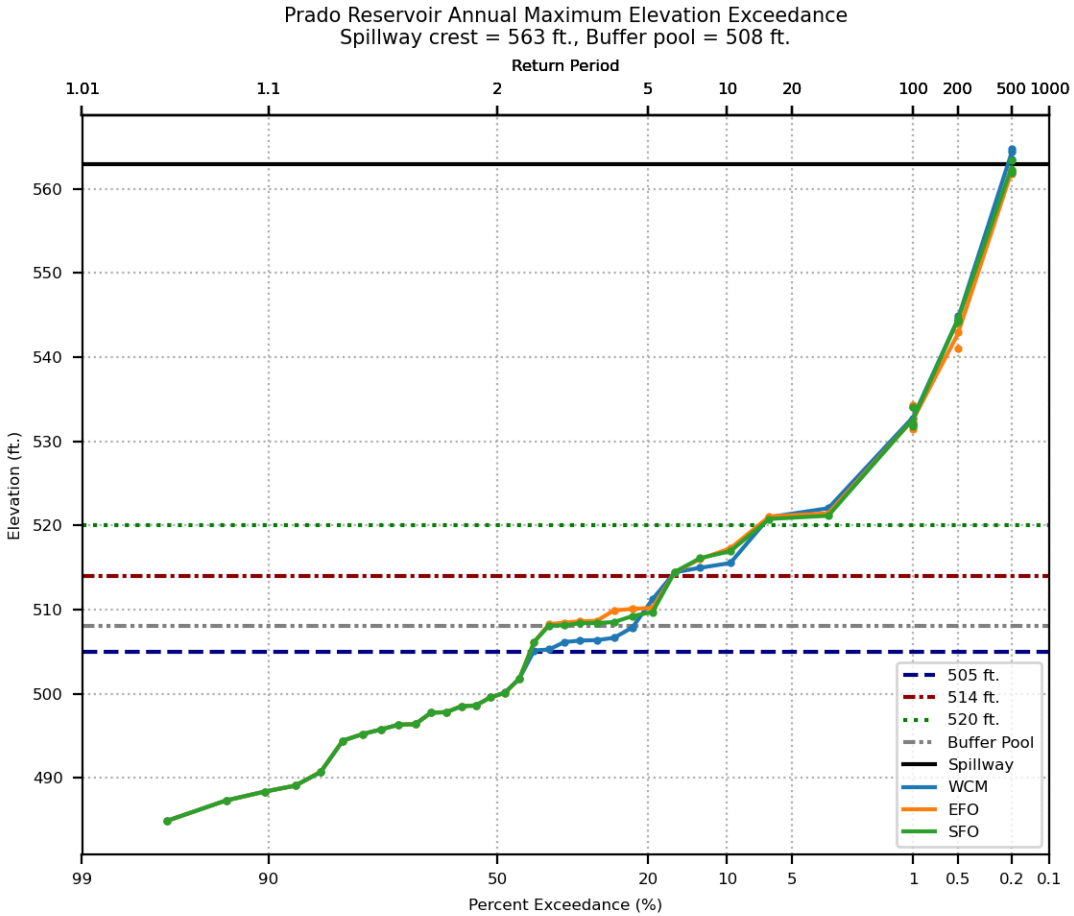

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 508 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
Elevation (ft.)
550
540
530
520
510
500
490
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
EFO
SFO

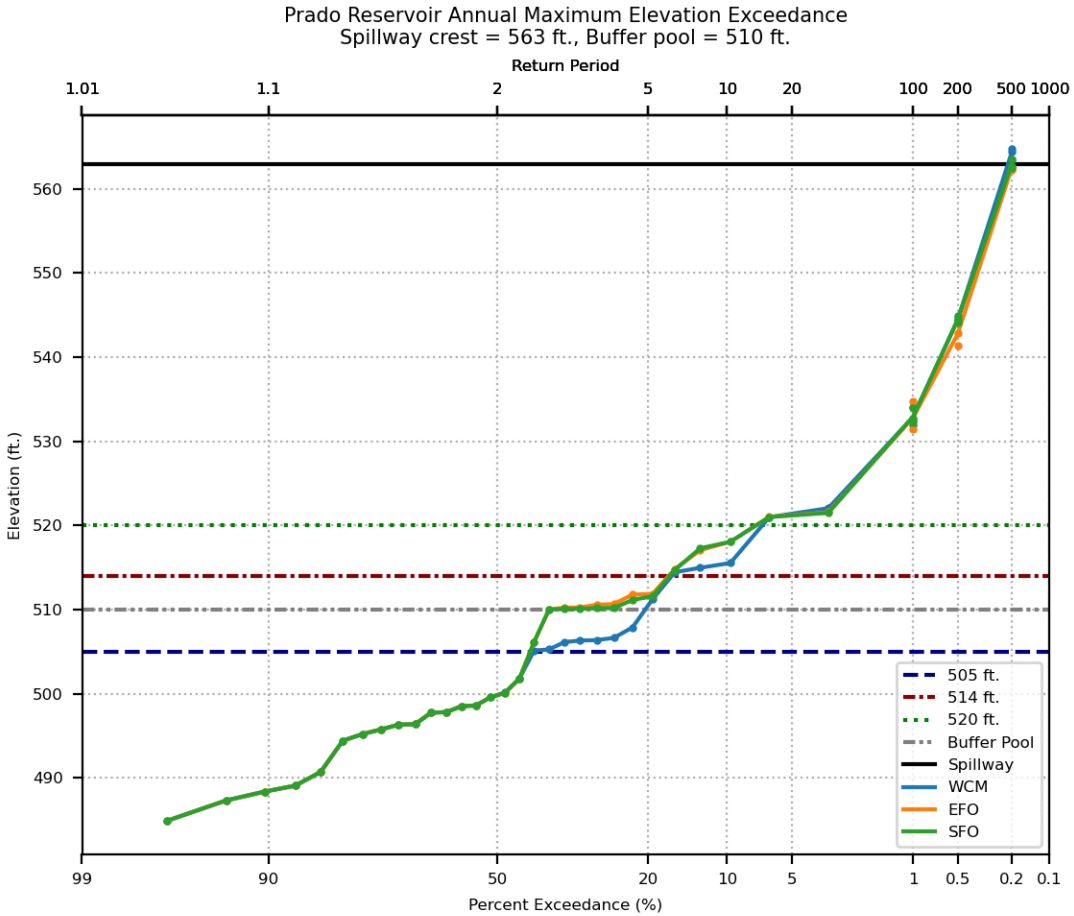

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 510 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
EFO
SFO

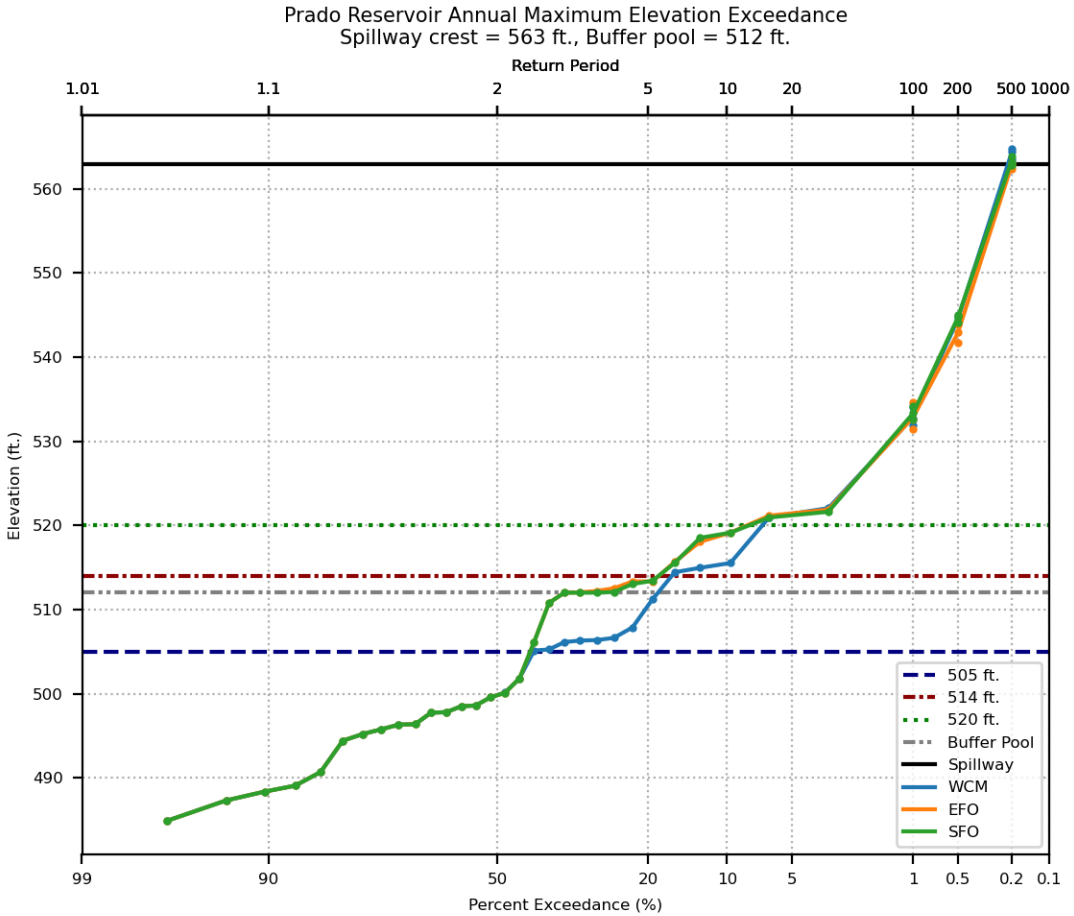

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 512 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
550
540
530
520
510
500
490
Elevation (ft.)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
EFO
SFO

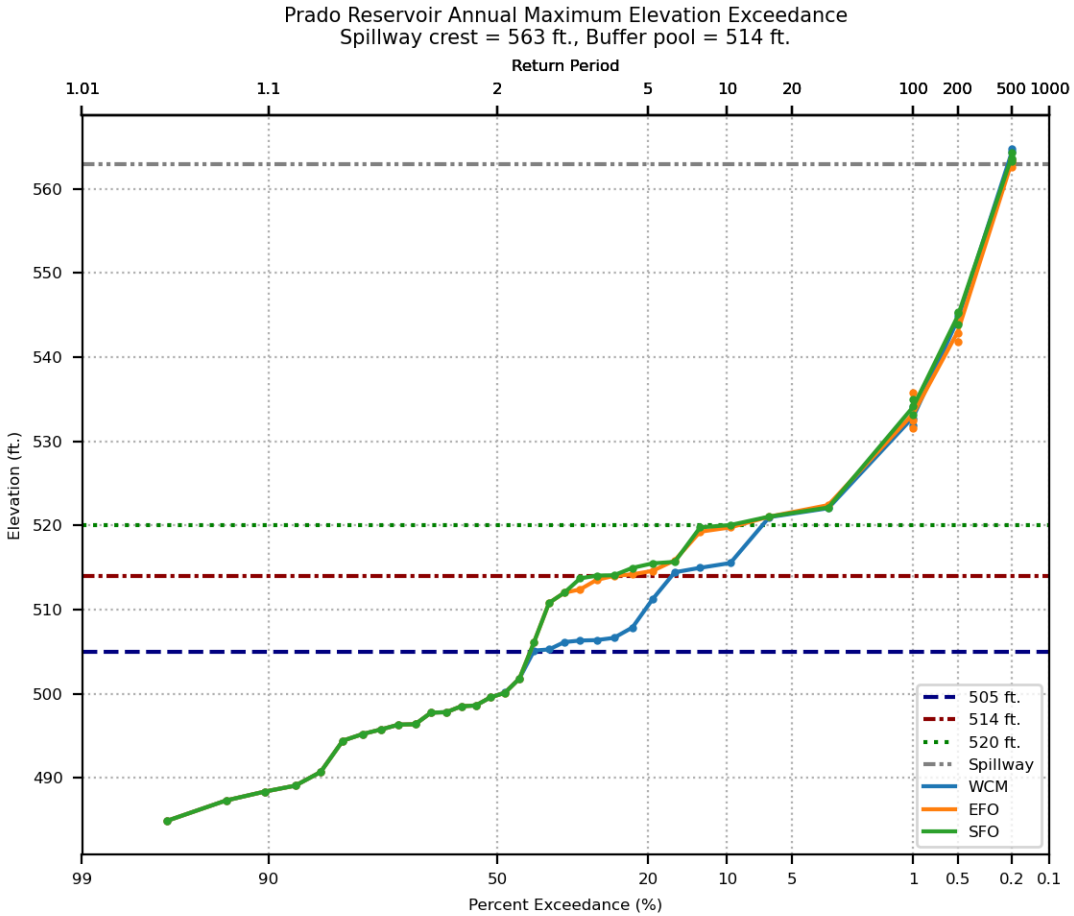

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 514 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
Elevation (ft.)
550
540
530
520
510
500
490
505 ft.
514 ft.
520 ft.
Spillway
WCM
EFO
SFO
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

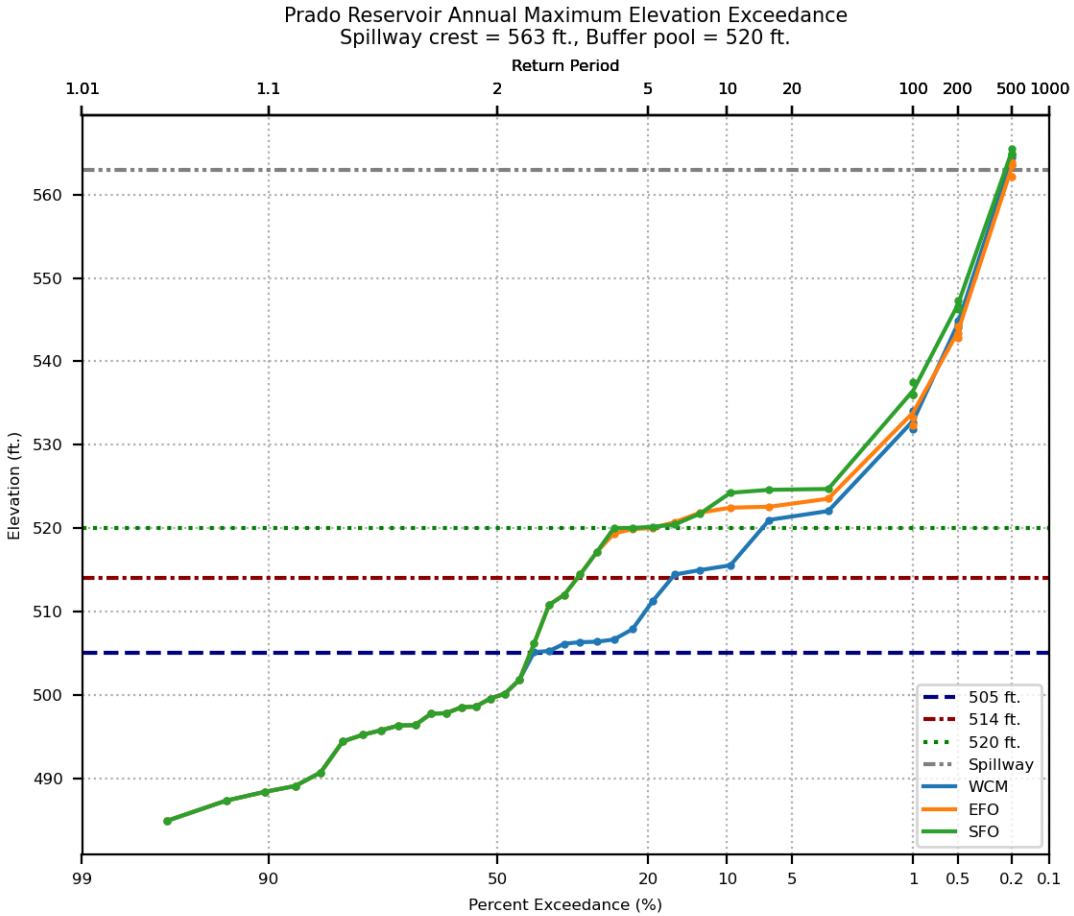

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 520 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
Elevation (ft.)
550
540
530
520
510
500
490
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Spillway
WCM
EFO
SFO

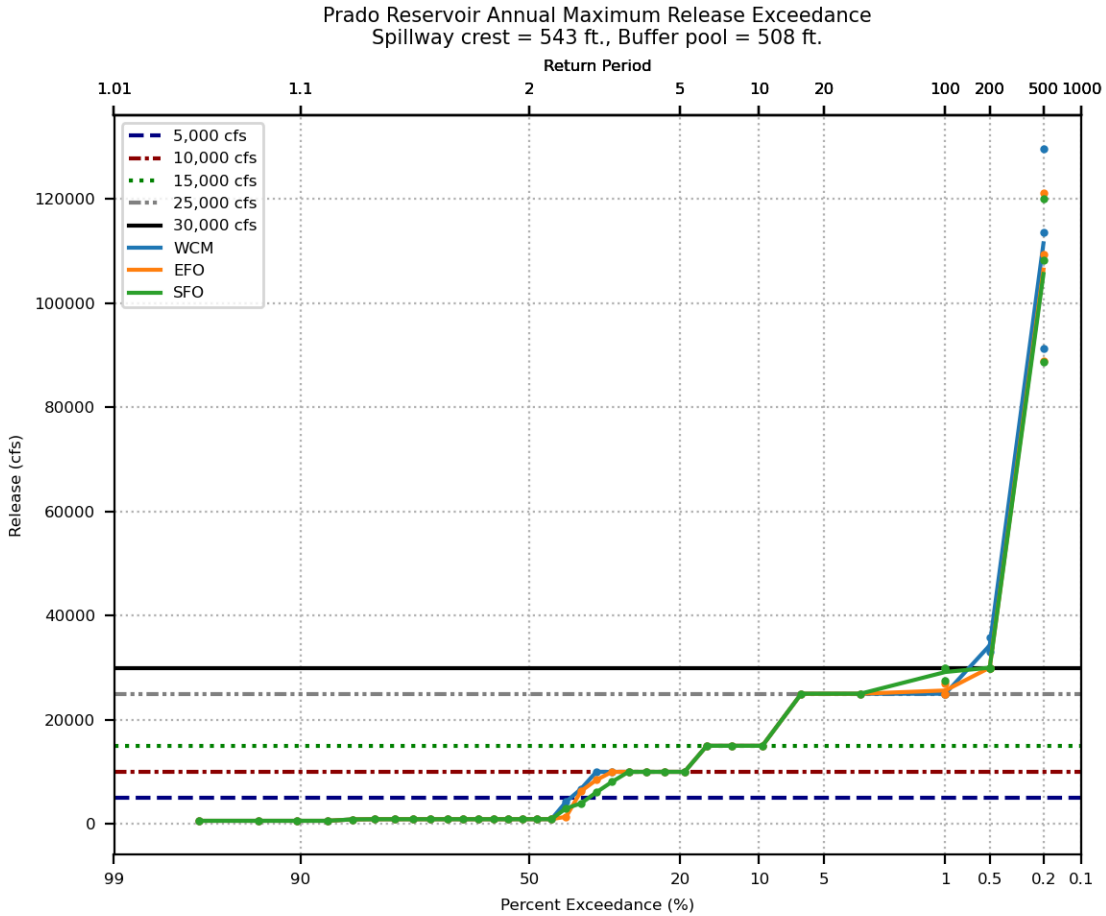

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 508 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
Elevation (ft.)
560
550
540
530
520
510
500
490
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
EFO
SFO

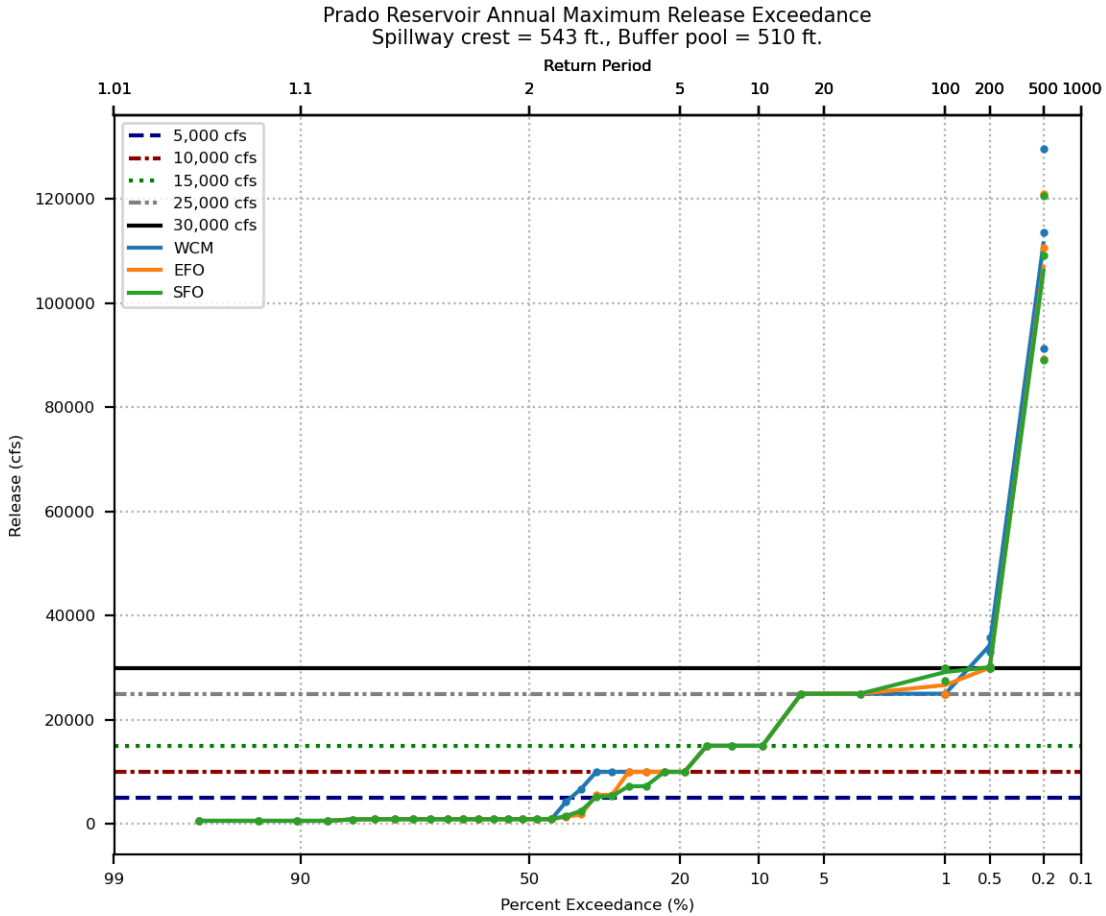

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 510 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
Elevation (ft.)
560
550
540
530
520
510
500
490
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
EFO
SFO

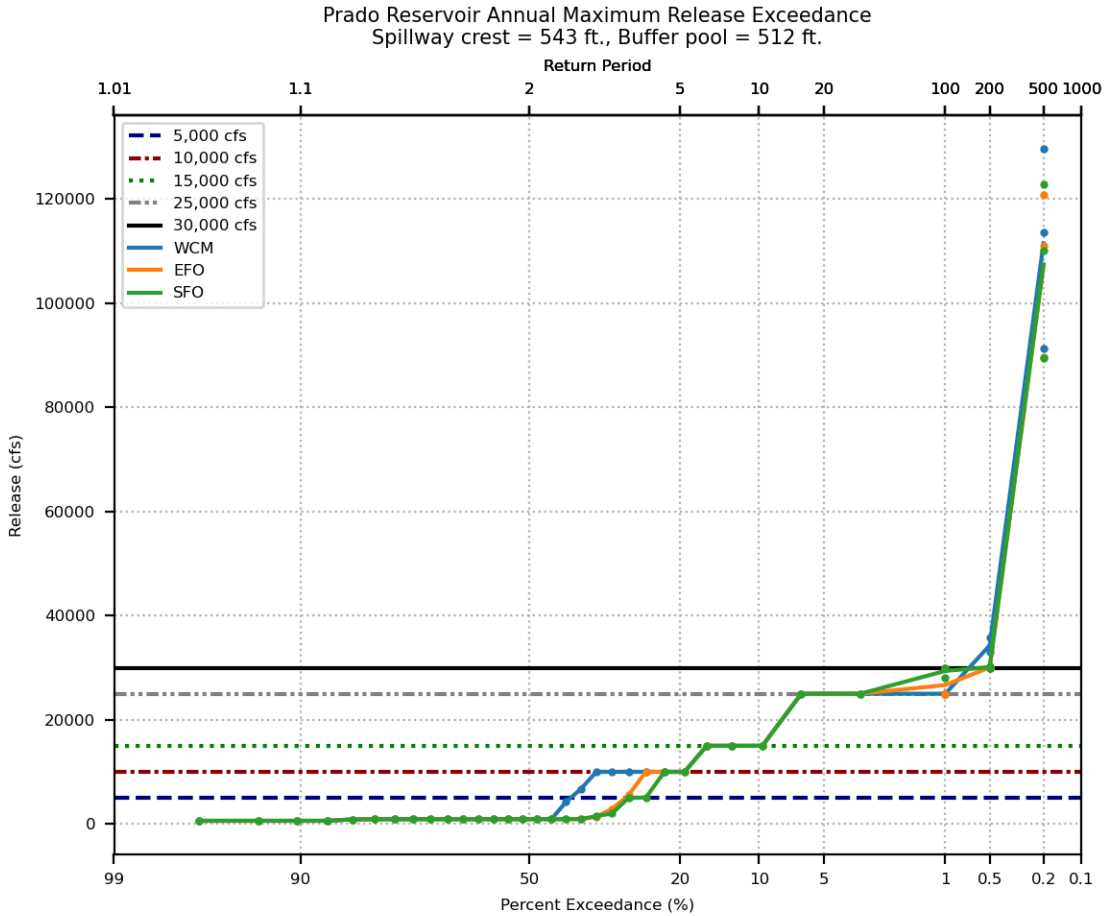

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 512 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
Elevation (ft.)
560
550
540
530
520
510
500
490
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
EFO
SFO

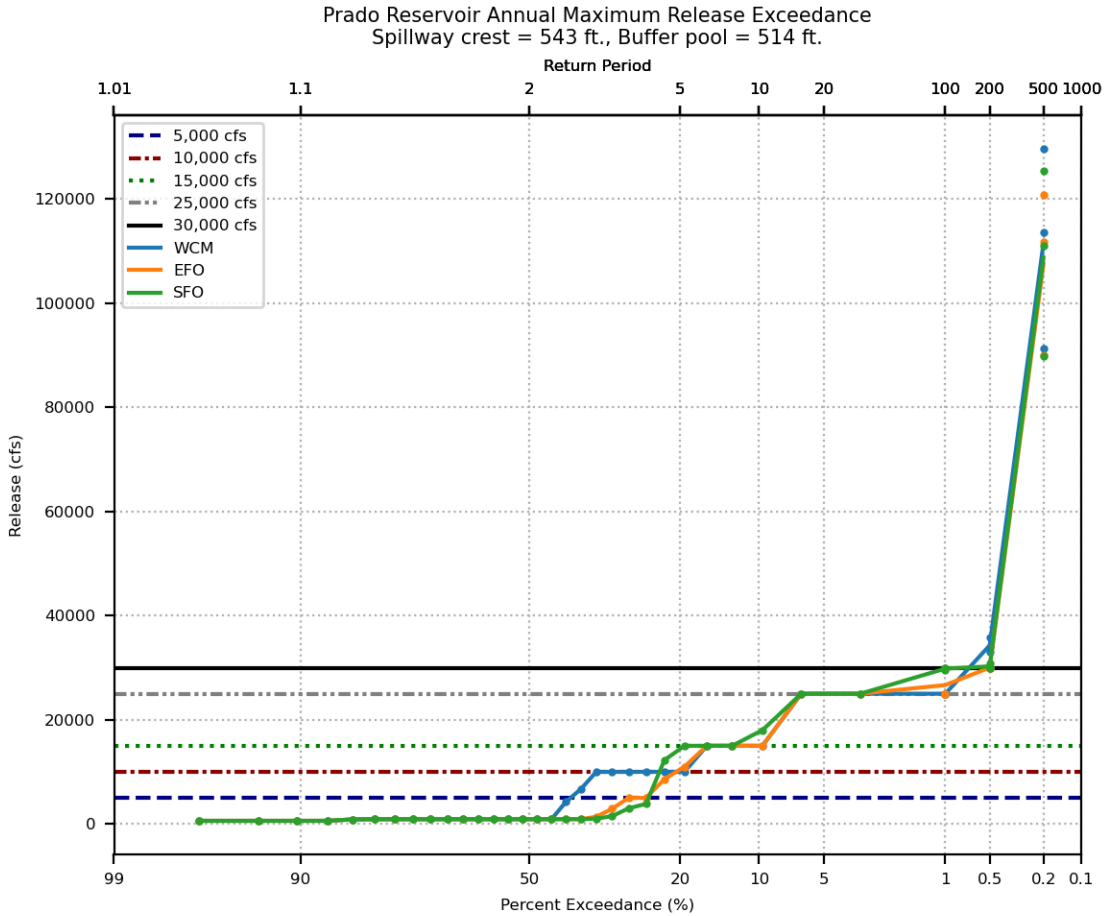

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 514 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
Elevation (ft.)
560
550
540
530
520
510
500
490
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Spillway
WCM
EFO
SFO

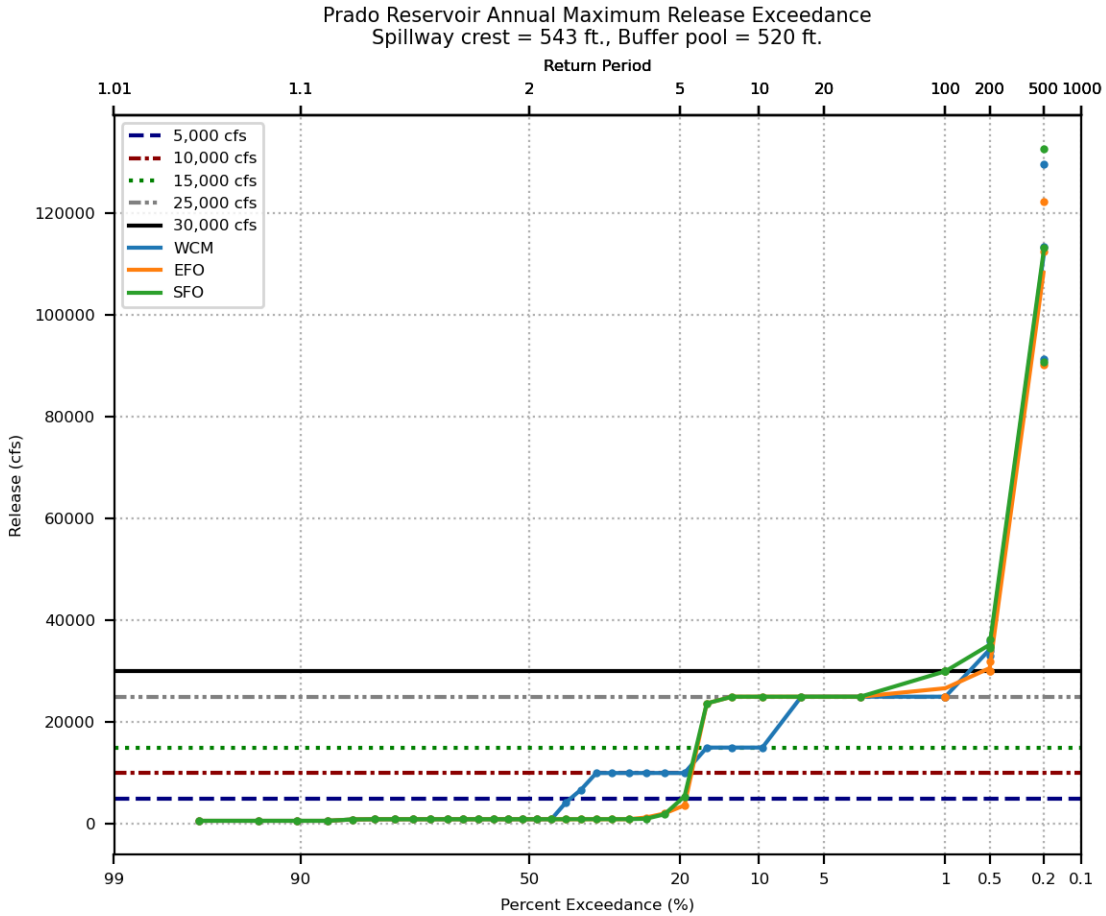

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 520 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
Elevation (ft.)
560
550
540
530
520
510
500
490
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Spillway
WCM
EFO
SFO

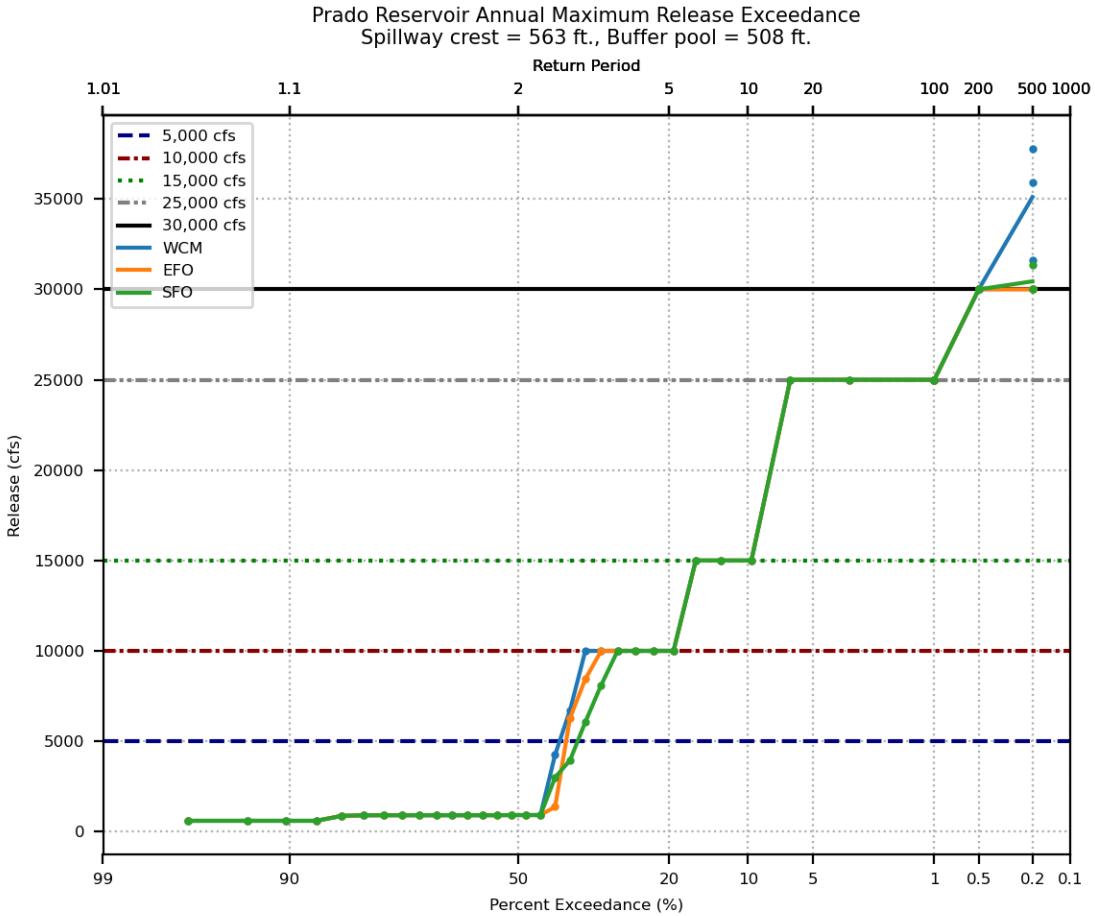

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 508 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
Release (cfs)
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

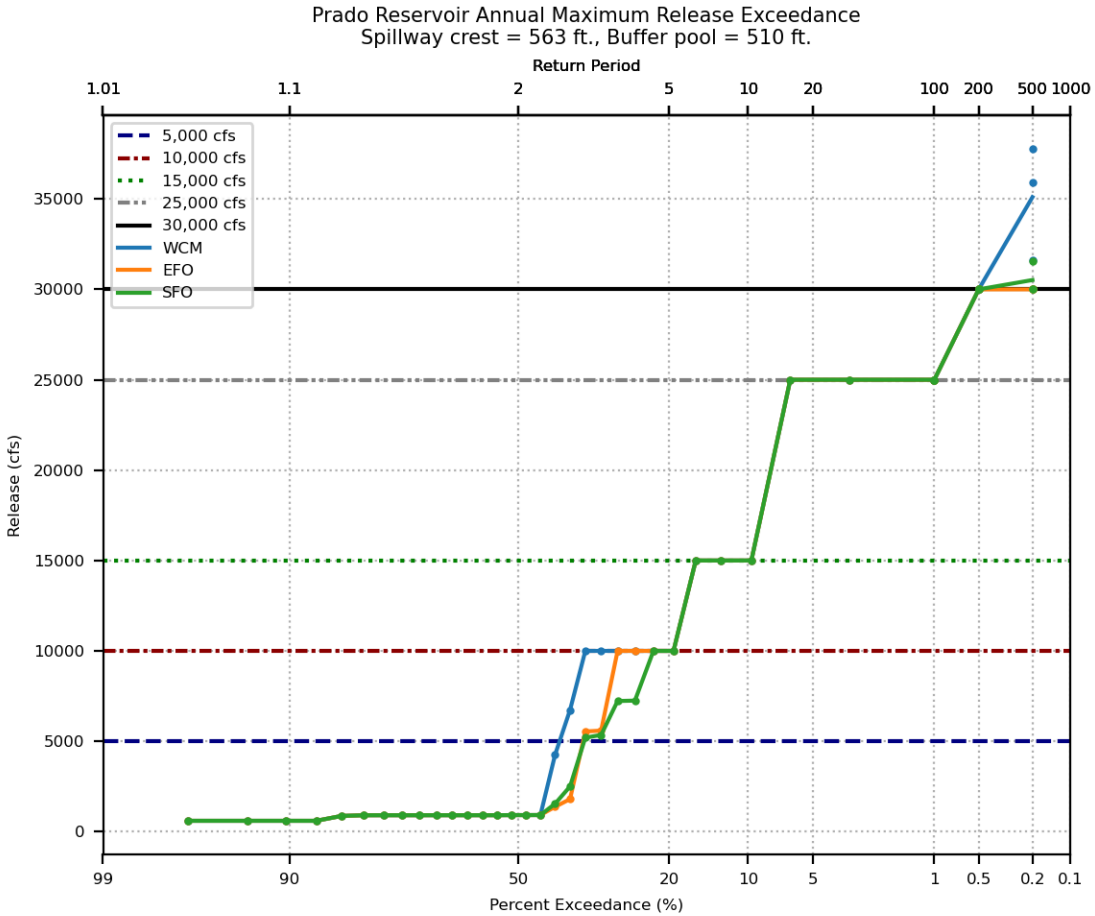

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 510 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
Release (cfs)
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

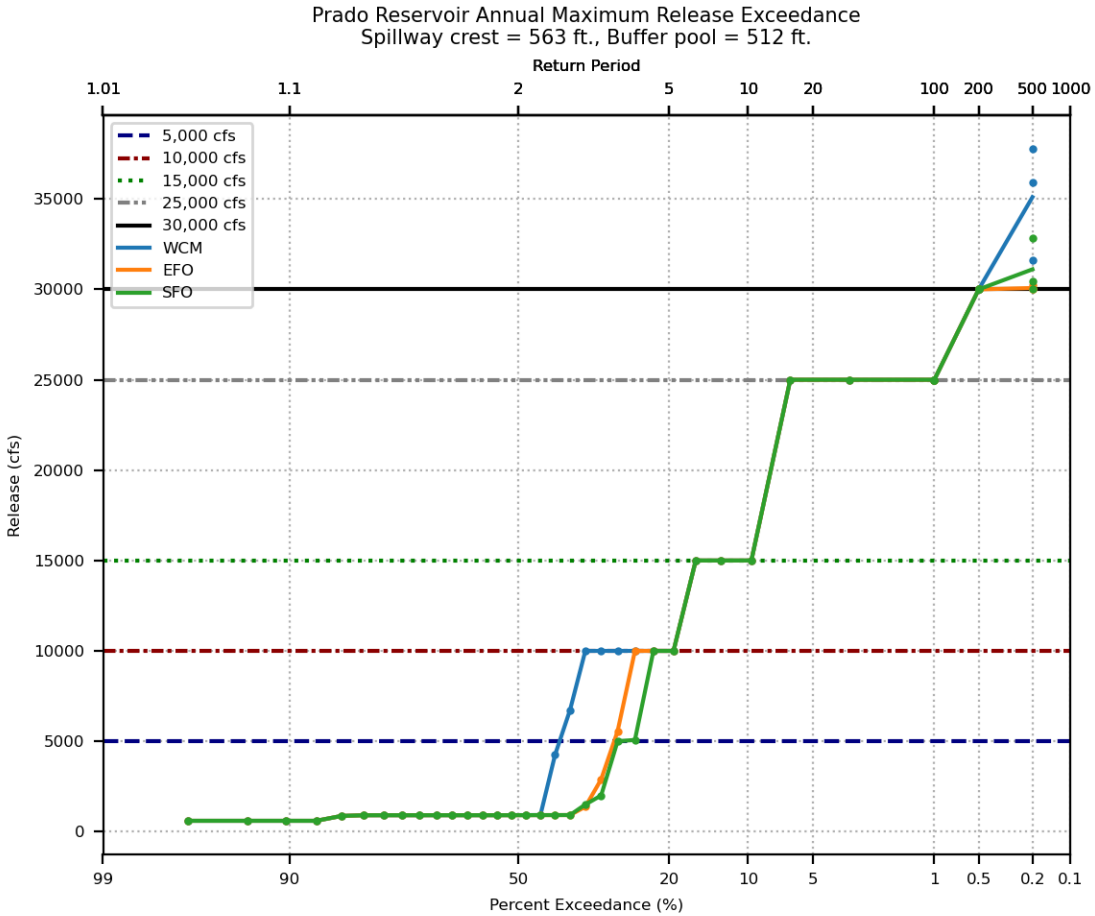

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 512 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
Release (cfs)
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

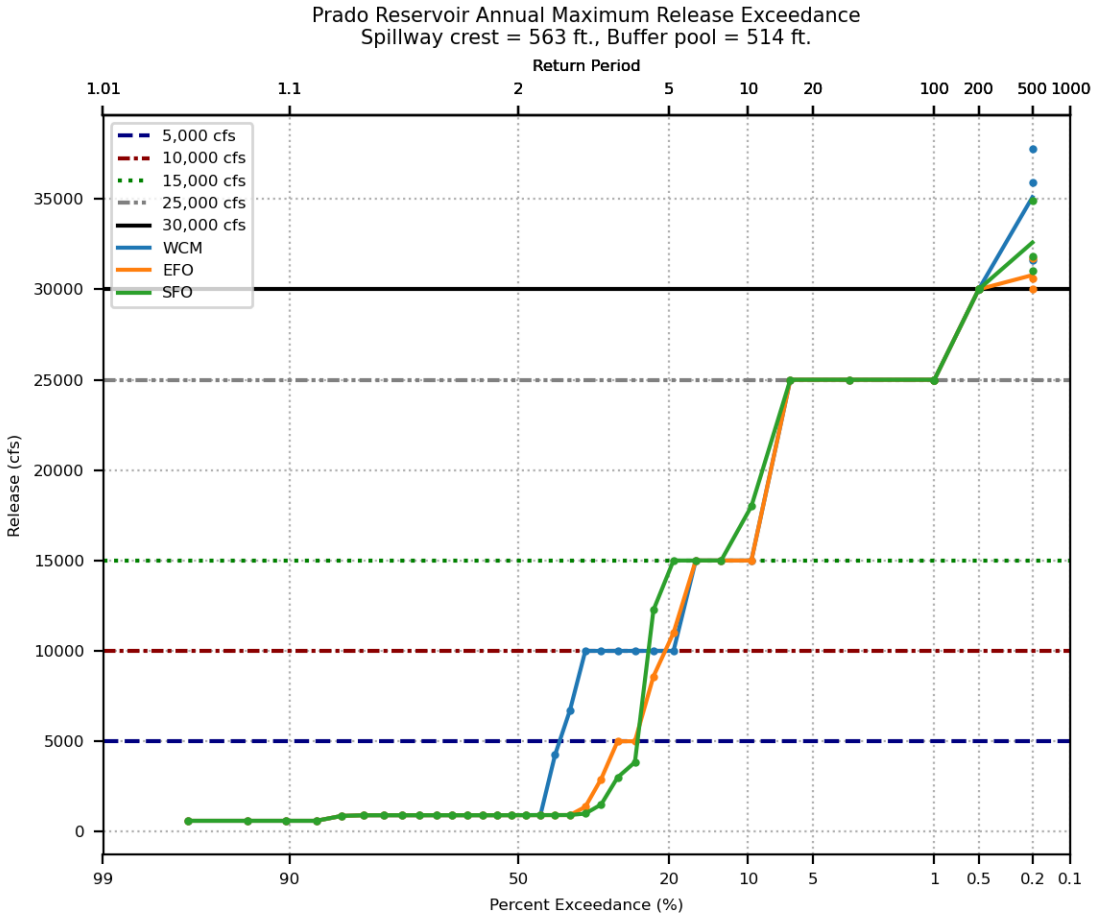

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 514 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
120000
100000
80000
60000
40000
20000
0
Release (cfs)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

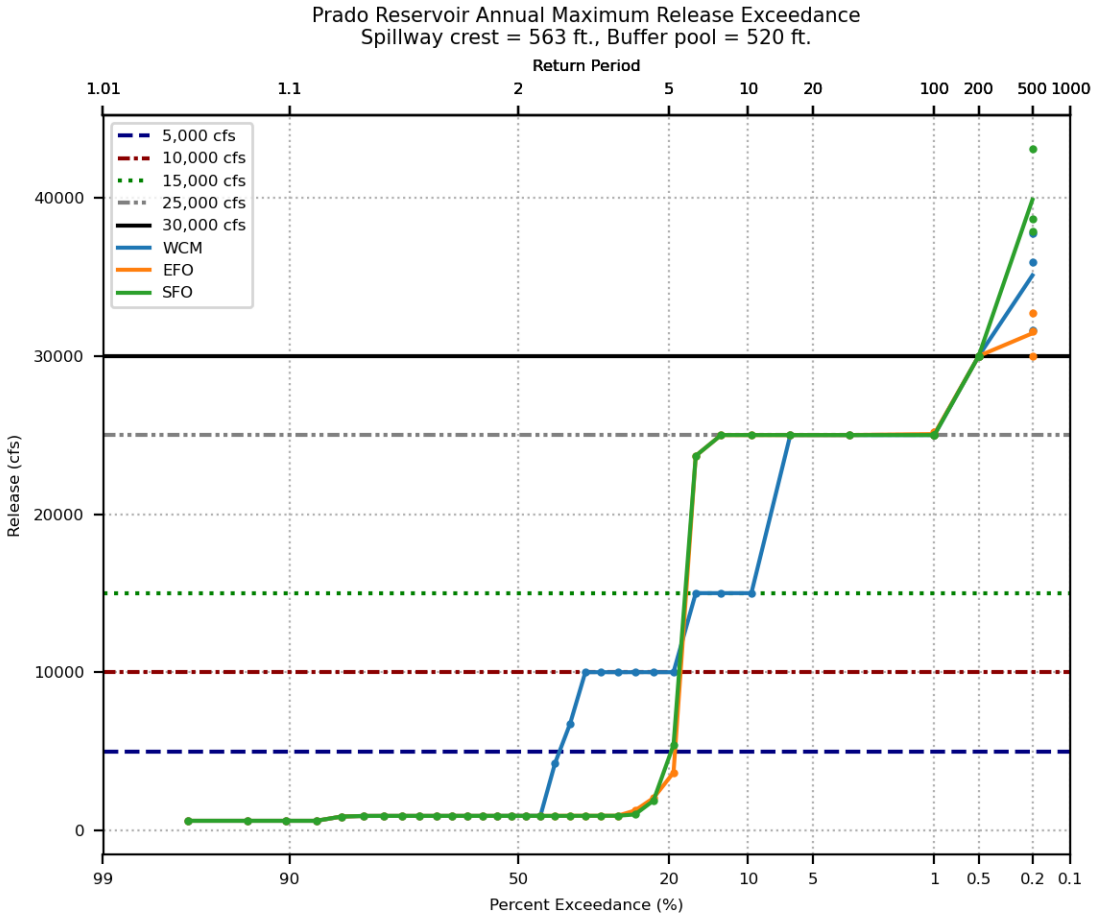

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 520 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
Release (cfs)
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 508 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
35000
30000
25000
20000
15000
10000
5000
0
Release (cfs)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 510 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
35000
30000
25000
20000
15000
10000
5000
0
Release (cfs)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

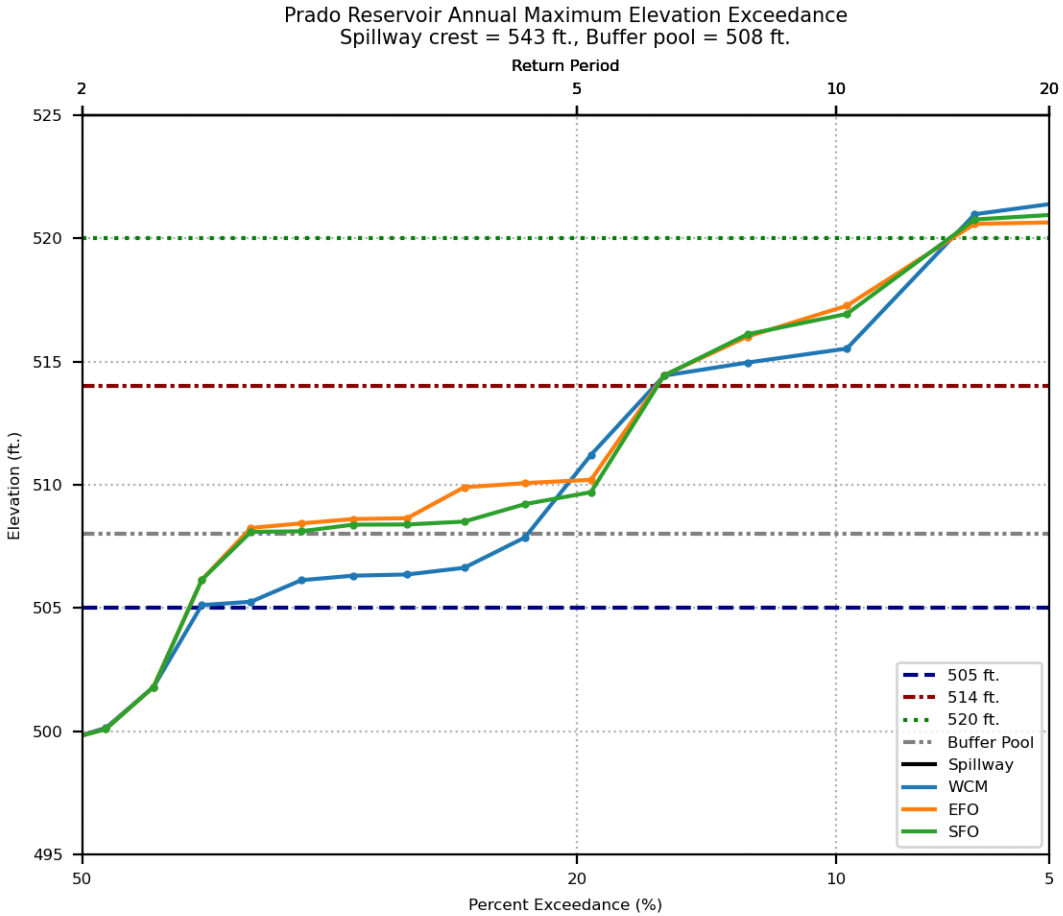

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 512 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
35000
30000
25000
20000
15000
10000
5000
0
Release (cfs)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

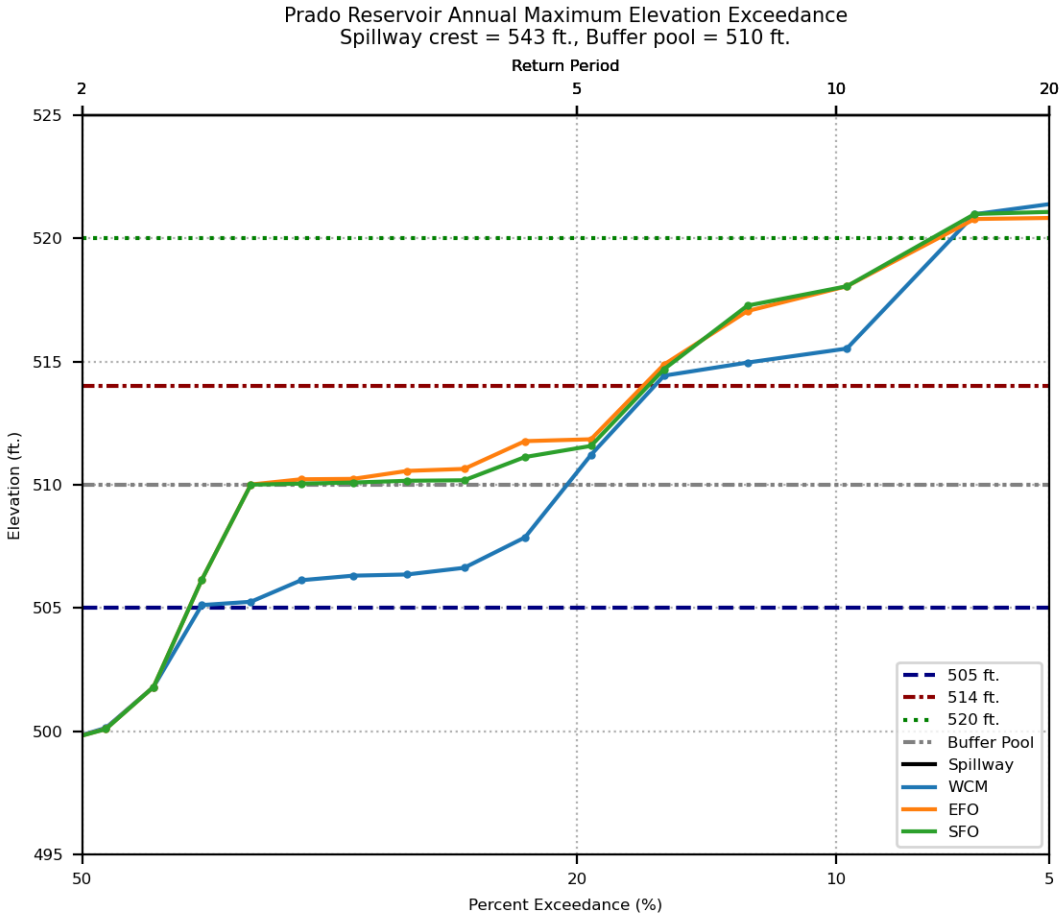

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 514 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
35000
30000
25000
20000
15000
10000
5000
0
Release (cfs)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

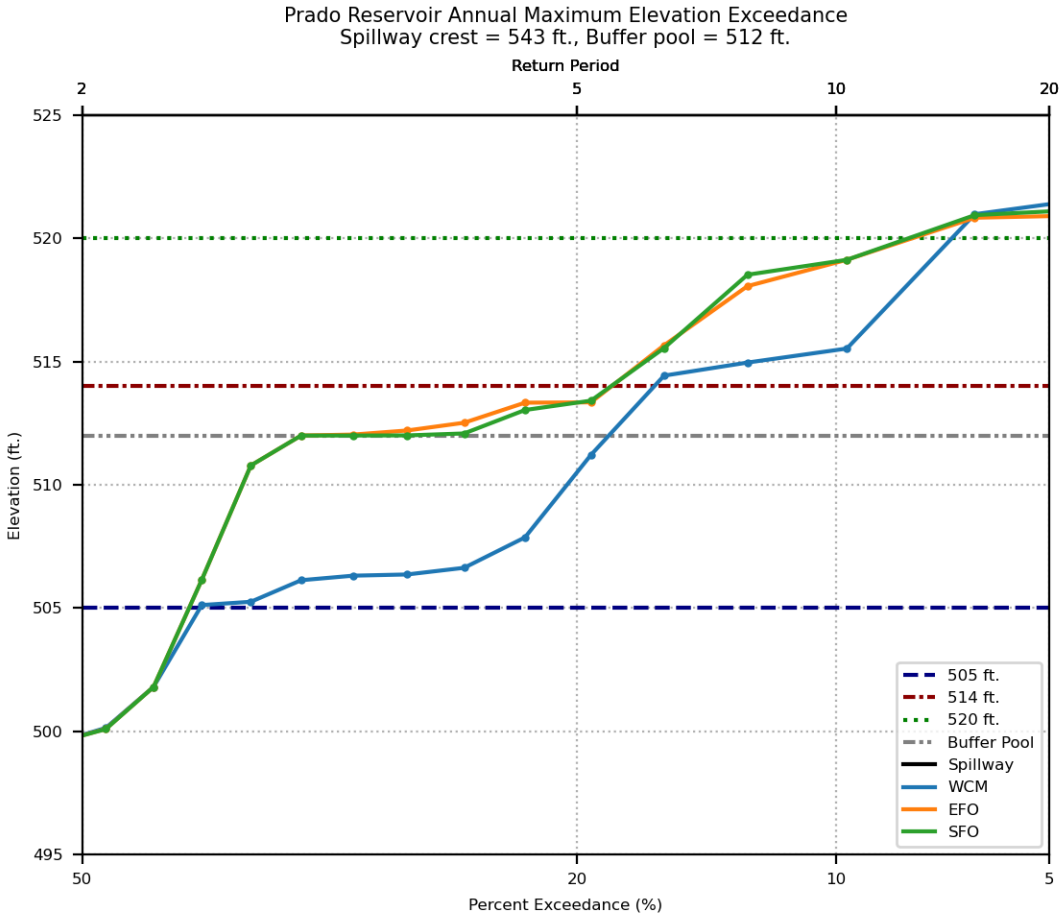

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 520 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
40000
30000
20000
10000
0
Release (cfs)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

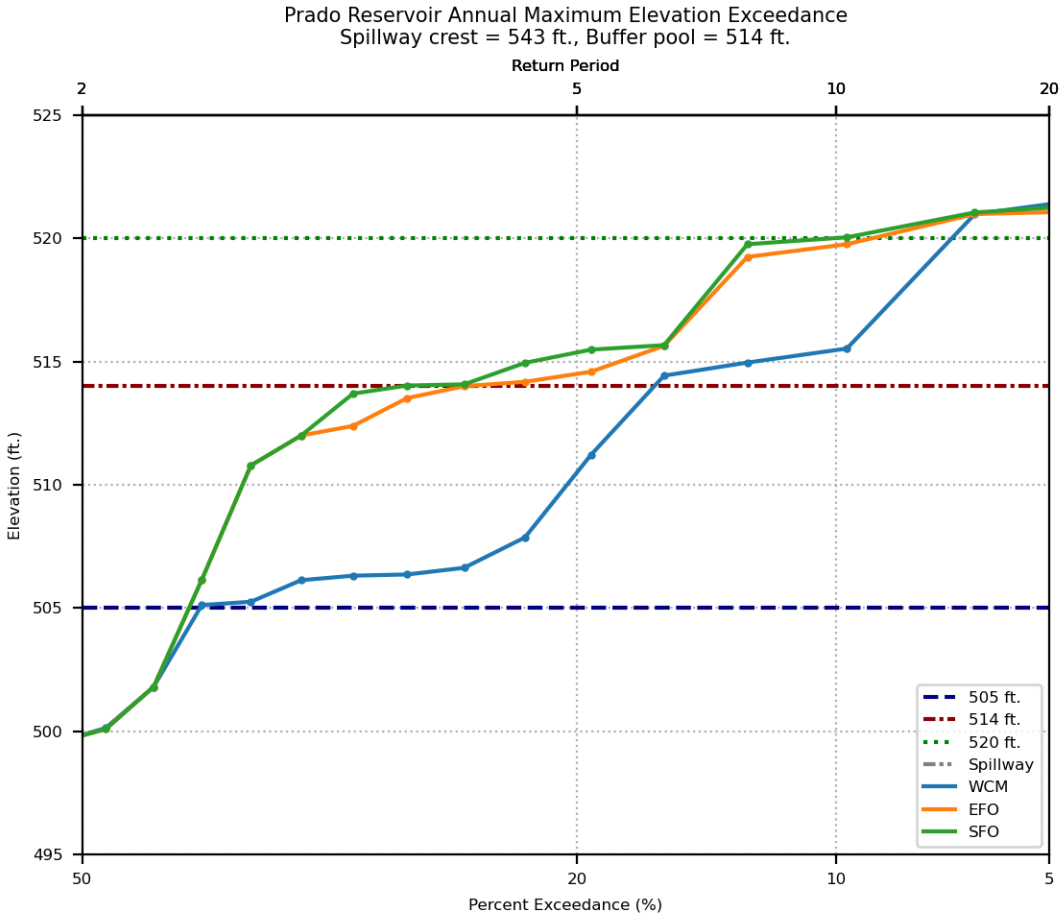
Frequency of Annual Maximum Pool Elevation *by Buffer Pool (NP/NF)* Zoomed

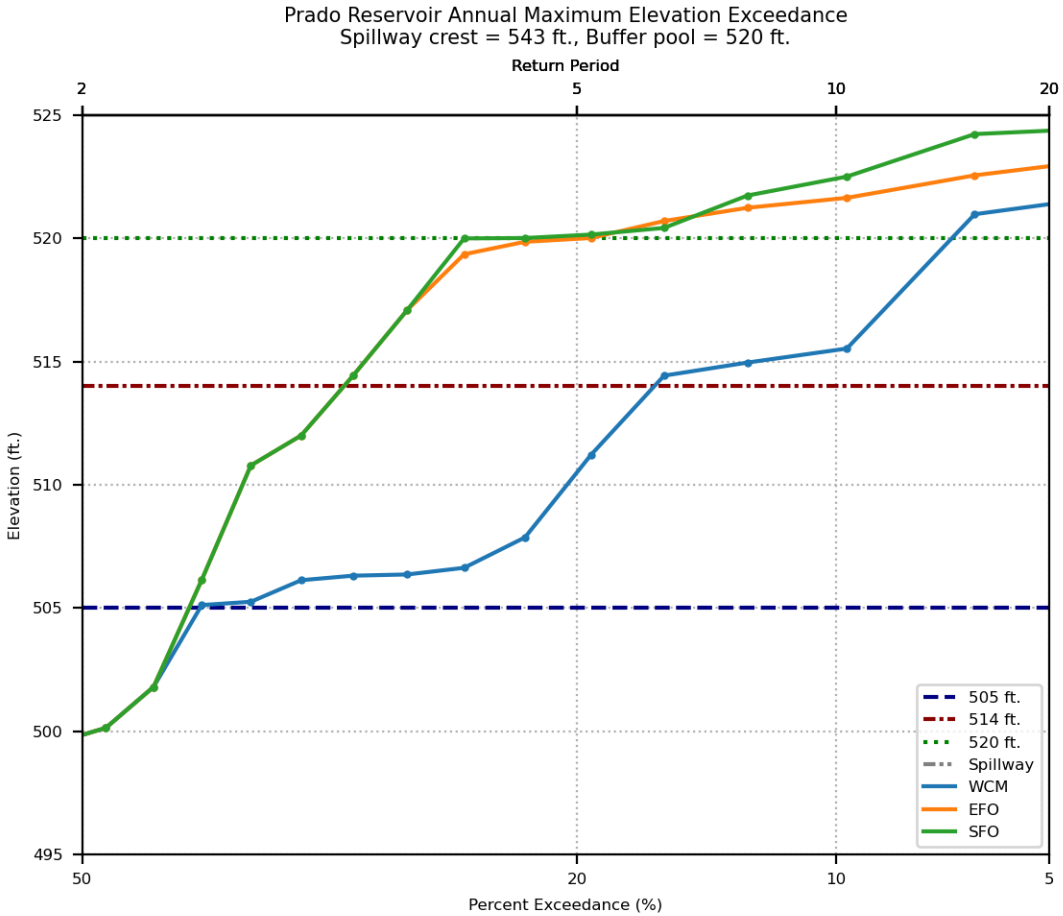
- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’
  - 510’
  - 512’
  - 514’
  - 520’
- WCP alternatives in legend
  - Perfect Forecast results omitted
  - No Forecast results omitted

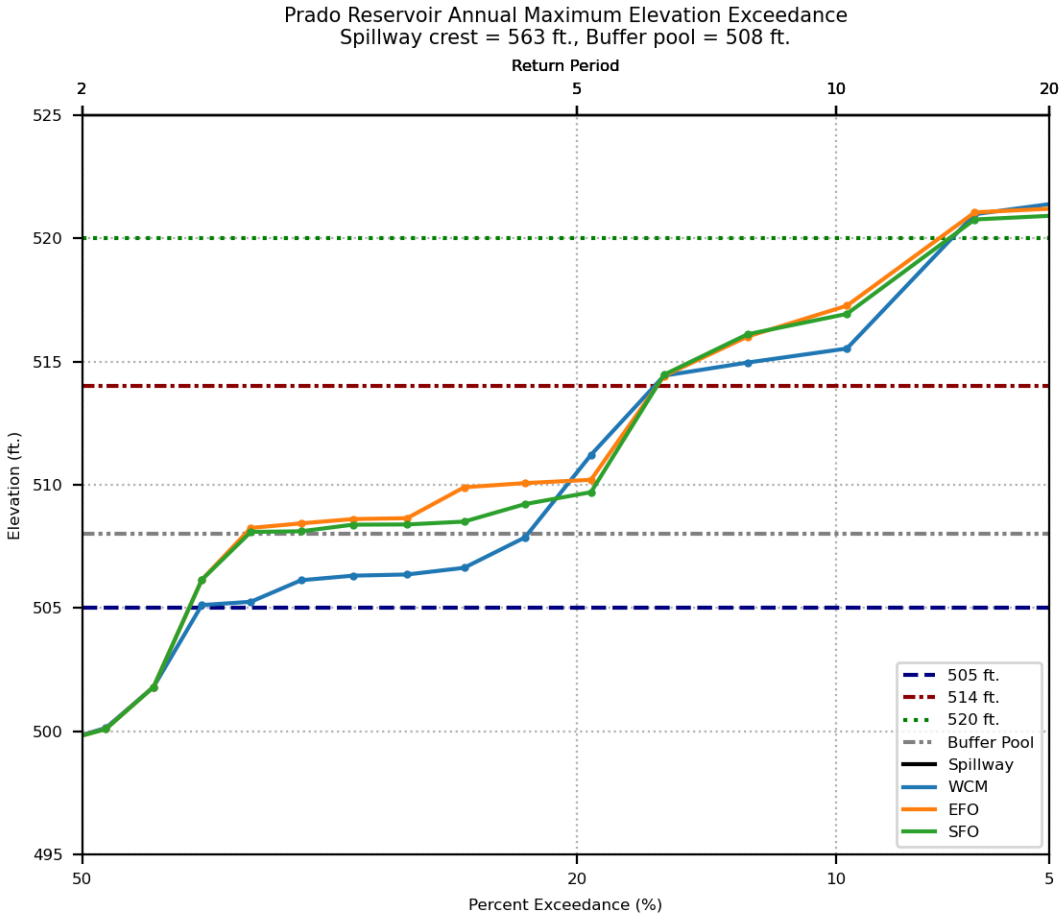

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 508 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
EFO
SFO

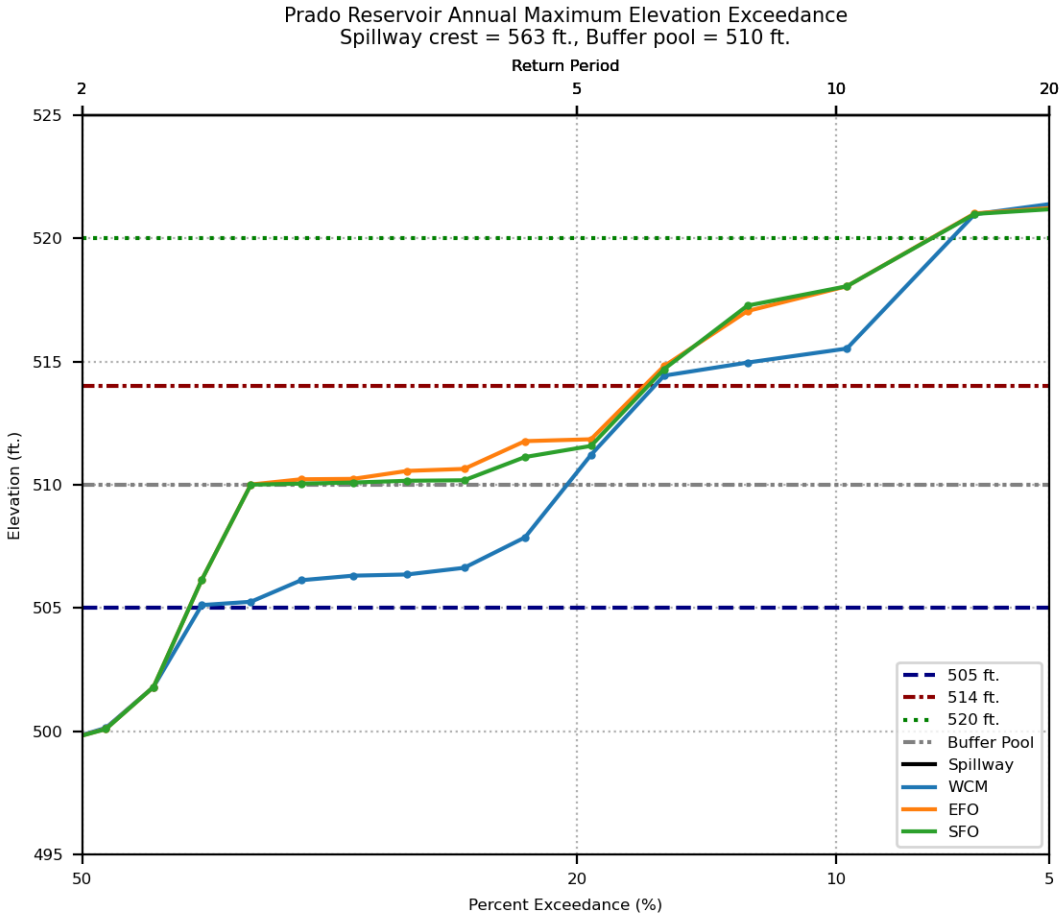

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 510 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
EFO
SFO

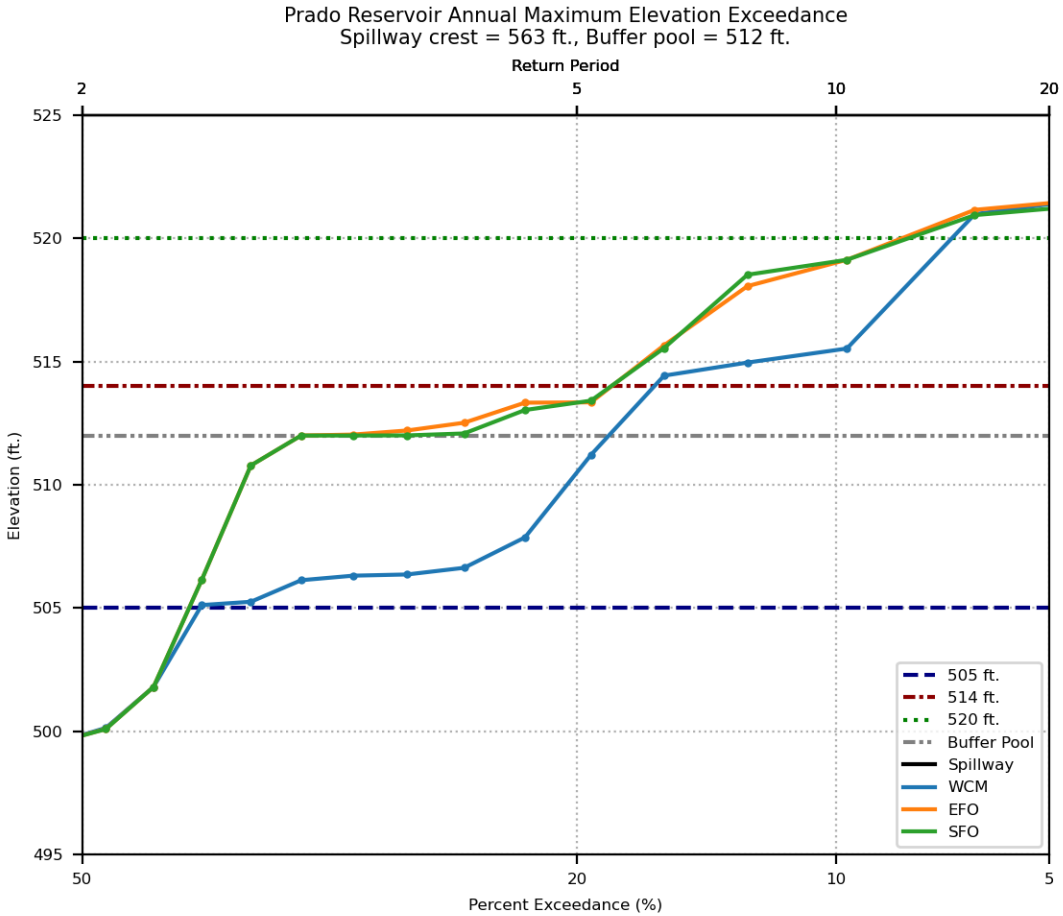

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 512 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
EFO
SFO

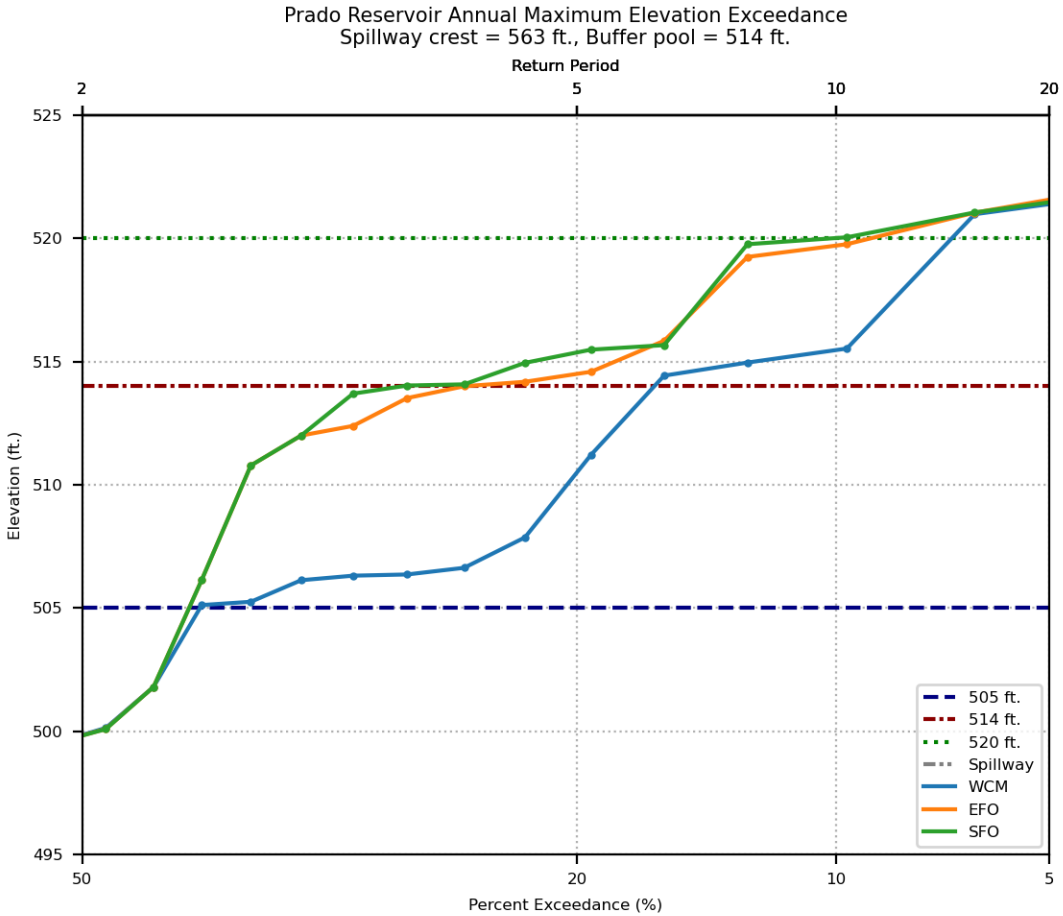

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 514 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Spillway
WCM
EFO
SFO

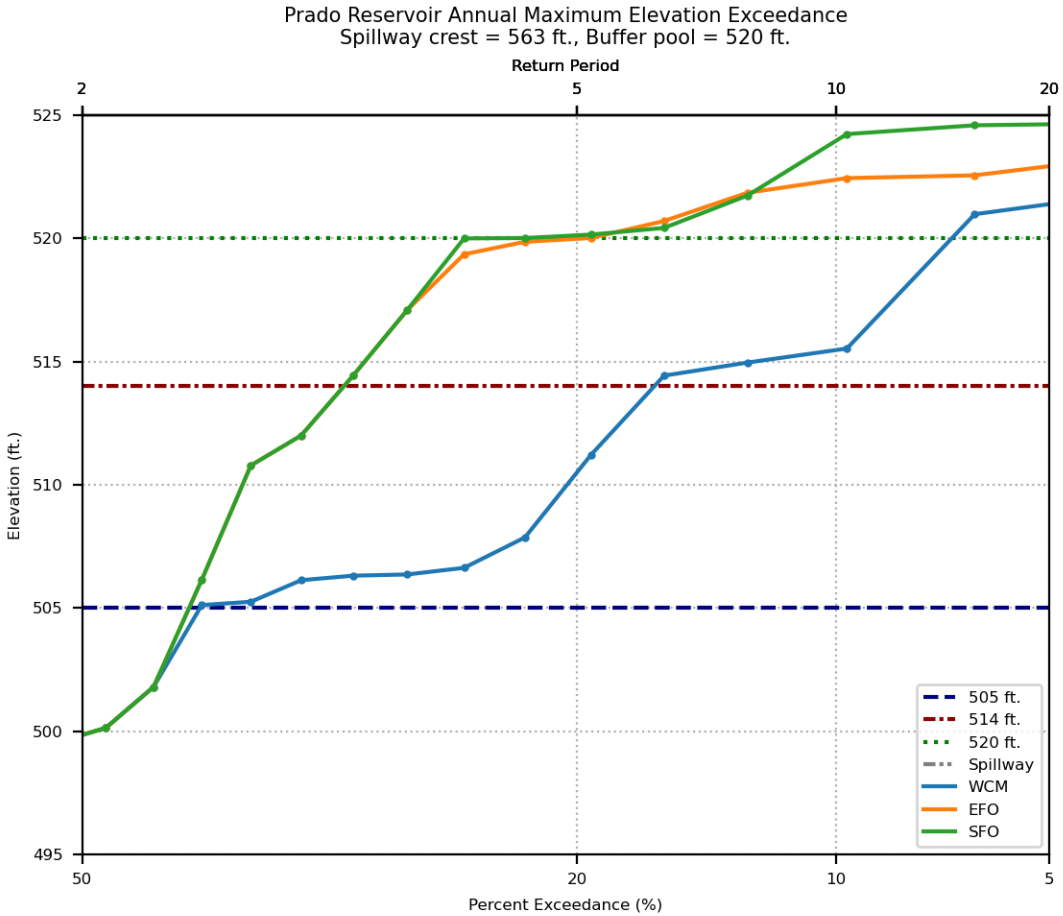

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 520 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Spillway
WCM
EFO
SFO

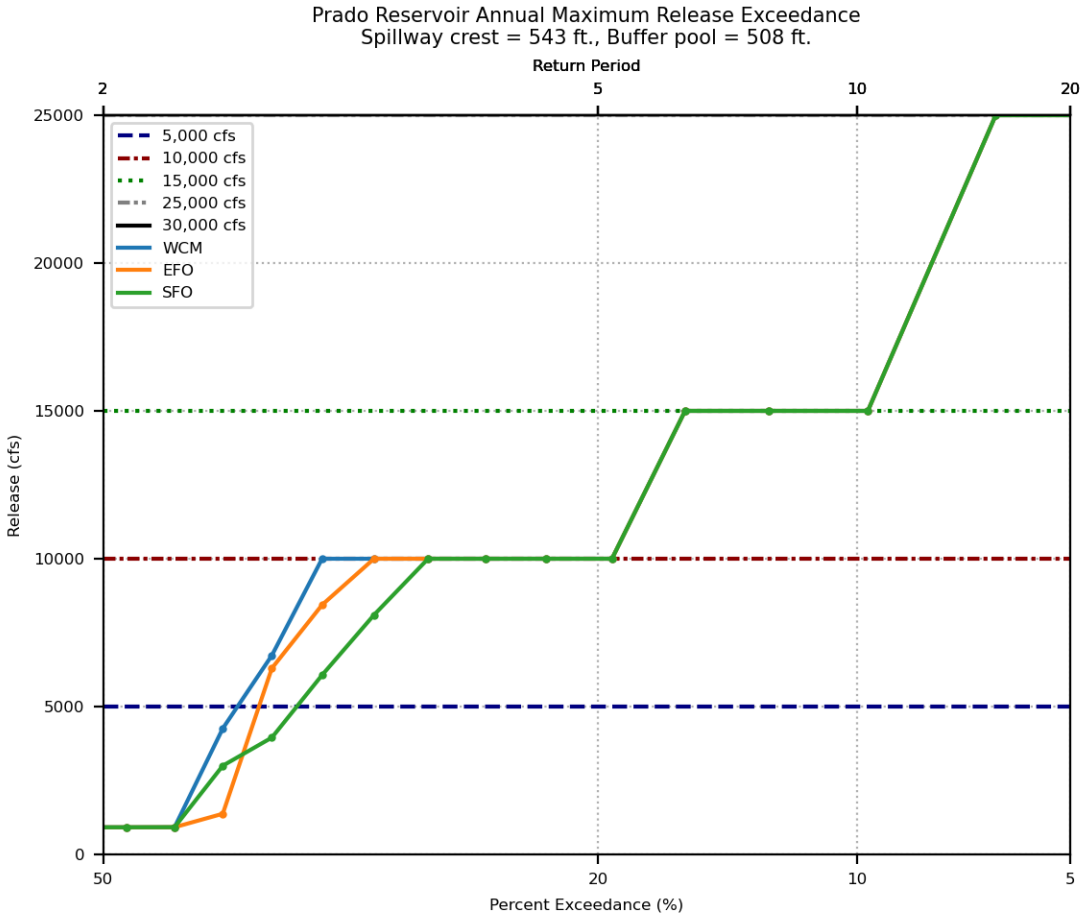

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 508 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
EFO
SFO

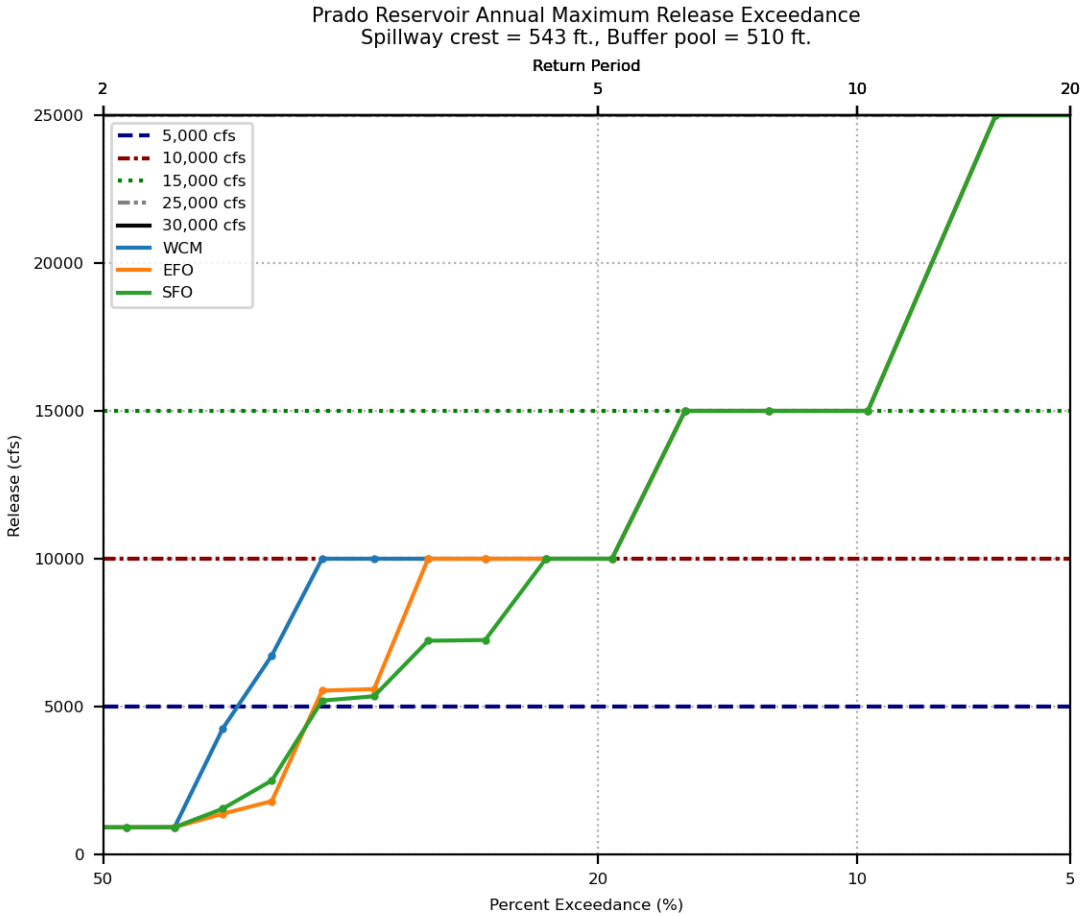

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 510 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
EFO
SFO

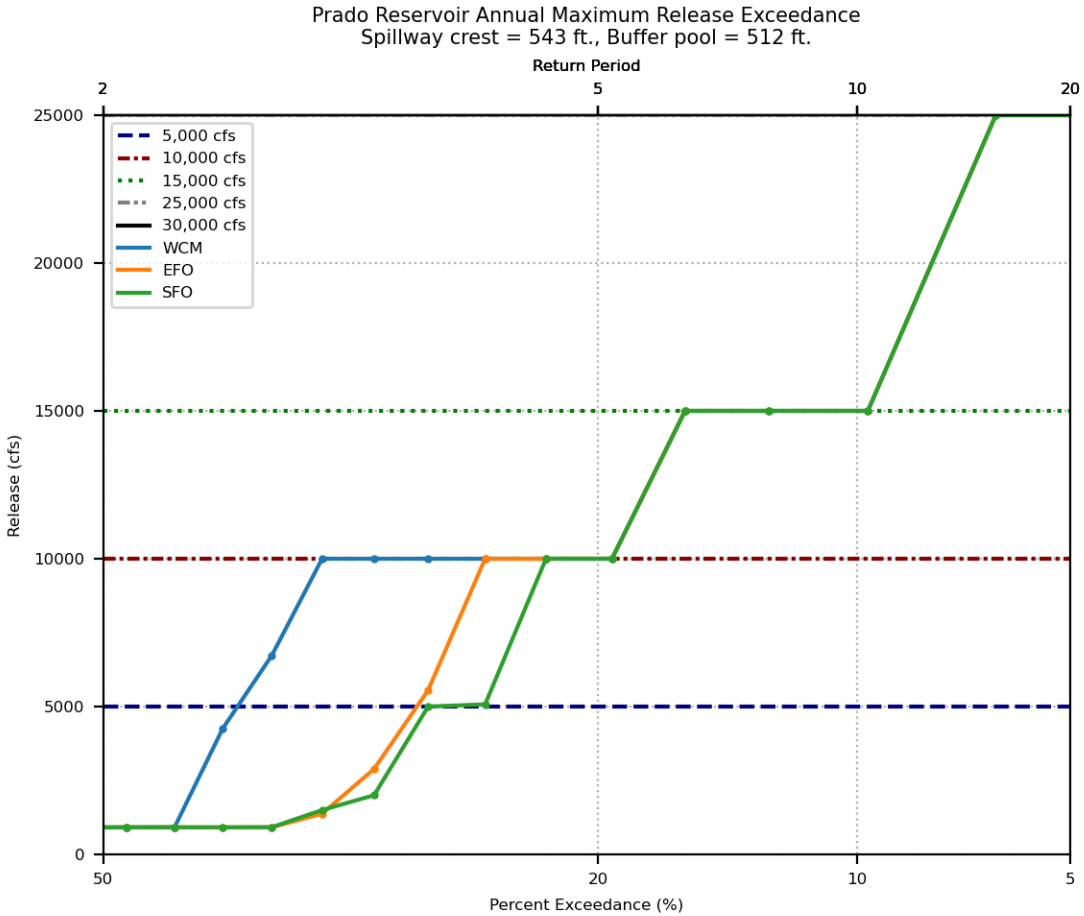

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 512 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
EFO
SFO

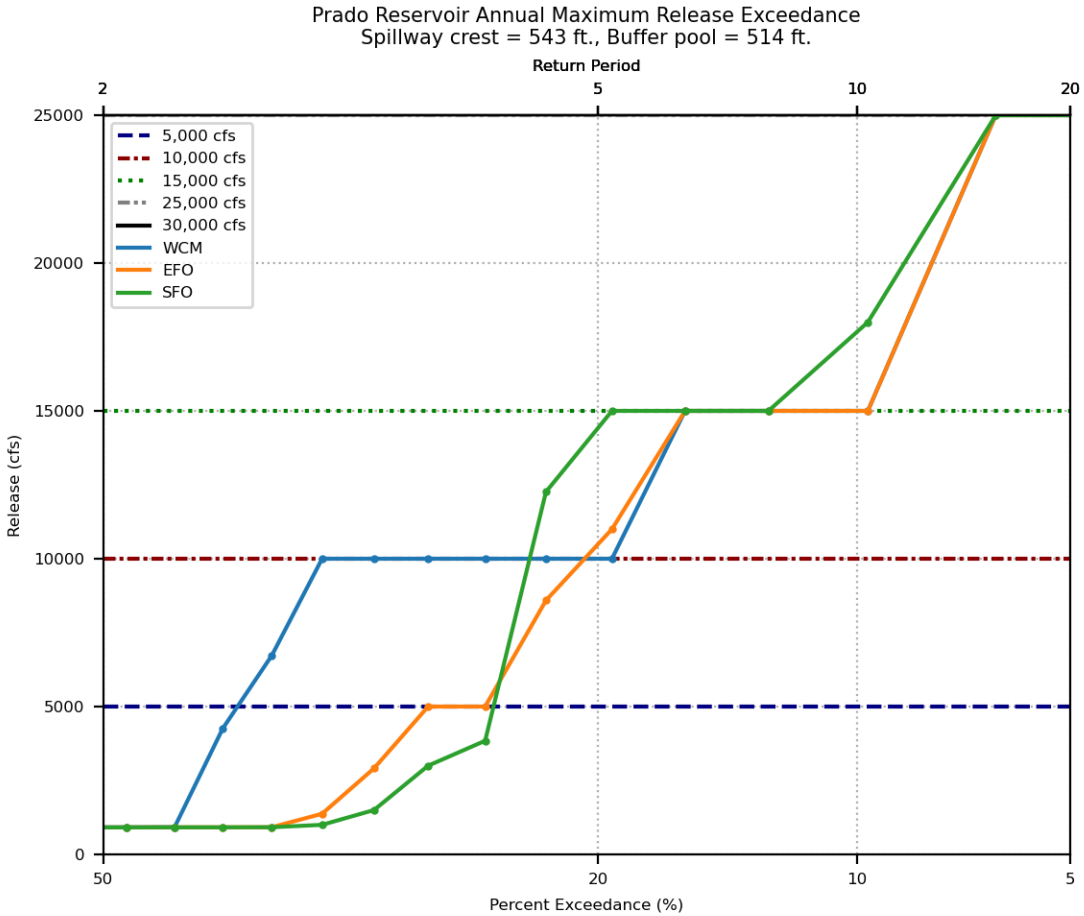

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 514 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Spillway
WCM
EFO
SFO

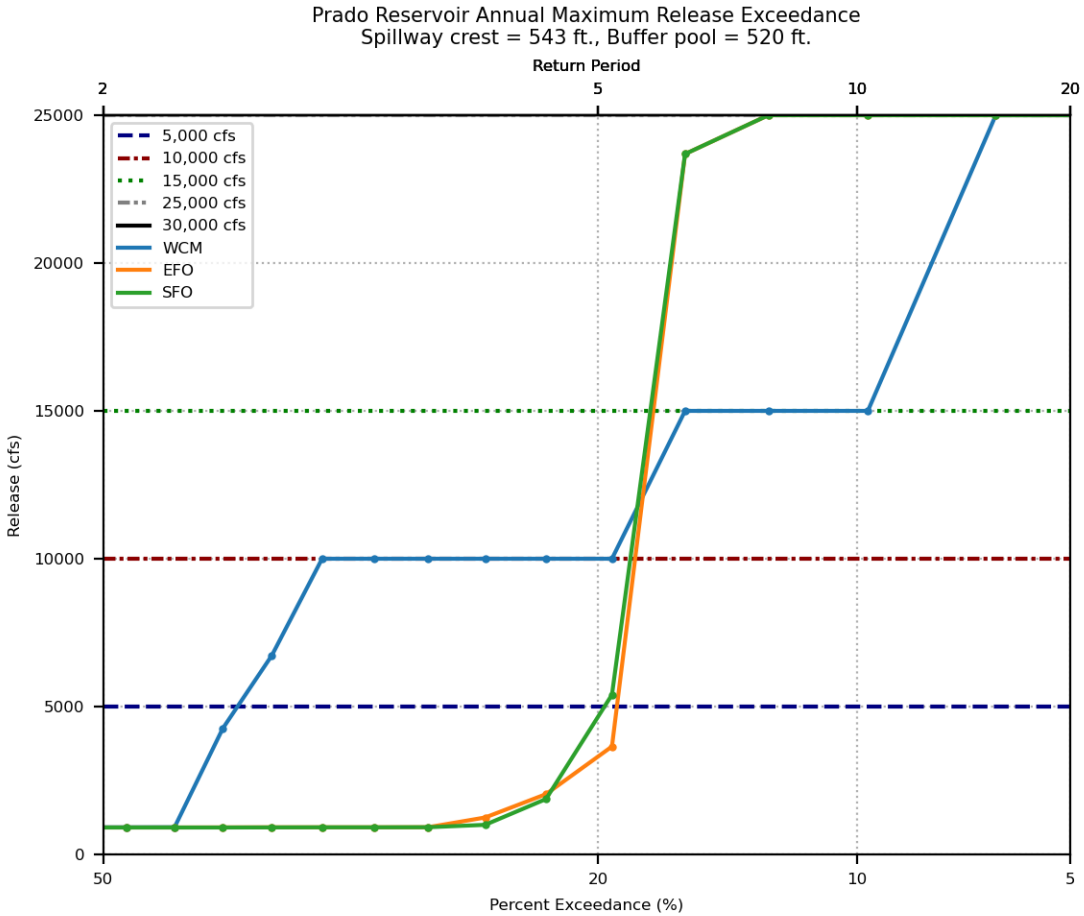

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 520 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Spillway
WCM
EFO
SFO

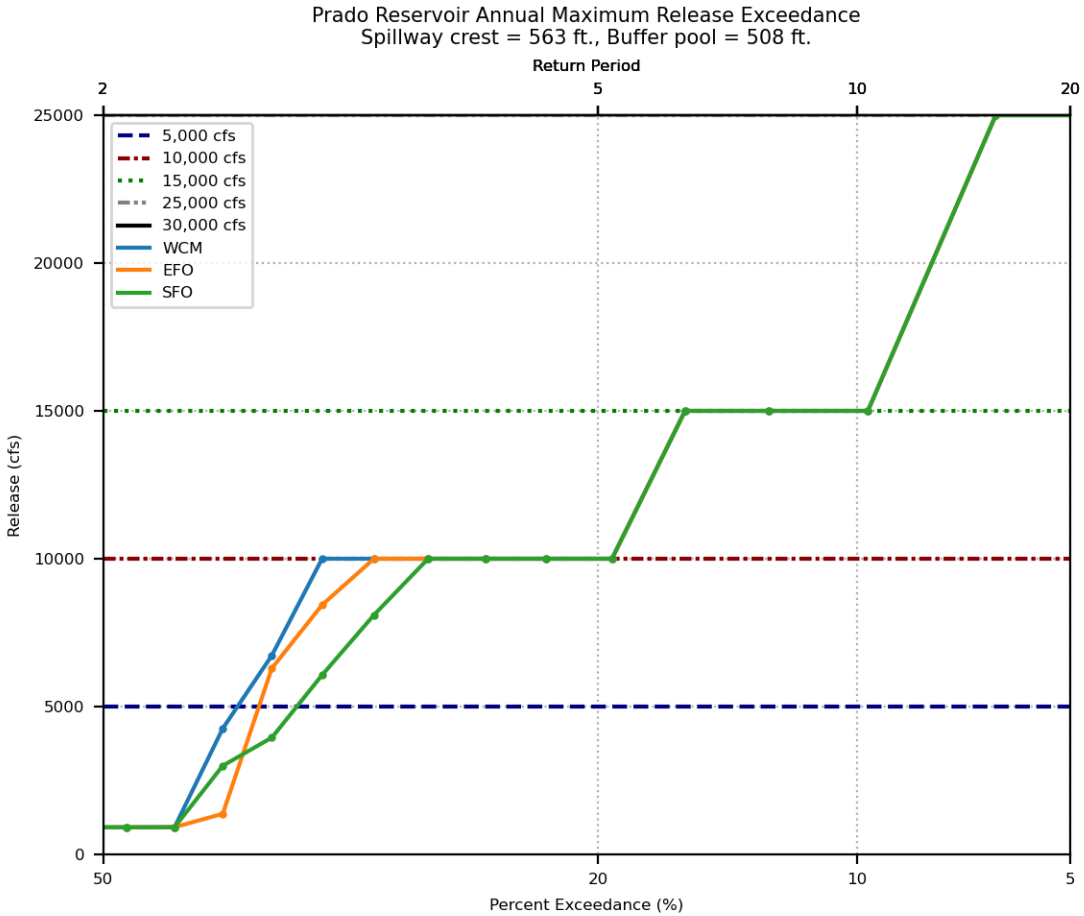

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 508 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
50
20
10
5
Percent Exceedance (%)

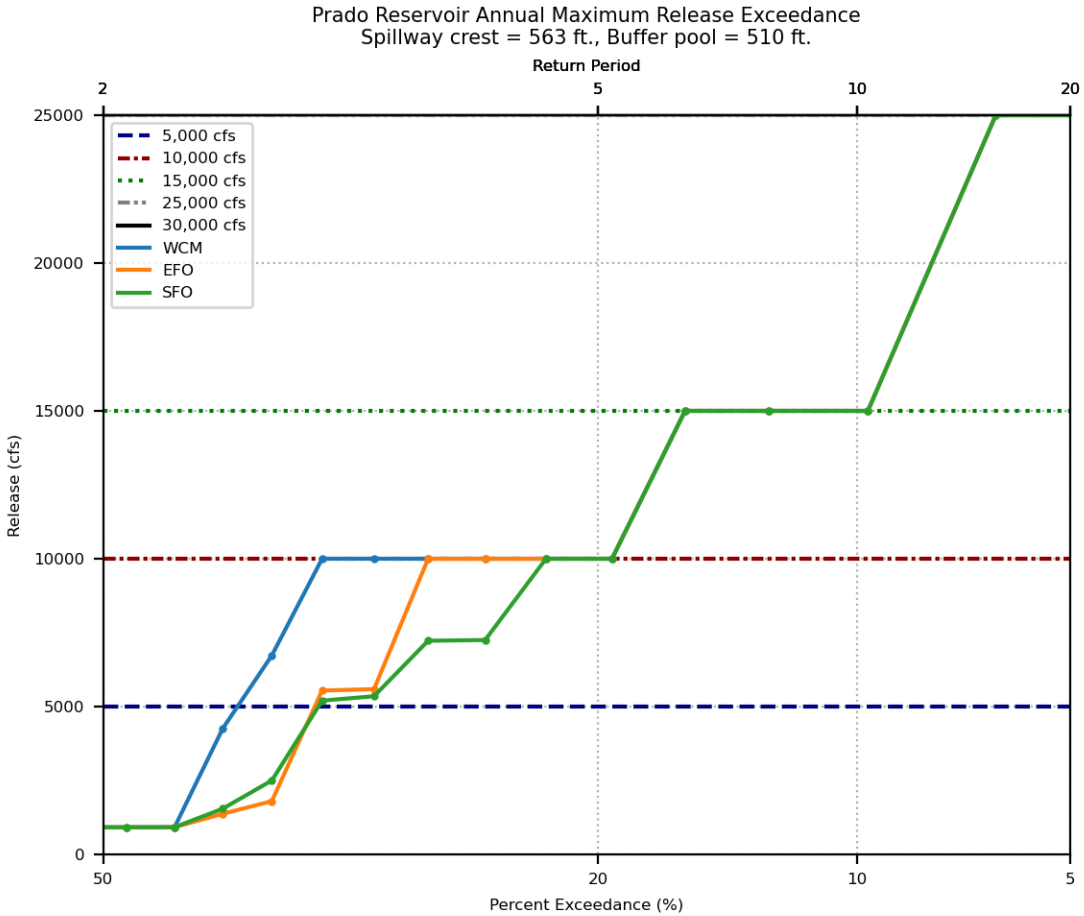

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 510 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
50
20
10
5
Percent Exceedance (%)

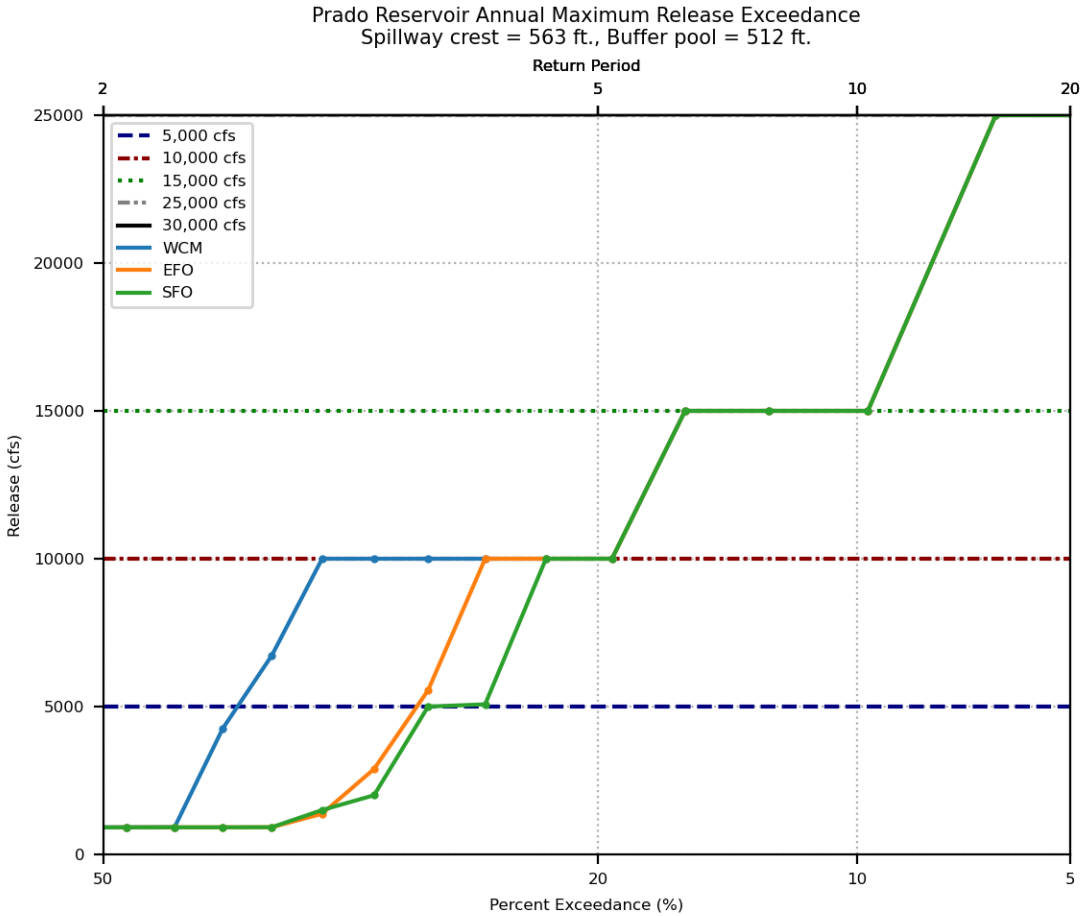

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 512 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
50
20
10
5
Percent Exceedance (%)

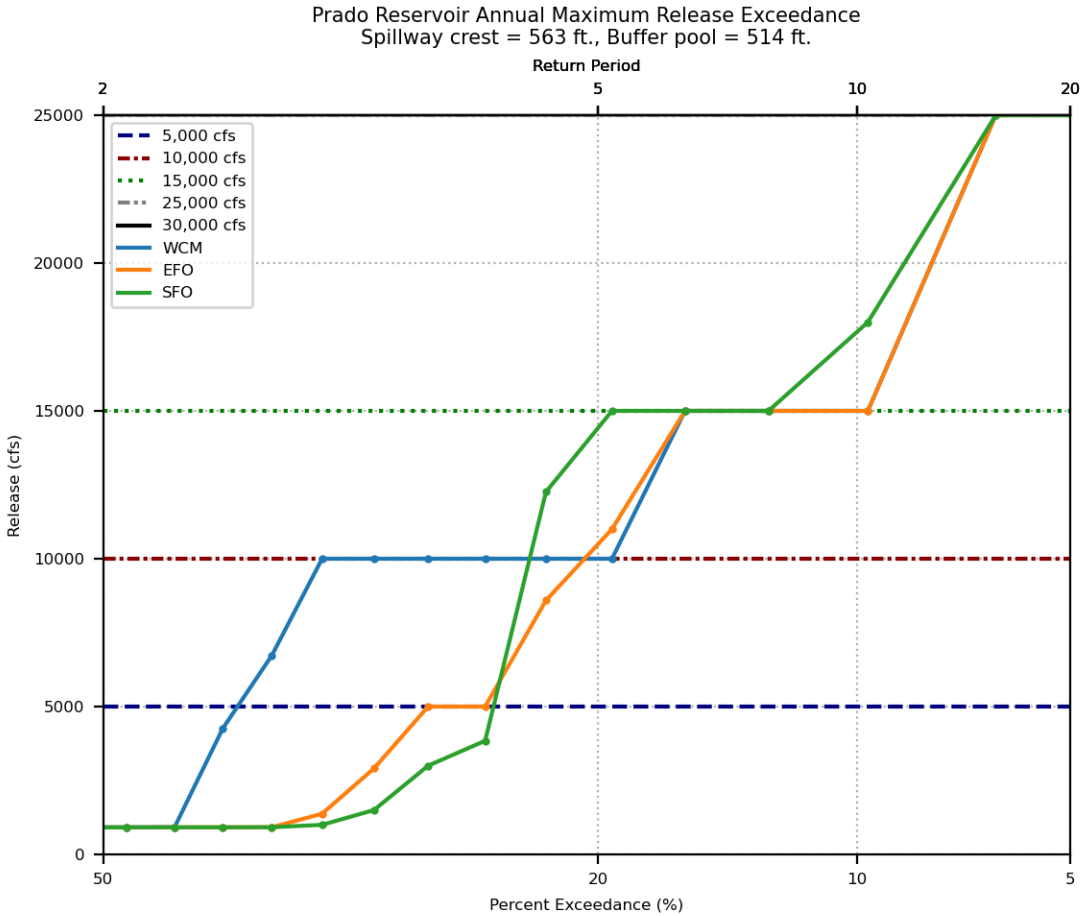

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 514 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
50
20
10
5
Percent Exceedance (%)

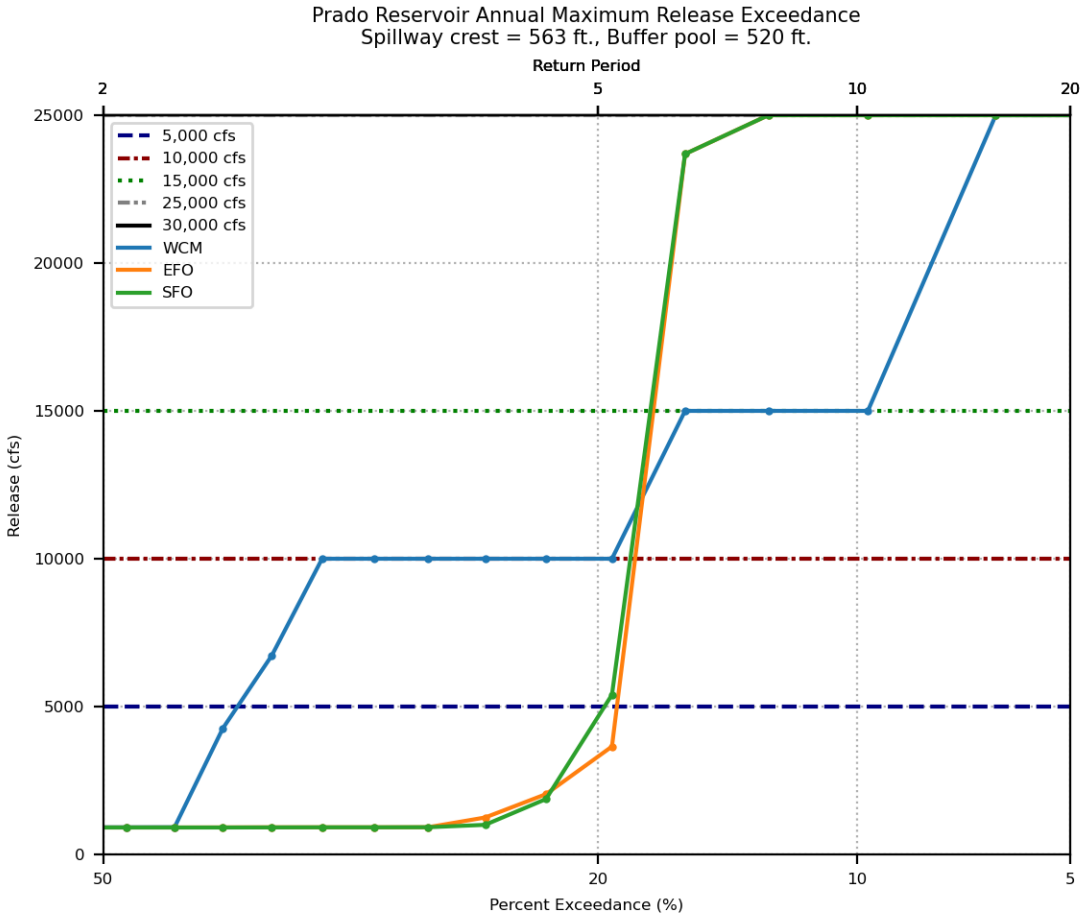

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 520 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
50
20
10
5
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 508 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
50
20
10
5
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 510 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
50
20
10
5
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 512 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
50
20
10
5
Percent Exceedance (%)

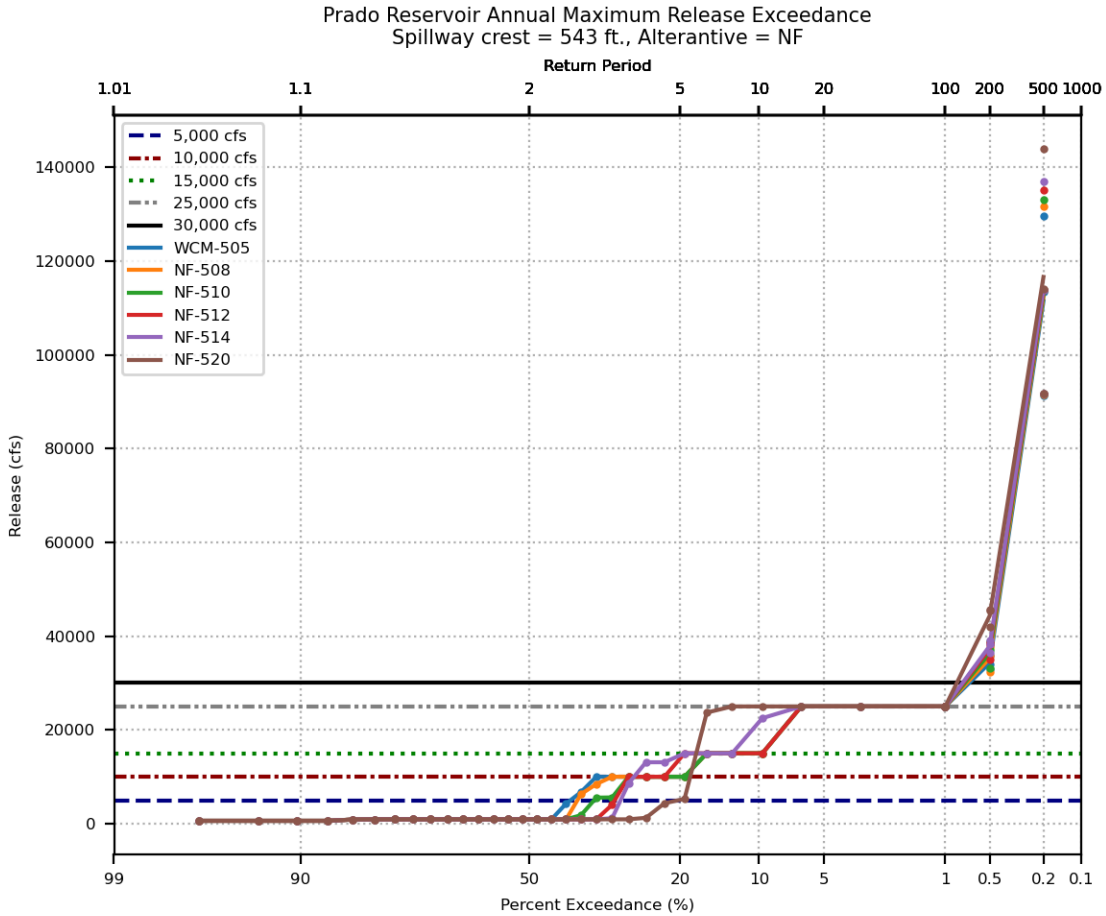

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 514 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
50
20
10
5
Percent Exceedance (%)

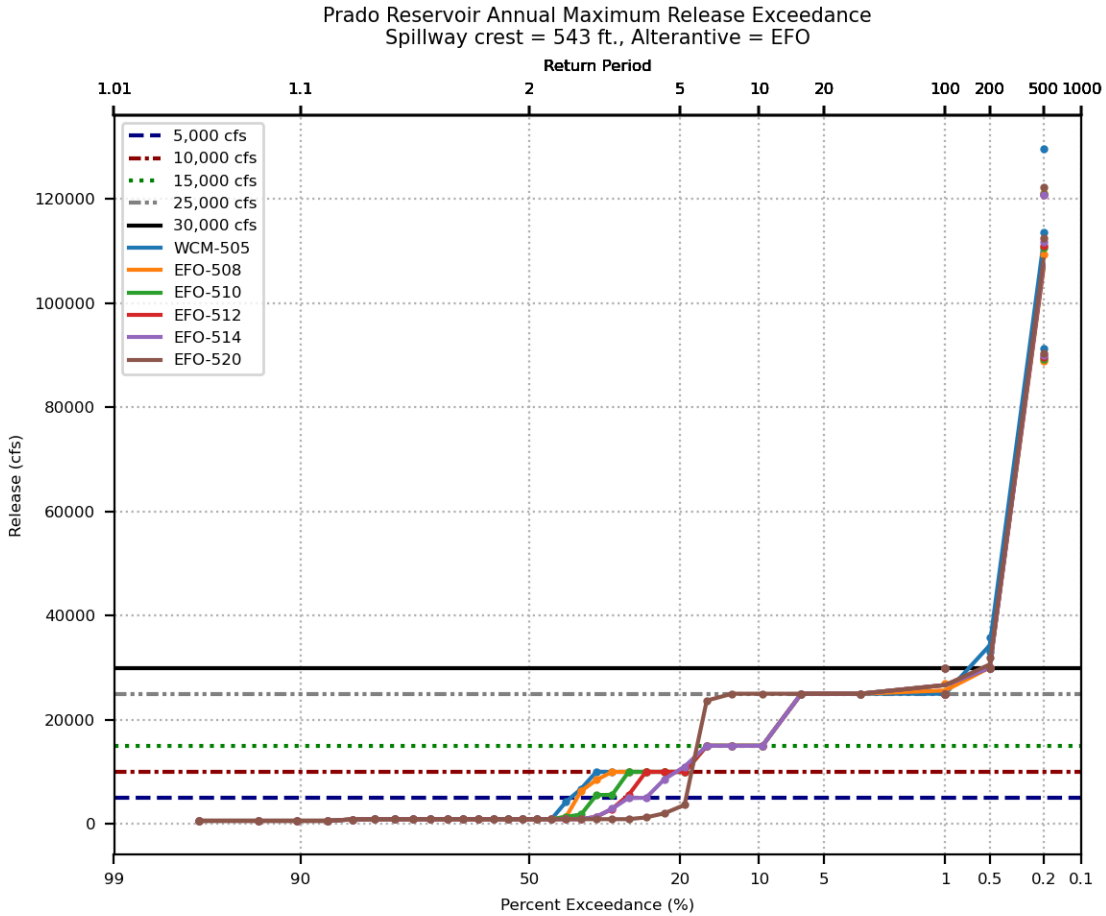

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 520 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
50
20
10
5
Percent Exceedance (%)

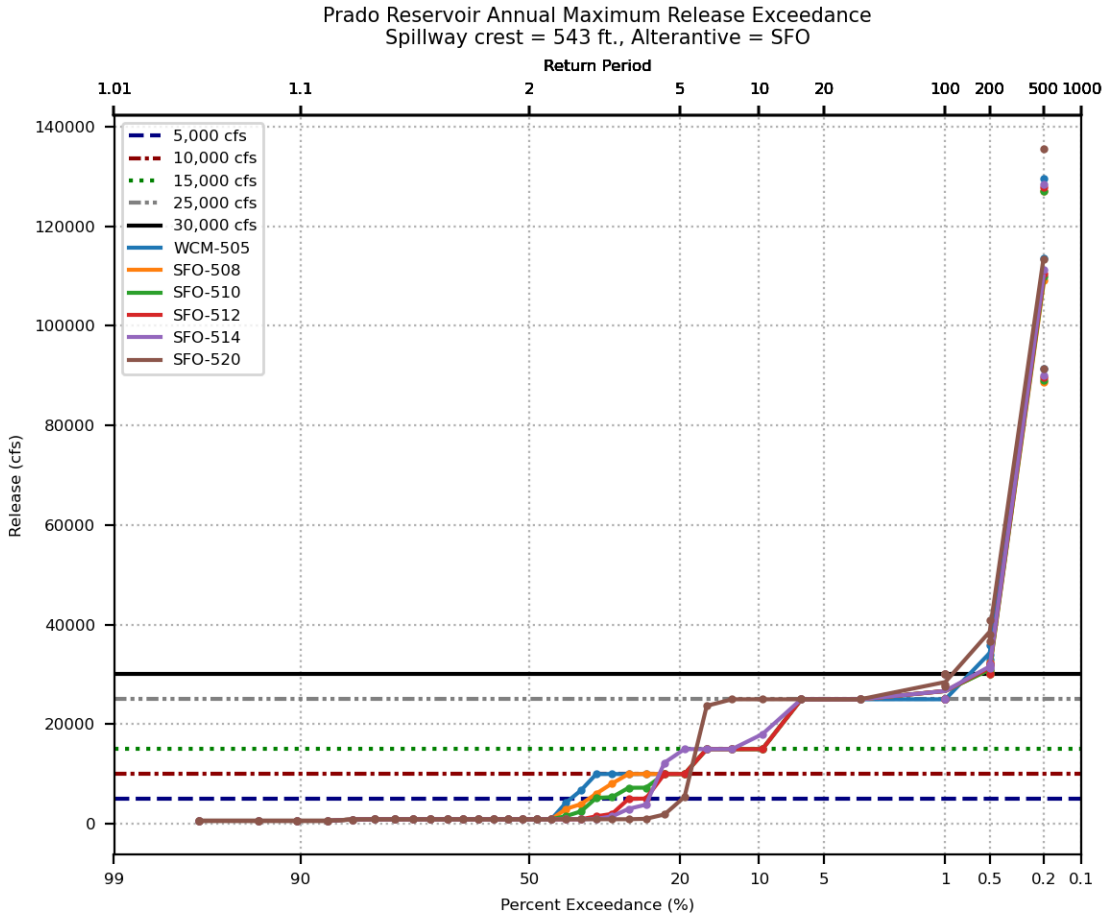
APPENDIX B-3

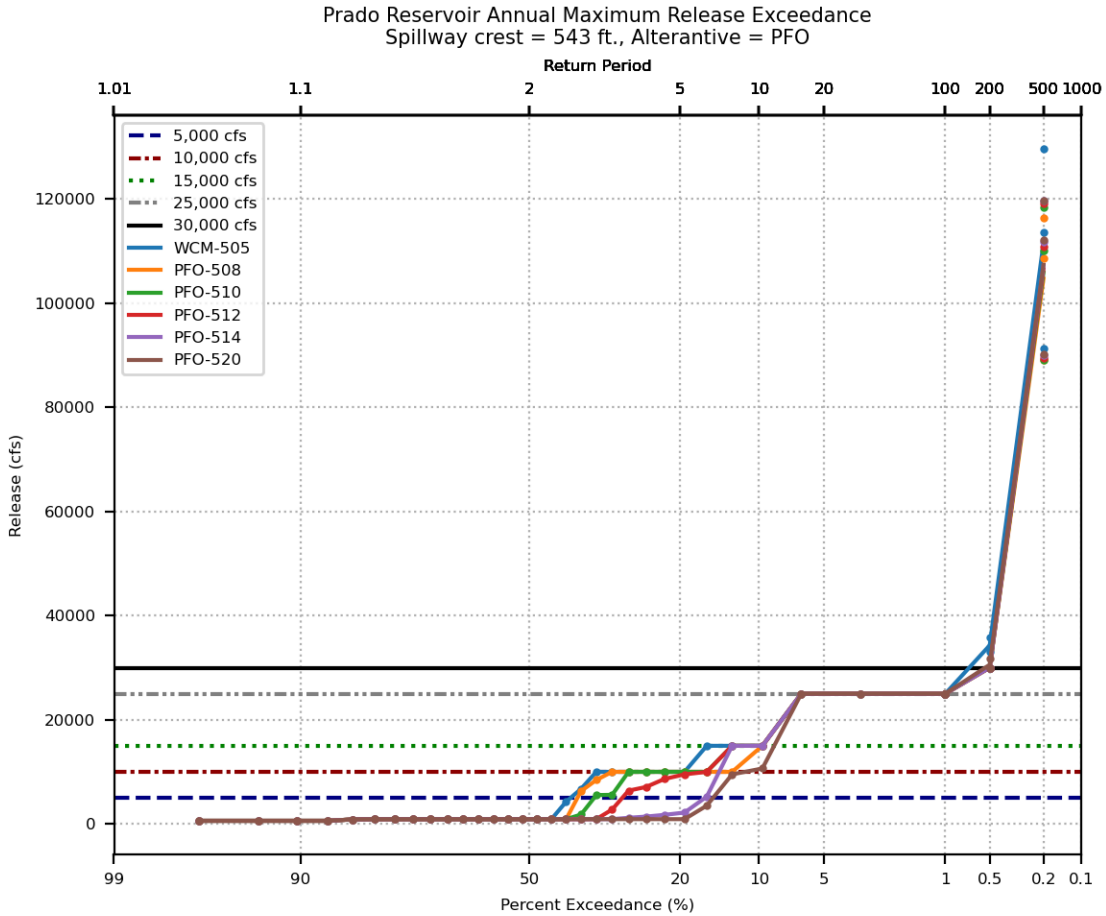
Frequency of Annual Maximum Reservoir Release by *WCP Alternative*

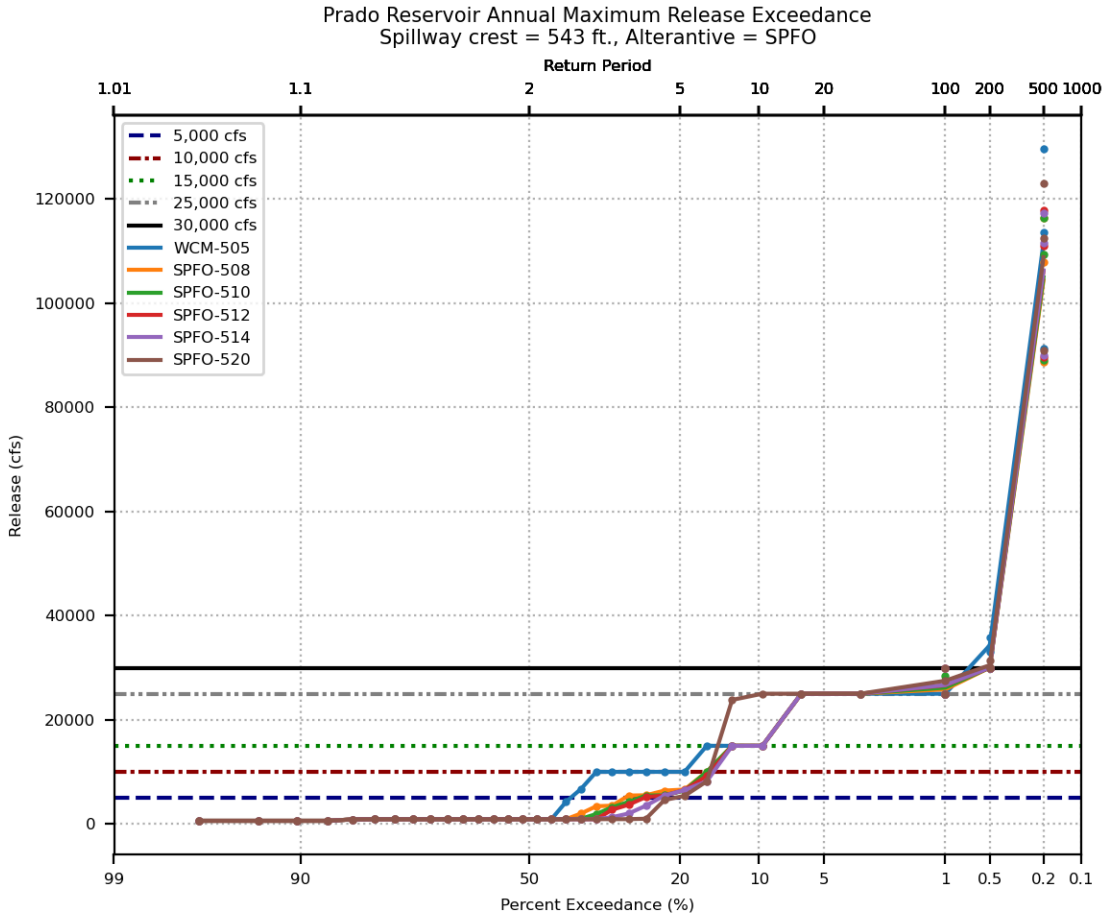
- Spillway elevations of 543’ and 563’
- WCP Alternatives
  - No Forecast (NF)
  - EFO
  - SFO
  - PFO (EFO w/perfect forecasts)
  - SPFO (SFO w/perfect forecasts)
- Maximum buffer pool elevations in legend

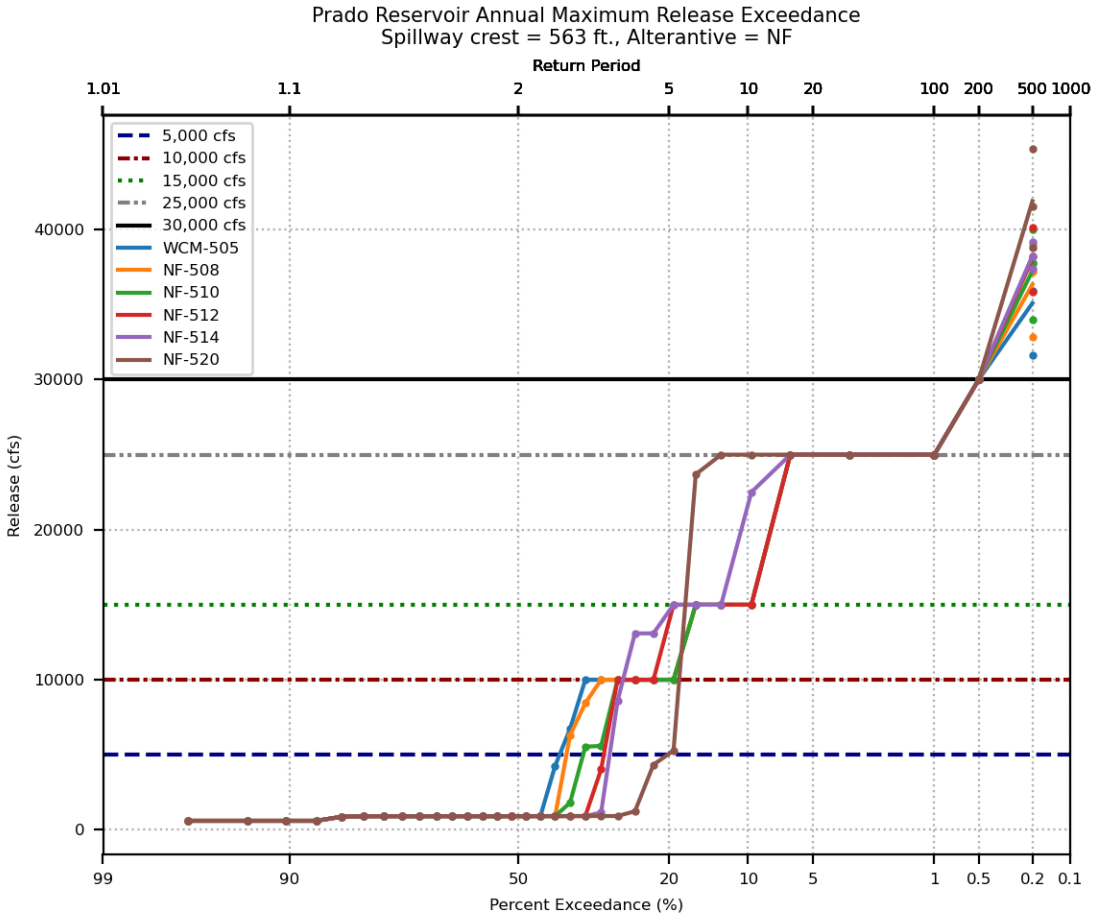

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Alterantive = NF
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Release (cfs)
140000
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

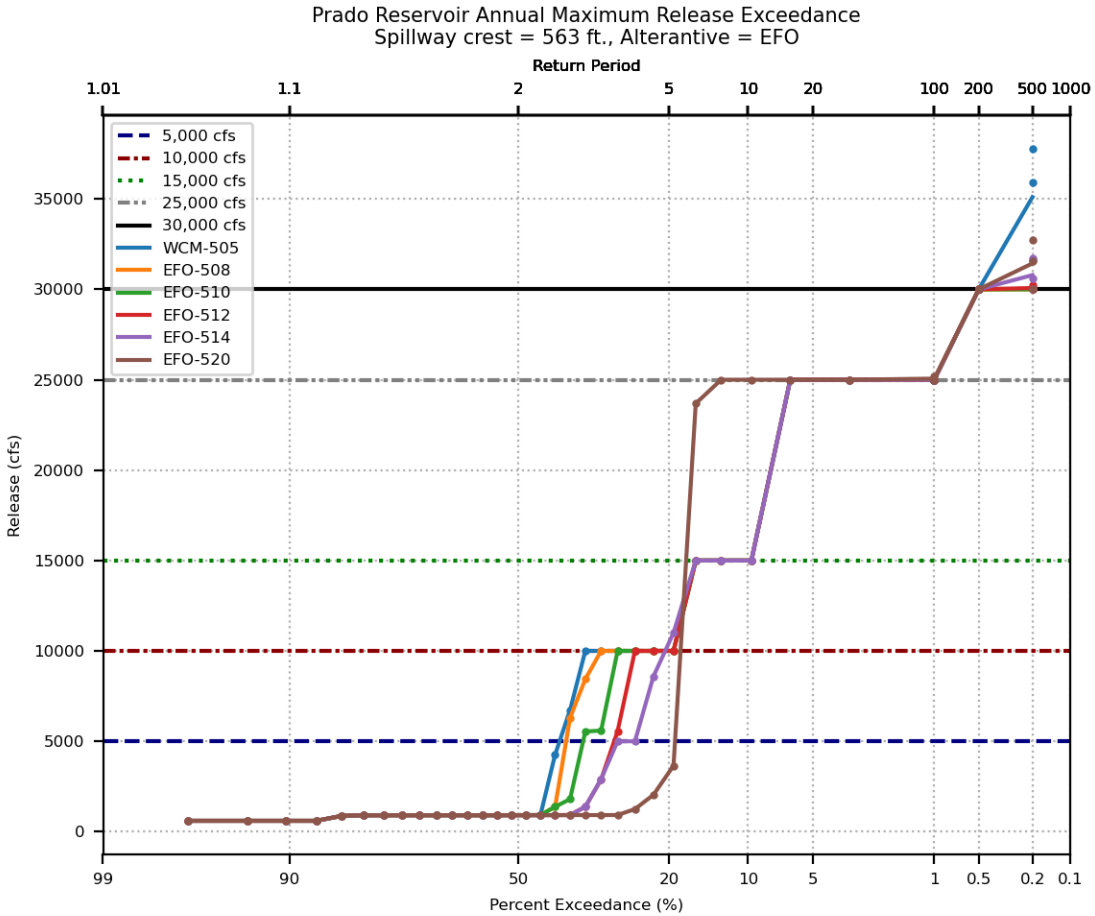

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Alterantive = EFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM-505
EFO-508
EFO-510
EFO-512
EFO-514
EFO-520
Release (cfs)
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

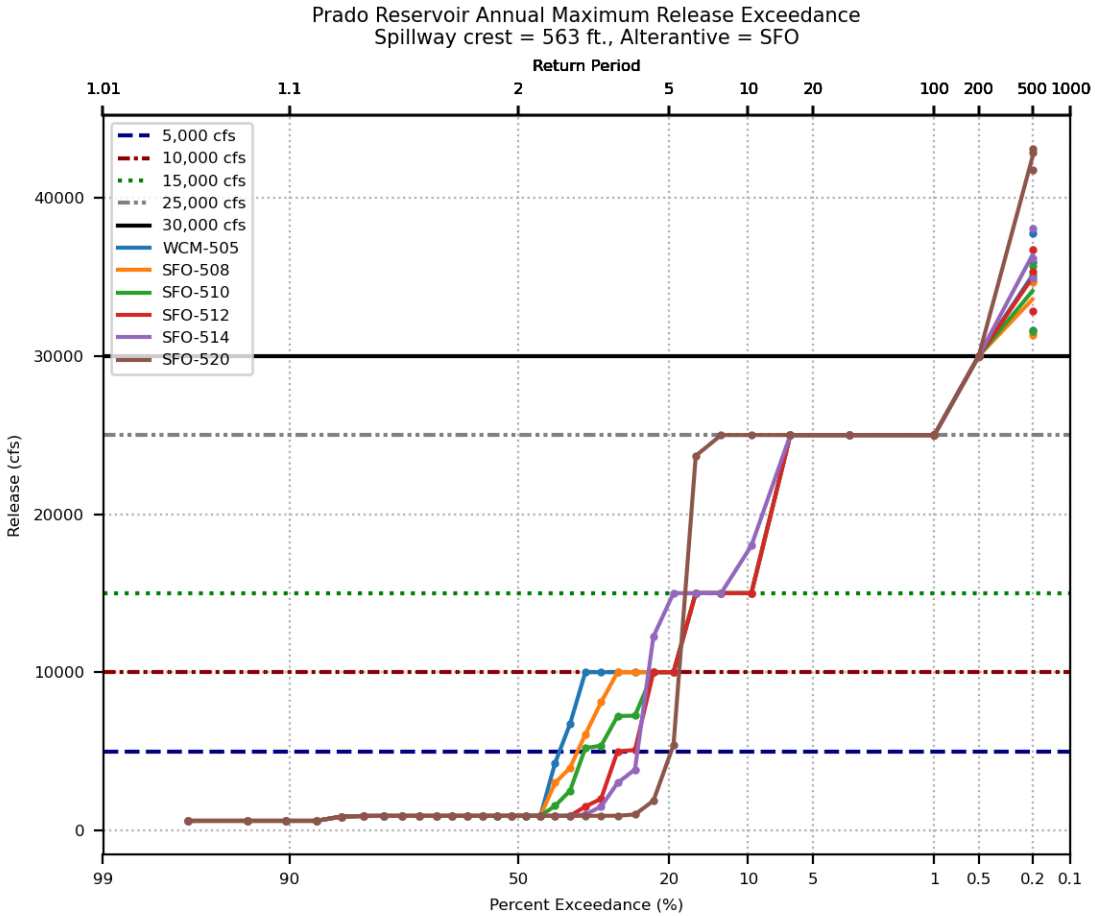

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Alterantive = SFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
140000
120000
100000
80000
60000
40000
20000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM-505
SFO-508
SFO-510
SFO-512
SFO-514
SFO-520
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

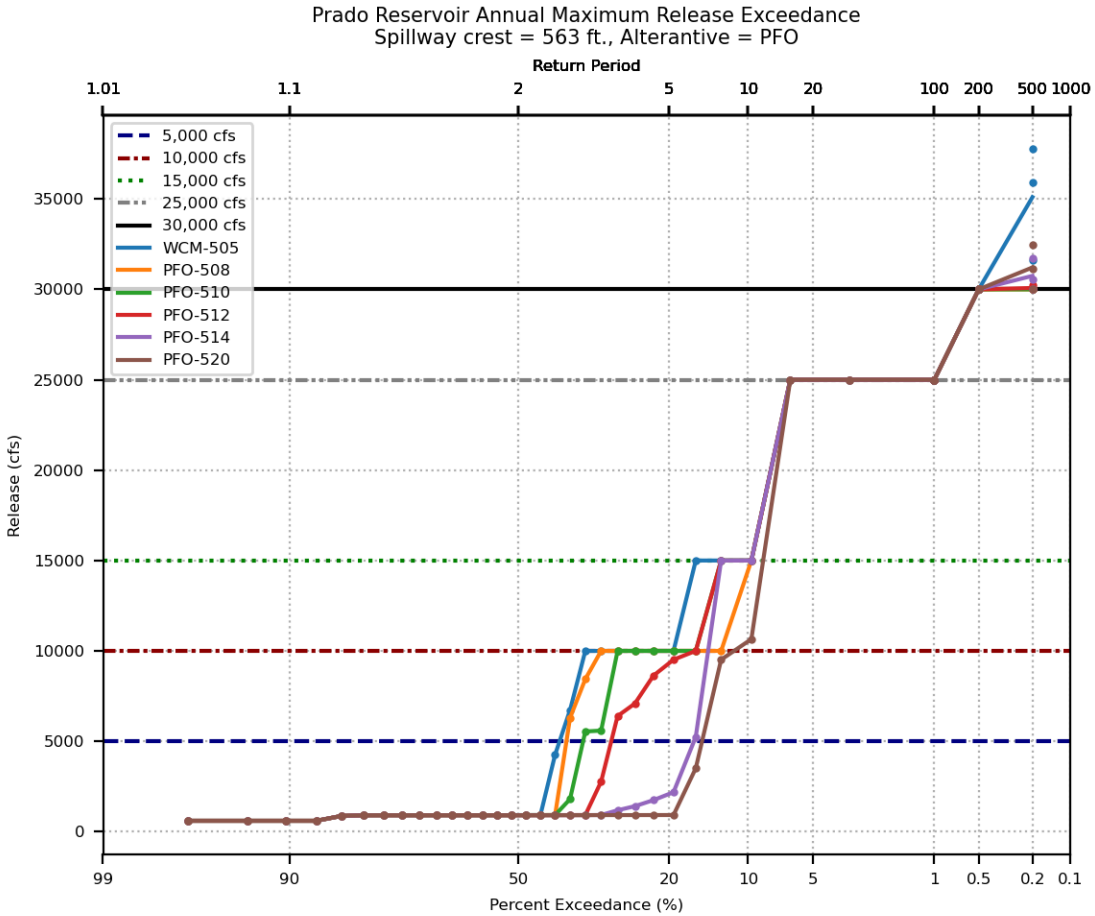

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Alterantive = PFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM-505
PFO-508
PFO-510
PFO-512
PFO-514
PFO-520
Release (cfs)
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

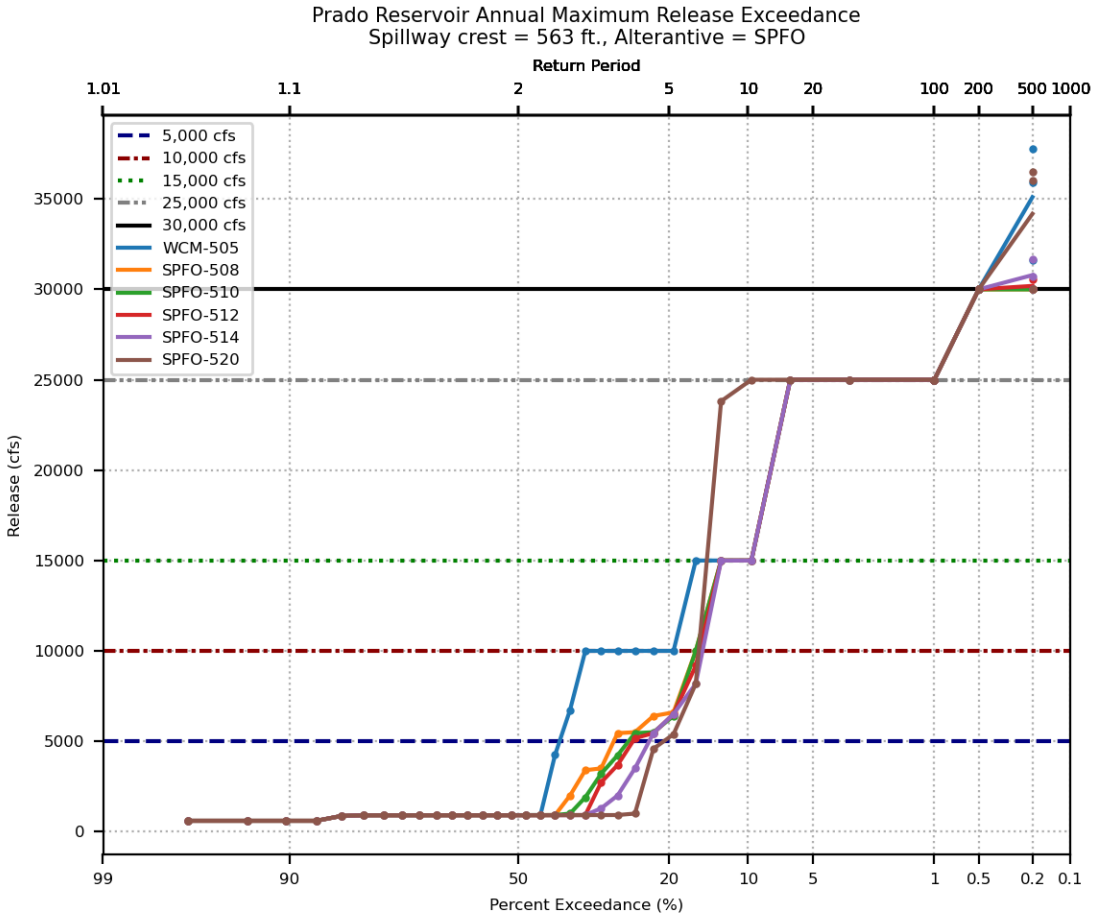

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Alterantive = SPFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM-505
SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
Release (cfs)
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Alterantive = NF
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Release (cfs)
40000
30000
20000
10000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Alterantive = EFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM-505
EFO-508
EFO-510
EFO-512
EFO-514
EFO-520
35000
30000
25000
20000
15000
10000
5000
0
Release (cfs)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

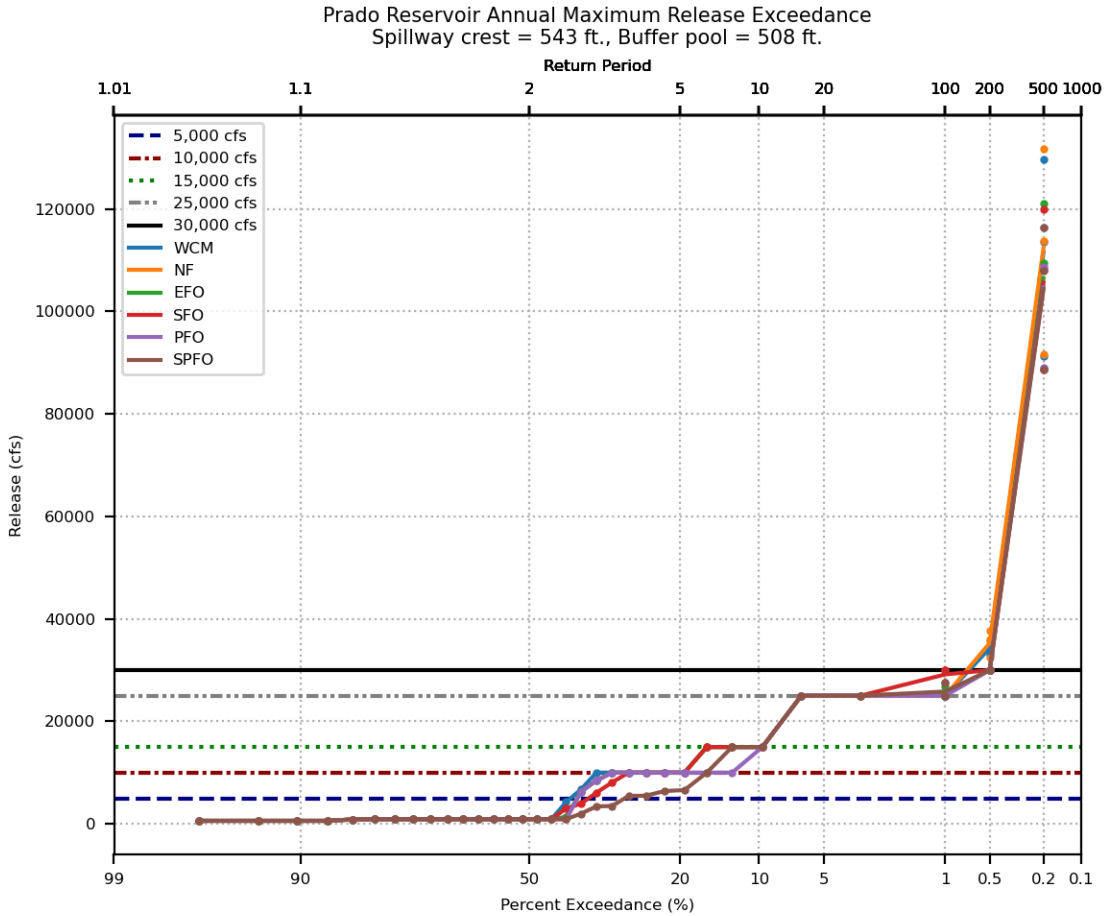

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Alterantive = SFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM-505
SFO-508
SFO-510
SFO-512
SFO-514
SFO-520
Release (cfs)
40000
30000
20000
10000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

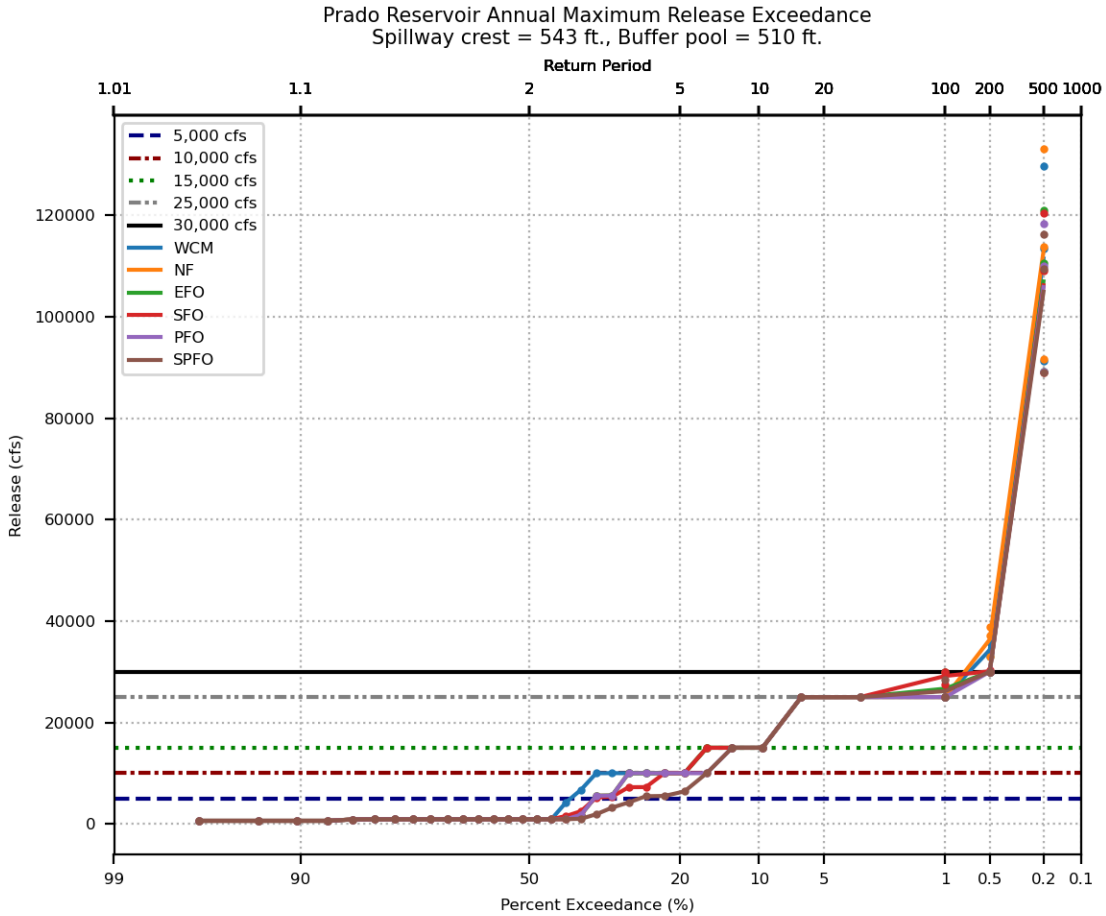

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Alterantive = PFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM-505
PFO-508
PFO-510
PFO-512
PFO-514
PFO-520
Release (cfs)
35000
30000
25000
20000
15000
10000
5000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

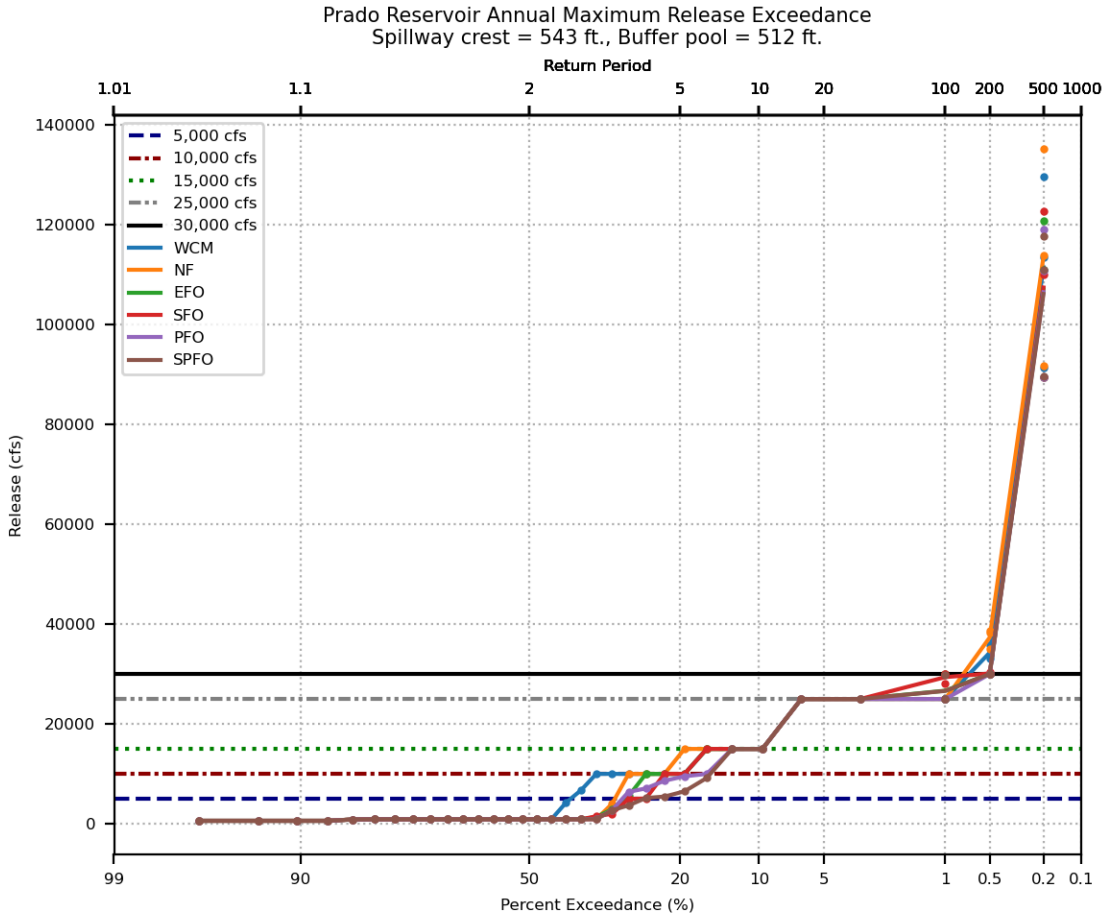

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Alterantive = SPFO
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM-505
SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
Release (cfs)
35000
30000
25000
20000
15000
10000
5000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

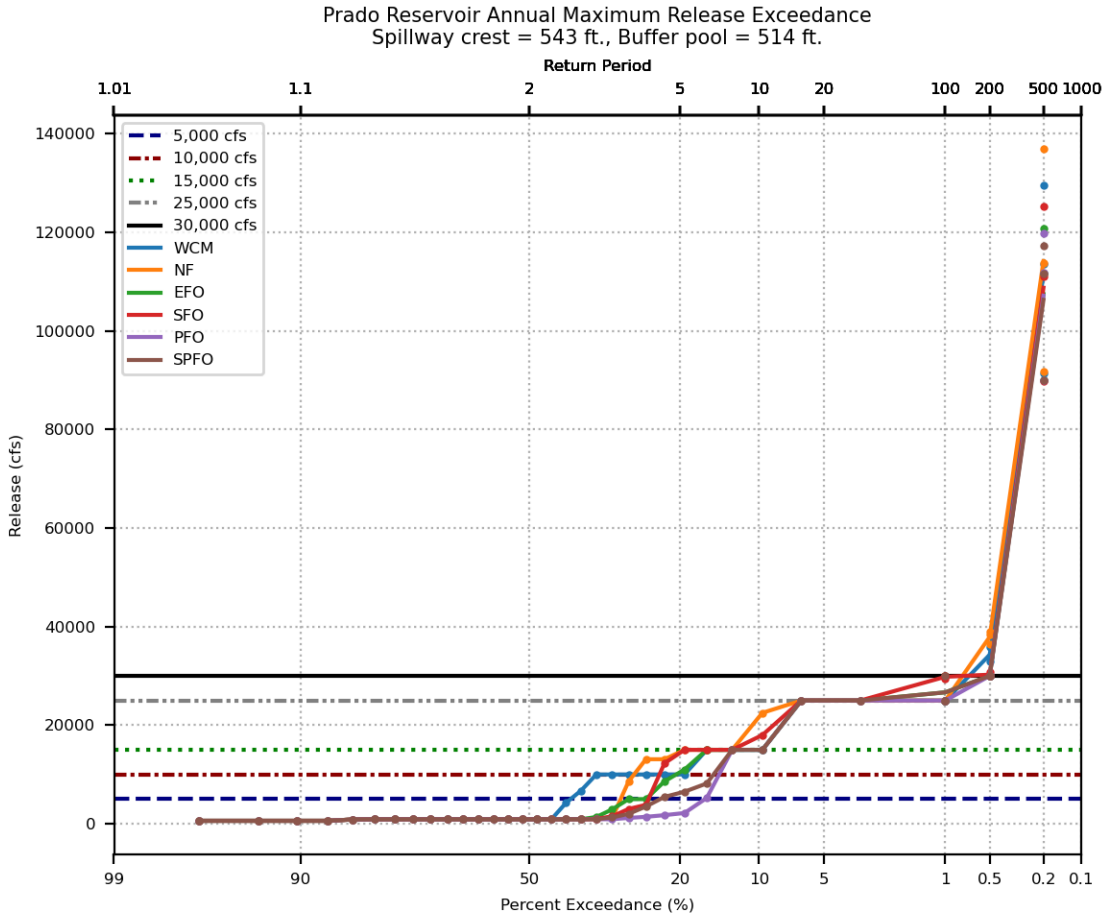
Frequency of Annual Maximum Reservoir Release *by Buffer Pool*

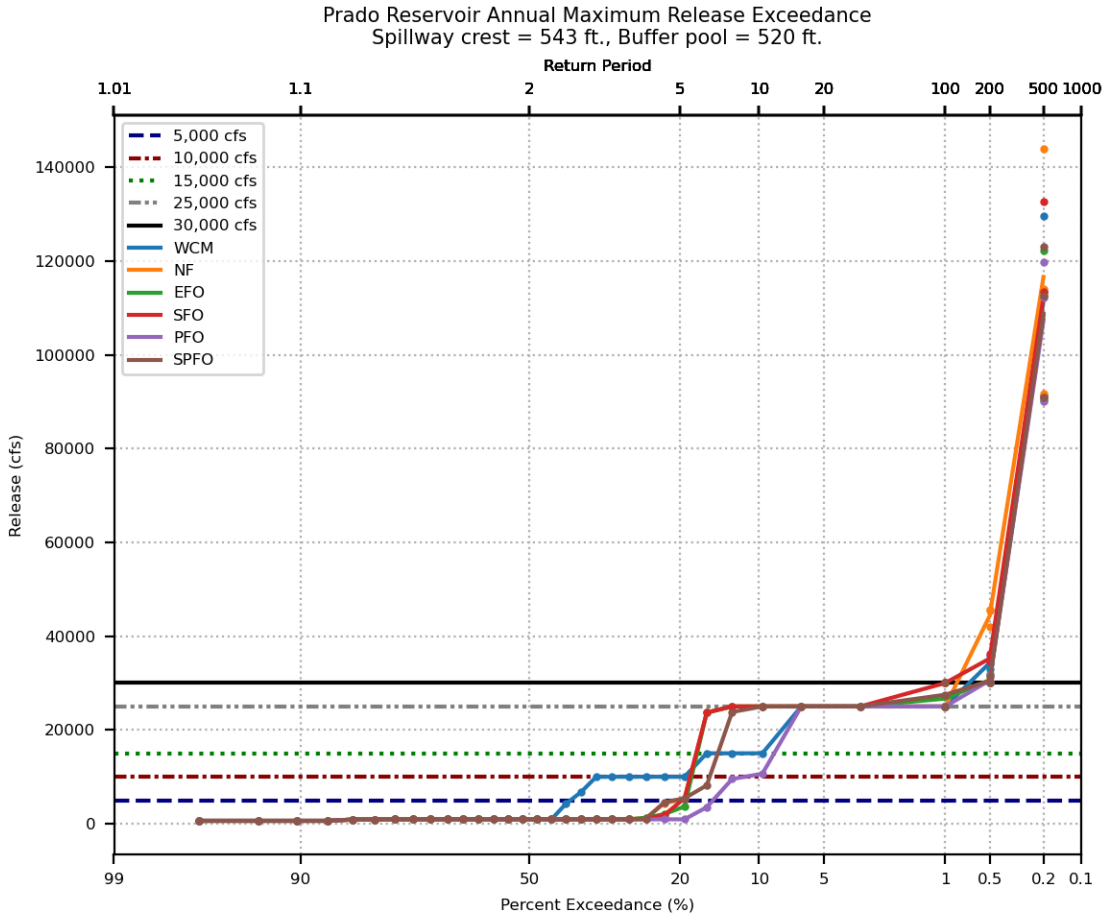
- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’
  - 510’
  - 512’
  - 514’
  - 520’
- WCP alternatives in legend

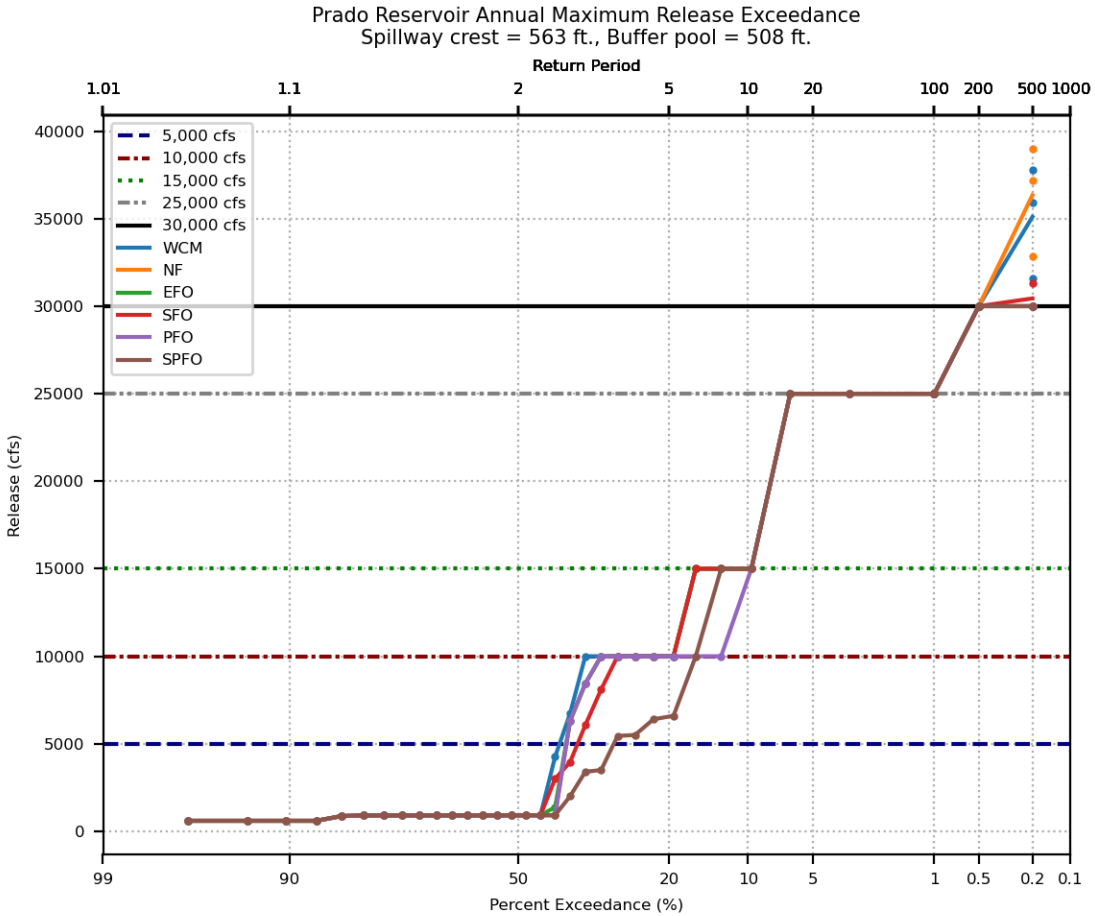

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 508 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
Release (cfs)
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

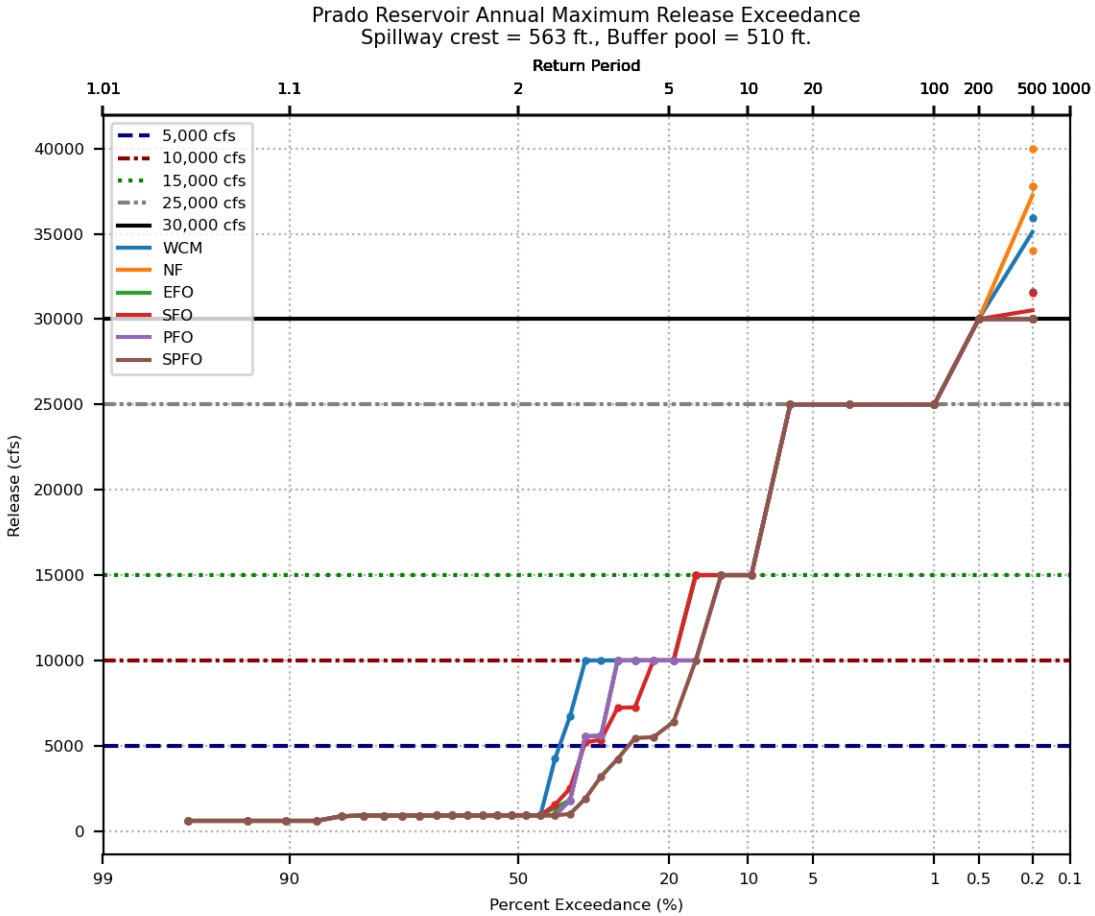

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 510 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
Release (cfs)
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

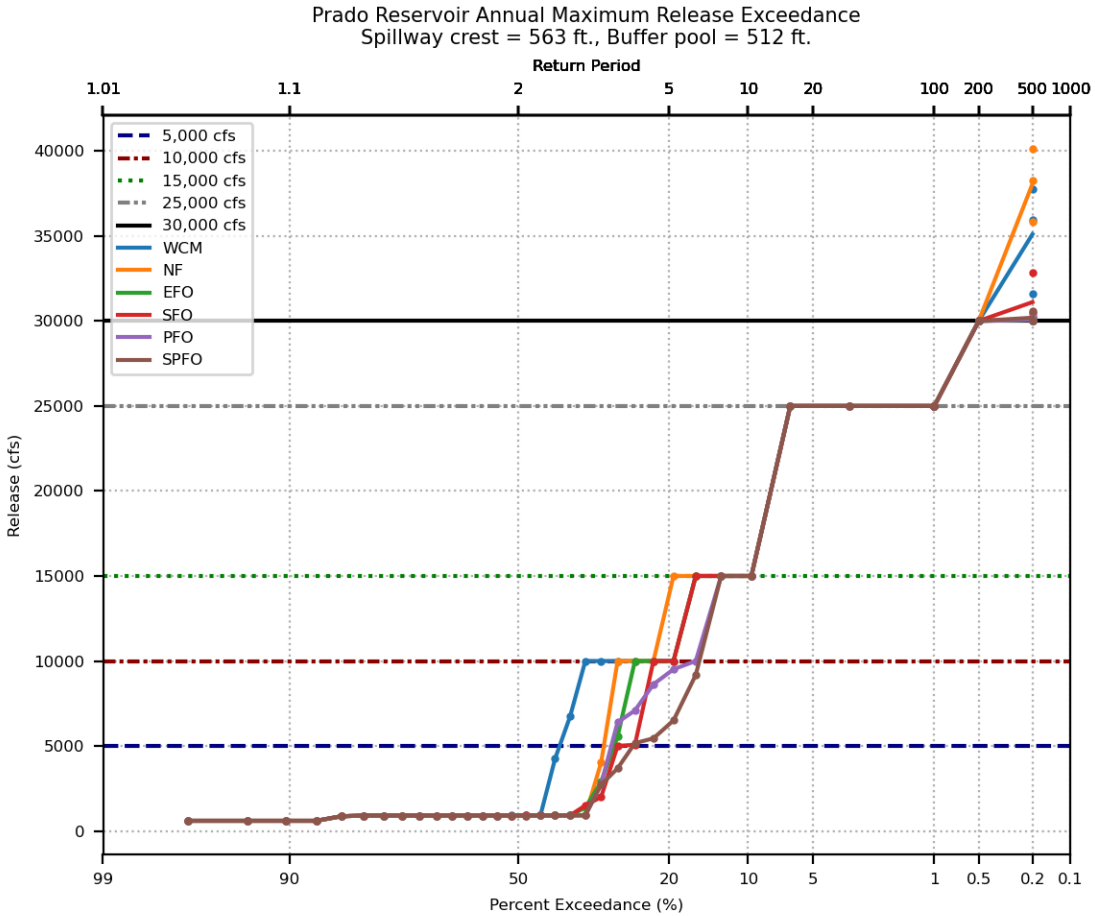

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 512 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
140000
120000
100000
80000
60000
40000
20000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

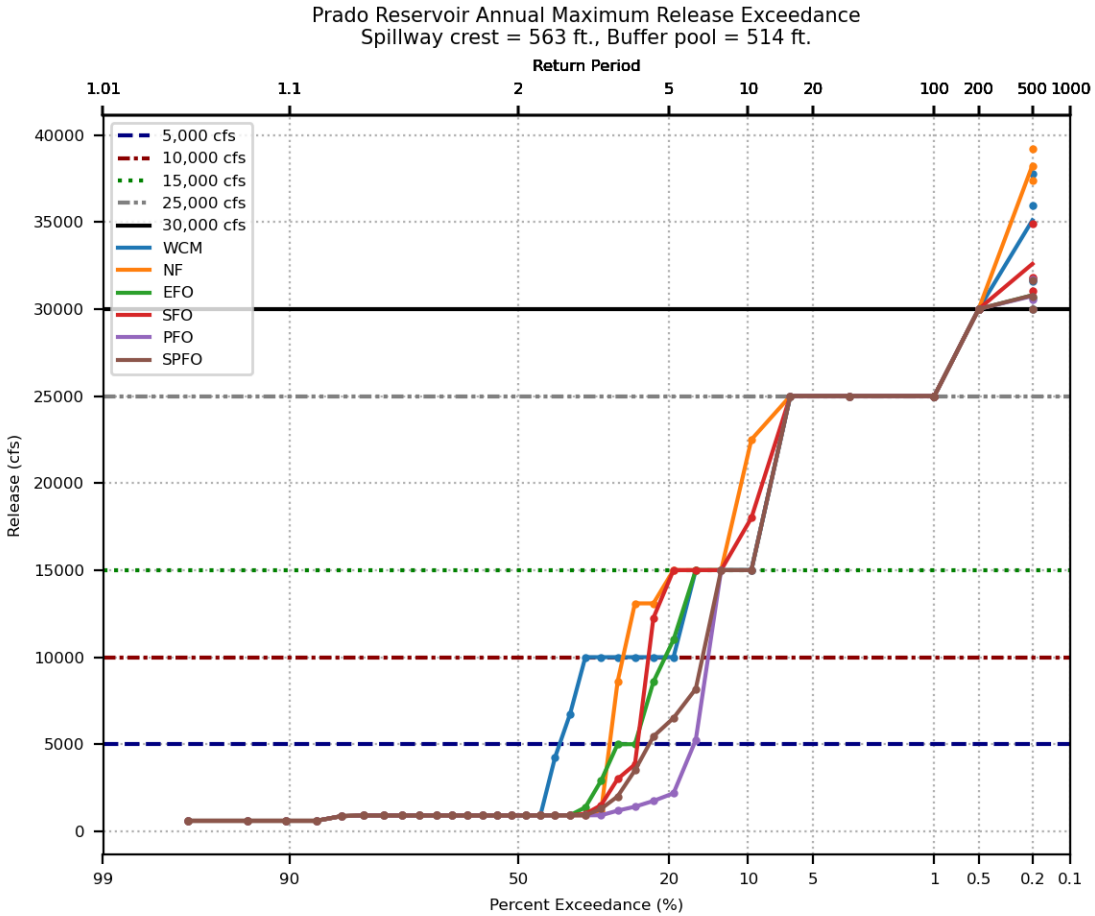

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 514 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
Release (cfs)
140000
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

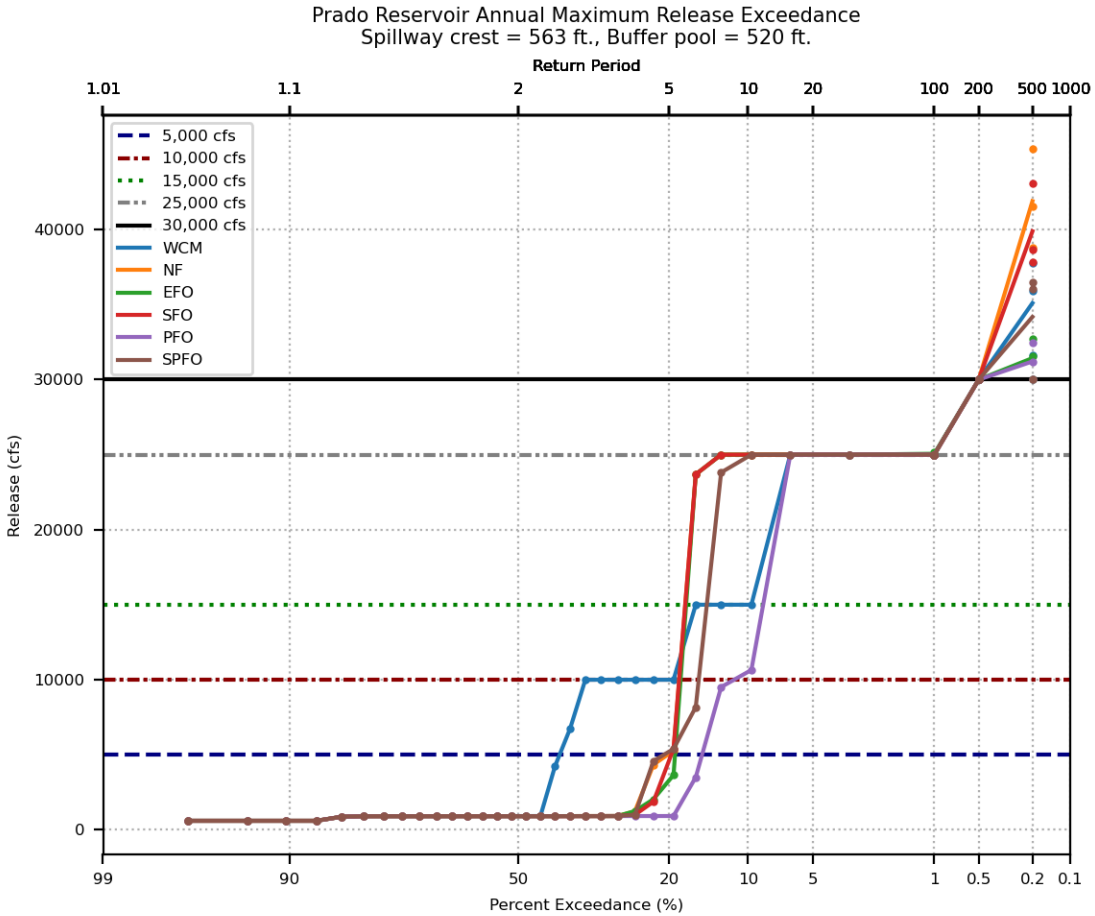

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 520 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
Release (cfs)
140000
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 508 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
Release (cfs)
40000
35000
30000
25000
20000
15000
10000
5000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 510 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
Release (cfs)
40000
35000
30000
25000
20000
15000
10000
5000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

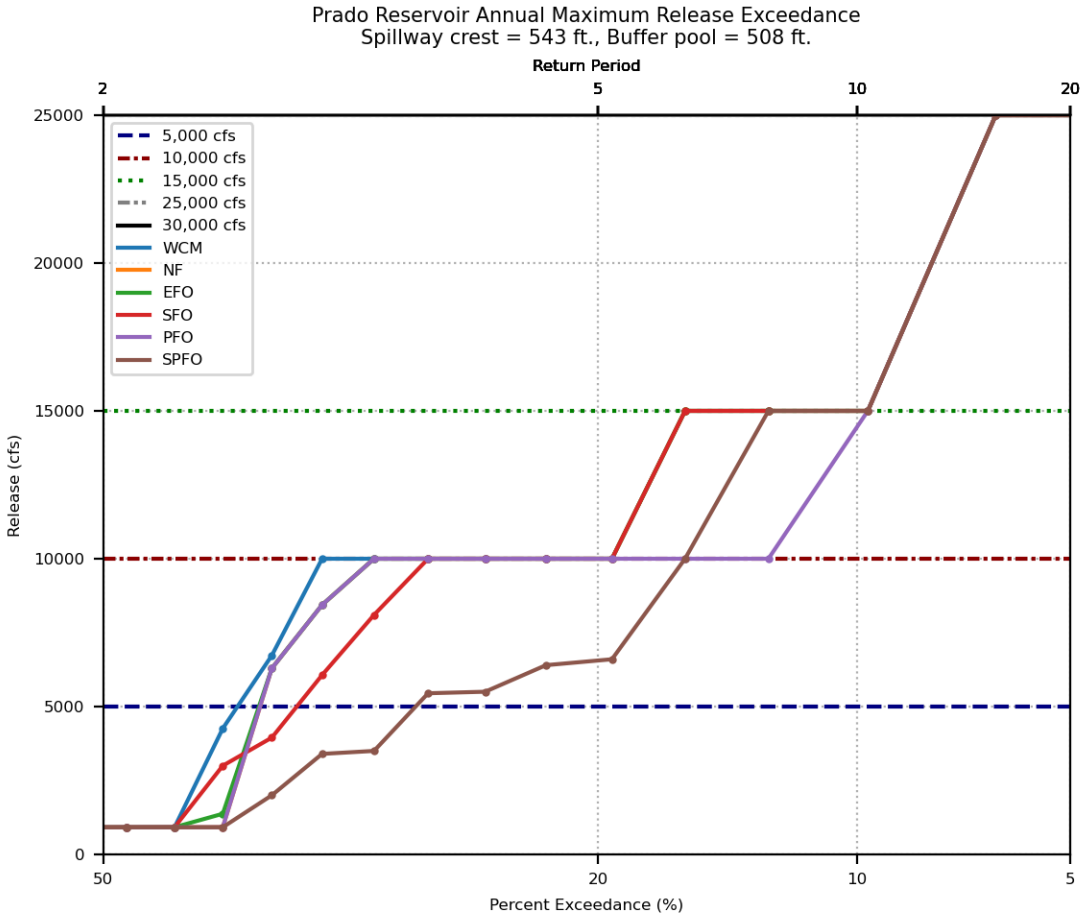

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 512 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
Release (cfs)
40000
35000
30000
25000
20000
15000
10000
5000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

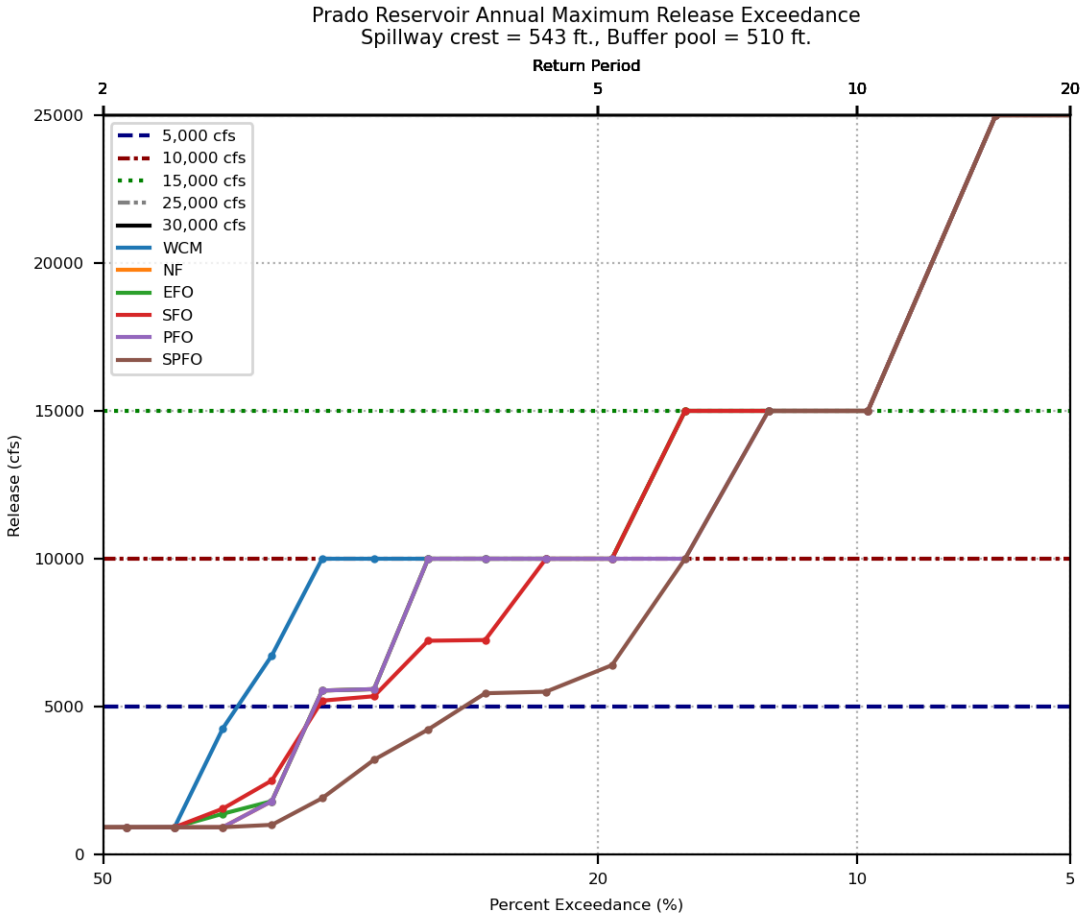

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 514 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
Release (cfs)
40000
35000
30000
25000
20000
15000
10000
5000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

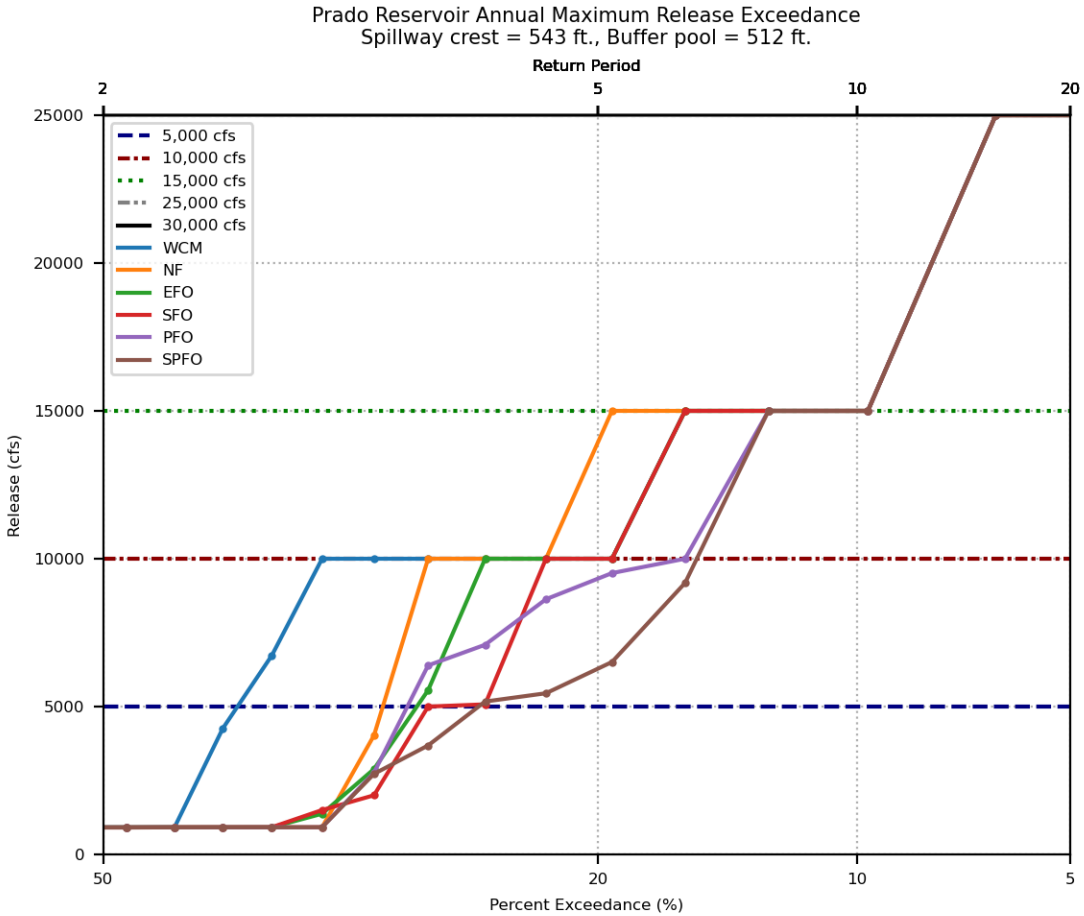

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 520 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
40000
30000
20000
10000
0
Release (cfs)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

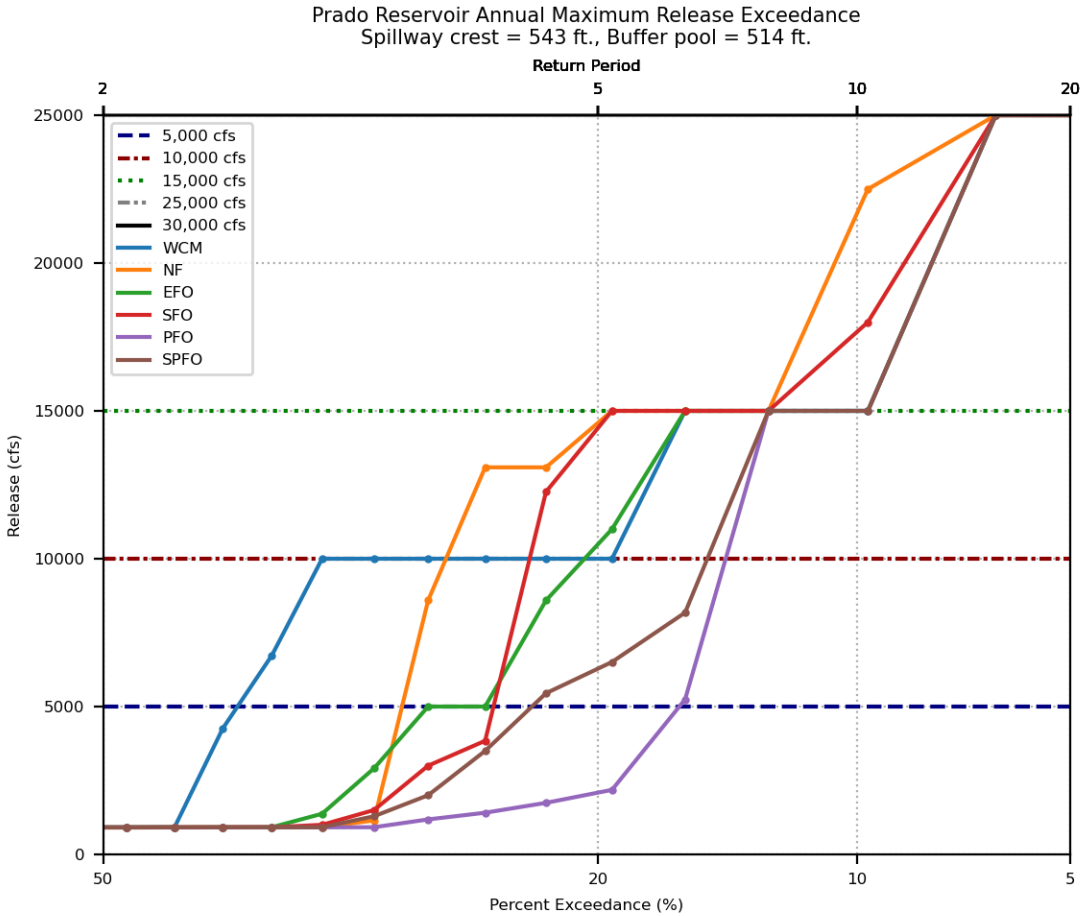
Frequency of Annual Maximum Reservoir Release *by Buffer Pool* - Zoomed

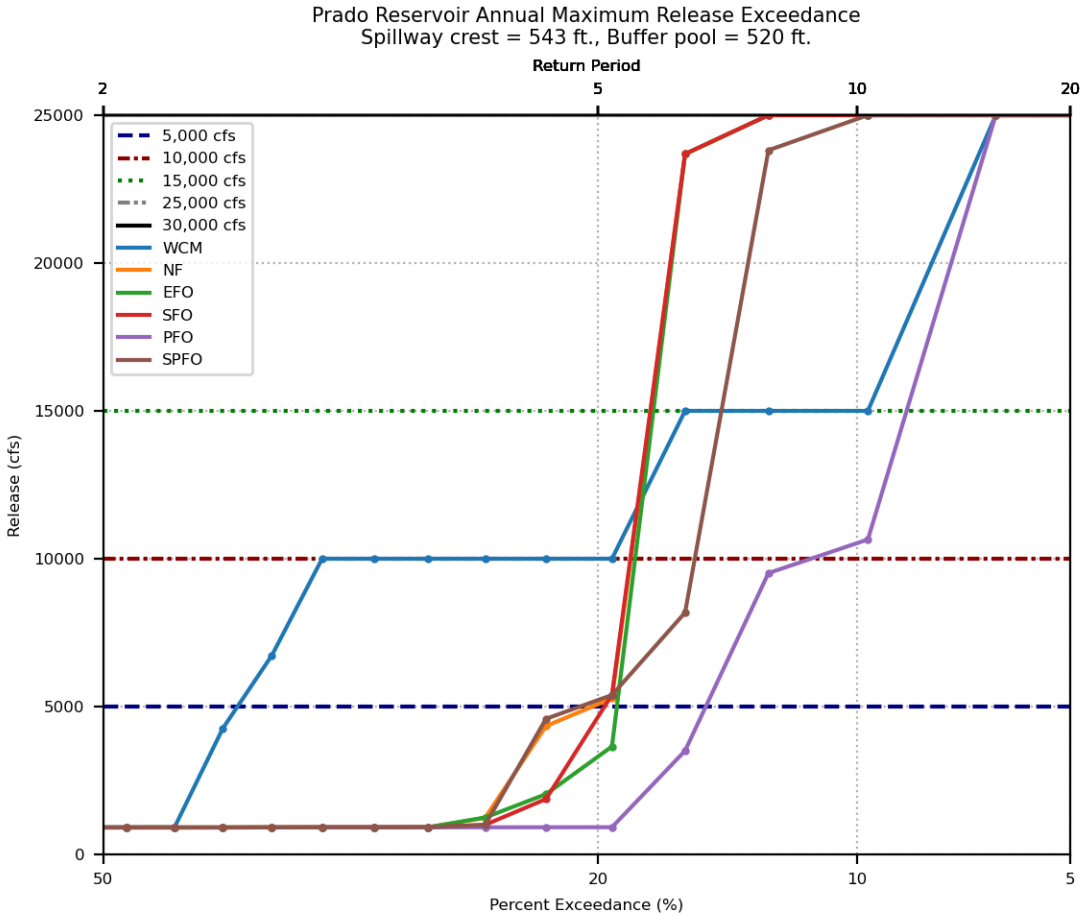
- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’
  - 510’
  - 512’
  - 514’
  - 520’
- WCP alternatives in legend

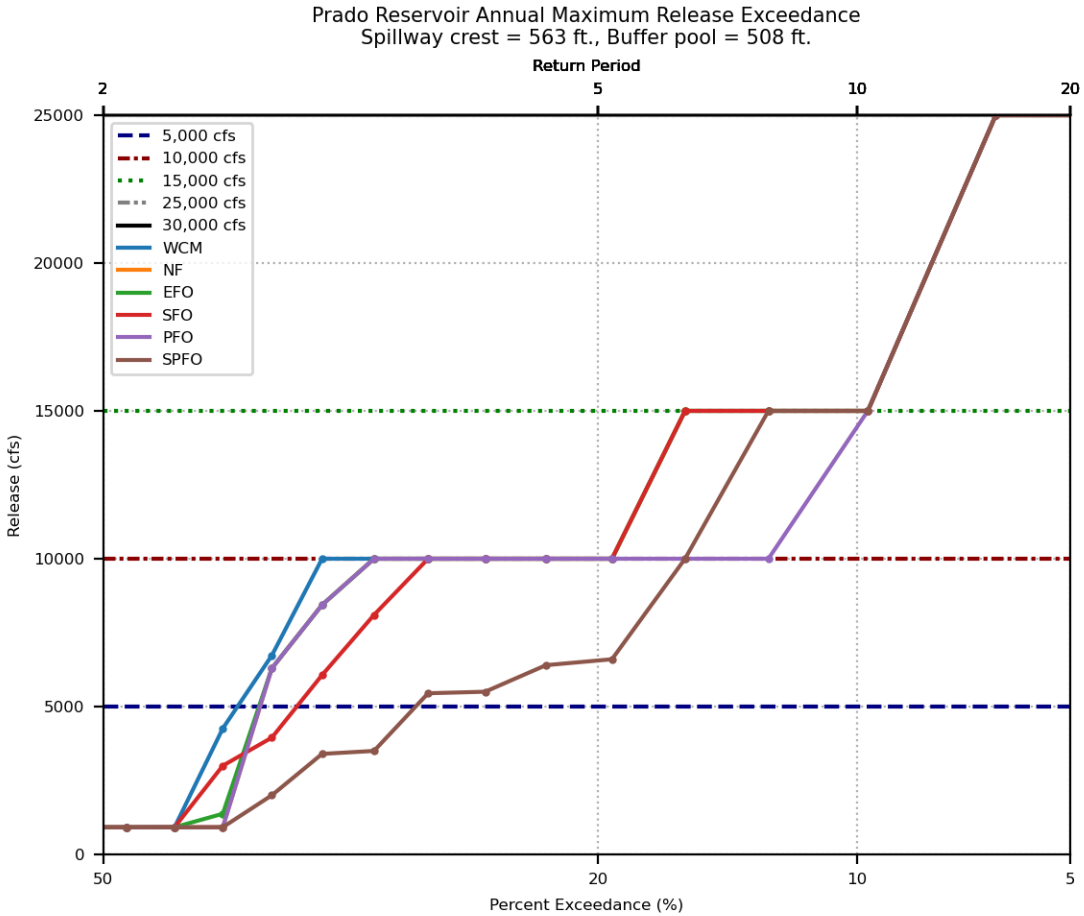

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 508 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)

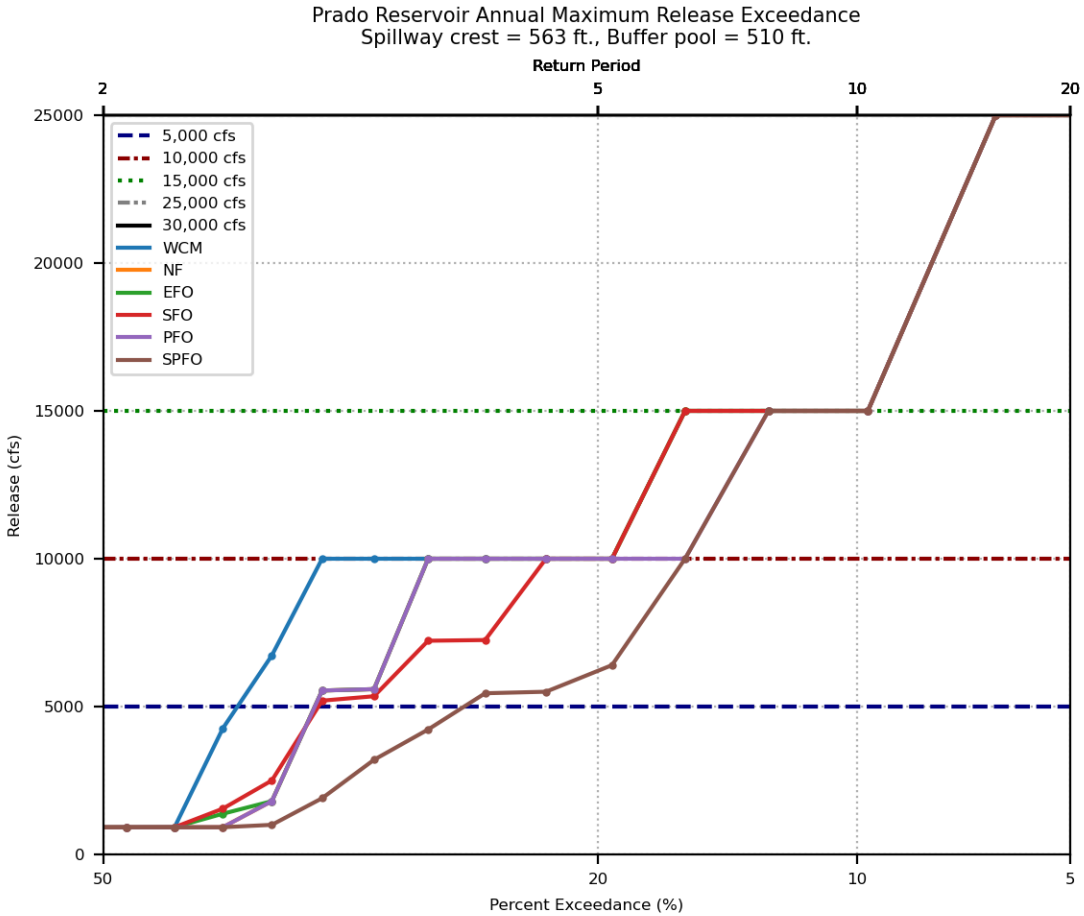

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 510 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)

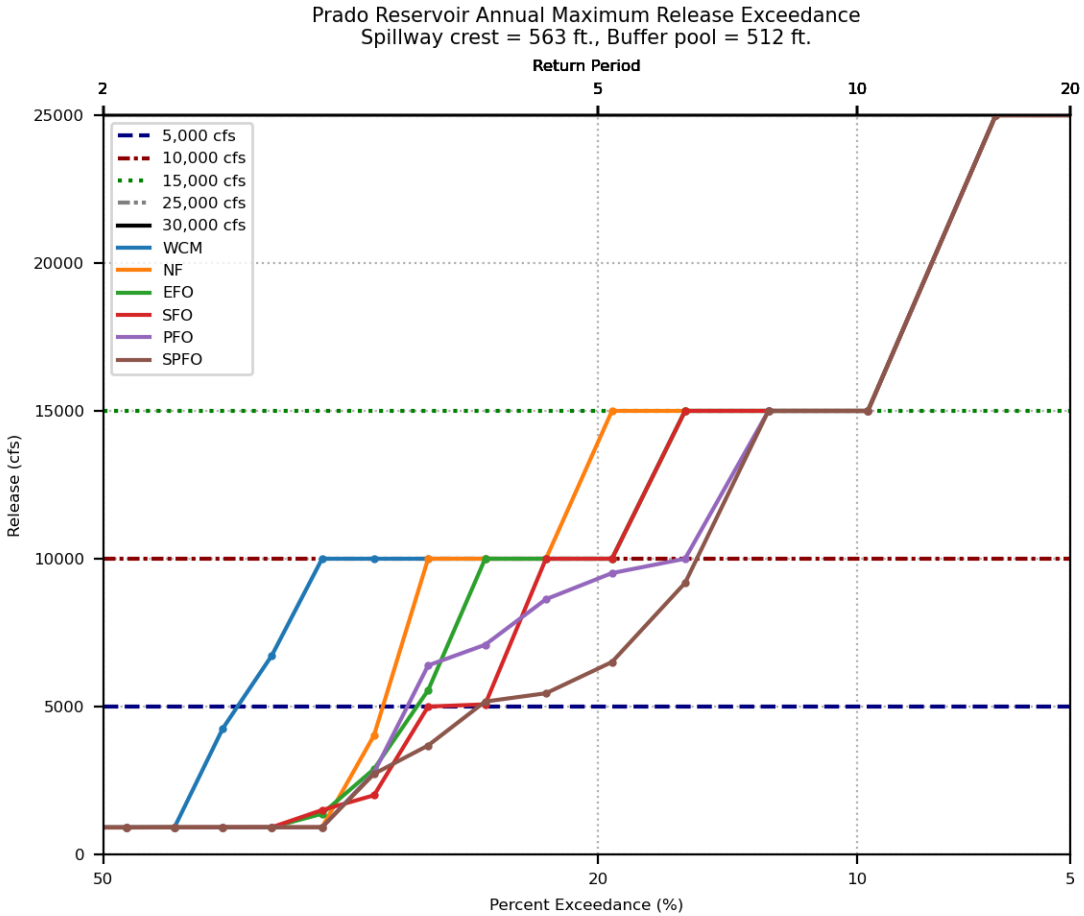

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 512 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)

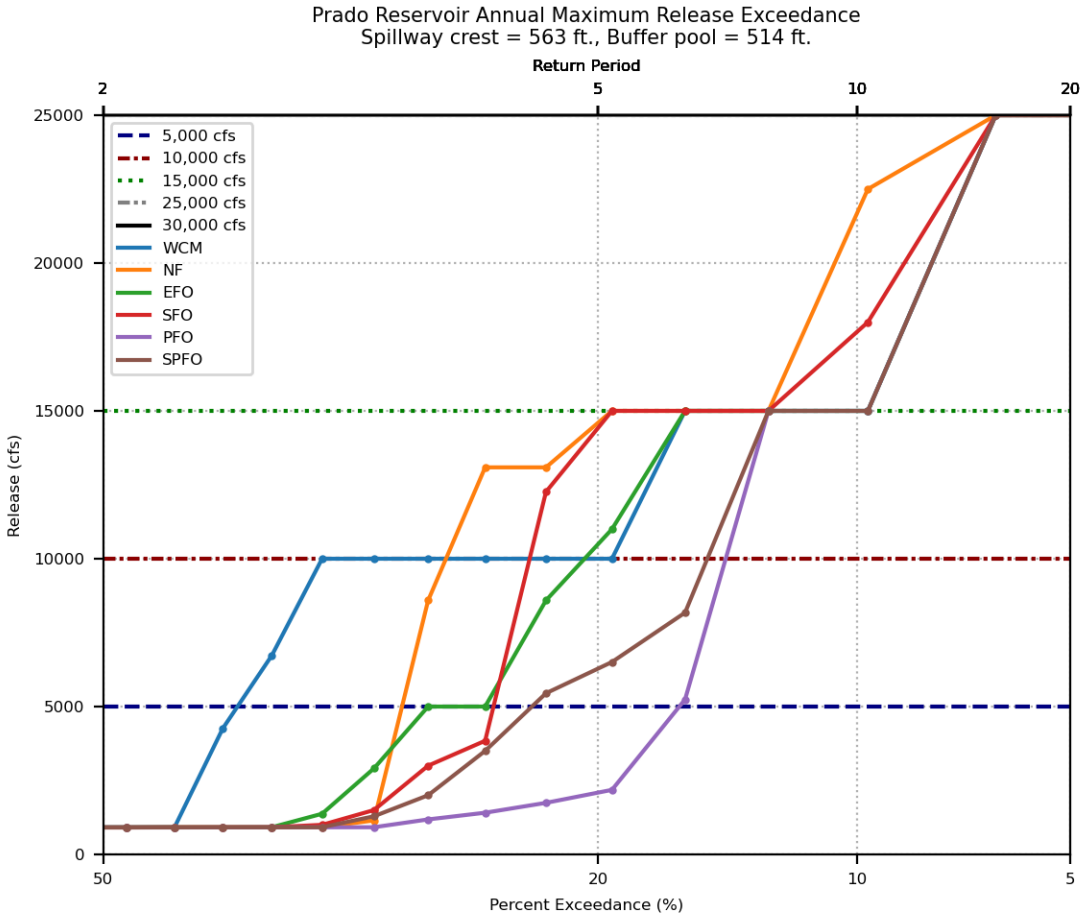

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 514 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)

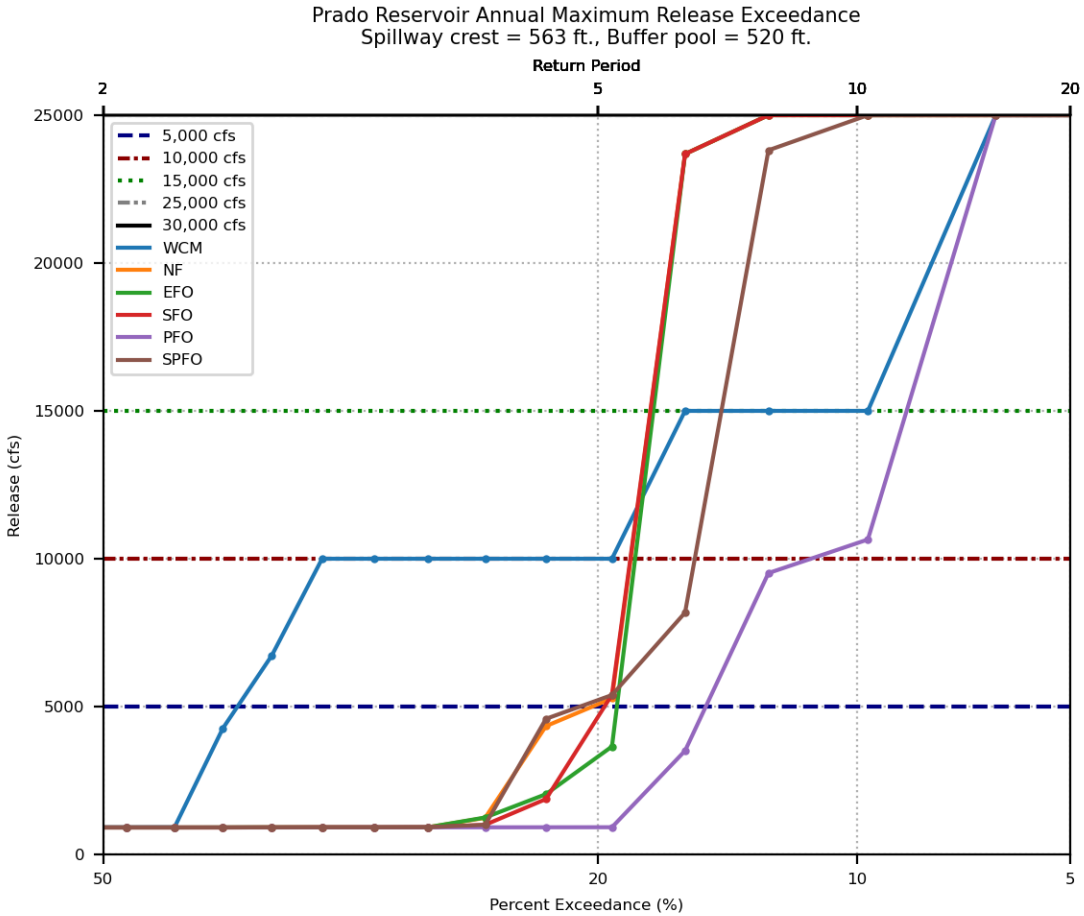

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 520 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 508 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 510 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)

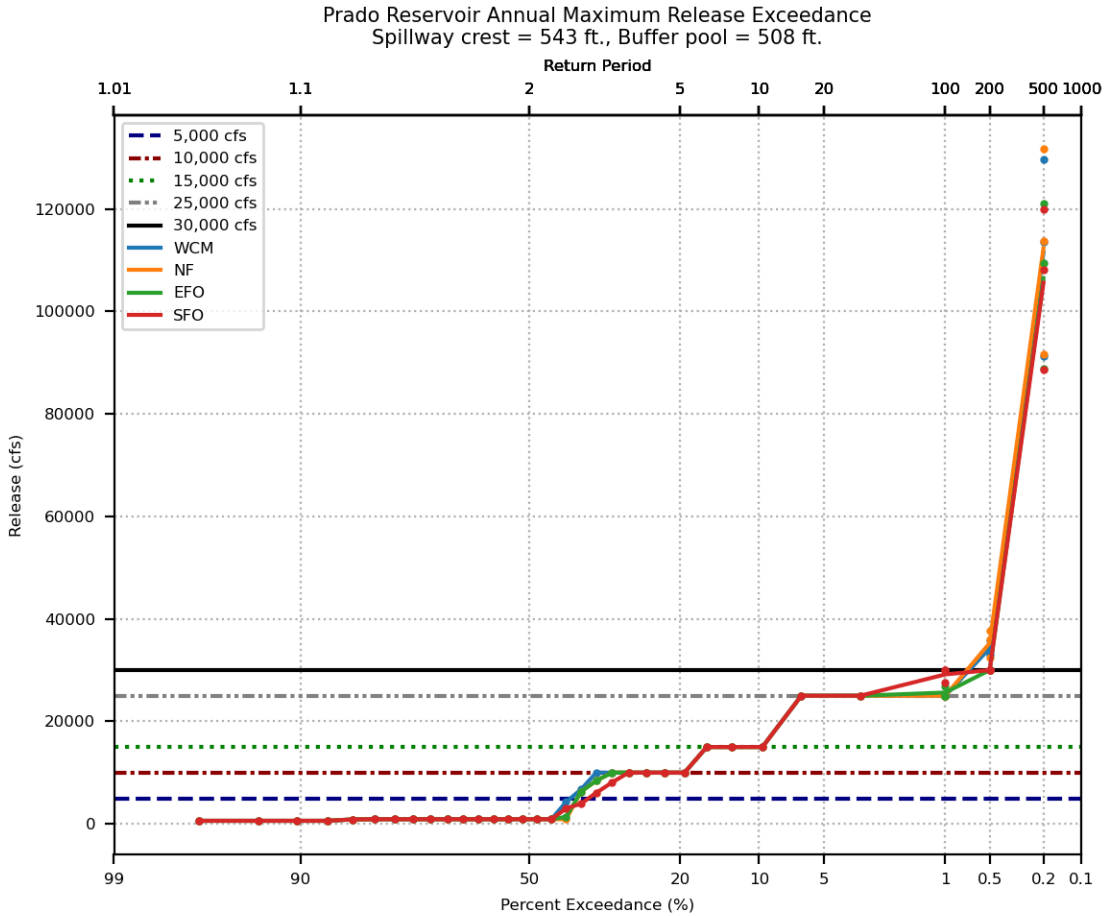

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 512 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)

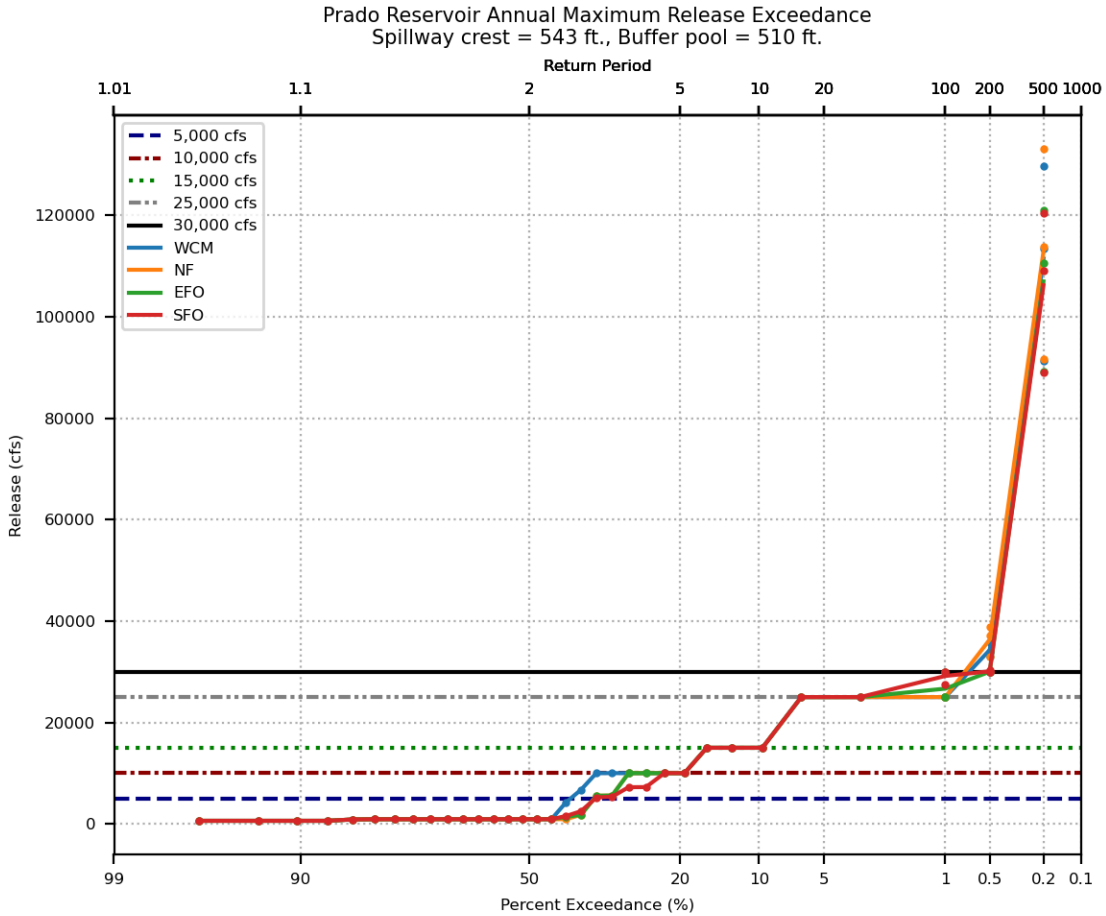

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 514 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)

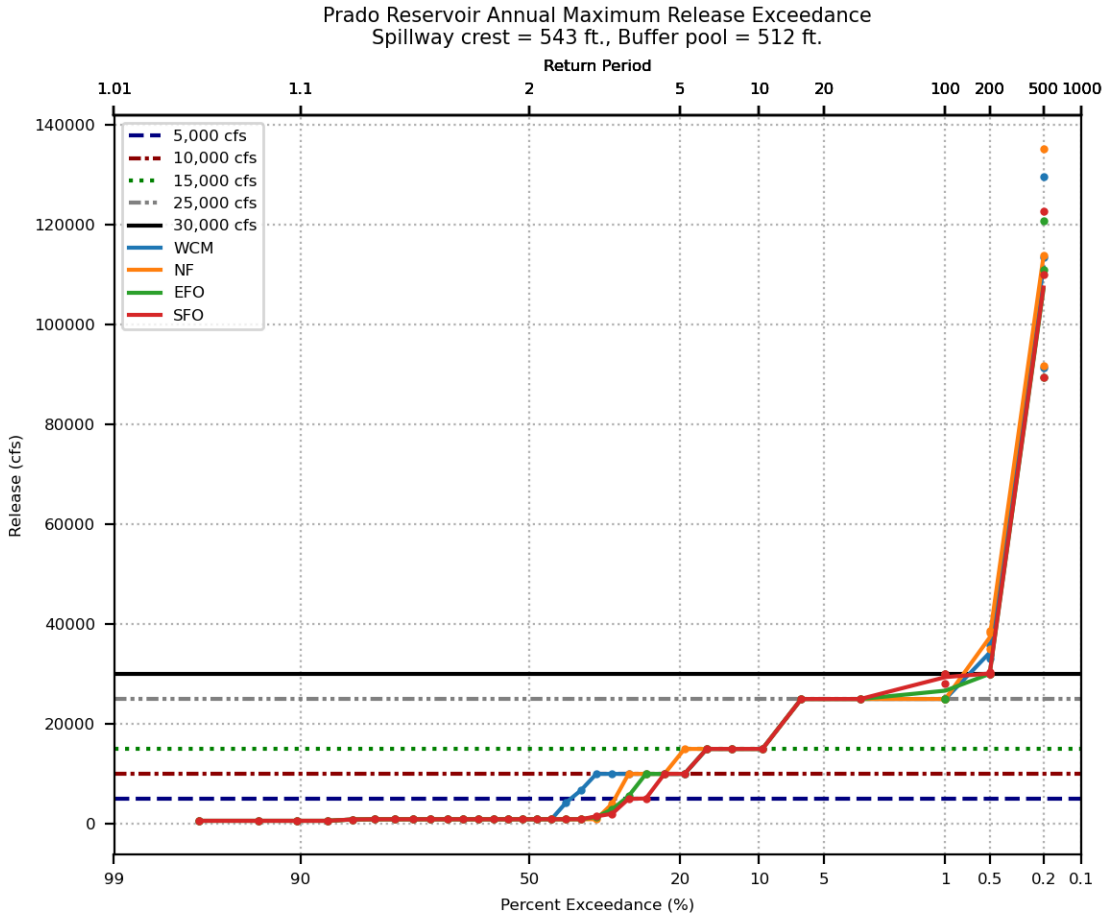

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 520 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
50
20
10
5
Percent Exceedance (%)

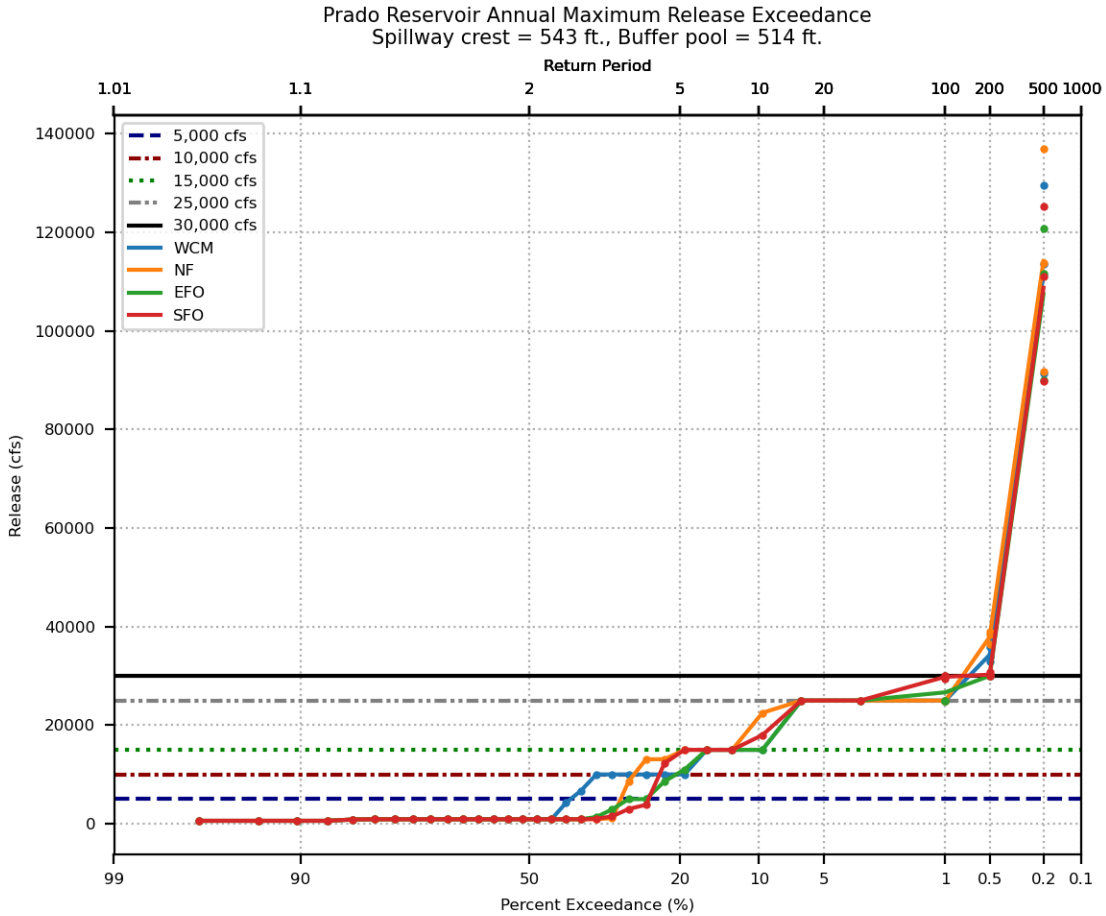
Frequency of Annual Maximum Reservoir Release *by Buffer Pool (NP)*

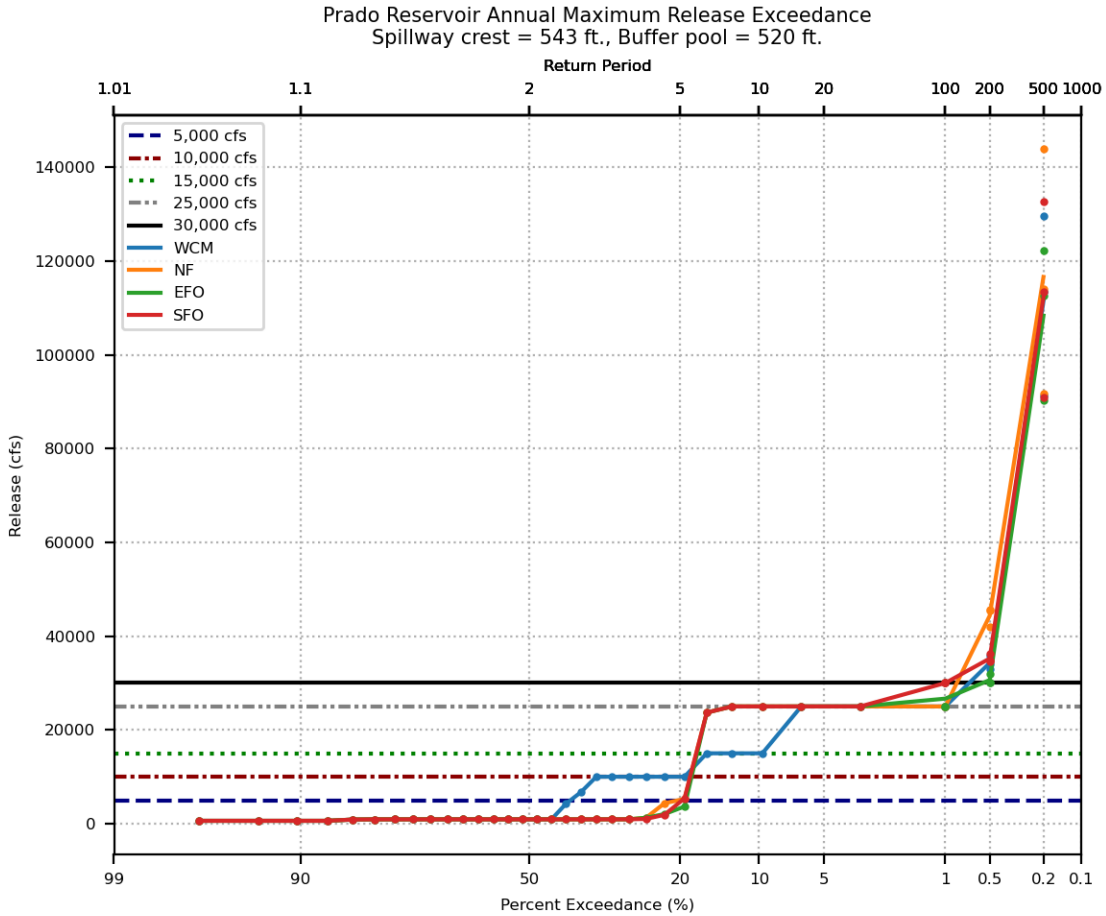
- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’
  - 510’
  - 512’
  - 514’
  - 520’
- WCP alternatives in legend
  - No perfect forecast results

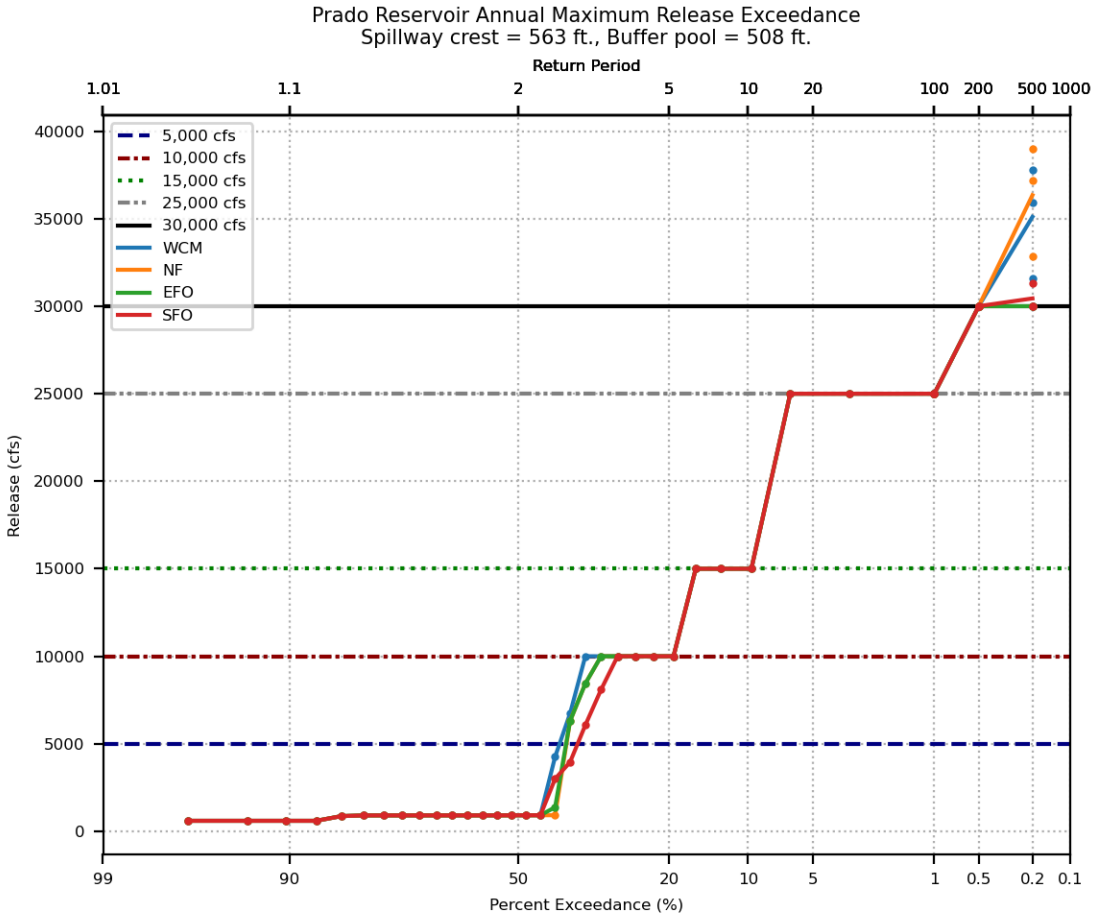

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 508 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
Release (cfs)
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

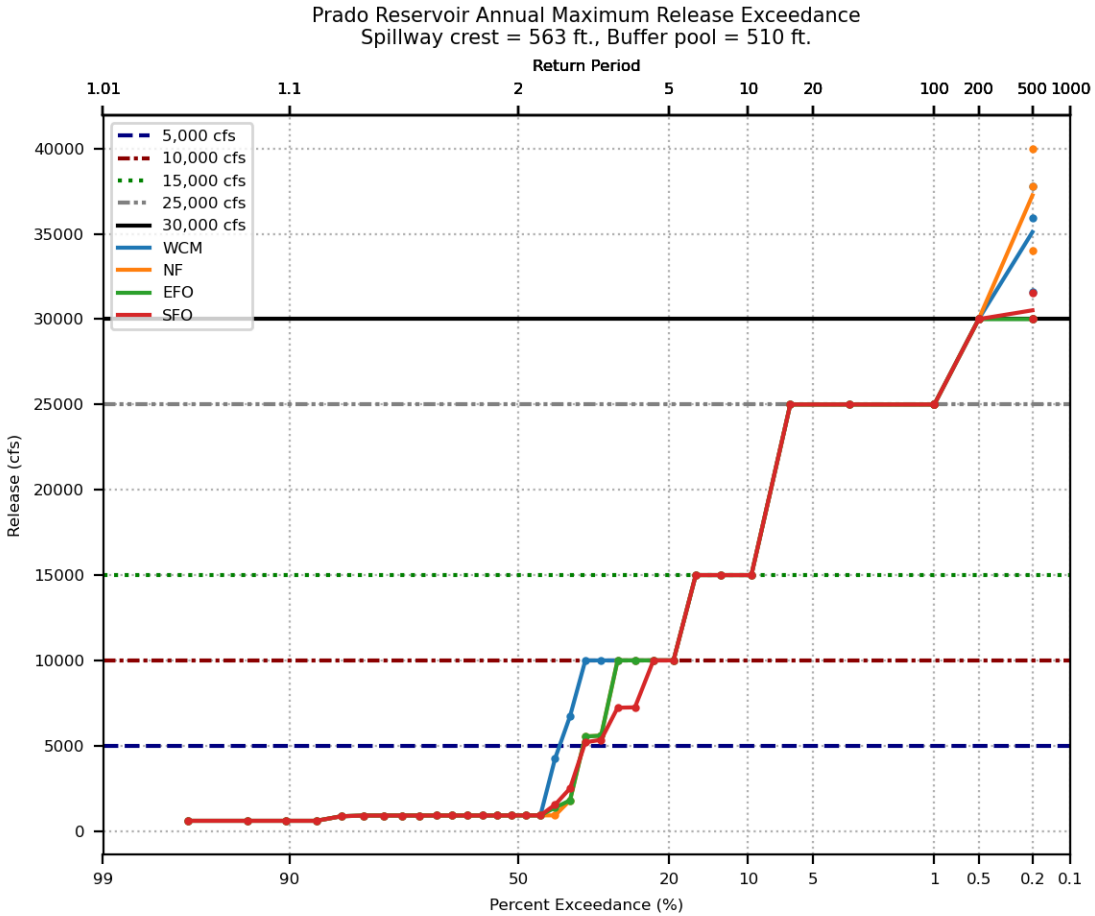

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 510 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
Release (cfs)
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

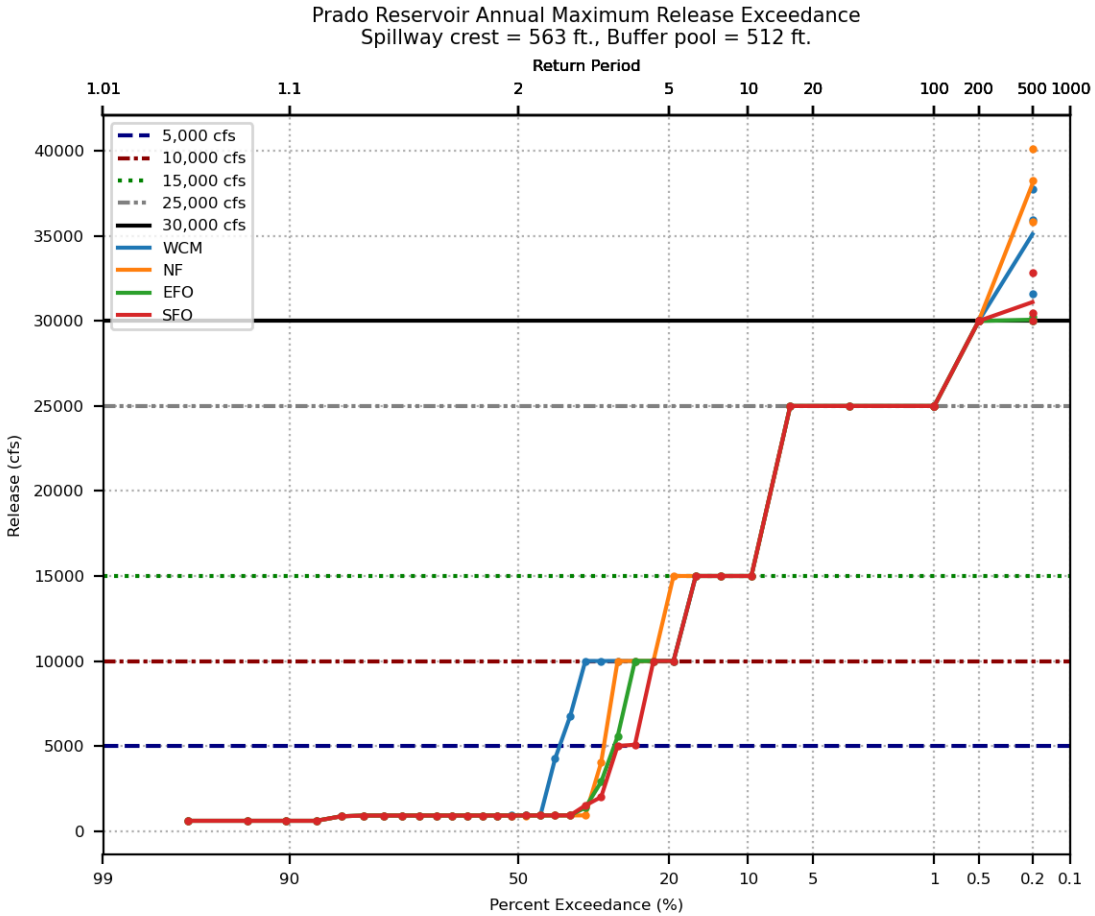

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 512 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
140000
120000
100000
80000
60000
40000
20000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

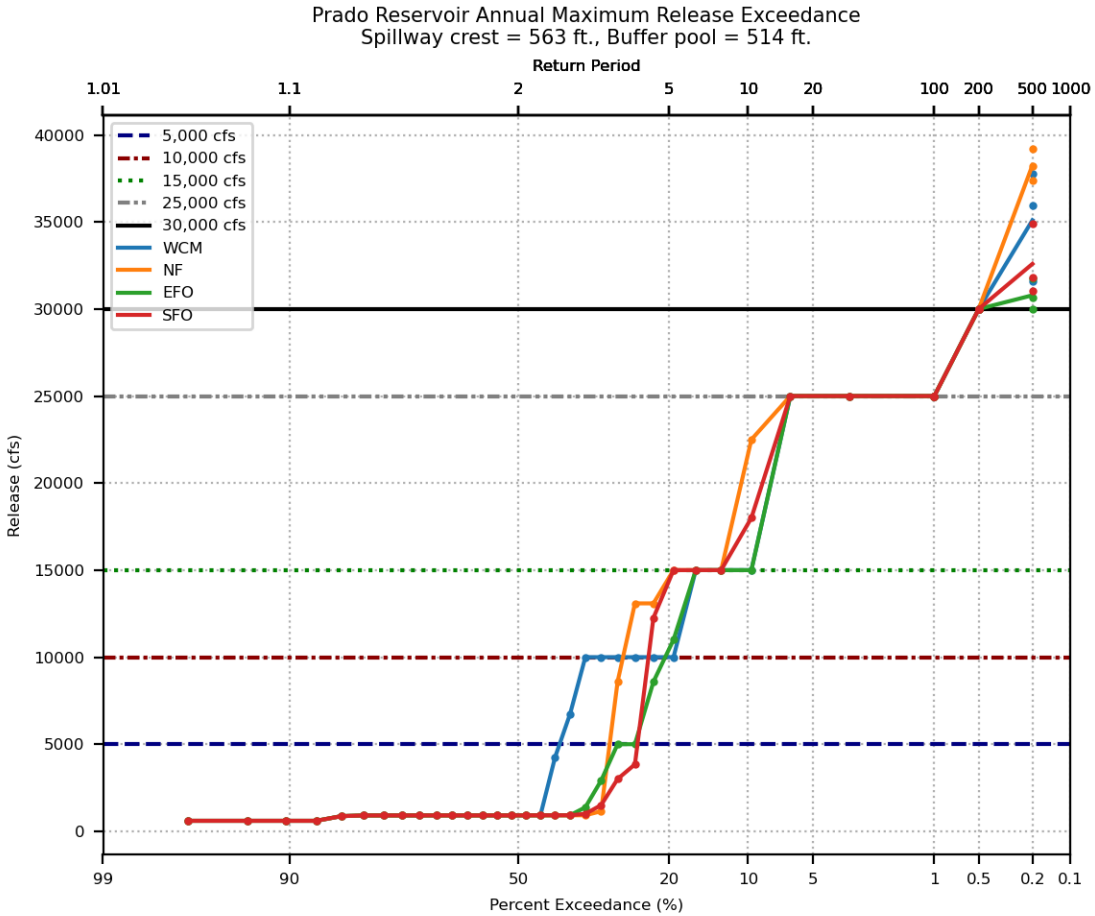

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 514 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
Release (cfs)
140000
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

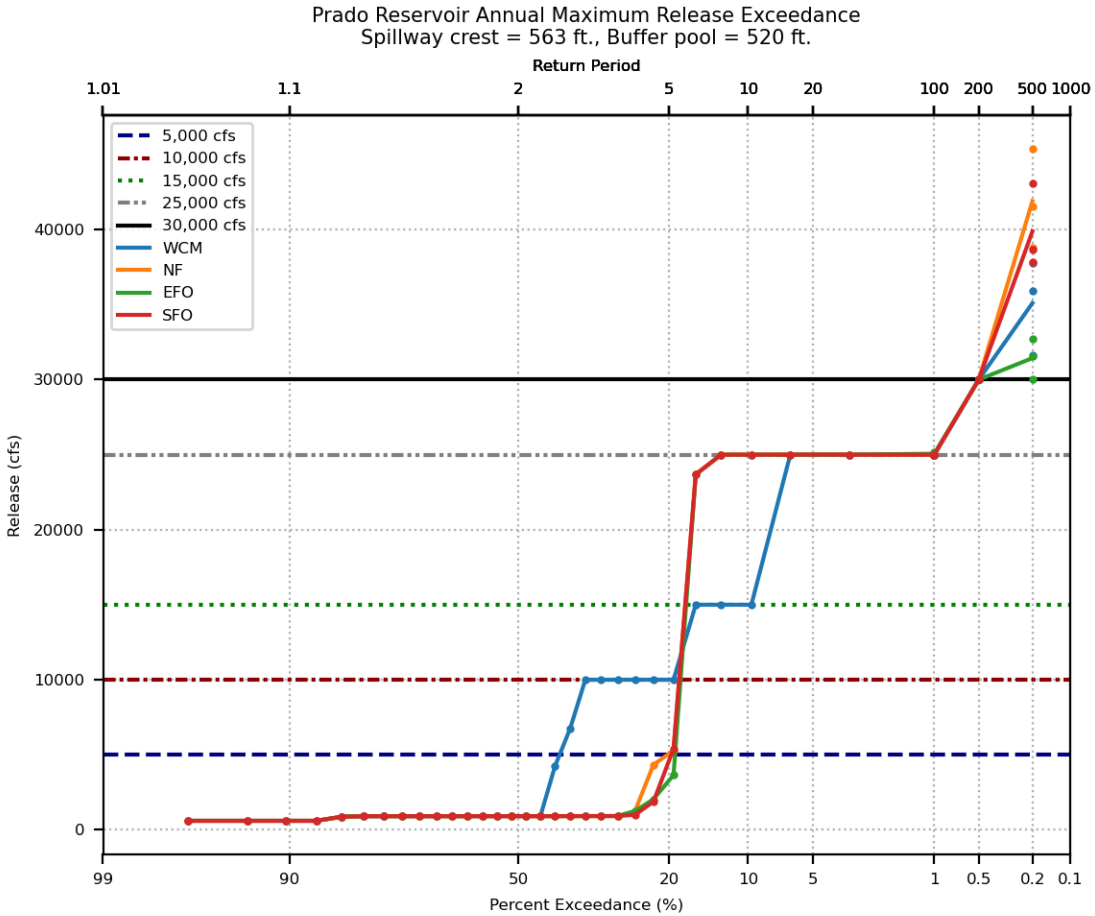

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 520 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
Release (cfs)
140000
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 508 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
Release (cfs)
40000
35000
30000
25000
20000
15000
10000
5000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 510 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
Release (cfs)
40000
35000
30000
25000
20000
15000
10000
5000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

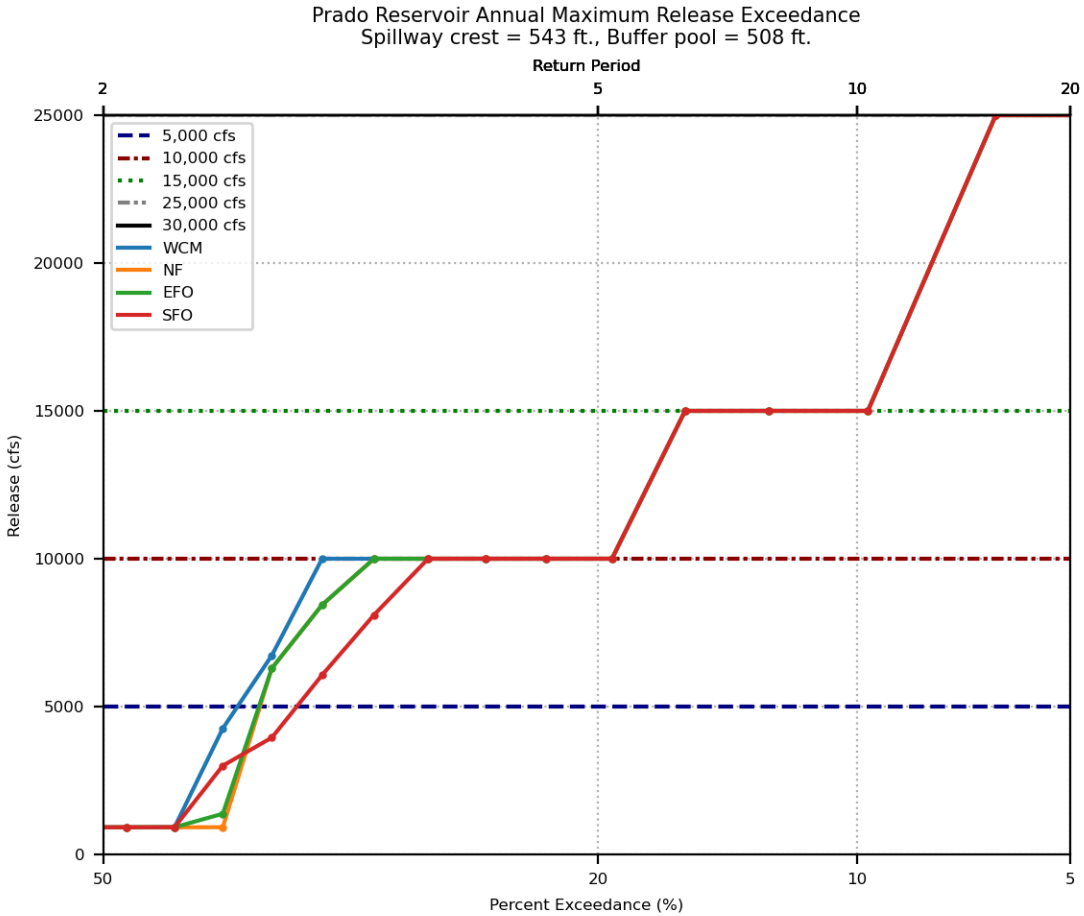

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 512 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
Release (cfs)
40000
35000
30000
25000
20000
15000
10000
5000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

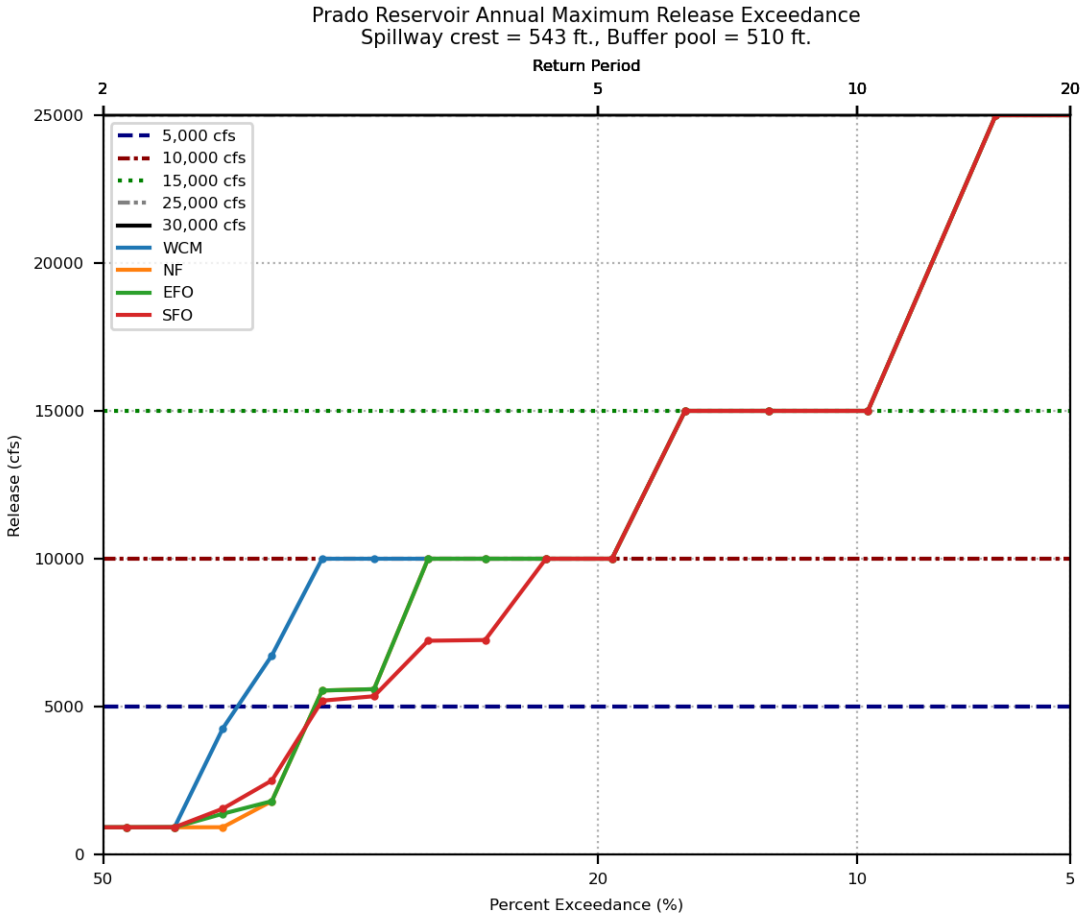

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 514 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
Release (cfs)
40000
35000
30000
25000
20000
15000
10000
5000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

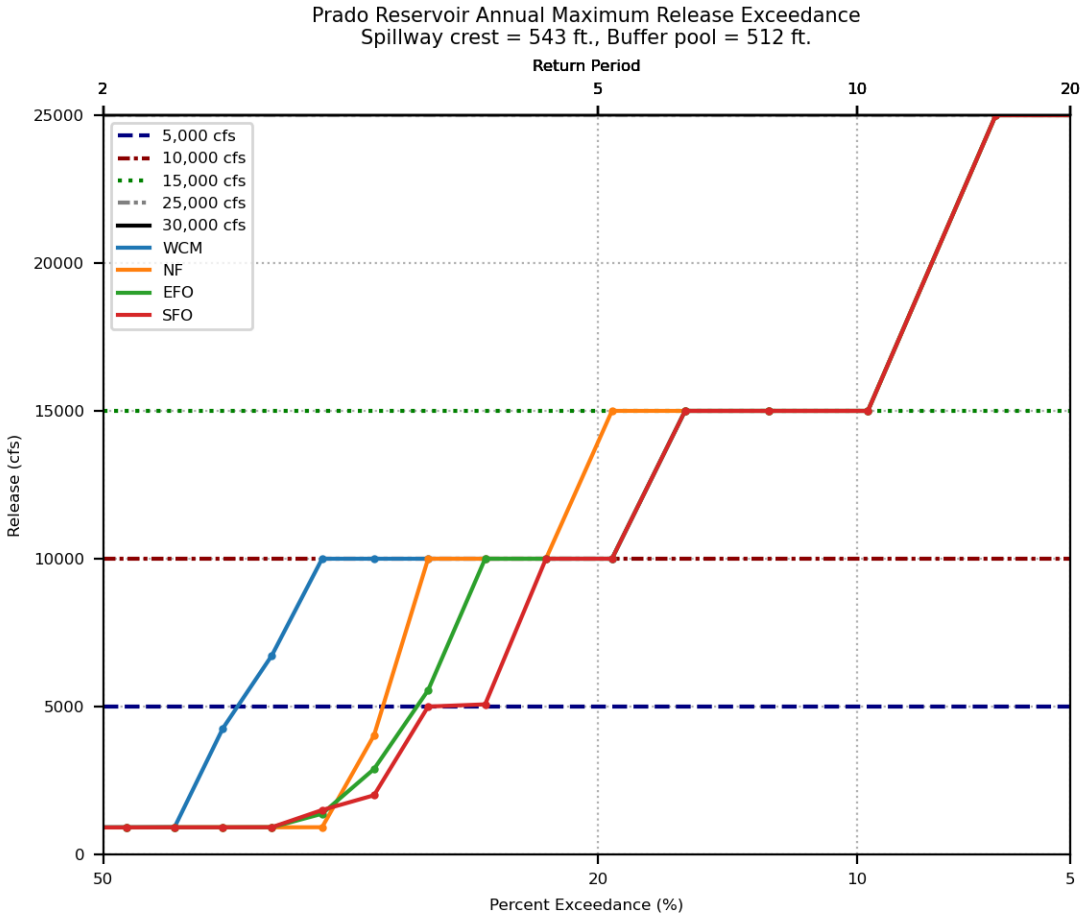

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 520 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
40000
30000
20000
10000
0
Release (cfs)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

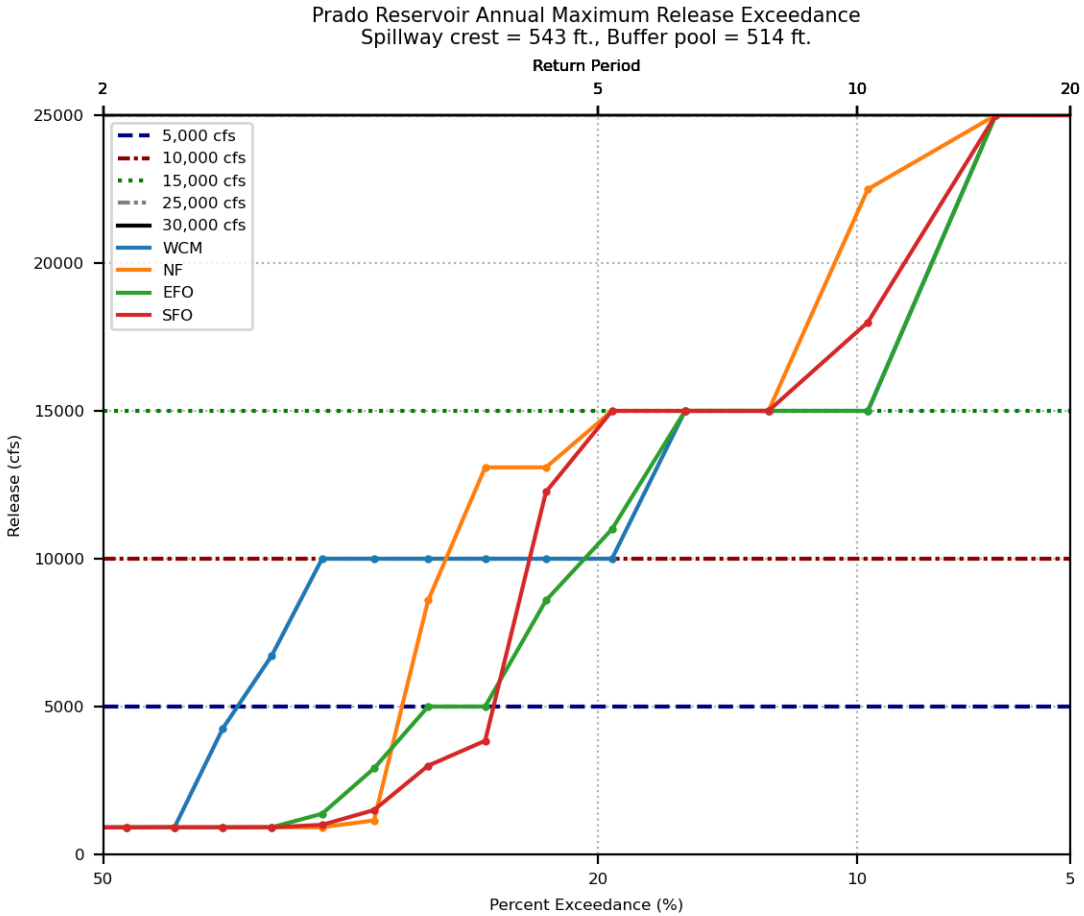
Frequency of Annual Maximum Reservoir Release *by Buffer Pool (NP)* – Zoomed

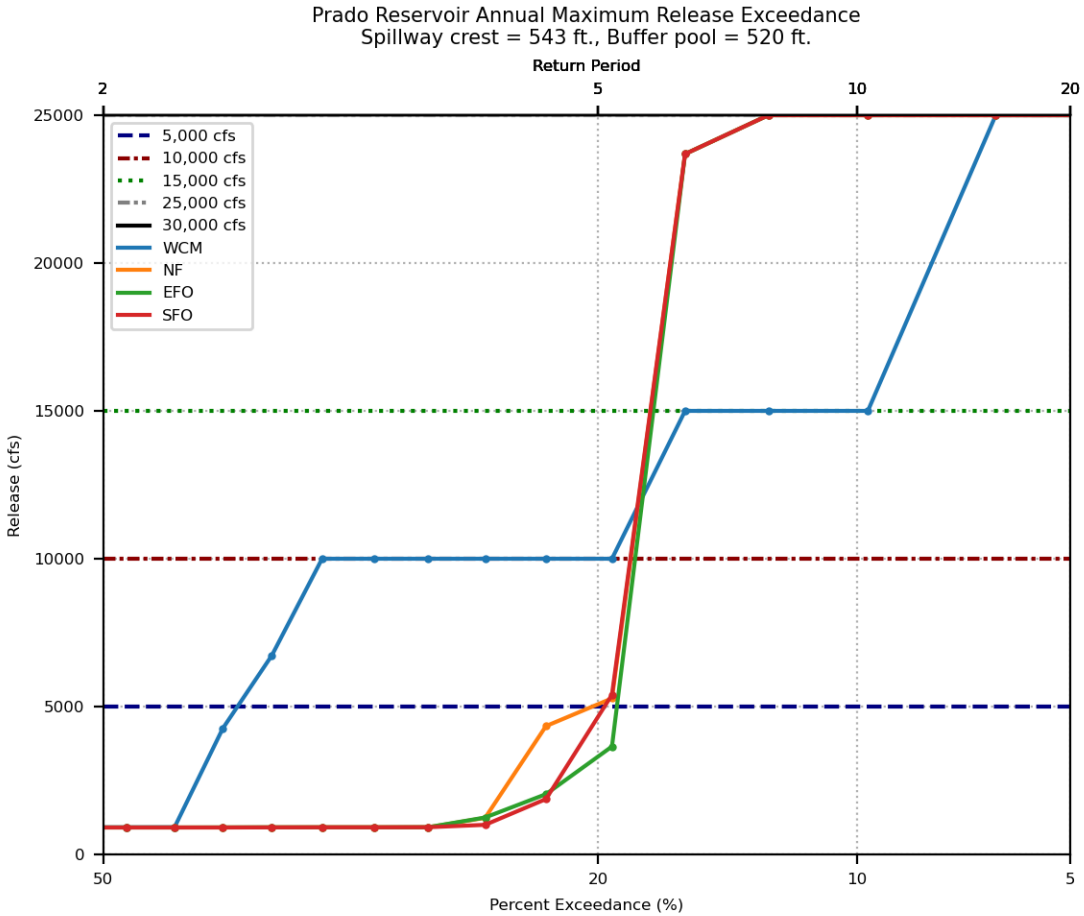
- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’
  - 510’
  - 512’
  - 514’
  - 520’
- WCP alternatives in legend
  - No perfect forecast results

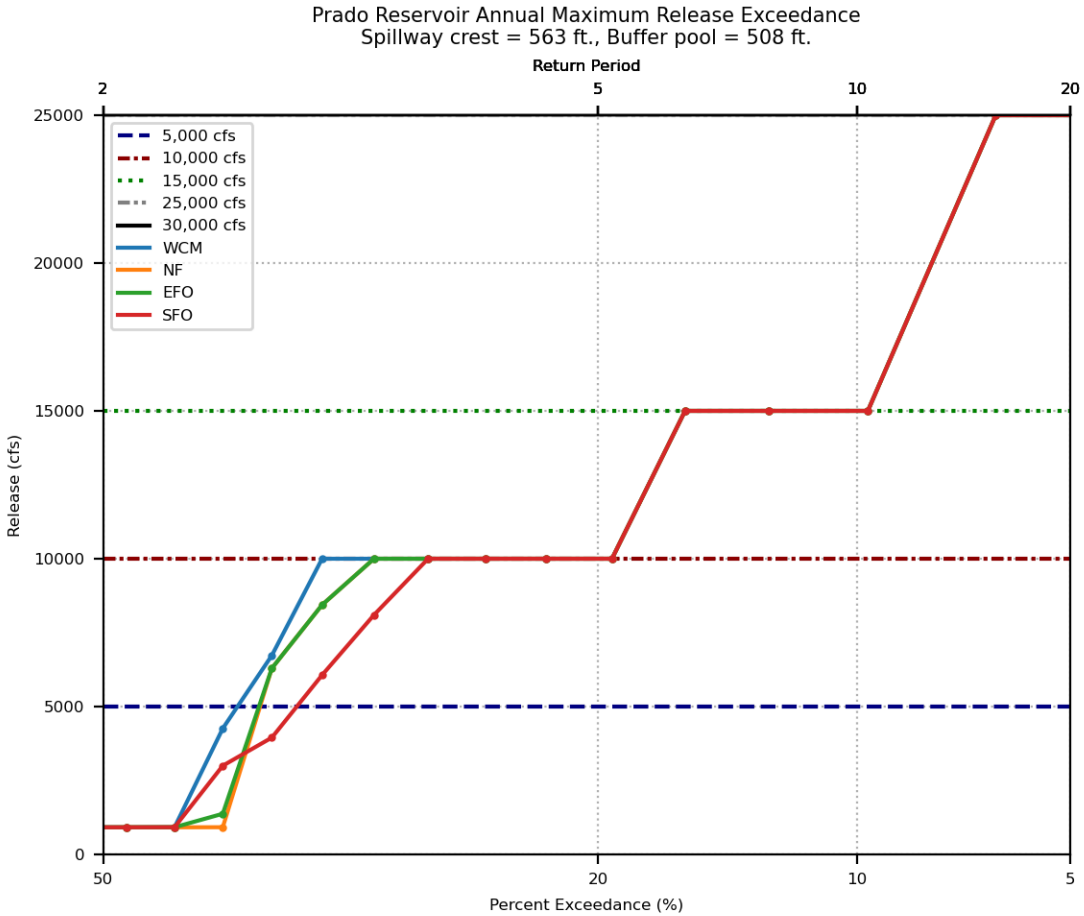

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 508 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
50
20
10
5
Percent Exceedance (%)

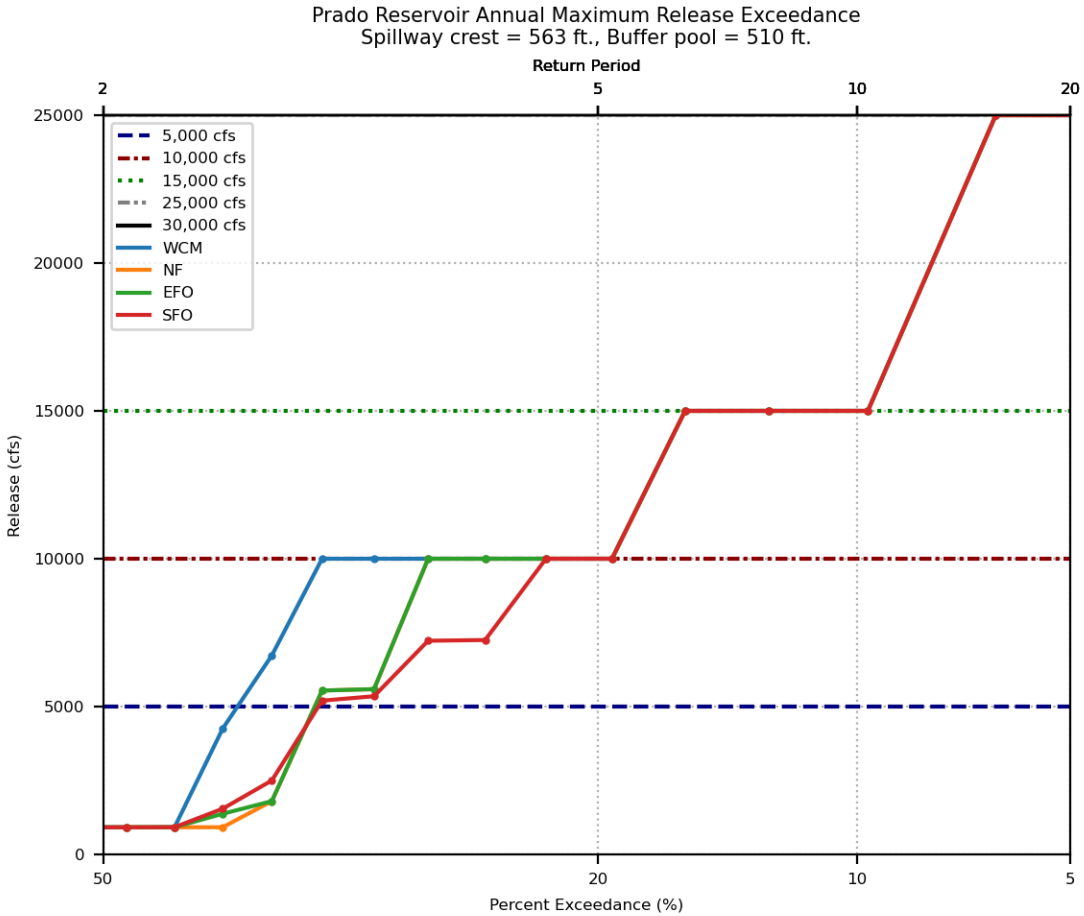

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 510 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
50
20
10
5
Percent Exceedance (%)

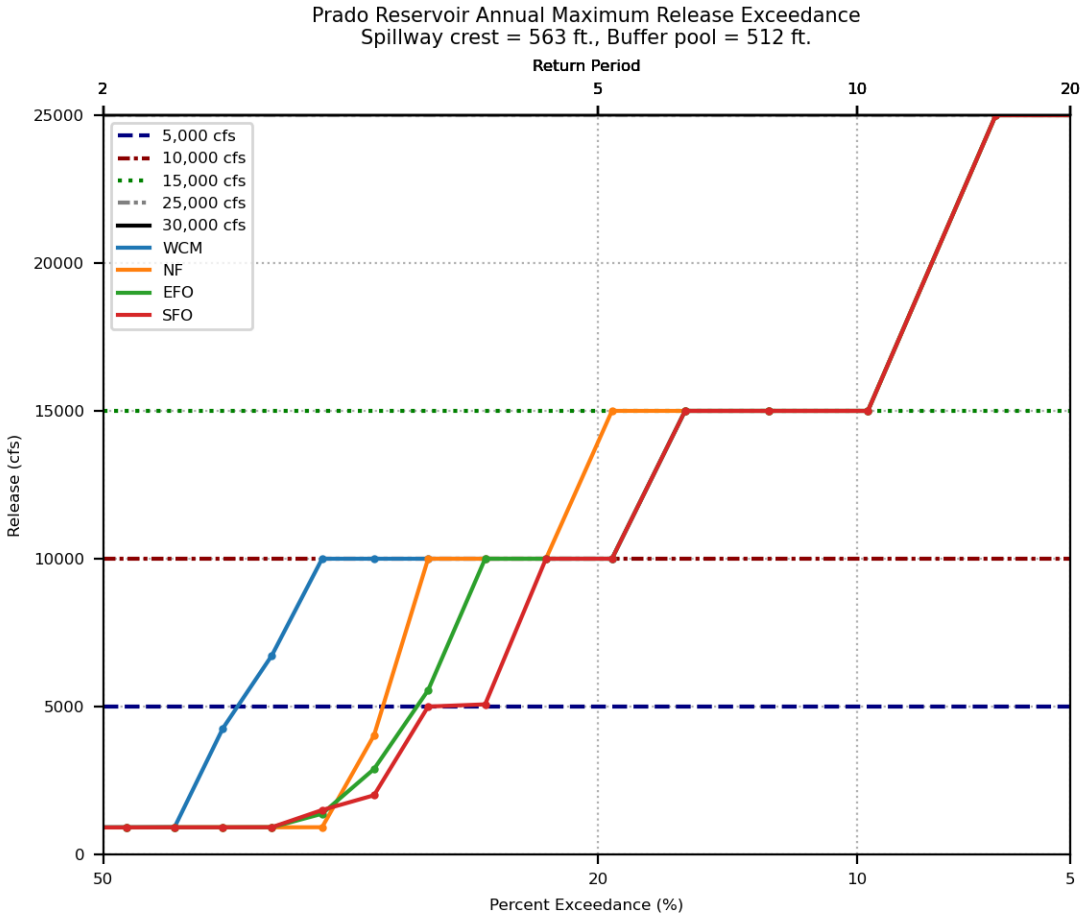

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 512 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
50
20
10
5
Percent Exceedance (%)

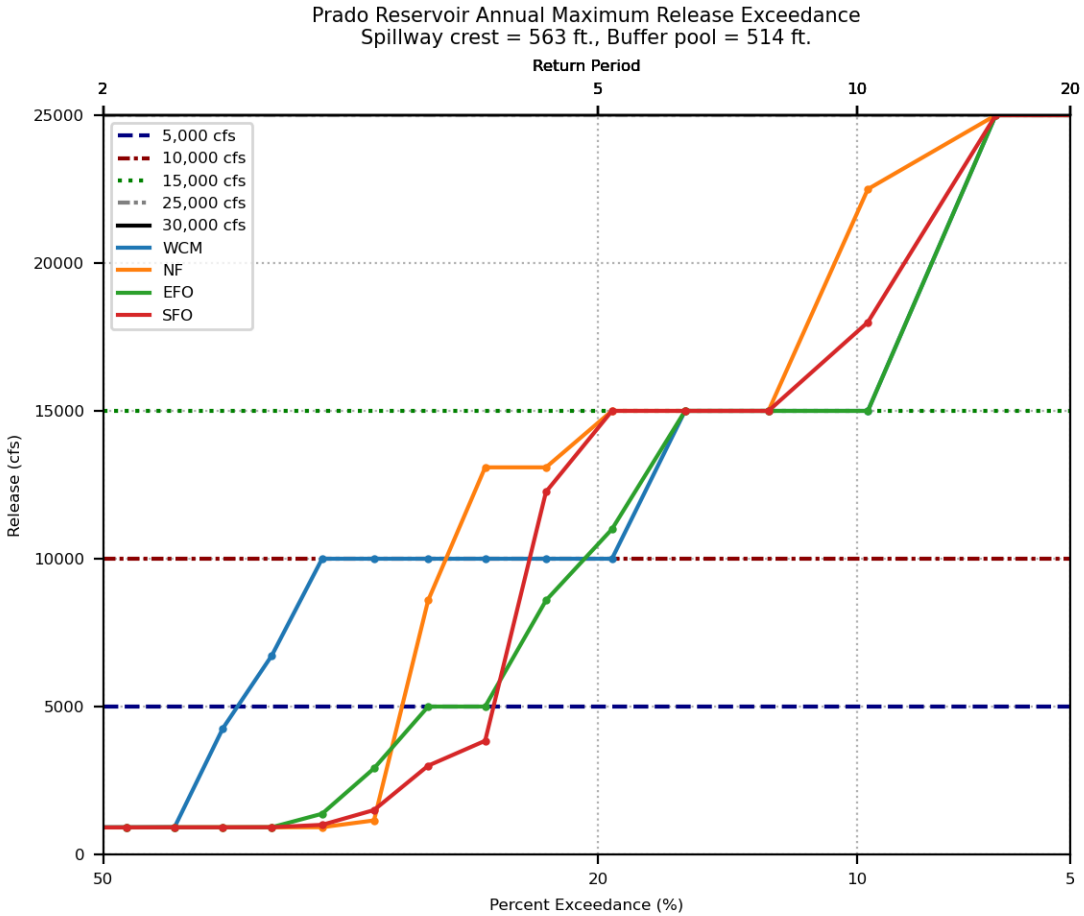

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 514 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
50
20
10
5
Percent Exceedance (%)

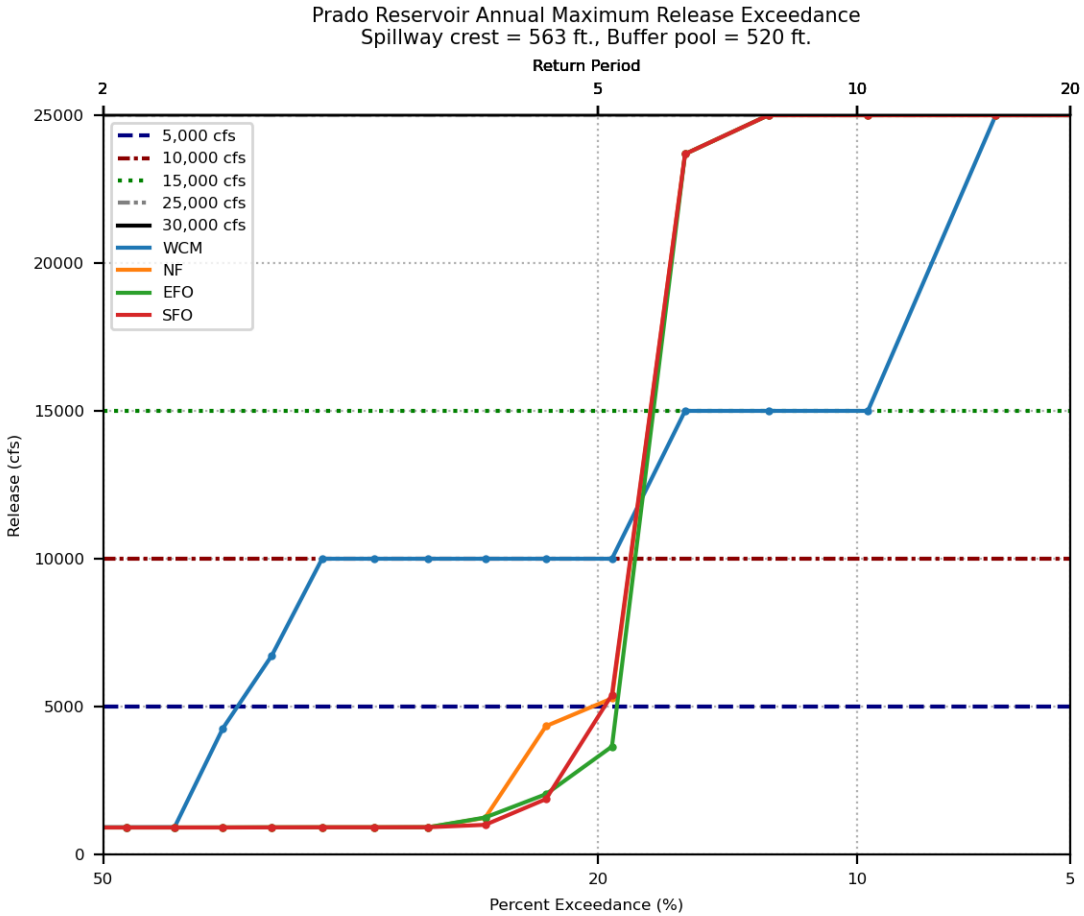

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 520 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
50
20
10
5
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 508 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
50
20
10
5
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 510 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
50
20
10
5
Percent Exceedance (%)

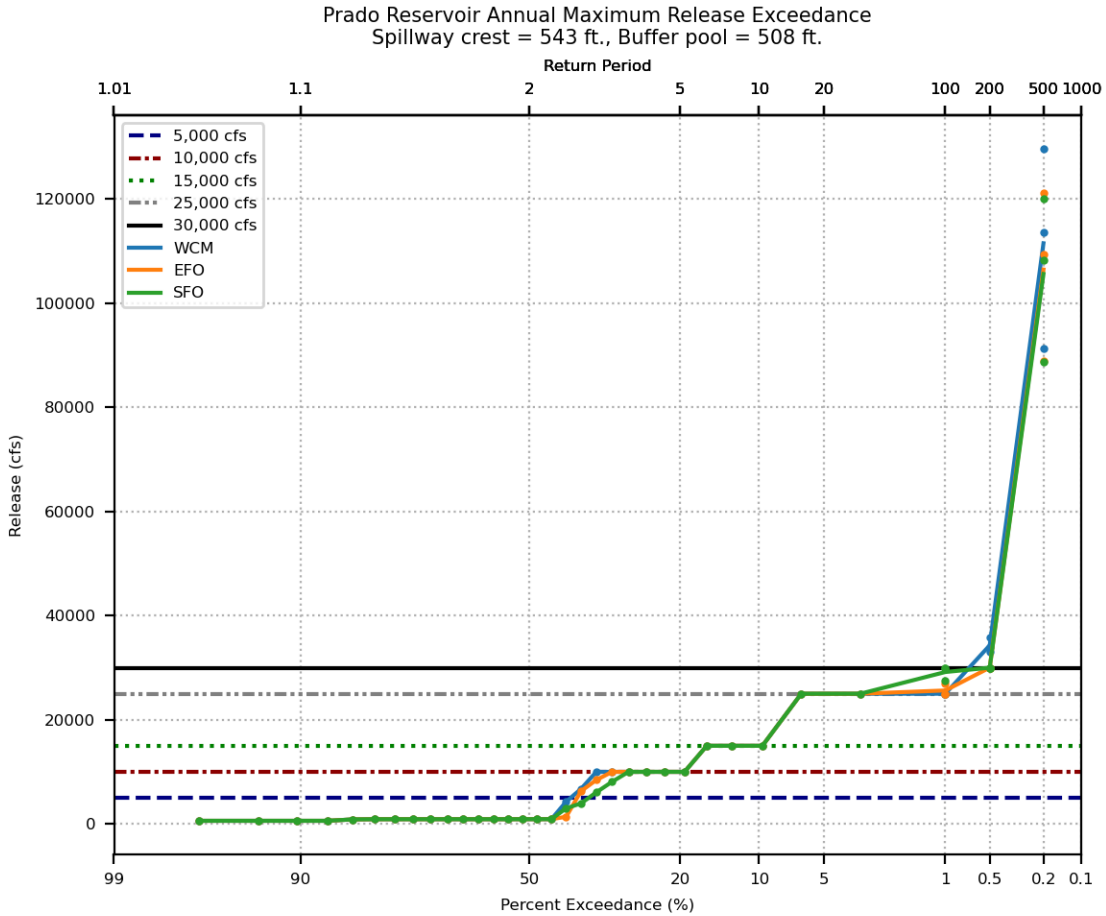

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 512 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
50
20
10
5
Percent Exceedance (%)

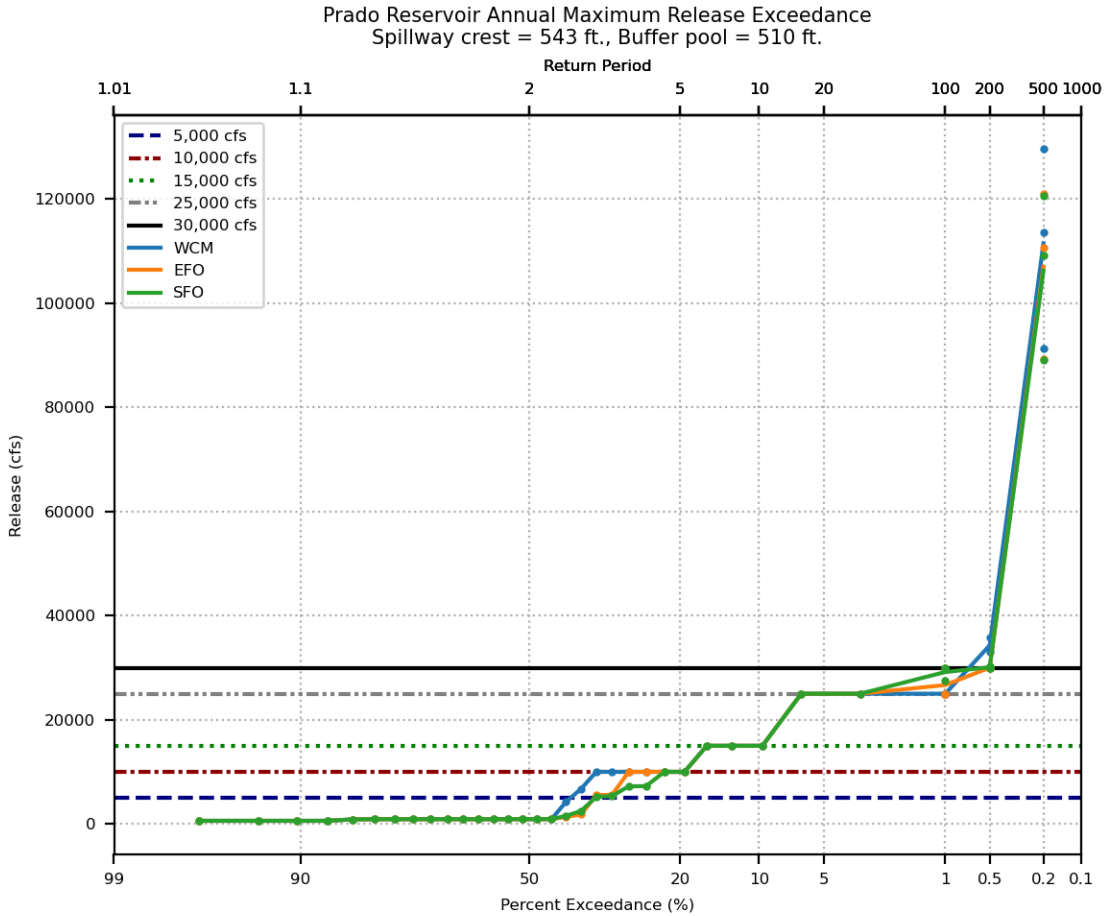

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 514 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
50
20
10
5
Percent Exceedance (%)

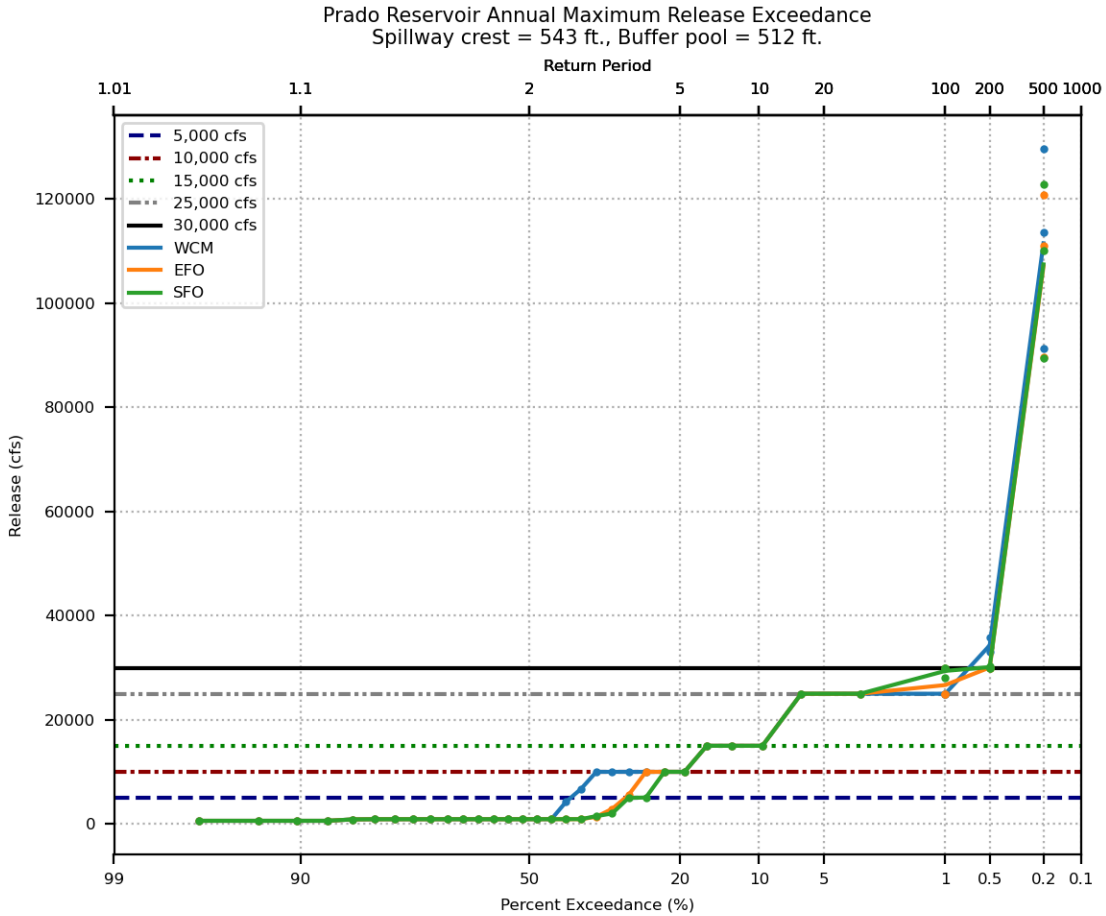

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 520 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
NF
EFO
SFO
50
20
10
5
Percent Exceedance (%)

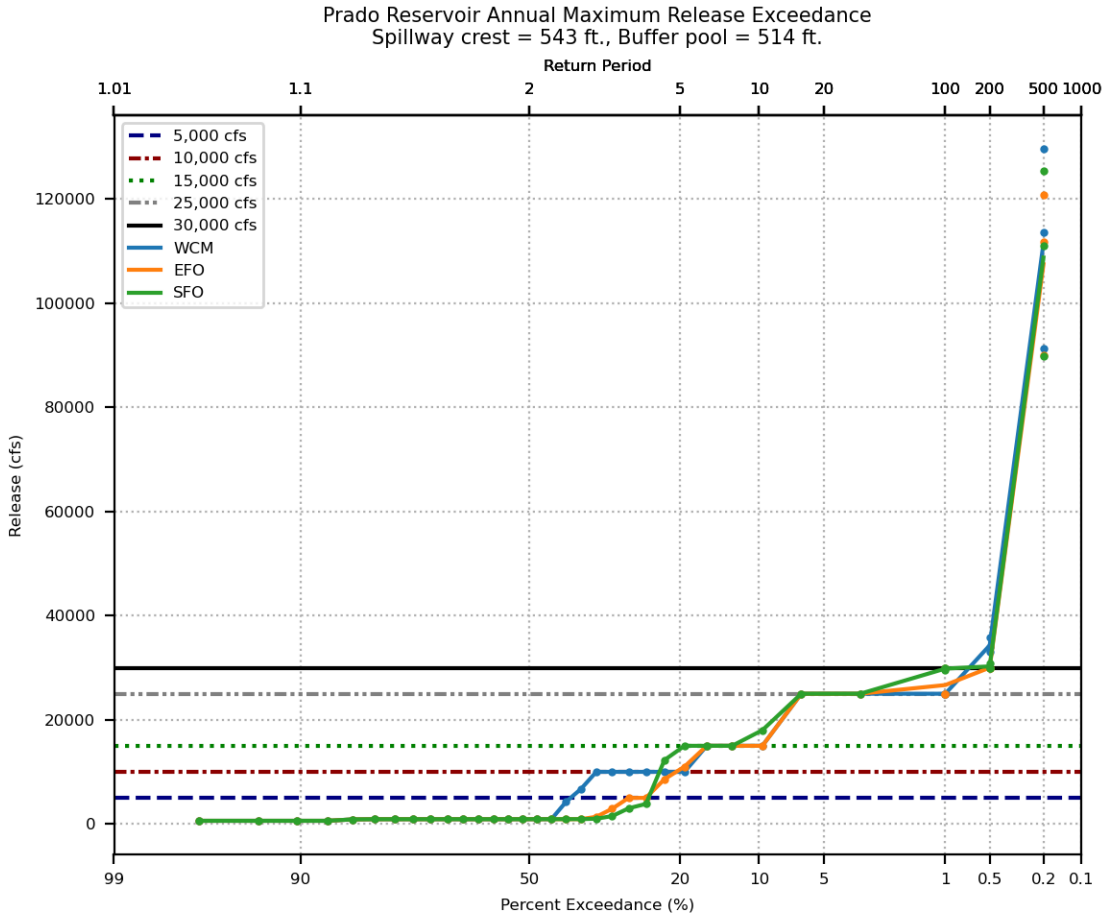
Frequency of Annual Maximum Reservoir Release *by Buffer Pool (NP/NF)*

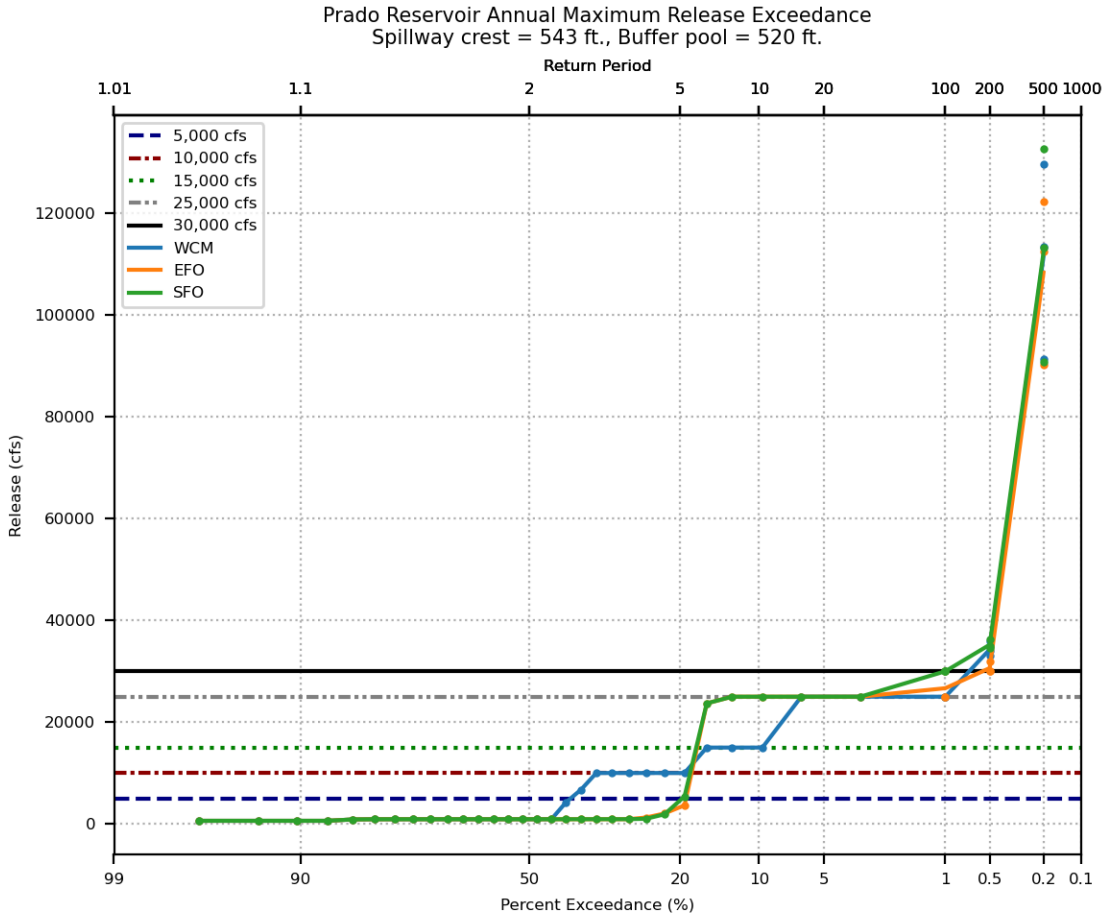
- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’
  - 510’
  - 512’
  - 514’
  - 520’
- WCP alternatives in legend
  - Perfect Forecast results omitted
  - No Forecast results omitted

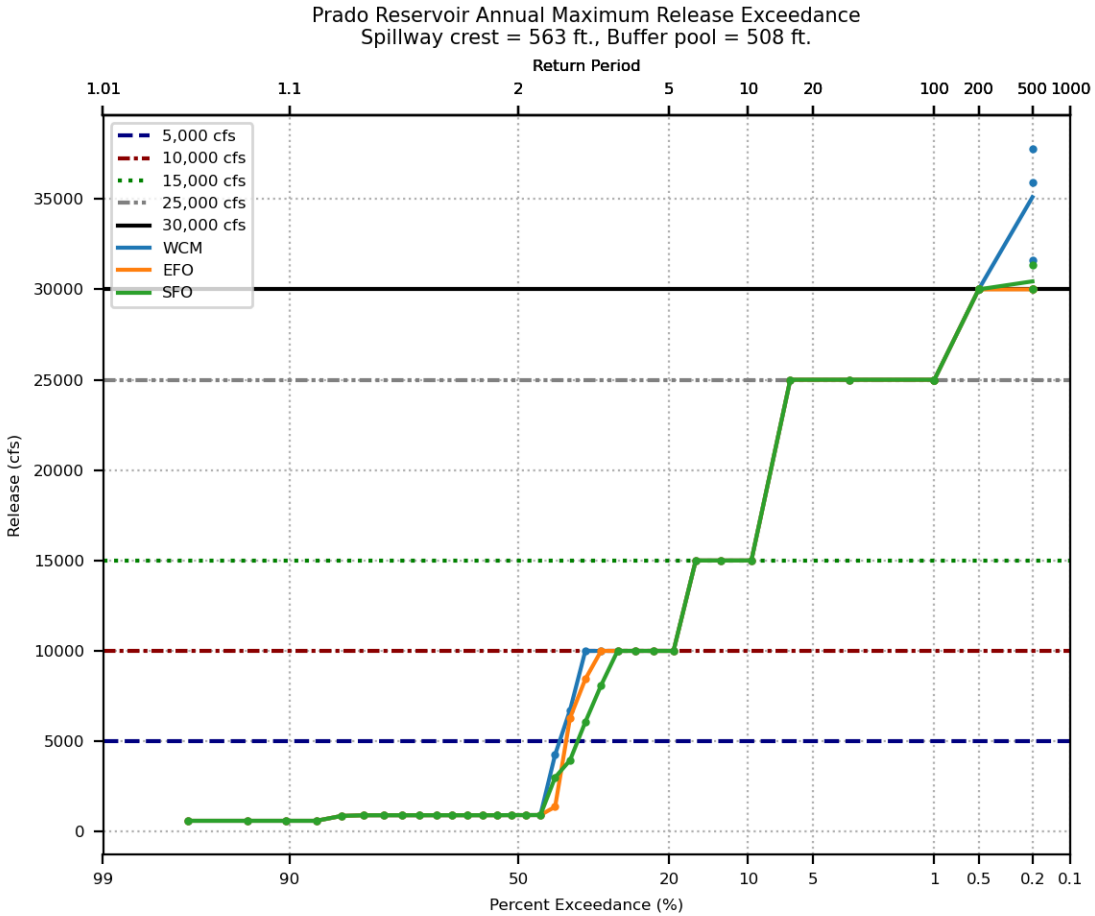

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 508 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
Release (cfs)
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

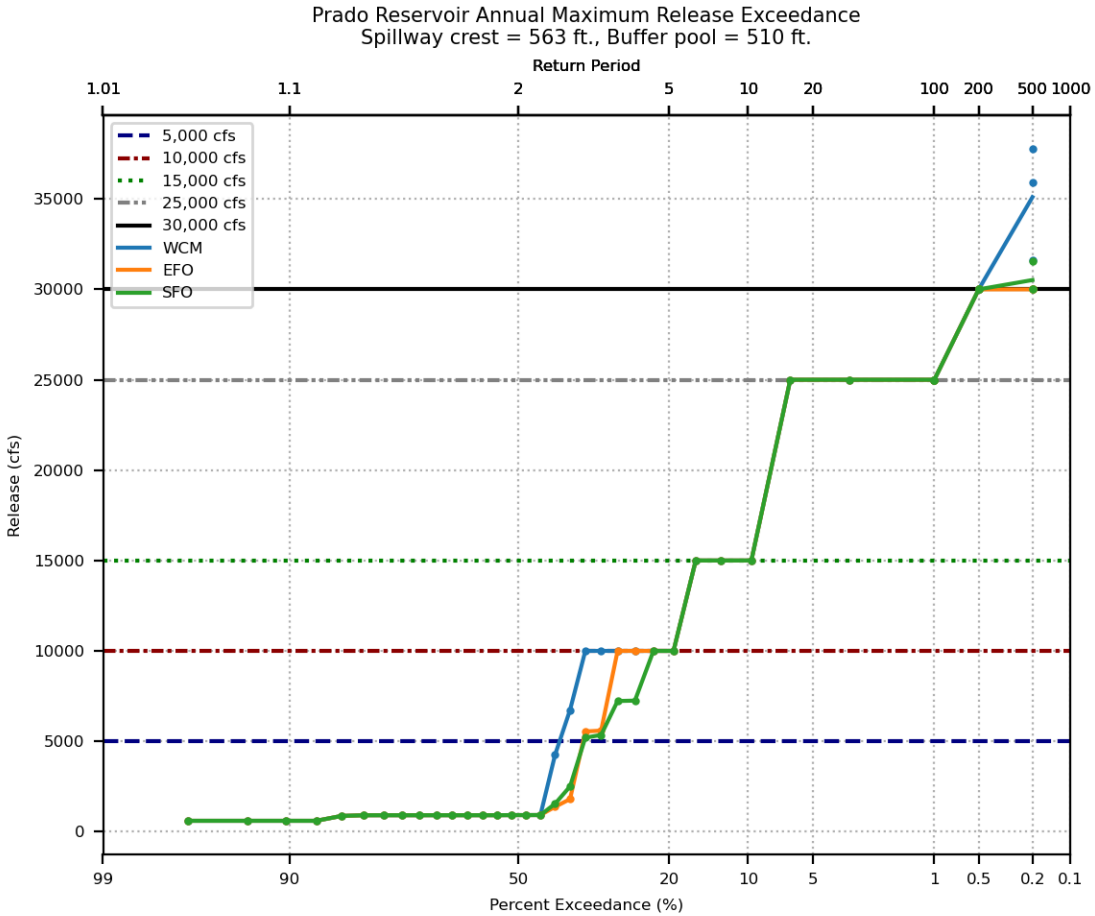

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 510 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
Release (cfs)
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

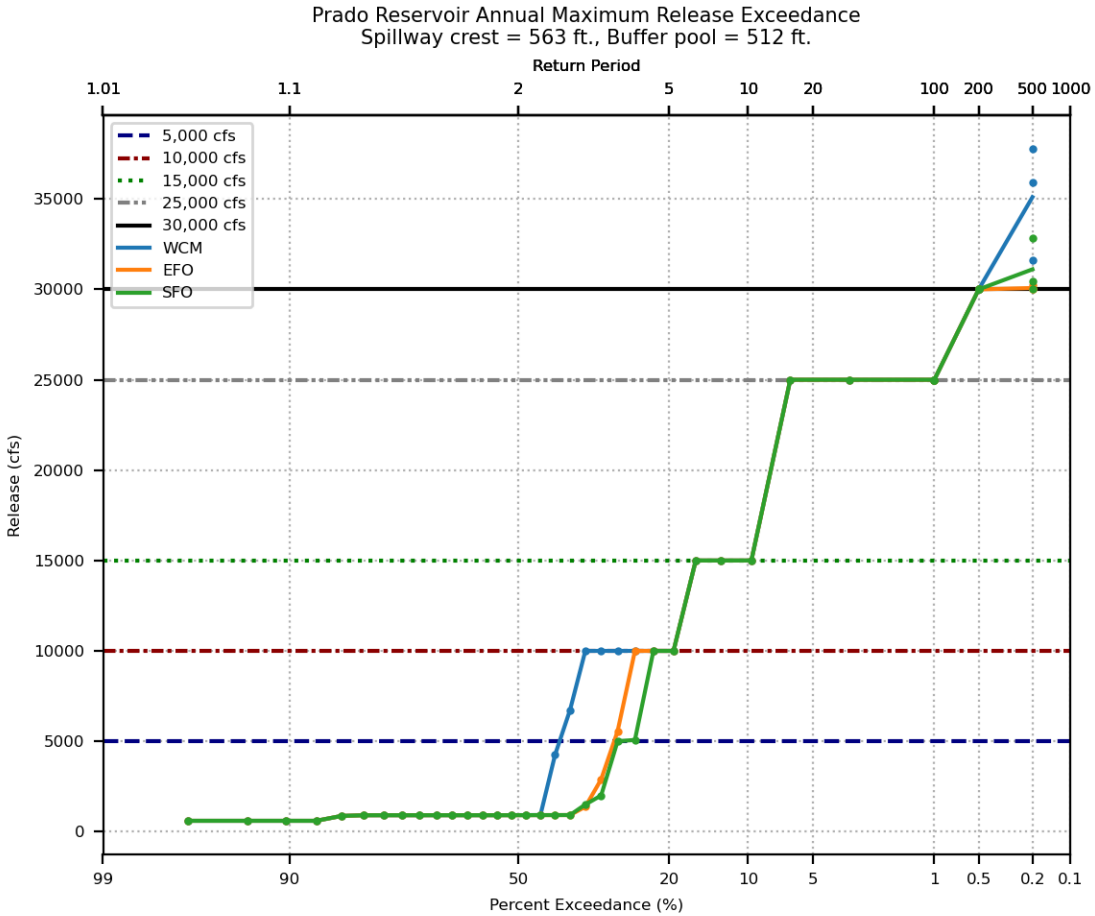

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 512 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
Release (cfs)
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

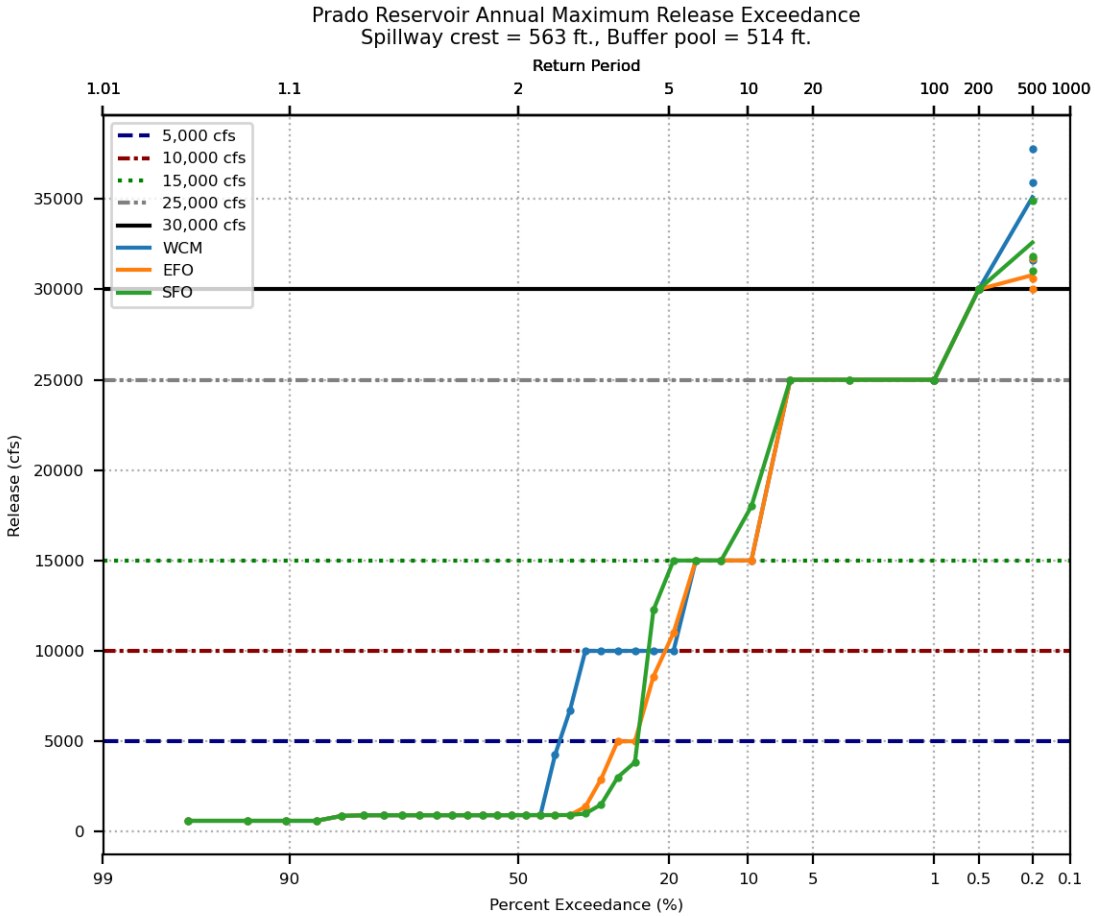

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 514 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
120000
100000
80000
60000
40000
20000
0
Release (cfs)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

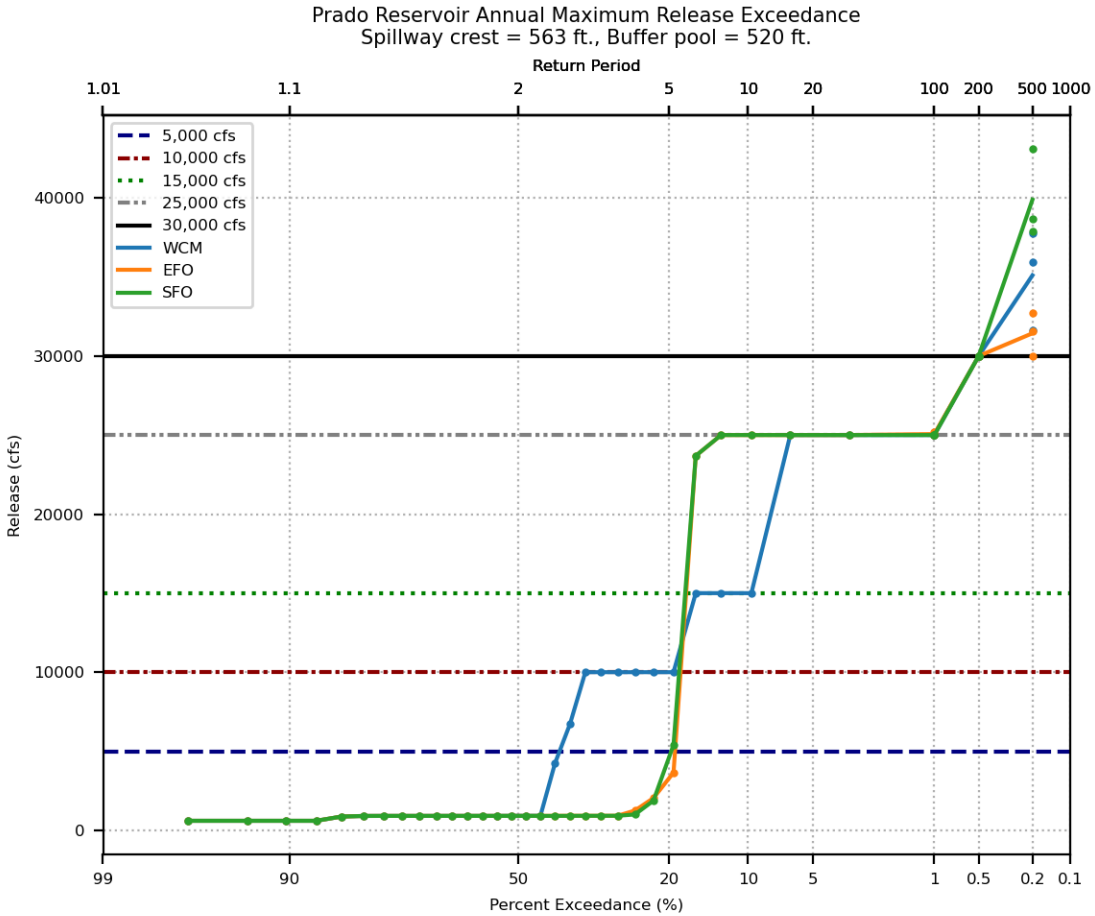

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 520 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
Release (cfs)
120000
100000
80000
60000
40000
20000
0
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 508 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
35000
30000
25000
20000
15000
10000
5000
0
Release (cfs)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 510 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
35000
30000
25000
20000
15000
10000
5000
0
Release (cfs)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

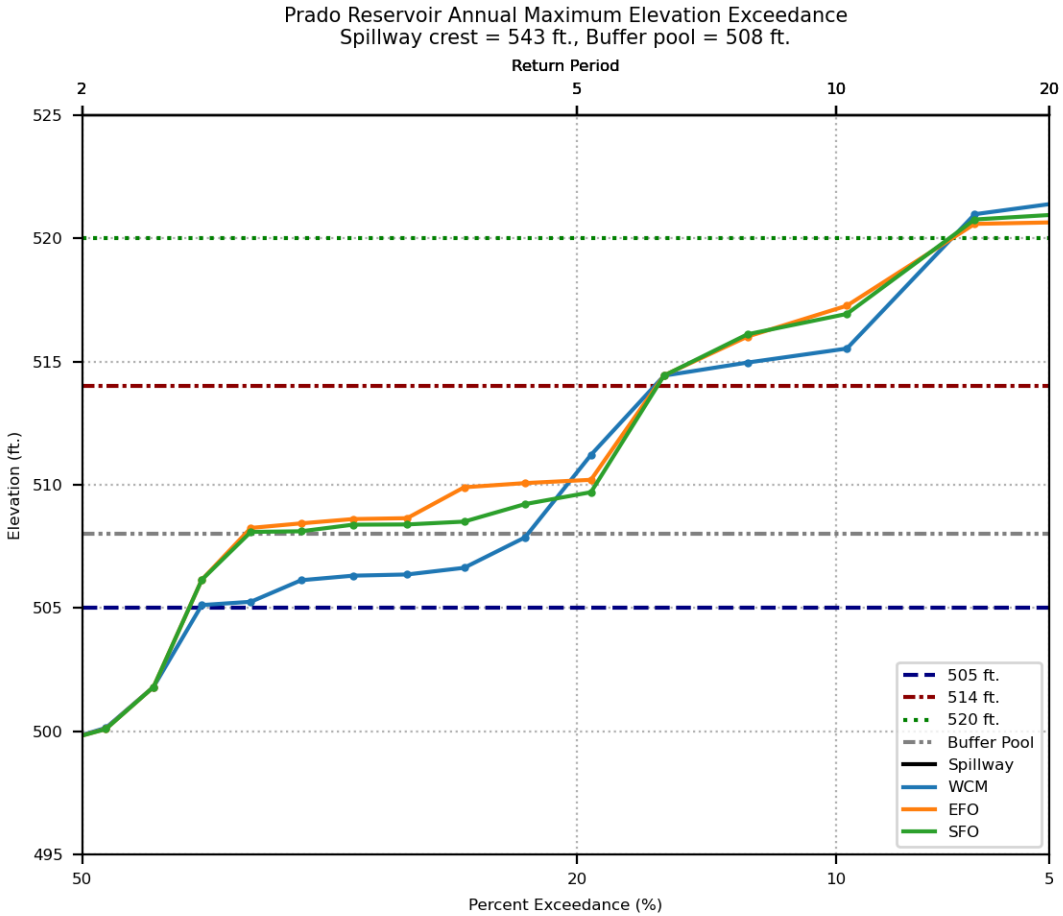

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 512 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
35000
30000
25000
20000
15000
10000
5000
0
Release (cfs)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

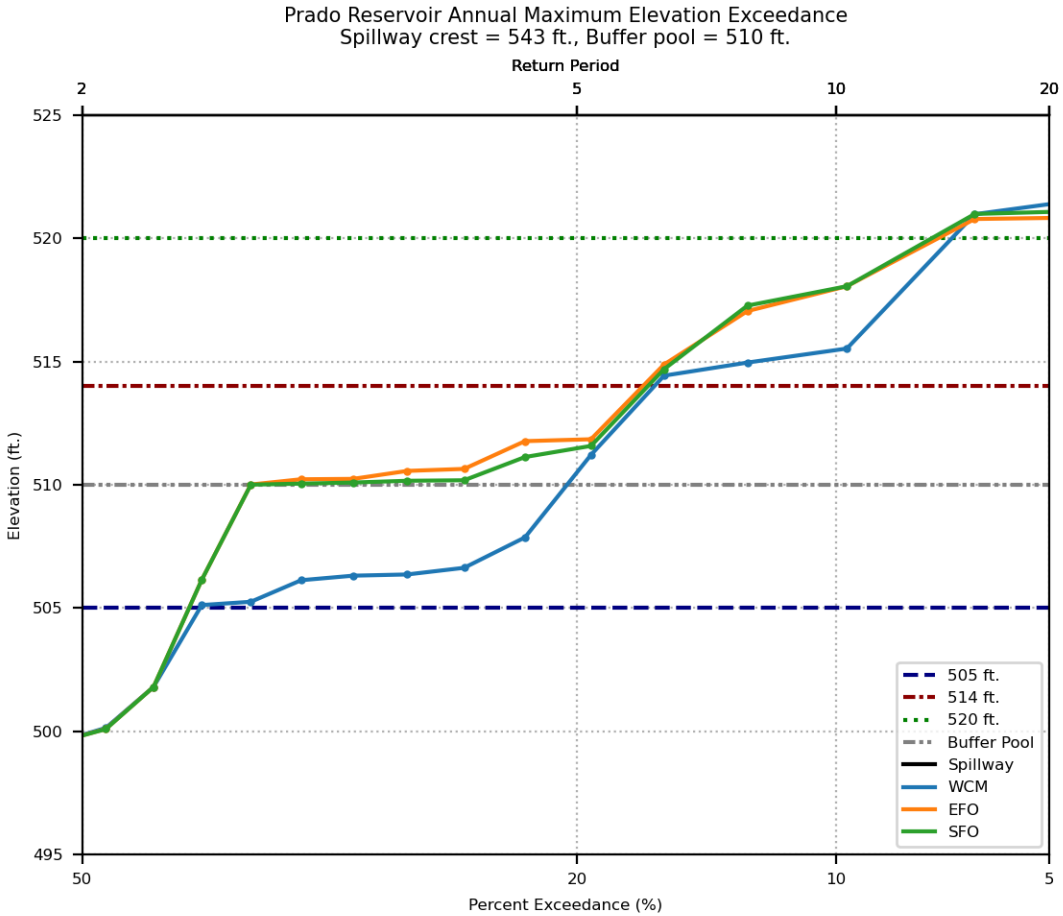

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 514 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
35000
30000
25000
20000
15000
10000
5000
0
Release (cfs)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

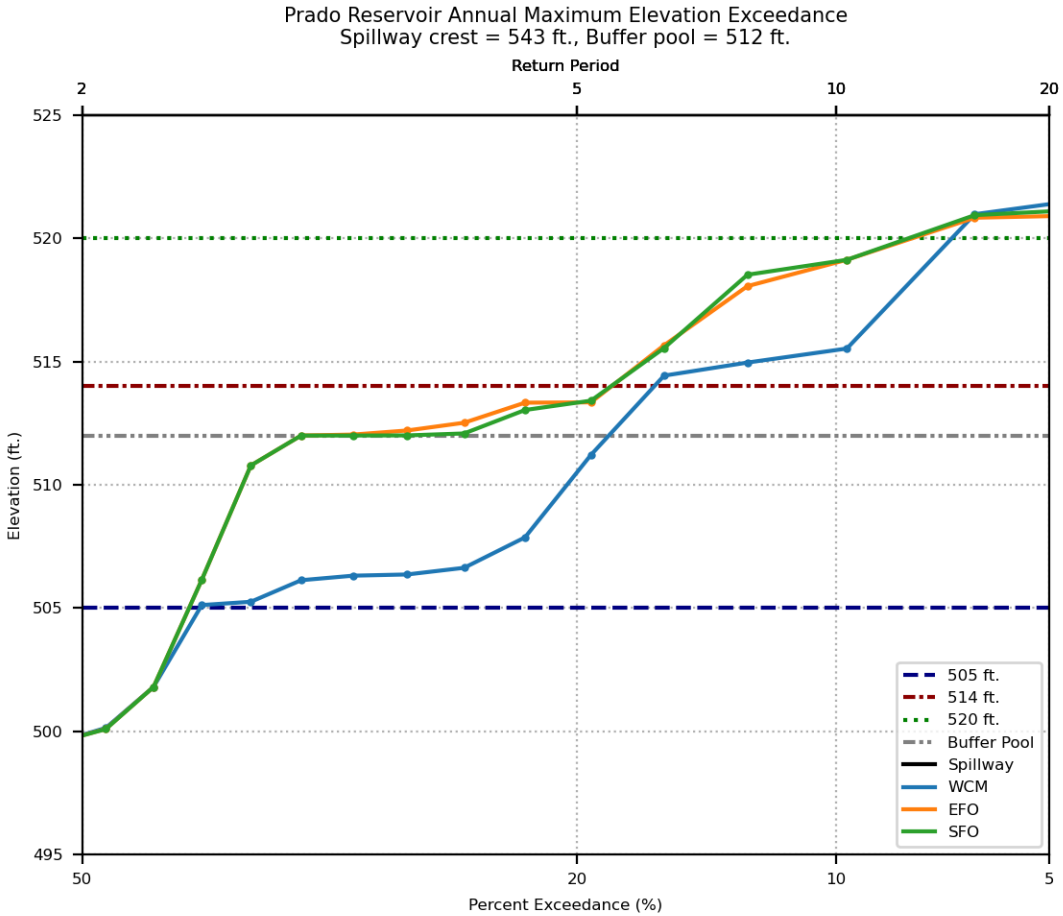

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 520 ft.
Return Period
1.01
1.1
2
5
10
20
100
200
500
1000
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
40000
30000
20000
10000
0
Release (cfs)
99
90
50
20
10
5
1
0.5
0.2
0.1
Percent Exceedance (%)

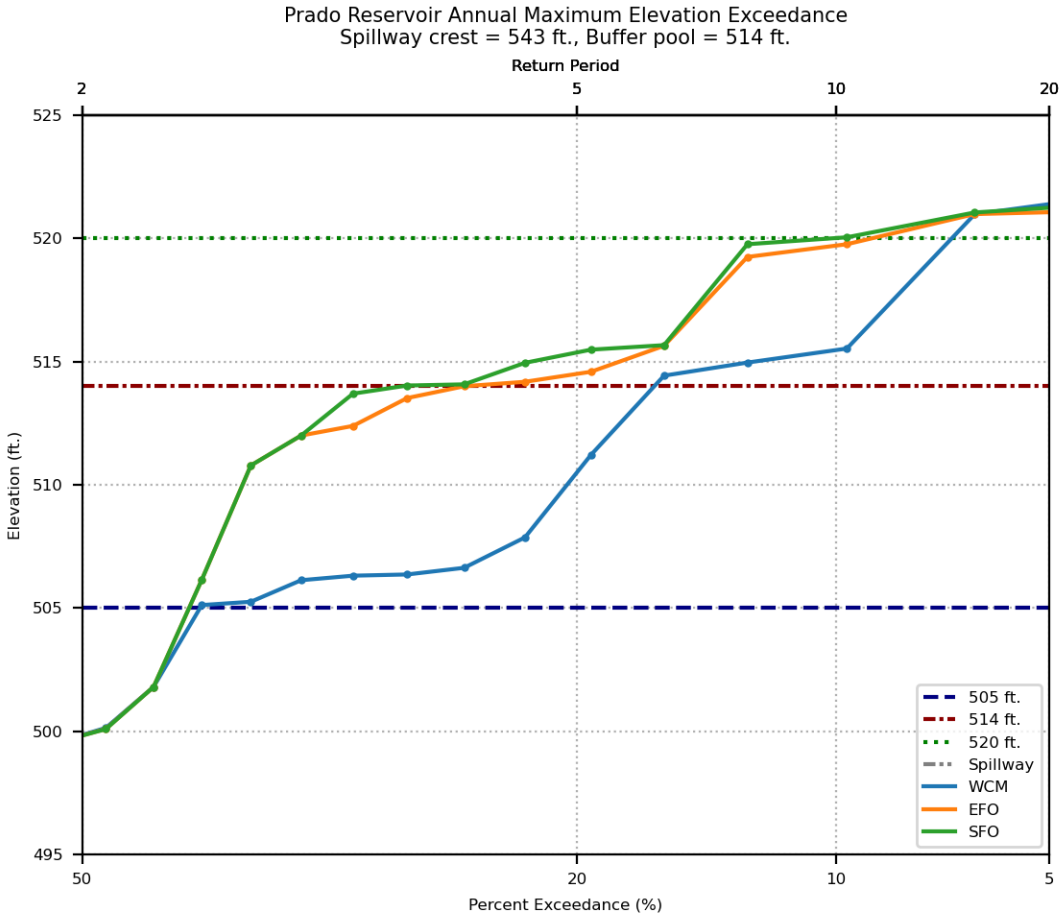
Frequency of Annual Maximum Reservoir Release *by Buffer Pool (NP/NF)* Zoomed

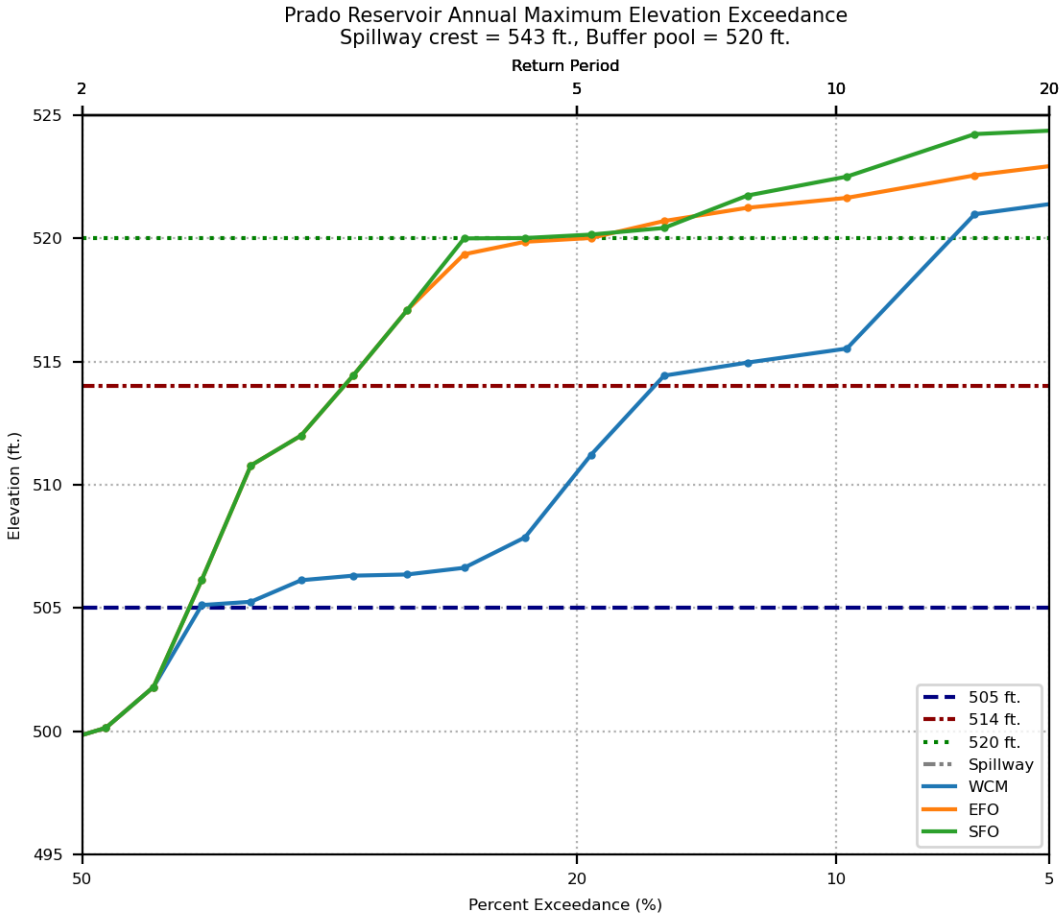
- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’
  - 510’
  - 512’
  - 514’
  - 520’
- WCP alternatives in legend
  - Perfect Forecast results omitted
  - No Forecast results omitted

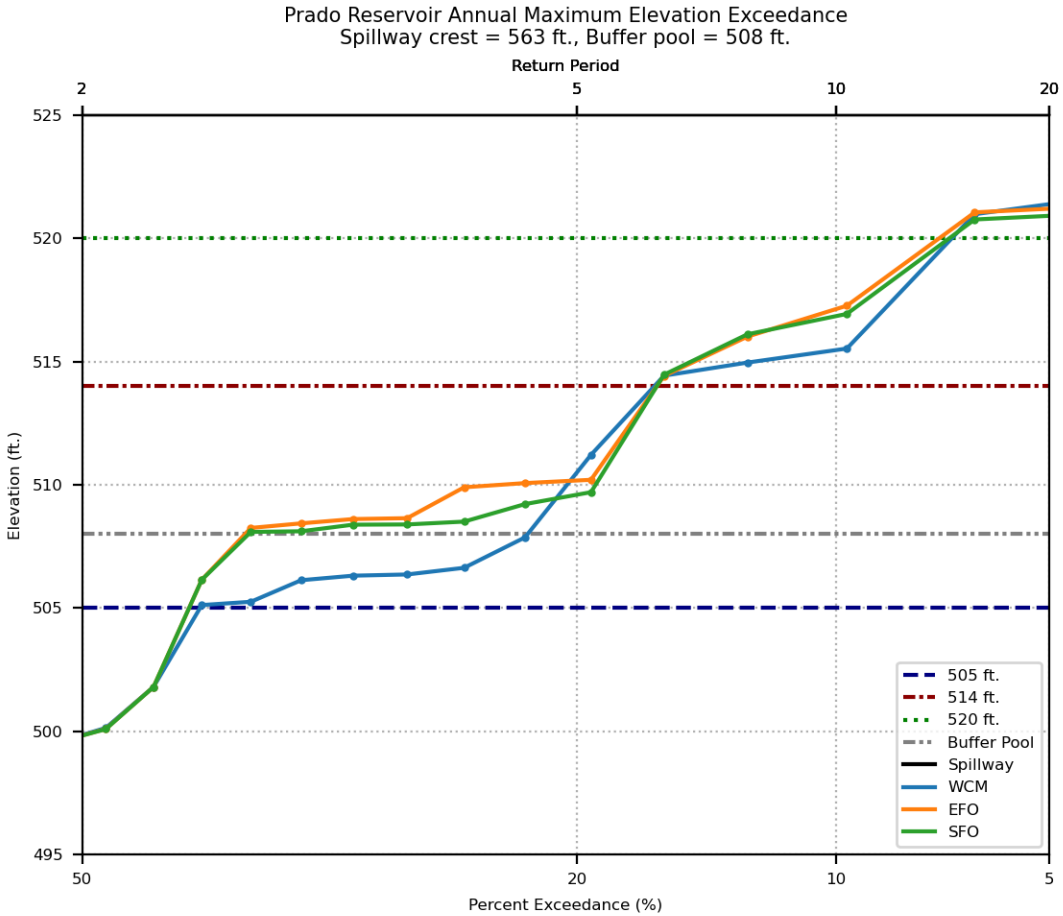

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 508 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
EFO
SFO

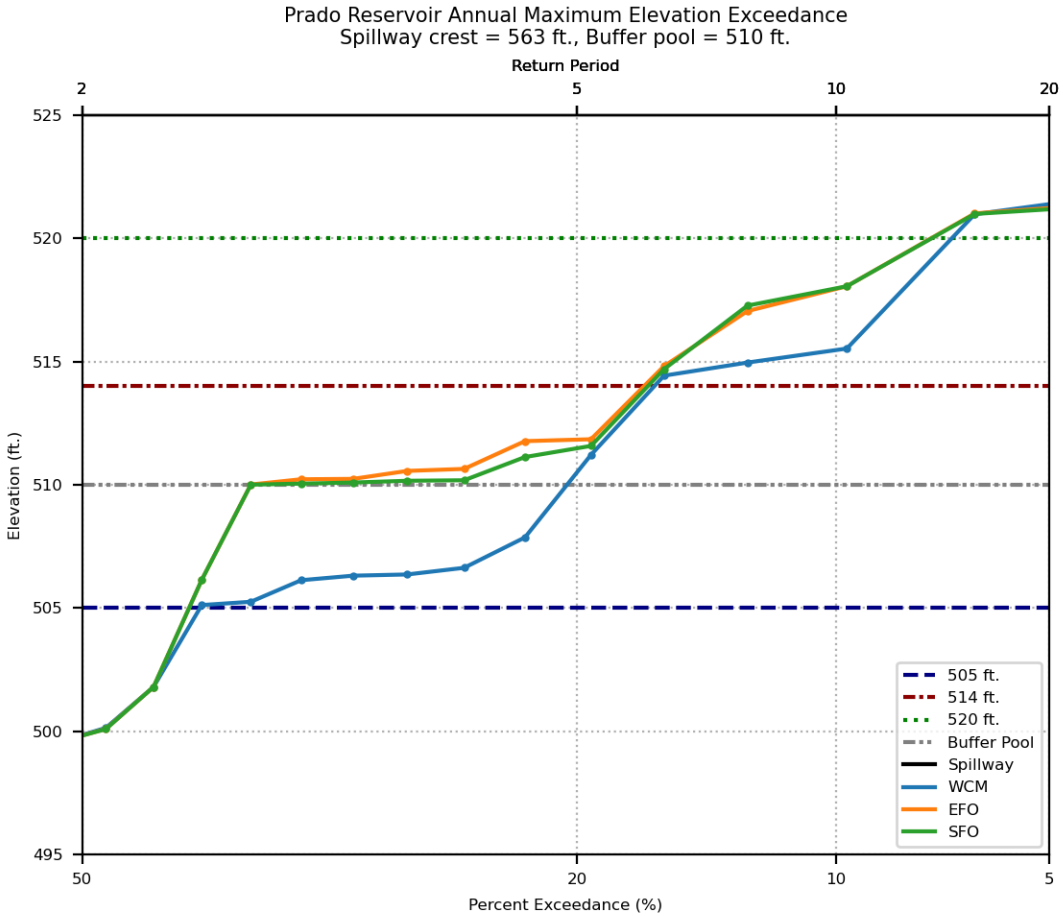

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 510 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
EFO
SFO

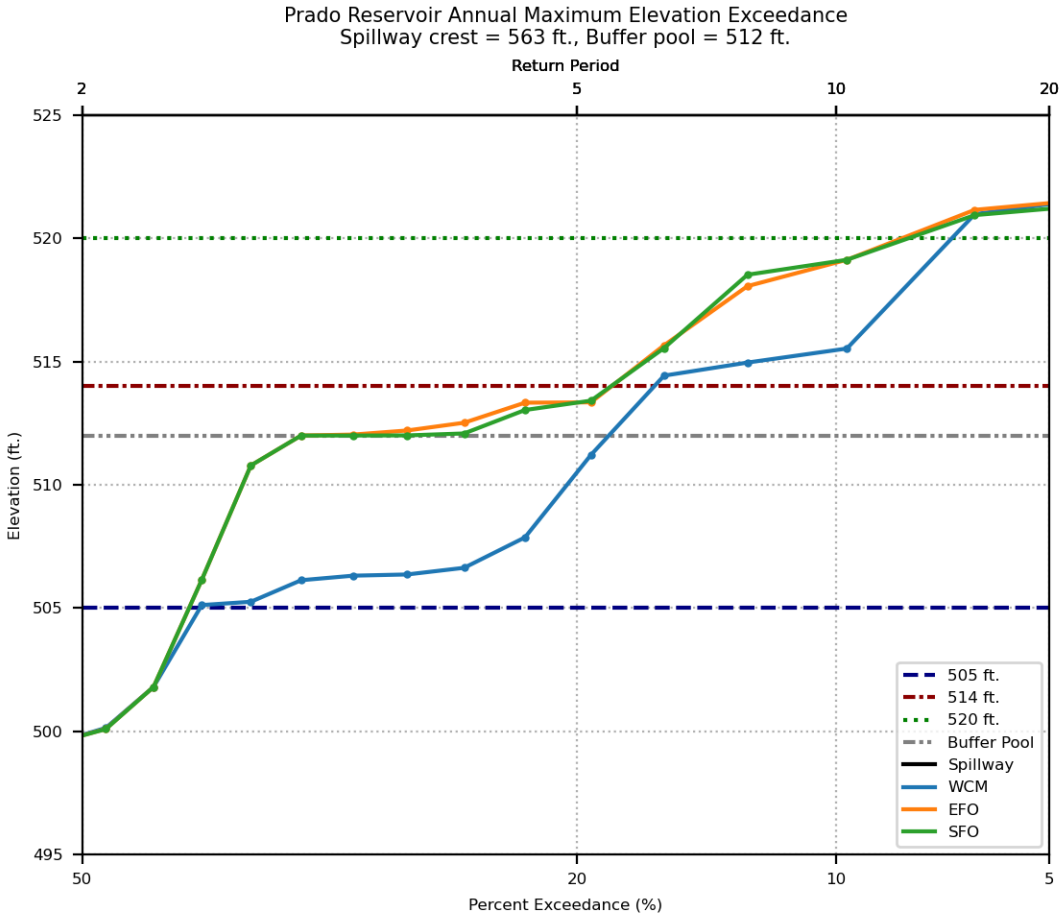

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 512 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
EFO
SFO

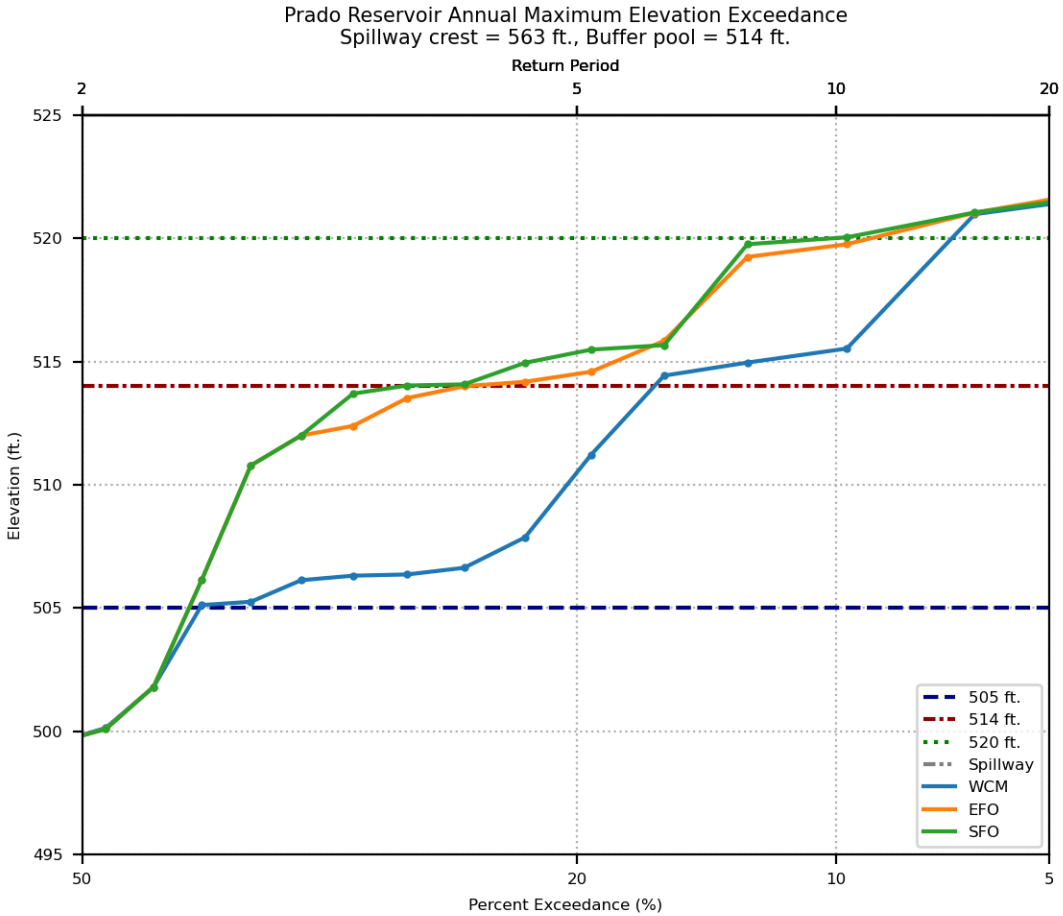

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 514 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Spillway
WCM
EFO
SFO

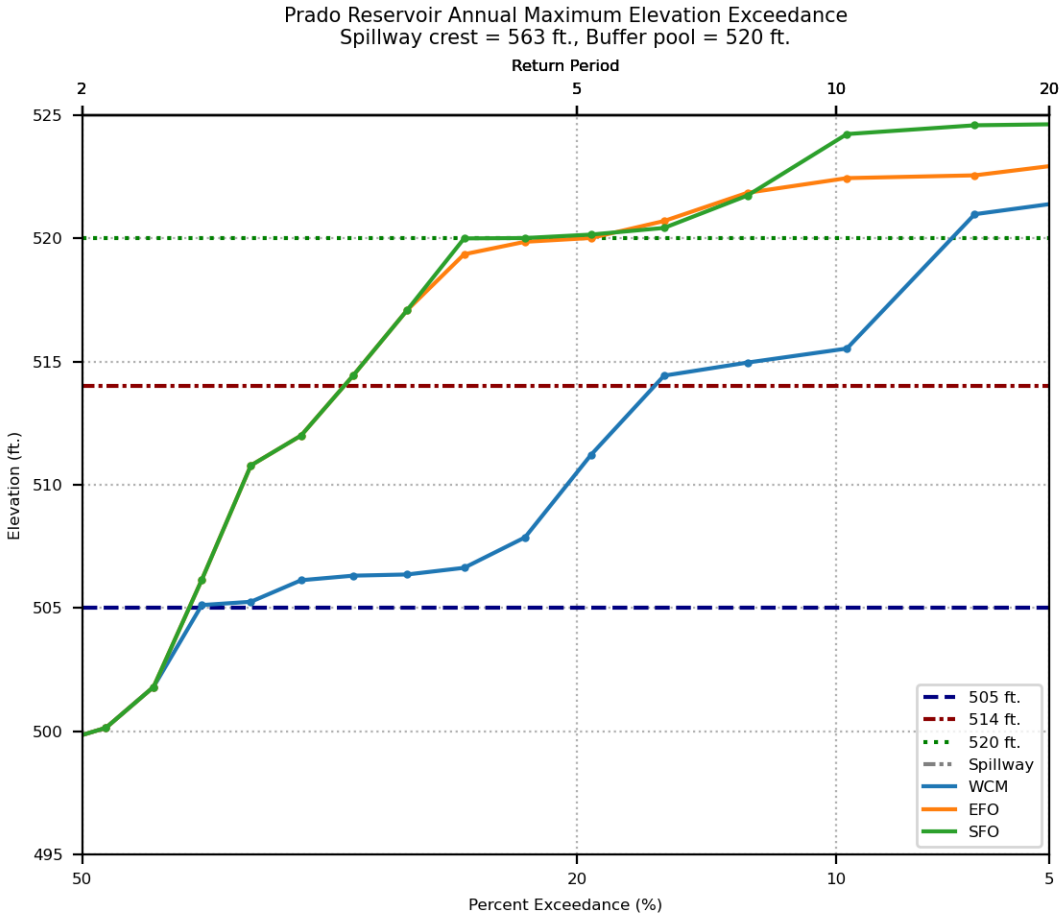

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 543 ft., Buffer pool = 520 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Spillway
WCM
EFO
SFO

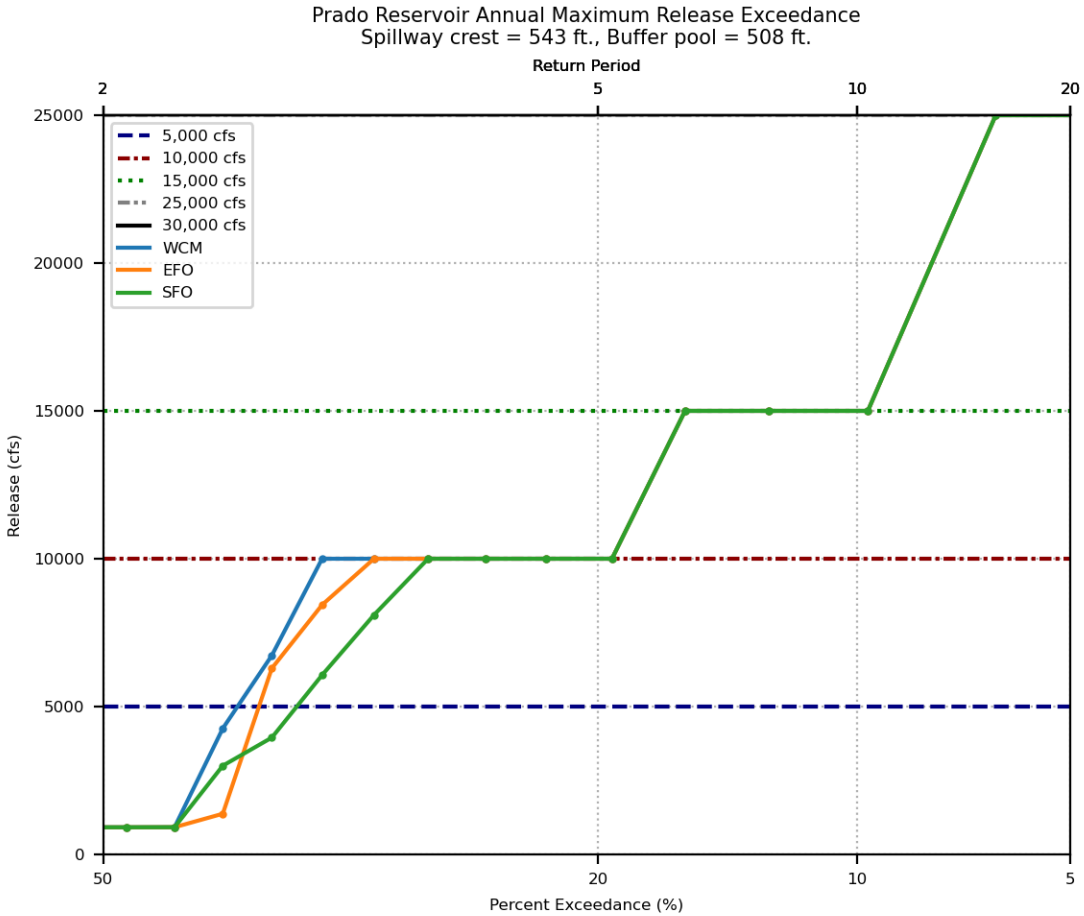

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 508 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
EFO
SFO

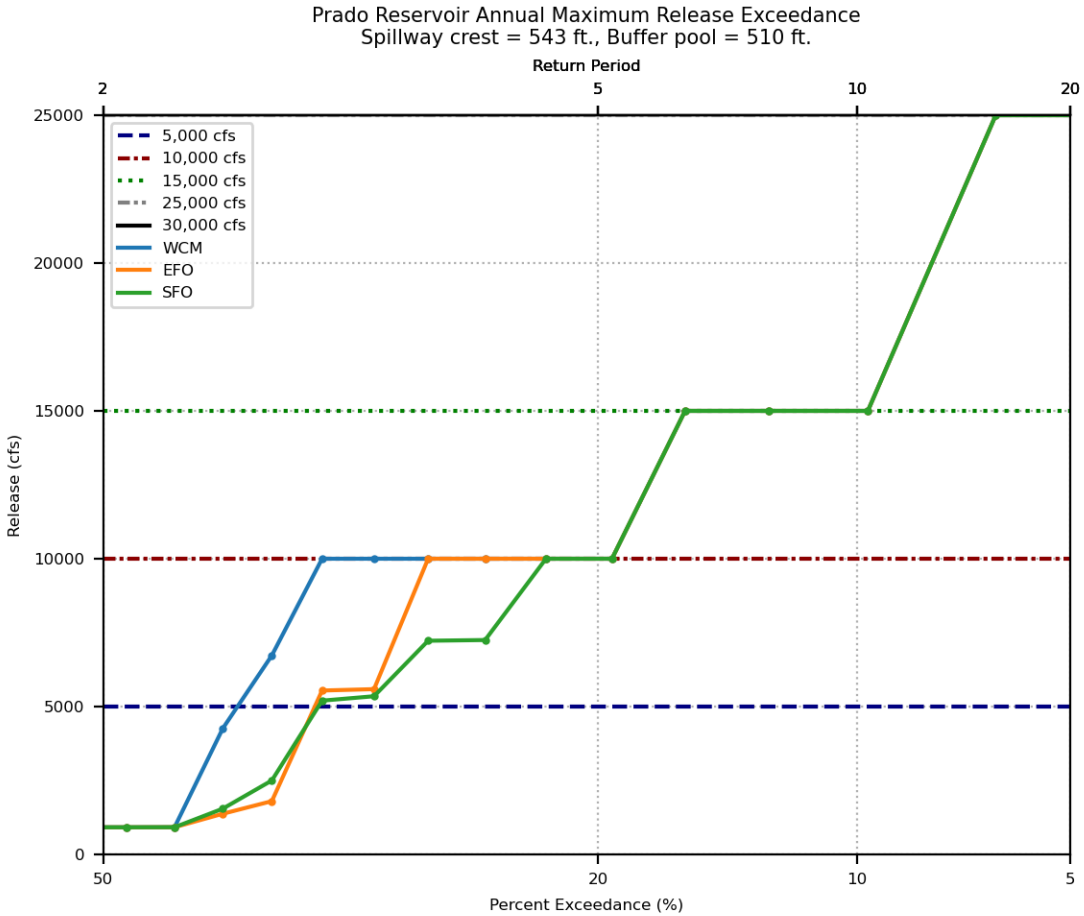

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 510 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
EFO
SFO

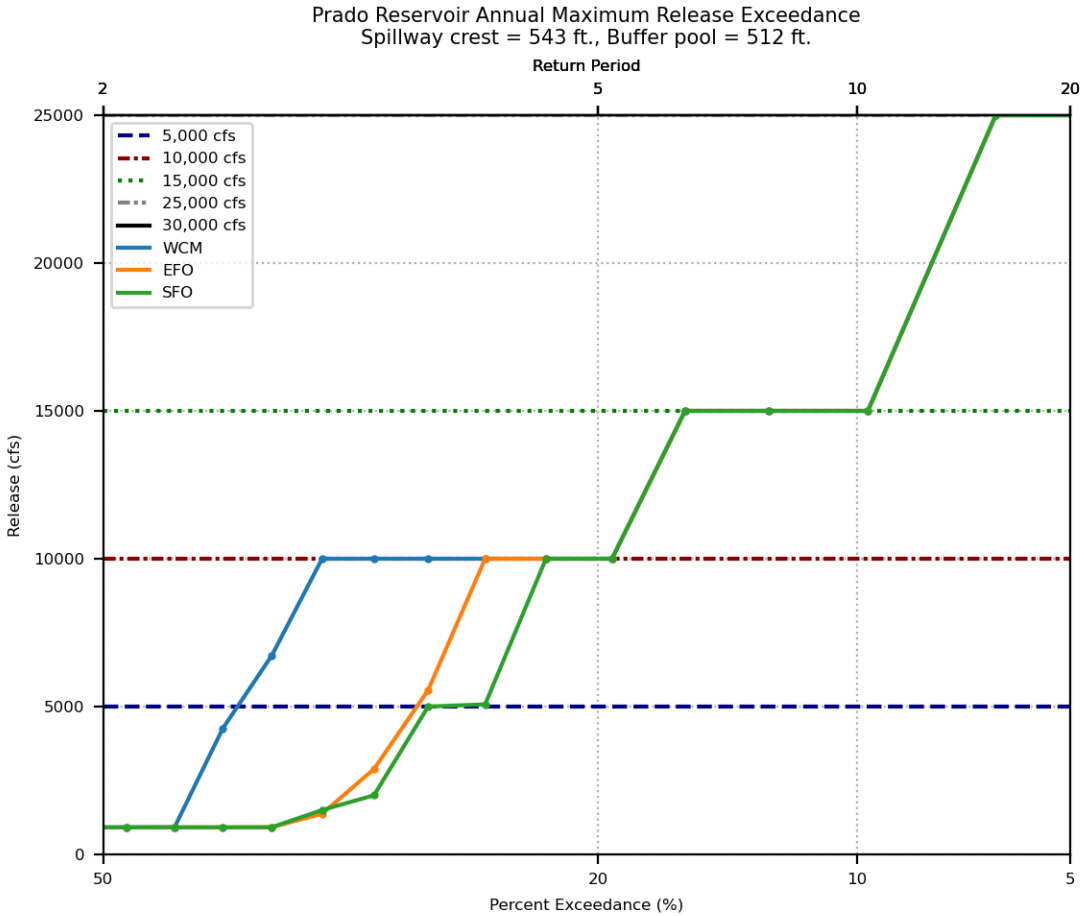

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 512 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Buffer Pool
Spillway
WCM
EFO
SFO

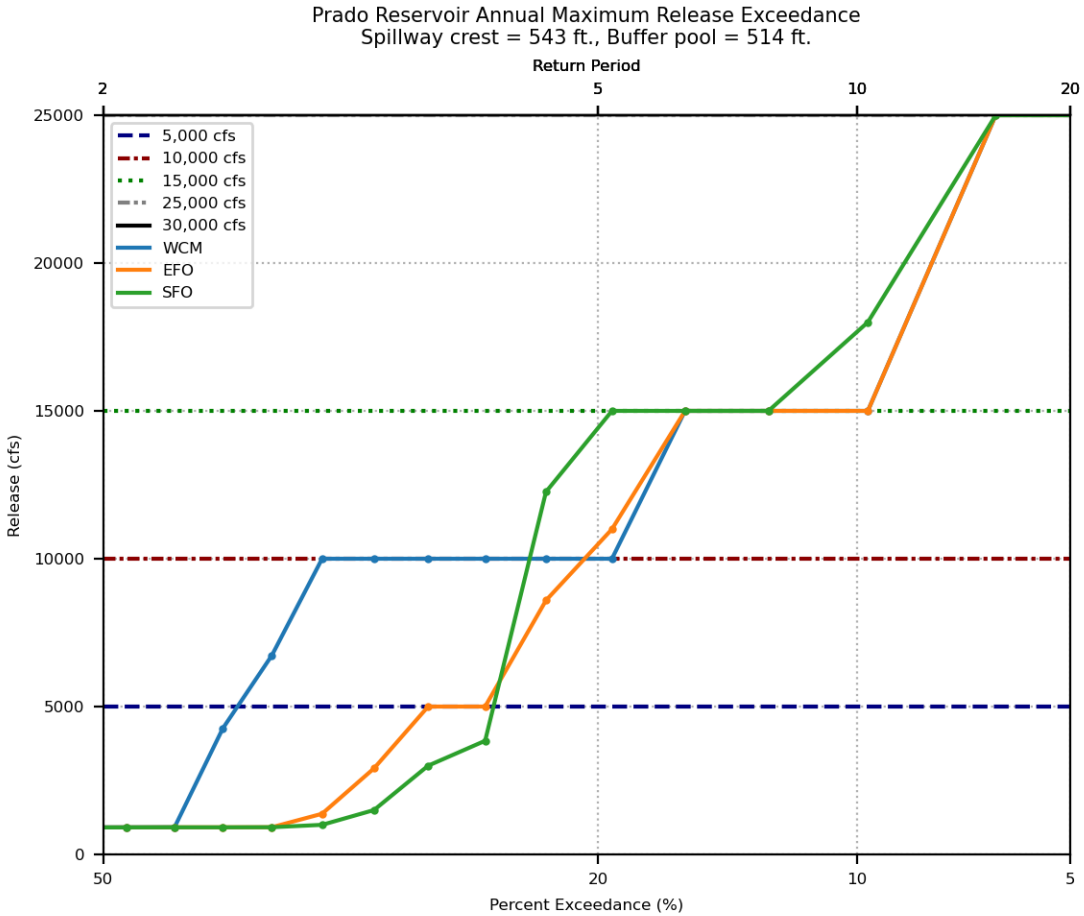

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 514 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Spillway
WCM
EFO
SFO

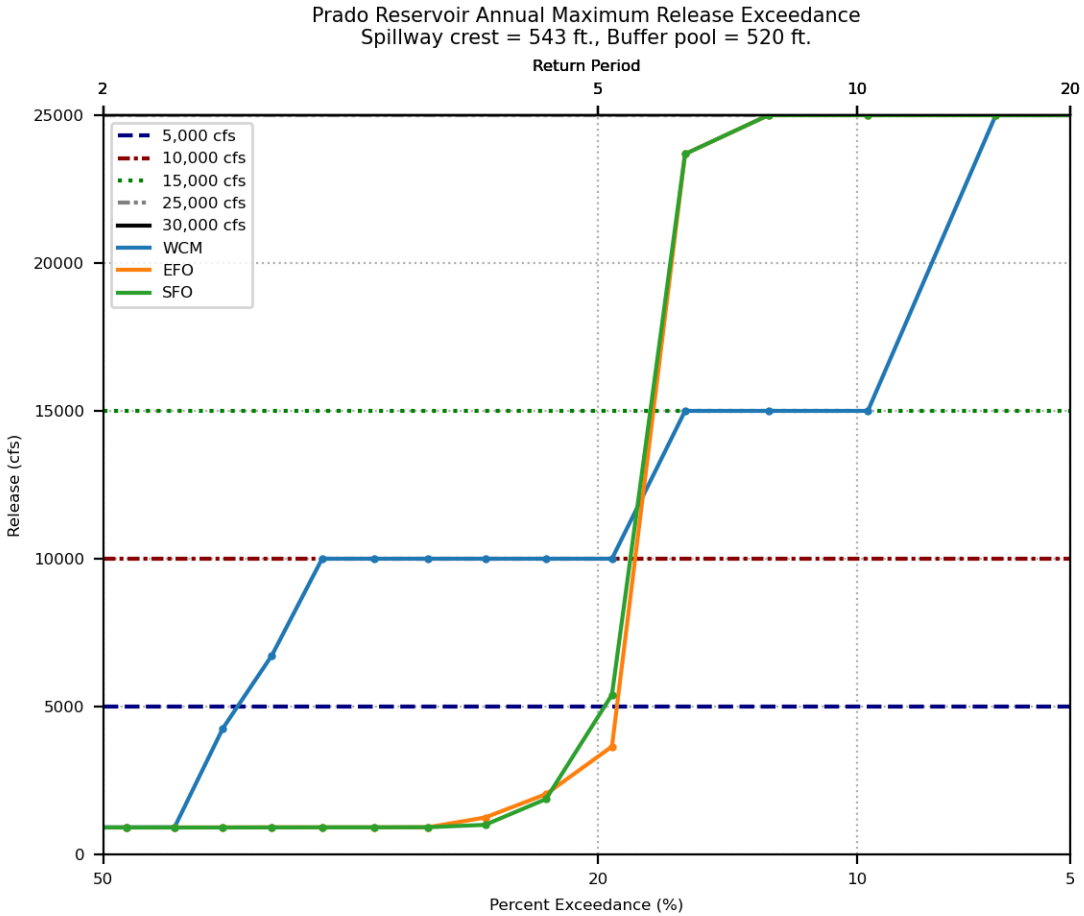

Prado Reservoir Annual Maximum Elevation Exceedance
Spillway crest = 563 ft., Buffer pool = 520 ft.
Return Period
2
5
10
20
525
520
515
510
505
500
495
Elevation (ft.)
50
20
10
5
Percent Exceedance (%)
505 ft.
514 ft.
520 ft.
Spillway
WCM
EFO
SFO

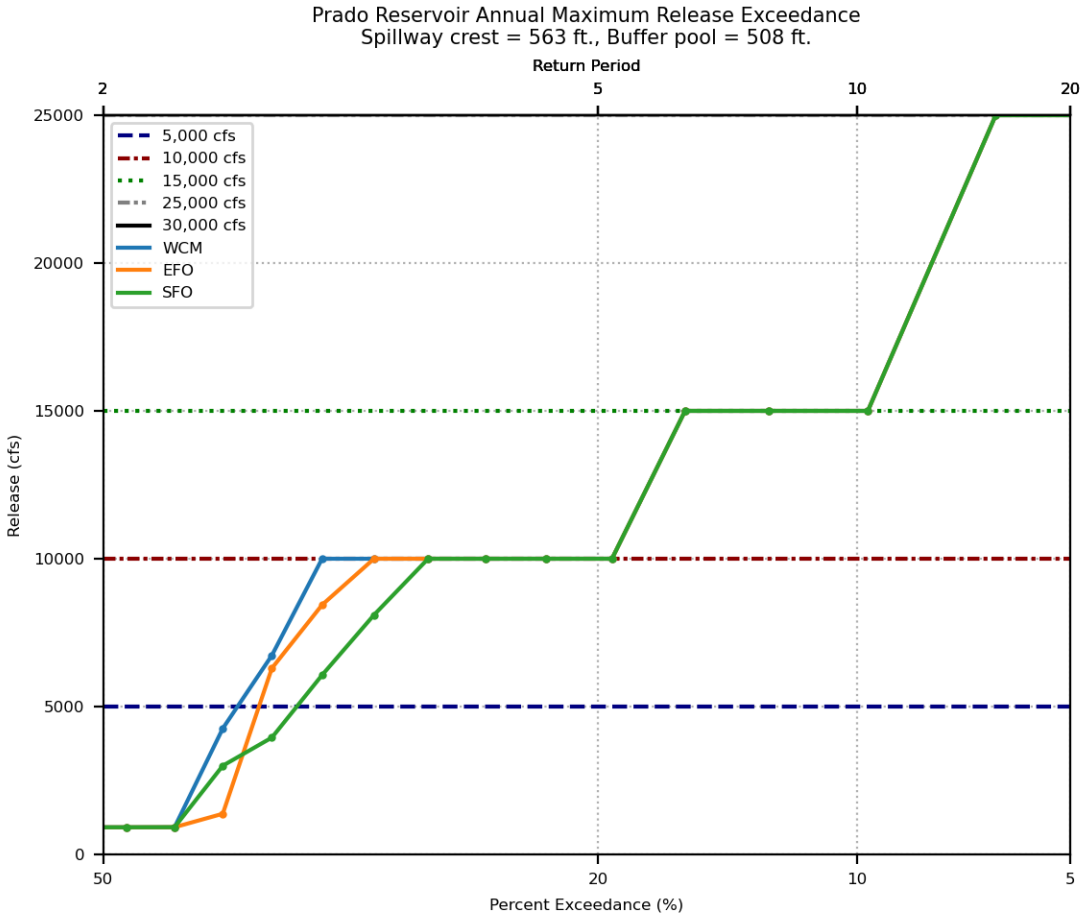

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 508 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
50
20
10
5
Percent Exceedance (%)

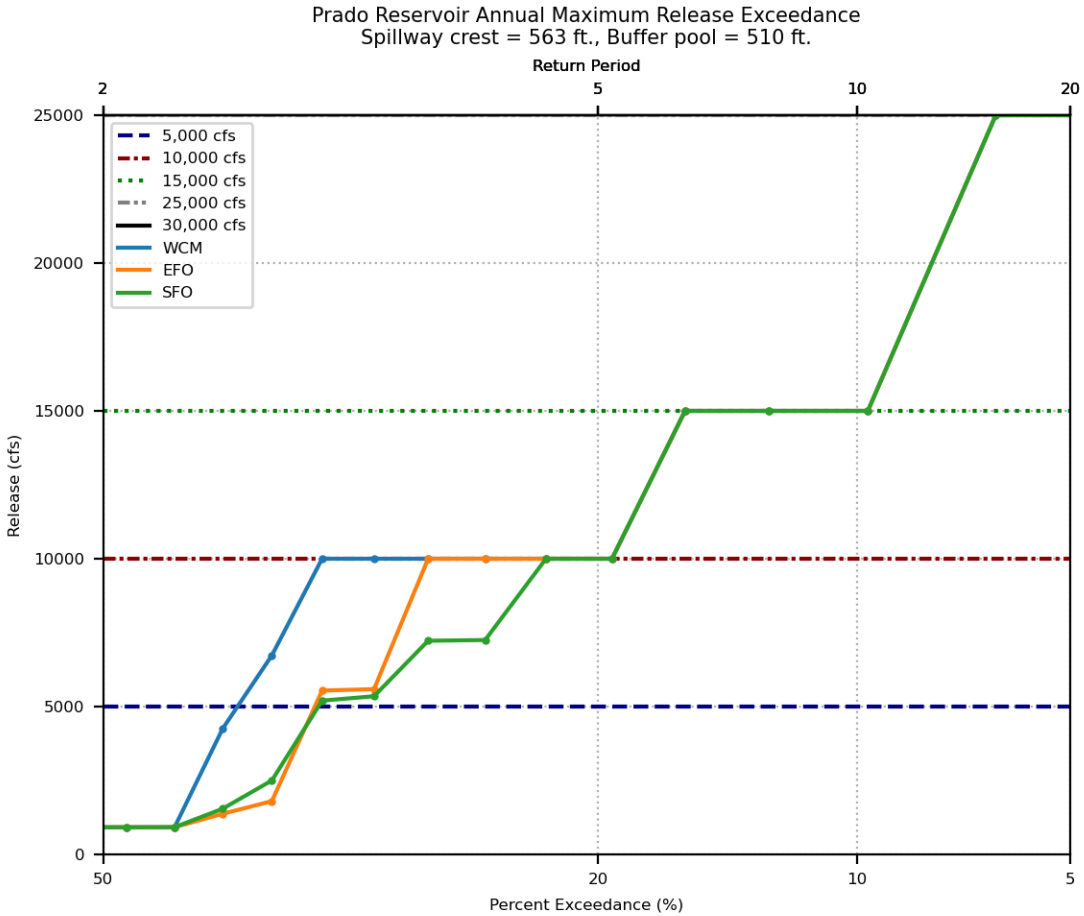

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 510 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
50
20
10
5
Percent Exceedance (%)

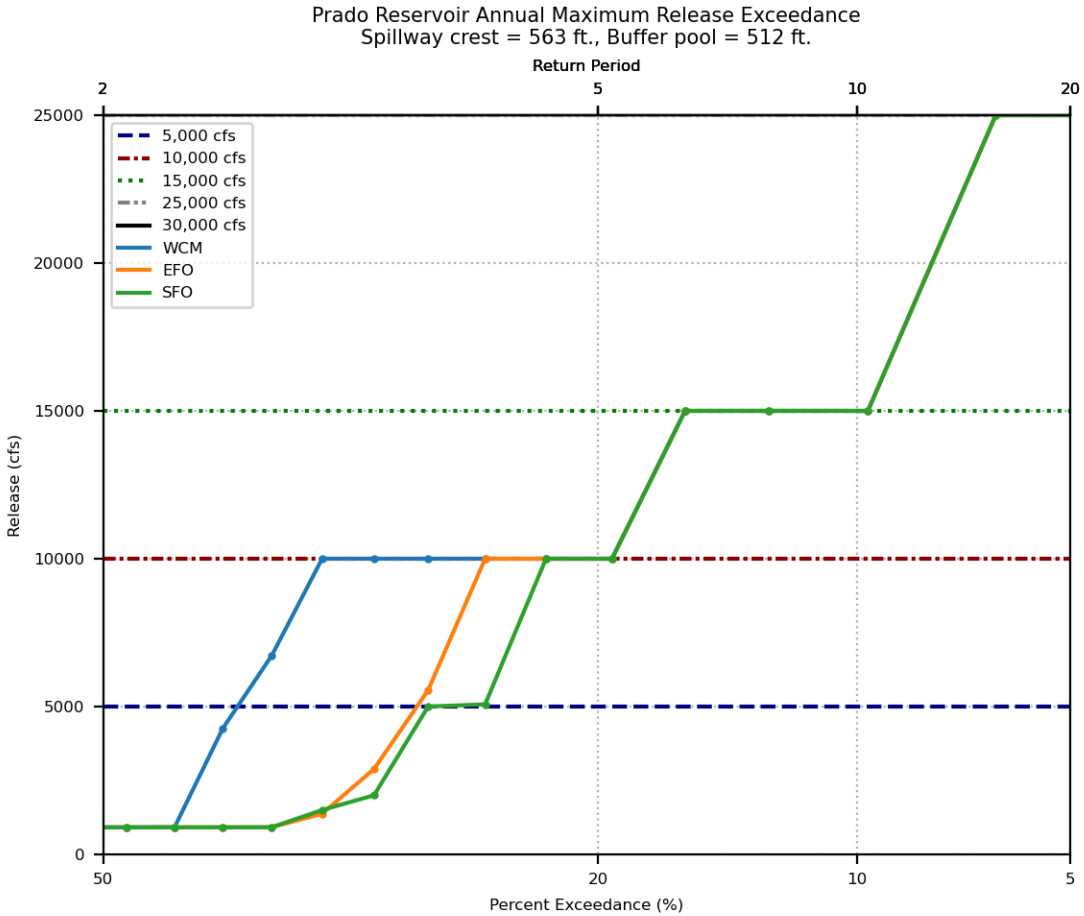

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 512 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
50
20
10
5
Percent Exceedance (%)

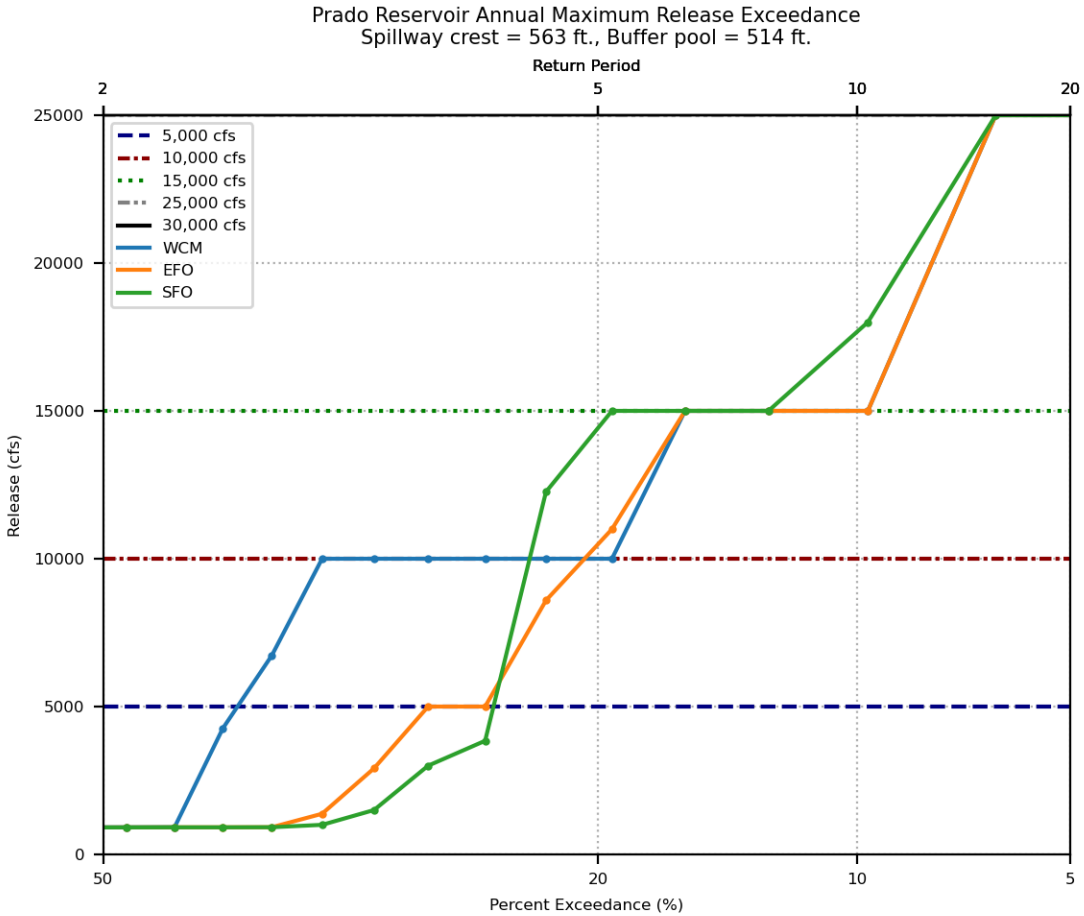

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 514 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
50
20
10
5
Percent Exceedance (%)

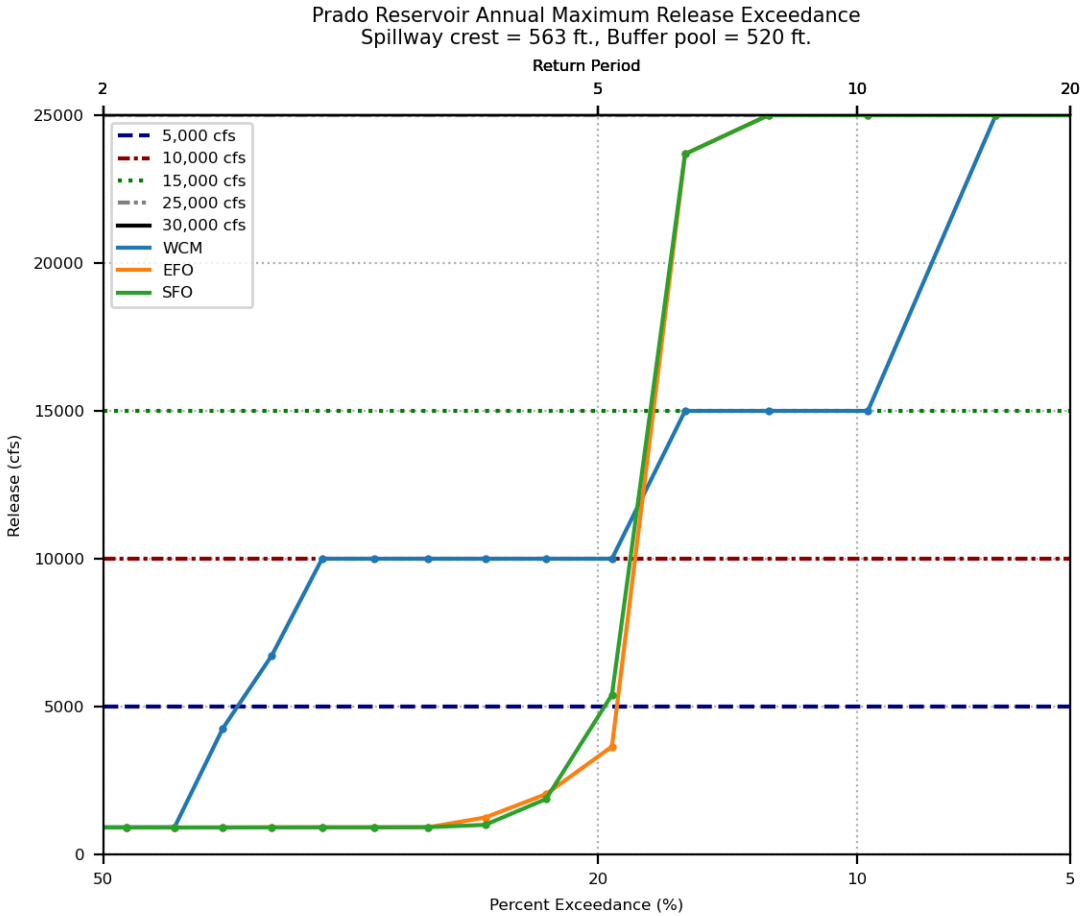

Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 543 ft., Buffer pool = 520 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
50
20
10
5
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 508 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
50
20
10
5
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 510 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
50
20
10
5
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 512 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
50
20
10
5
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 514 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
50
20
10
5
Percent Exceedance (%)


Prado Reservoir Annual Maximum Release Exceedance
Spillway crest = 563 ft., Buffer pool = 520 ft.
Return Period
2
5
10
20
25000
20000
15000
10000
5000
0
Release (cfs)
5,000 cfs
10,000 cfs
15,000 cfs
25,000 cfs
30,000 cfs
WCM
EFO
SFO
50
20
10
5
Percent Exceedance (%)

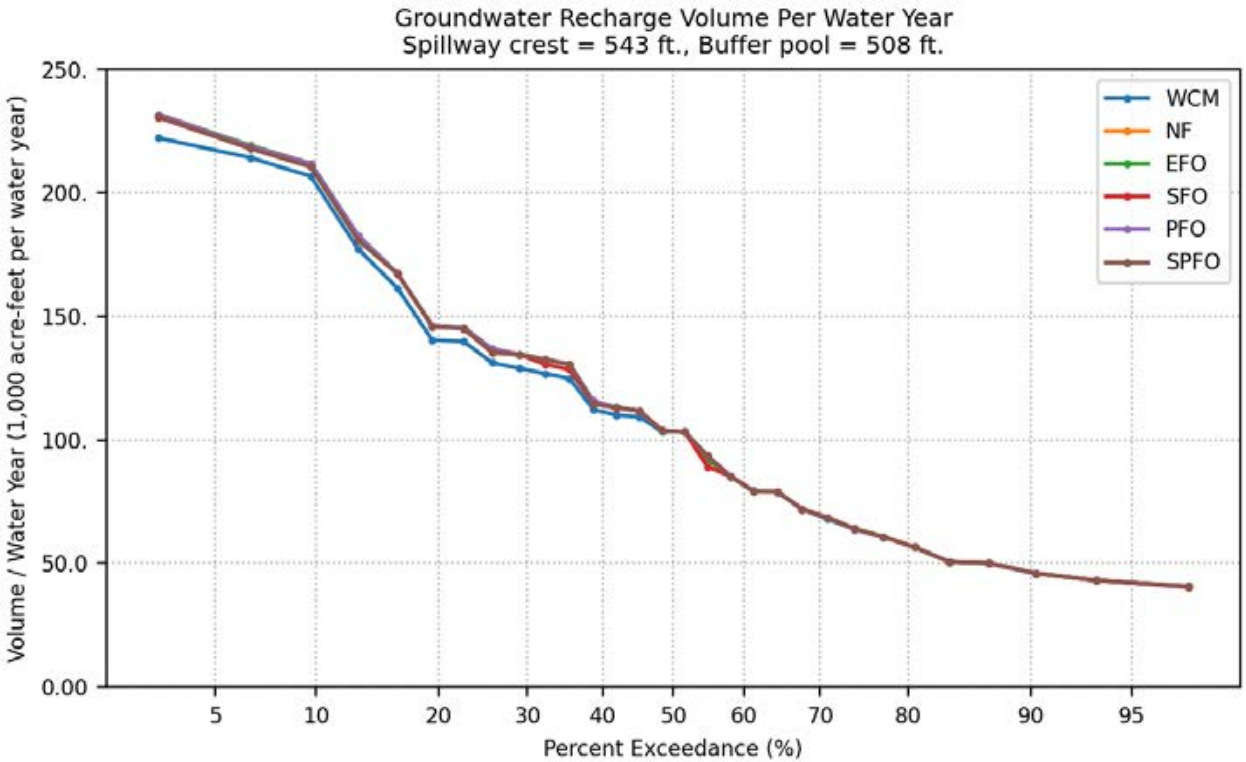
APPENDIX B-4

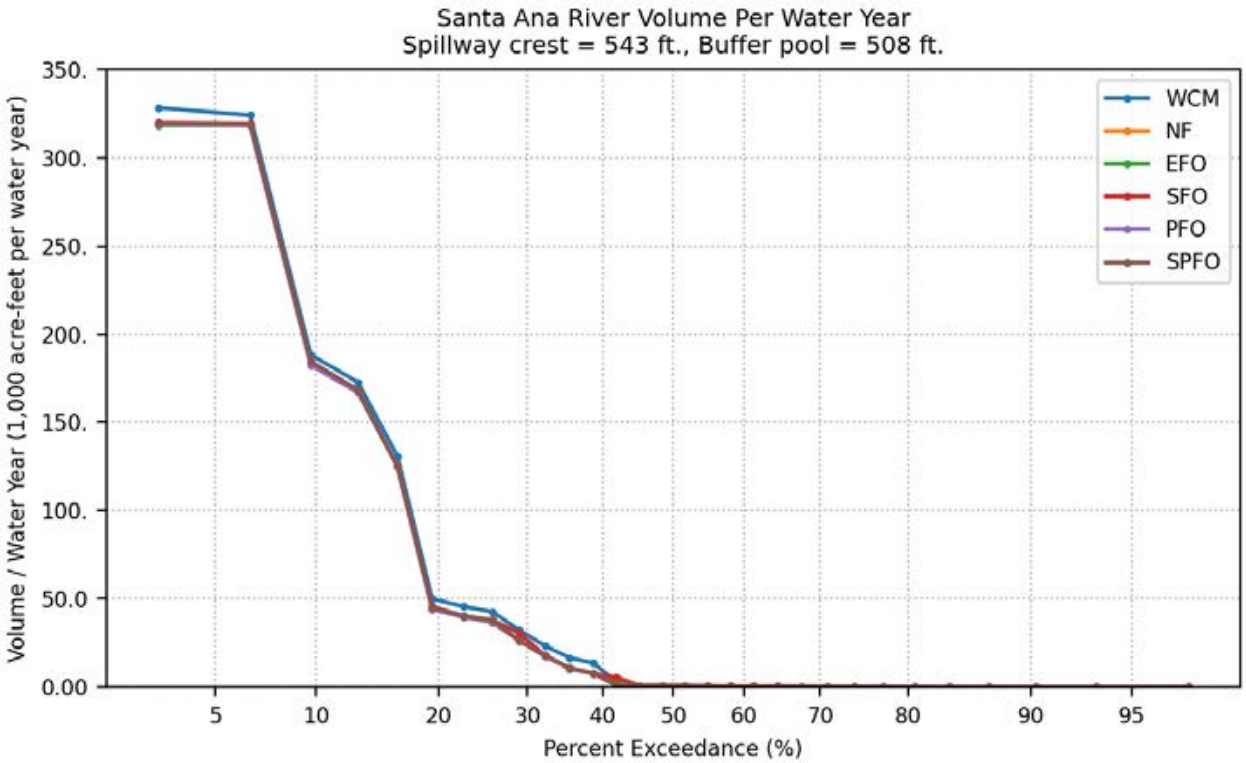
HEMP Metrics

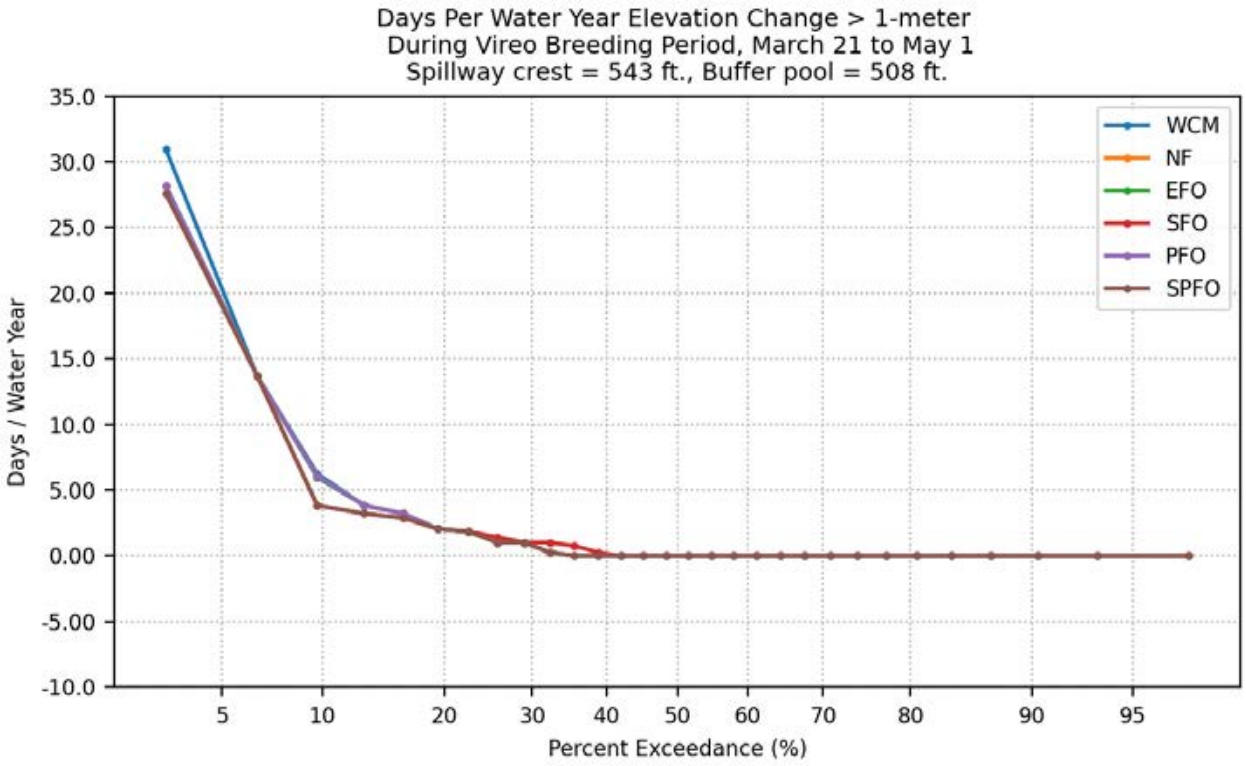
- Groundwater Recharge (KAF/yr)
- Discharge to Pacific Ocean (KAF/yr)
- >1 meter rise between 3/21 and 5/1 (days/yr)
- Pool elevation > 505’, 508’, 510’, 512’, 514’, 520’ (days/yr)
- Reservoir release > 5,000 cfs, 10,000 cfs, 15,000 cfs (days/yr)

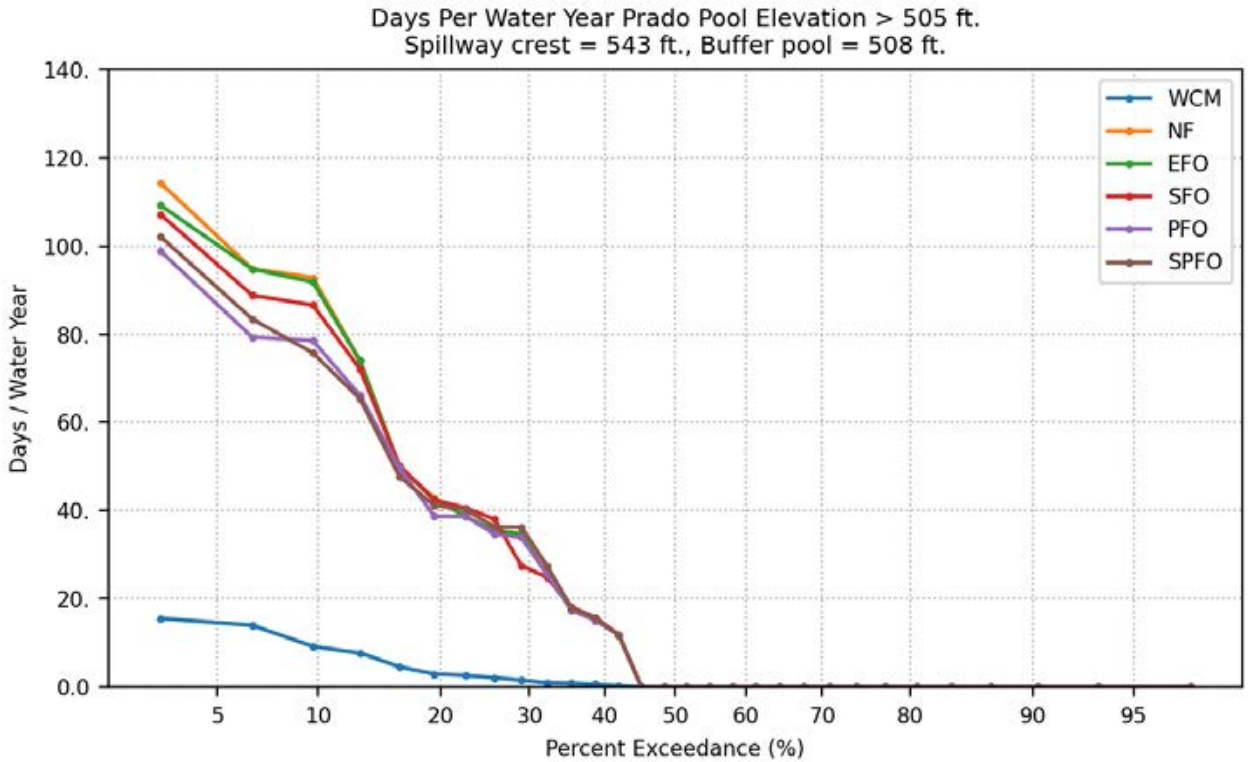
HEMP Metrics

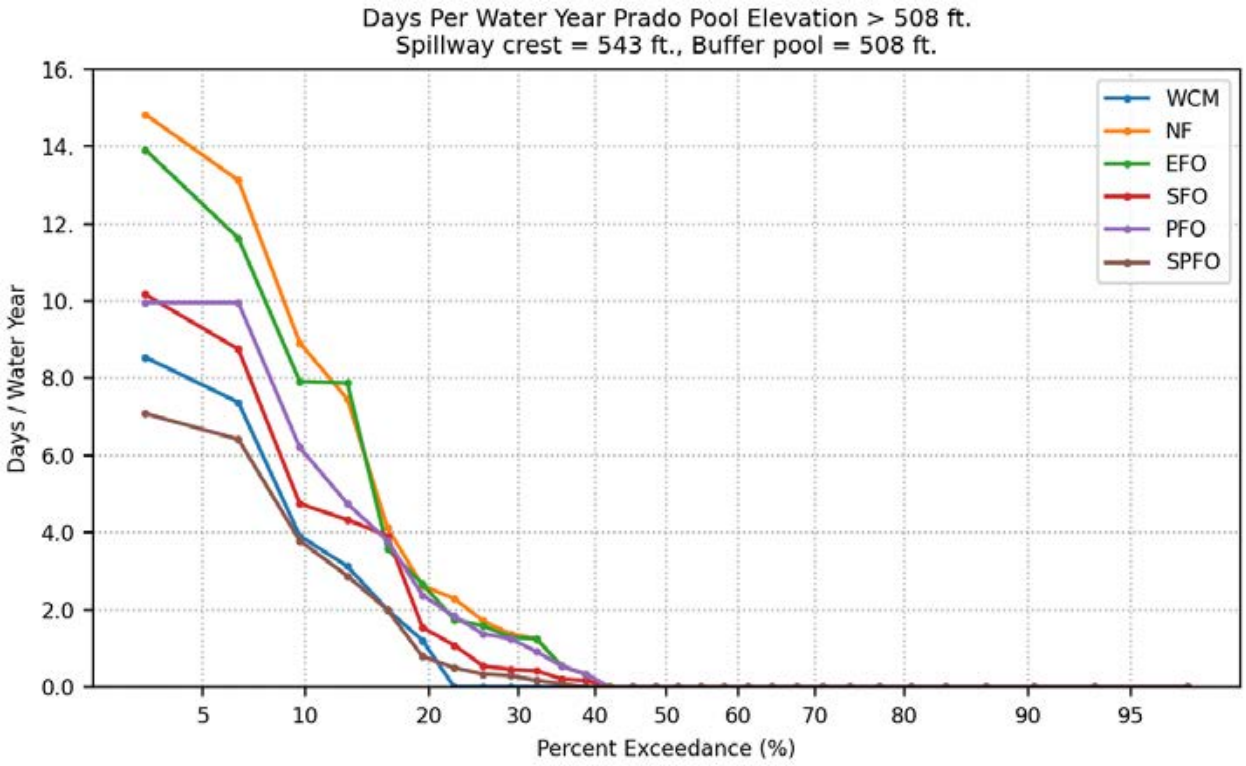
- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’, 510’, 512’, 514’, 520’
- WCP alternatives in legend

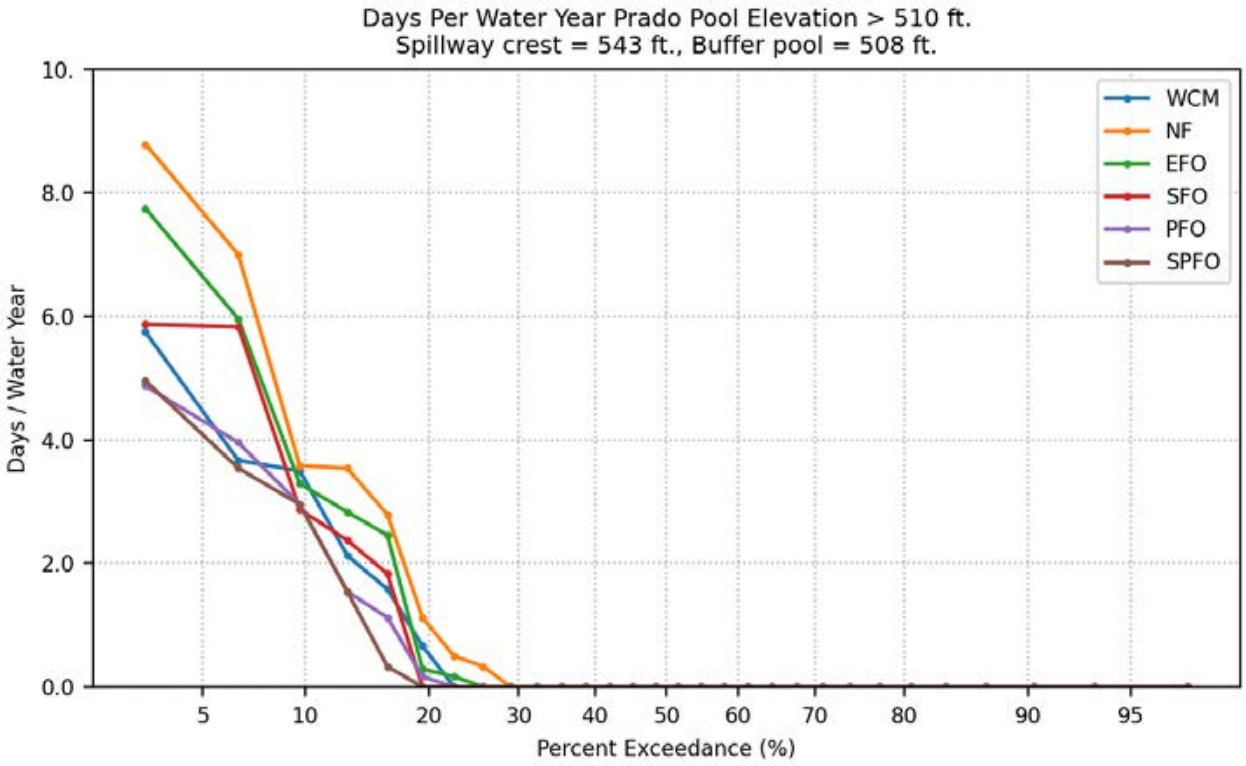

Groundwater Recharge Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 508 ft.
Volume / Water Year (1,000 acre-feet per water year)
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

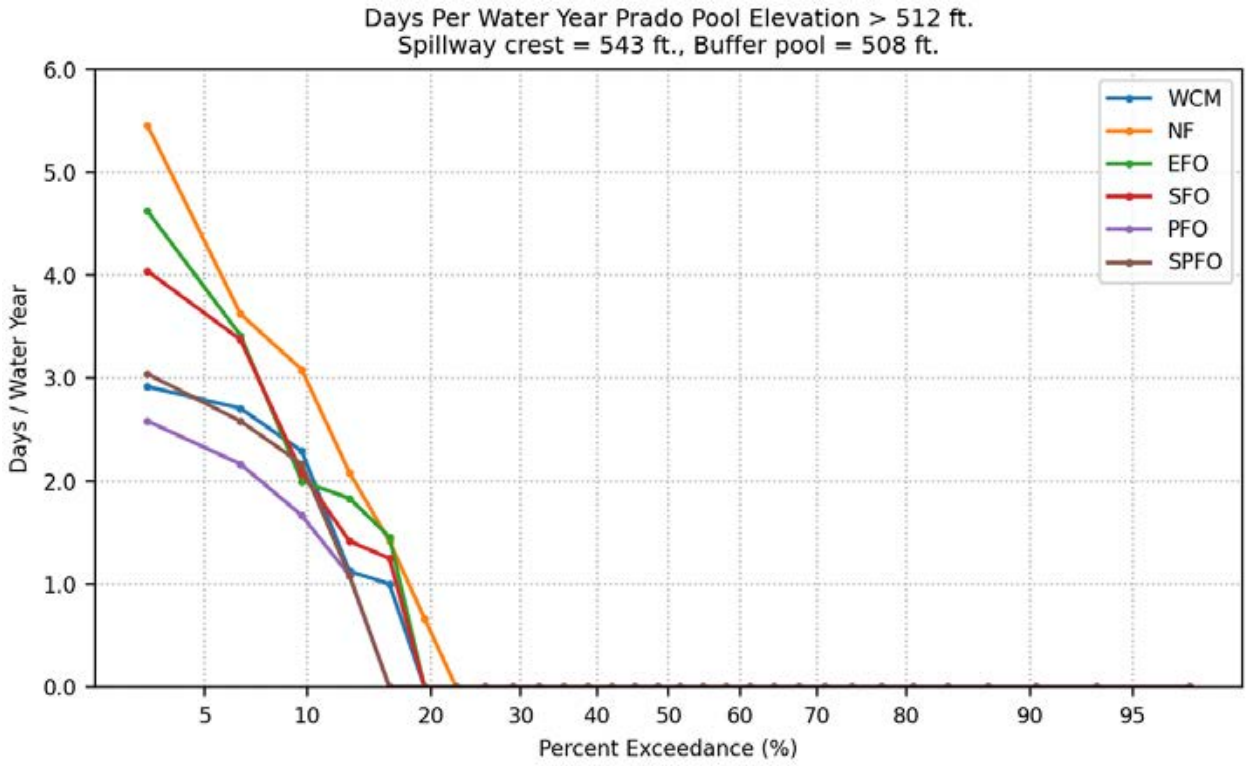

Santa Ana River Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 508 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

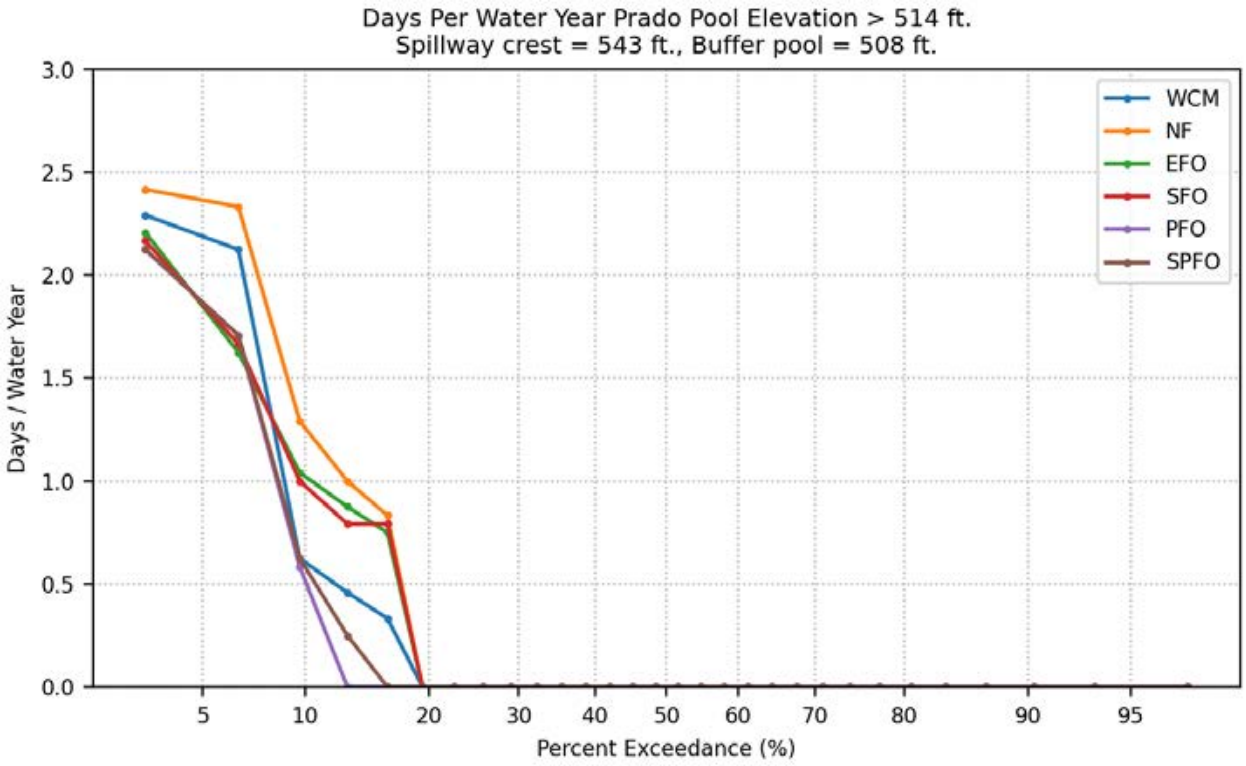

Days Per Water Year Elevation Change > 1-meter
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
35.0
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

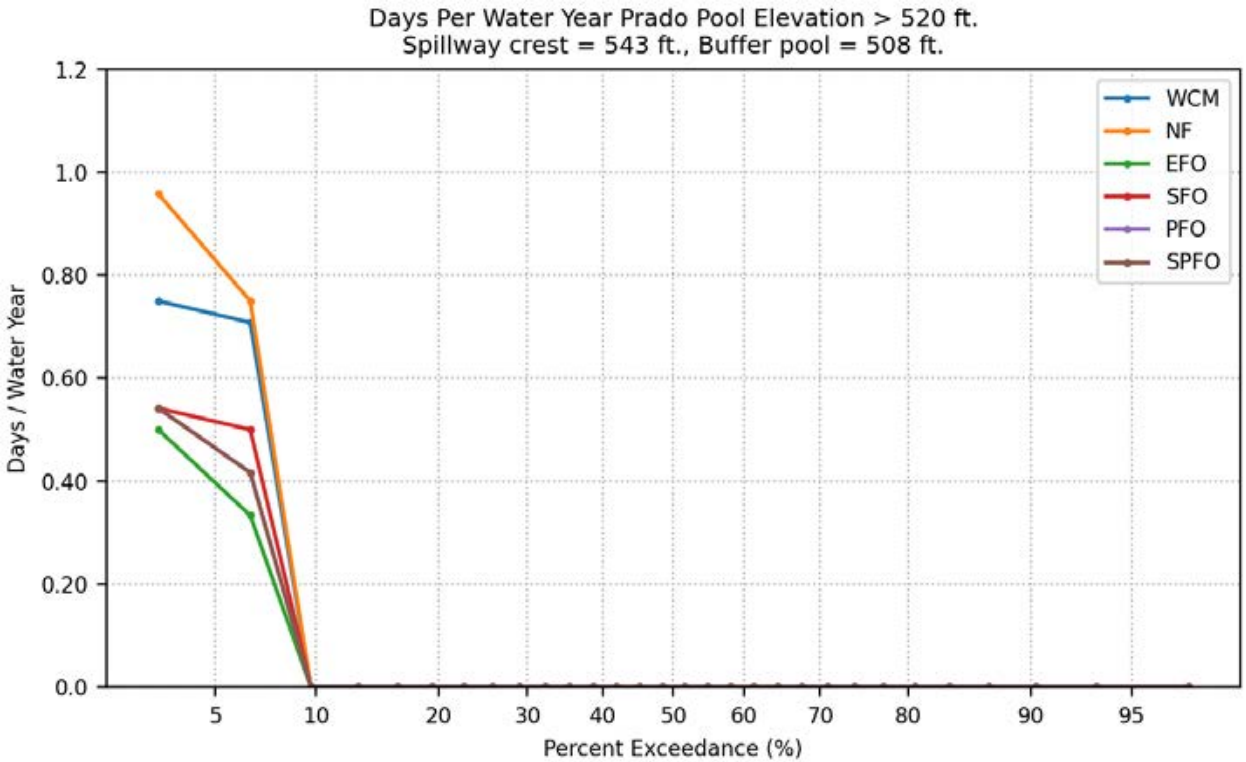

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

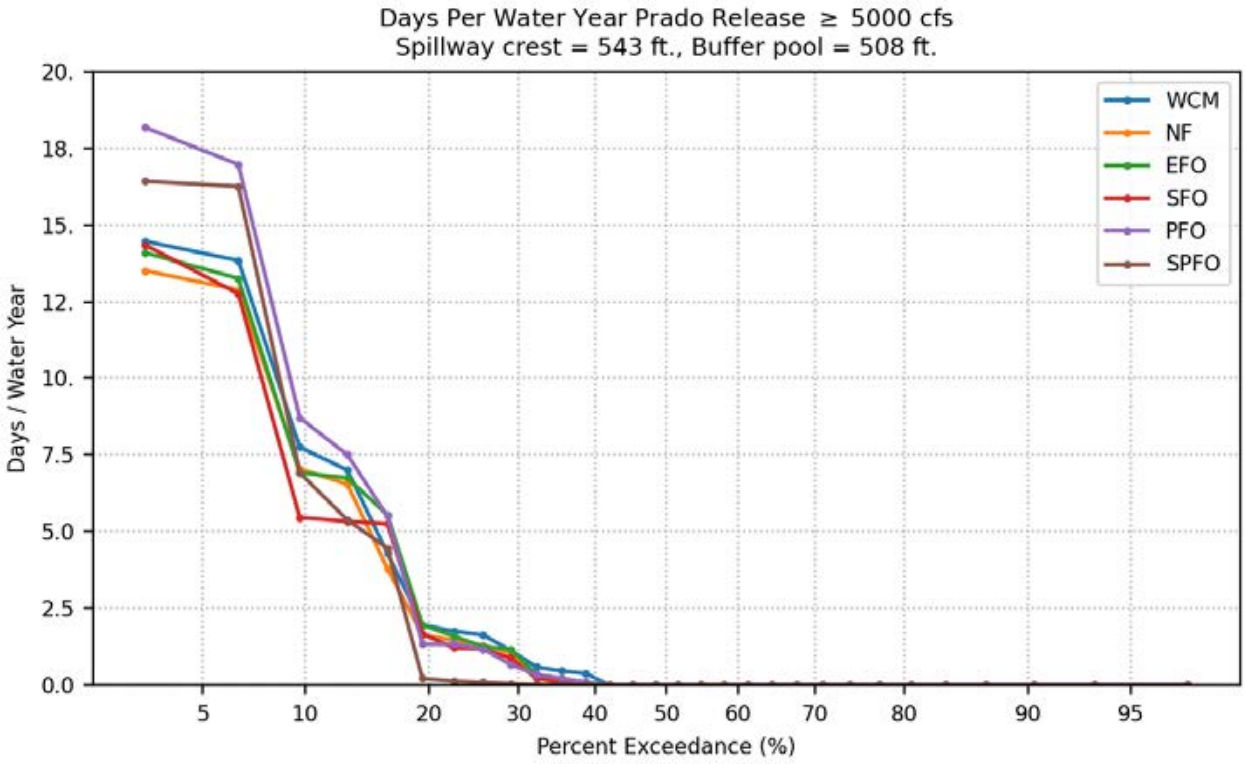

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

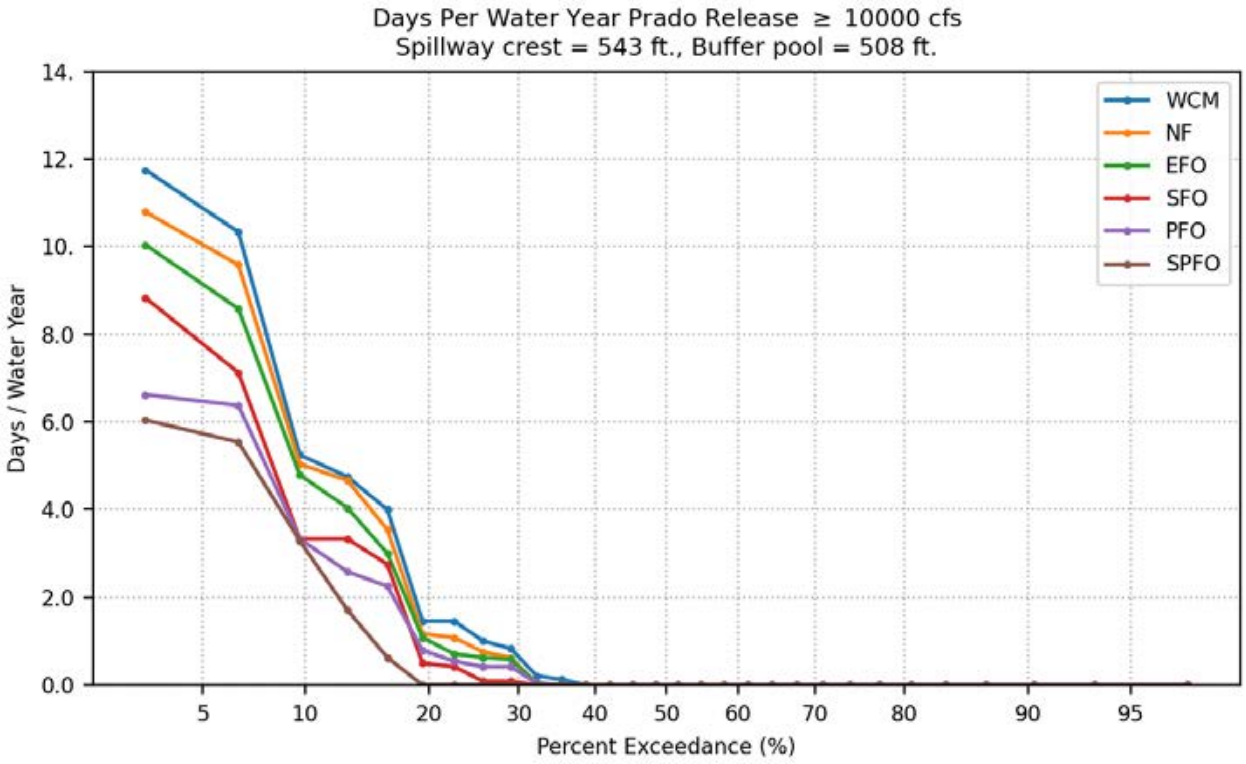

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

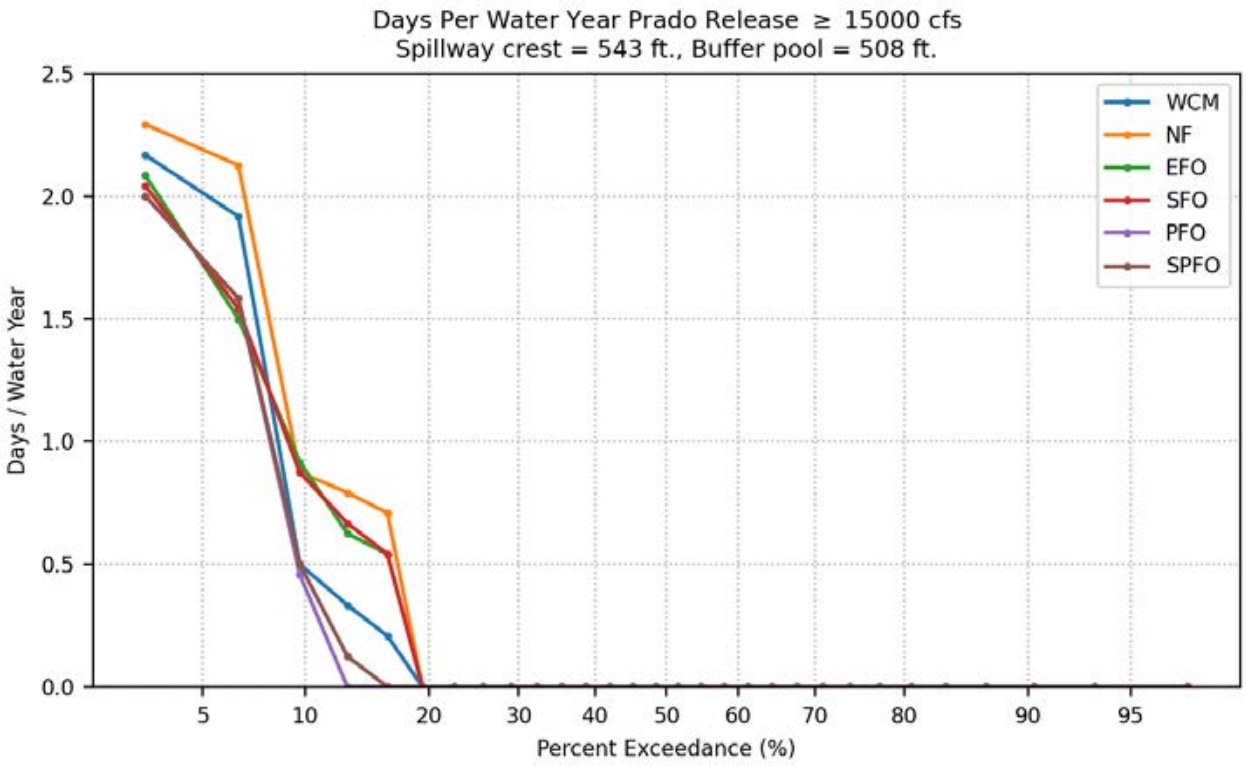

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

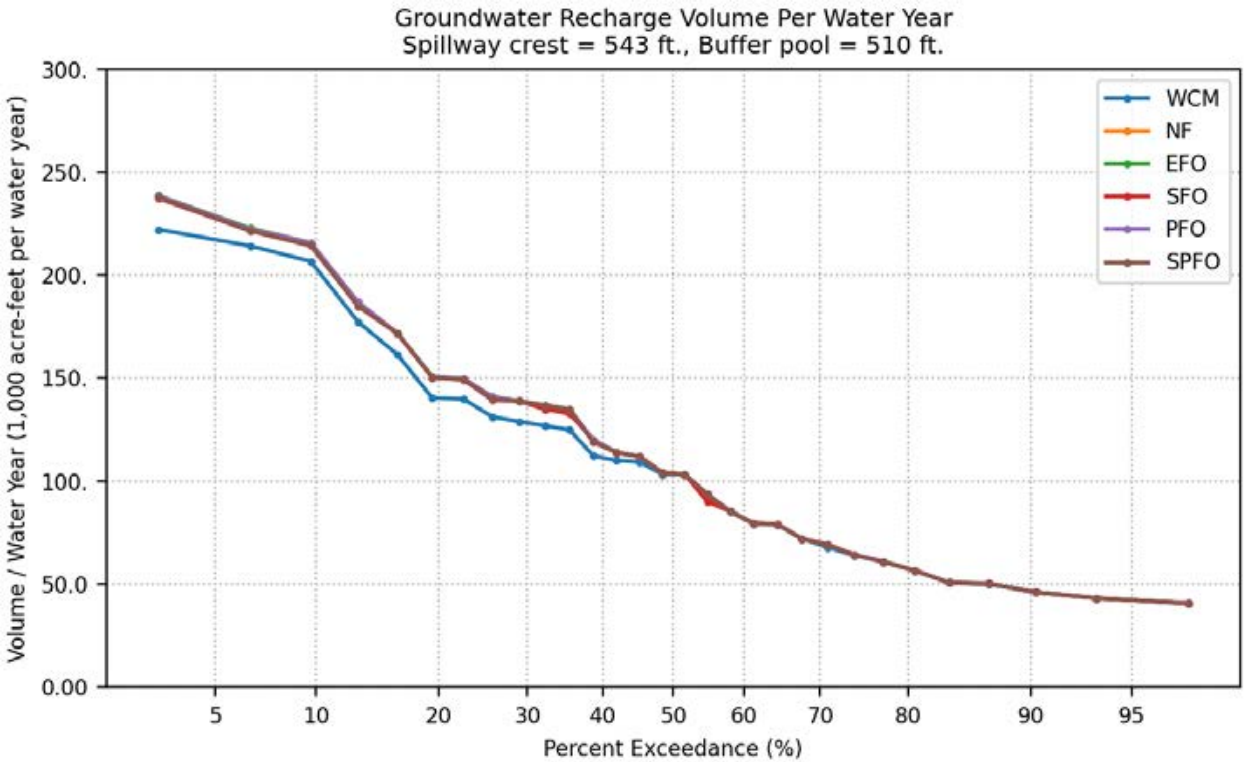

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

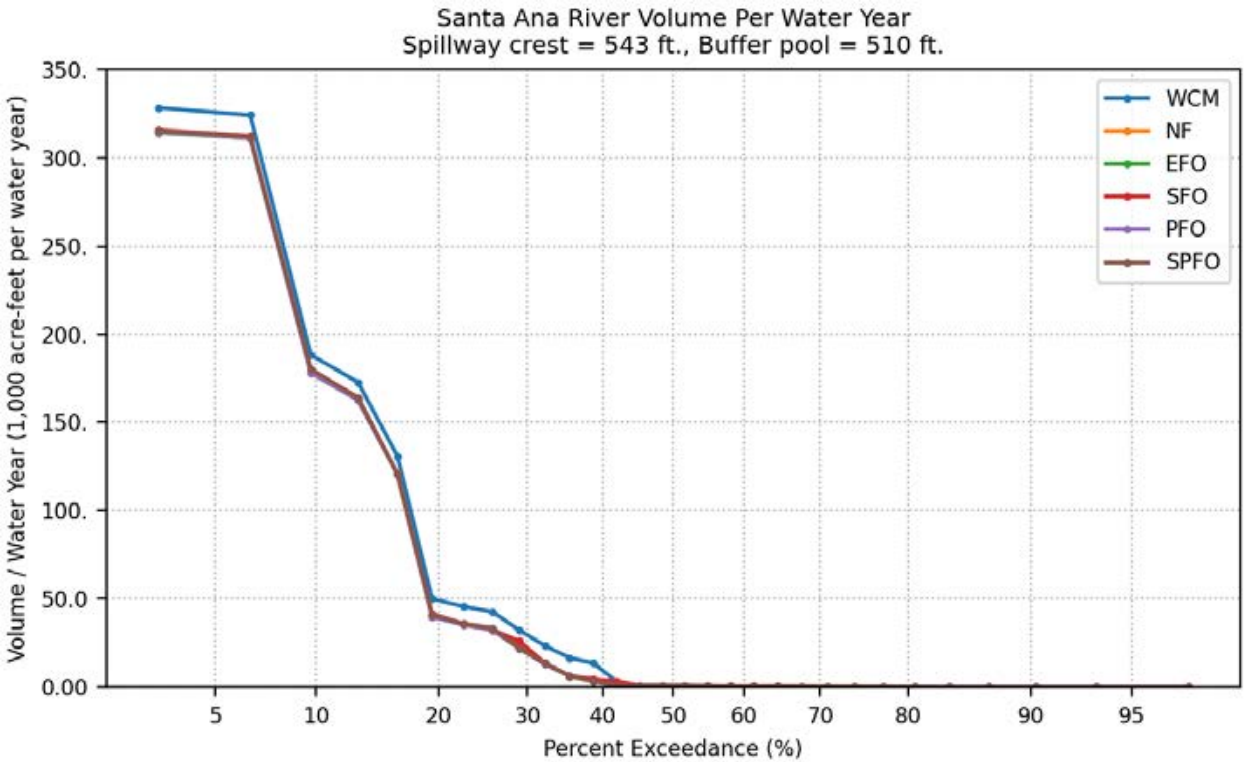

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
1.2
1.0
0.80
0.60
0.40
0.20
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

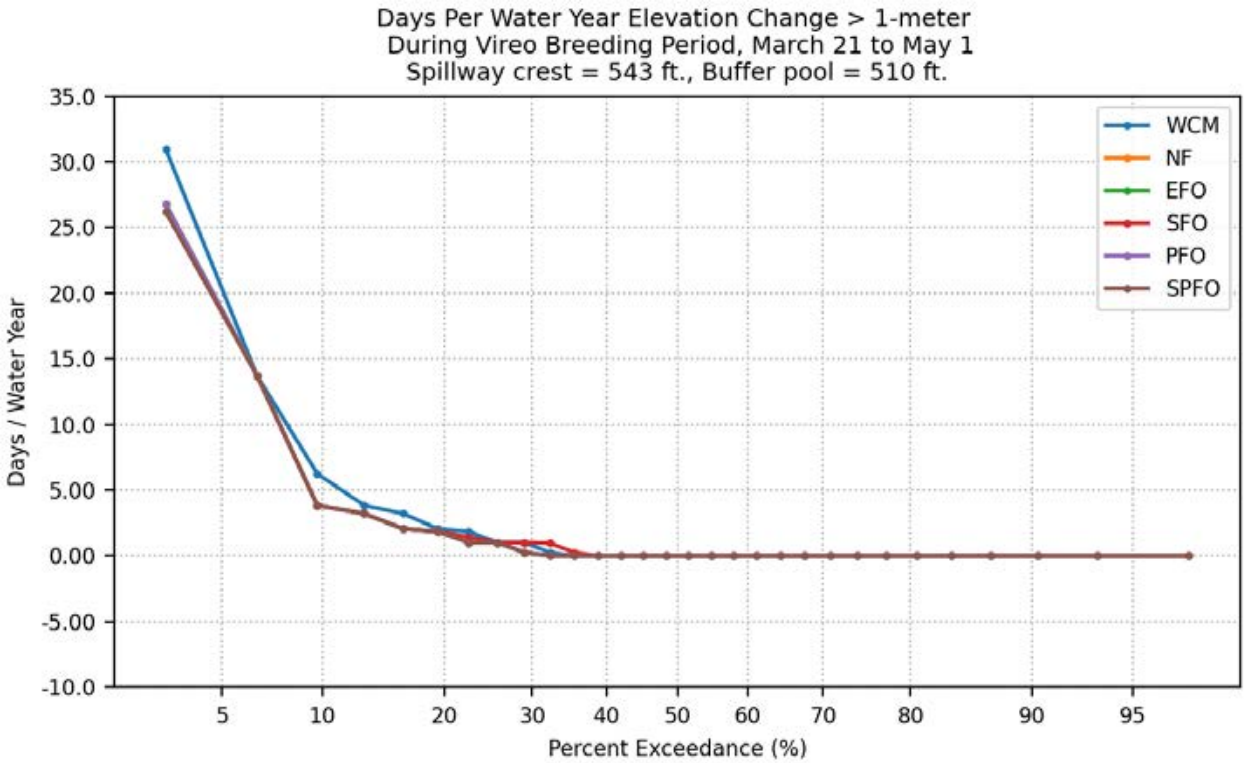

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
20.
18.
15.
12.
10.
7.5
5.0
2.5
0.0
5
10
20
30
40
50
60
70
80
90
95

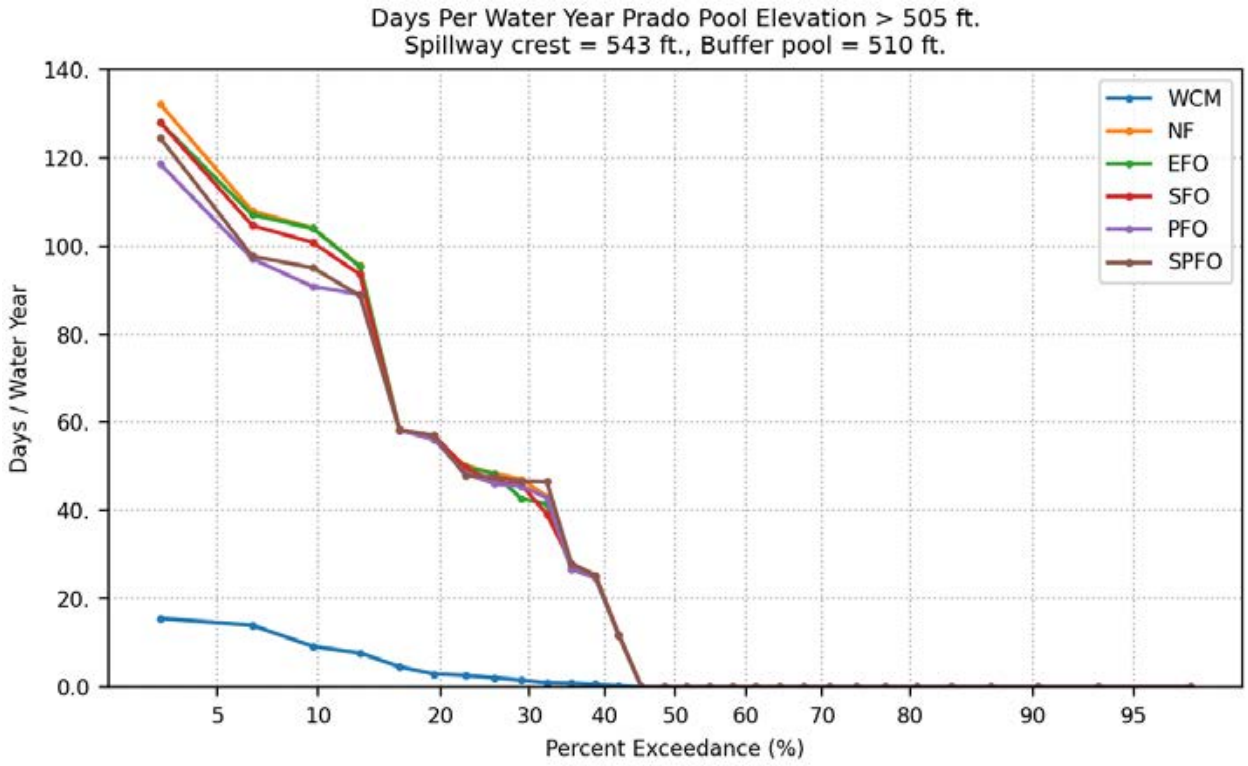

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

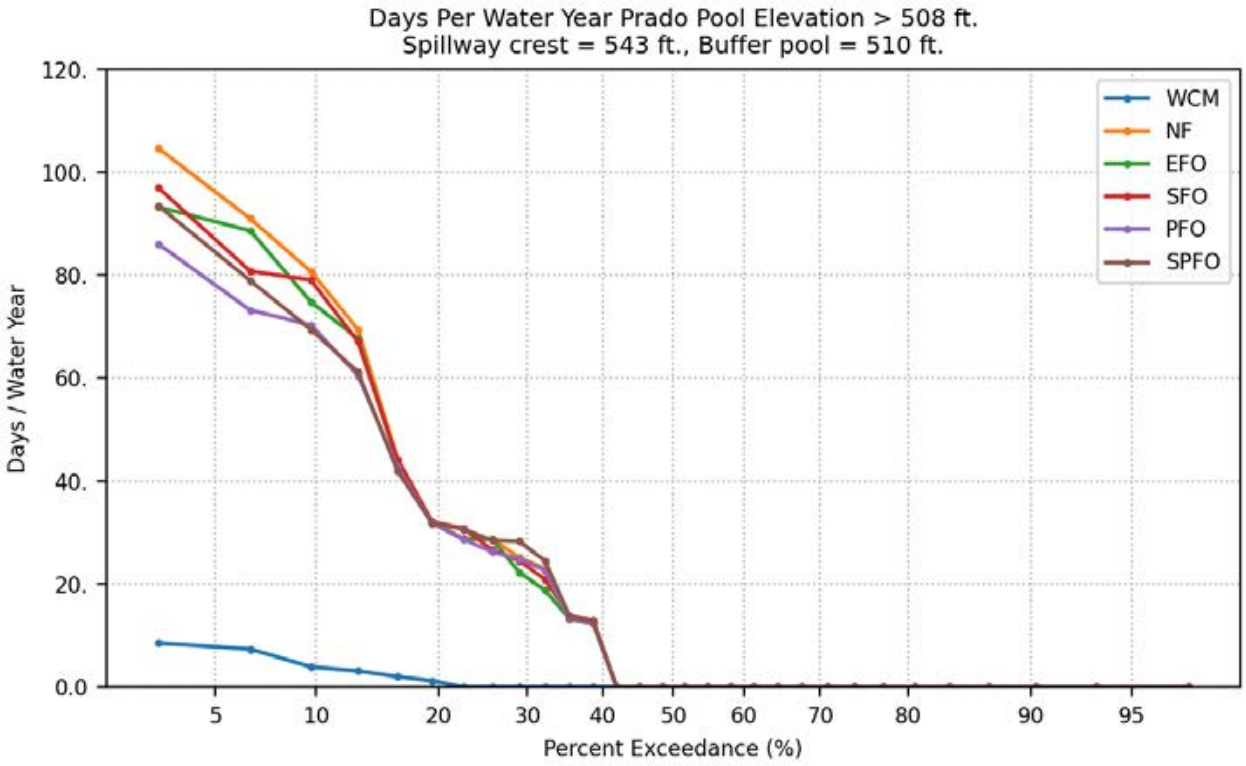

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
0.0
0.5
1.0
1.5
2.0
2.5
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

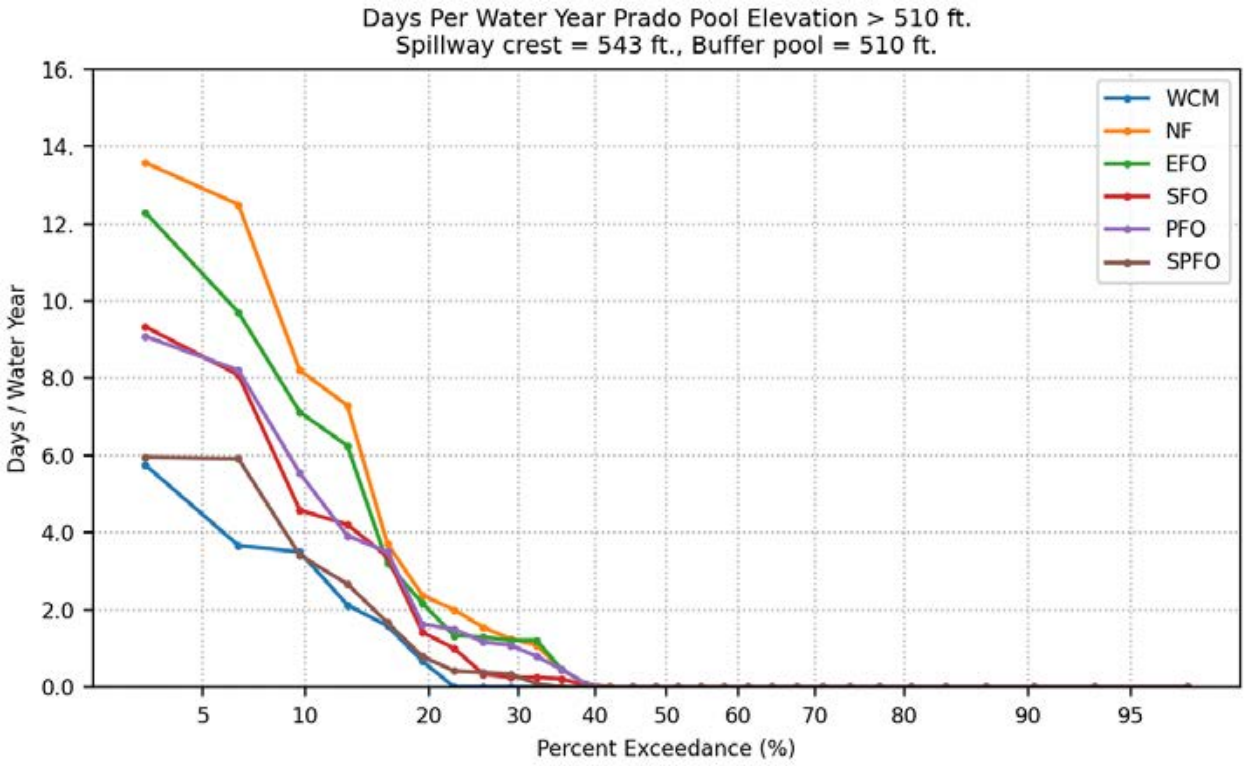

Groundwater Recharge Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 510 ft.
Volume / Water Year (1,000 acre-feet per water year)
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

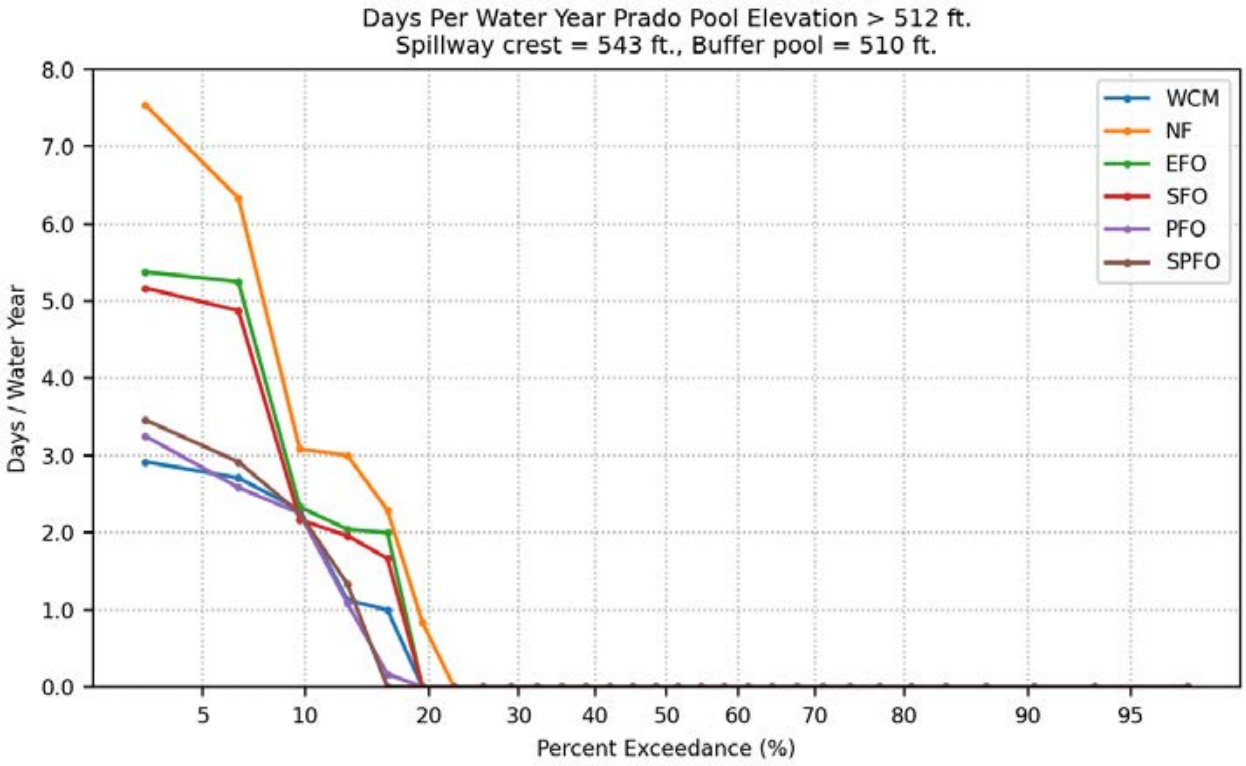

Santa Ana River Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 510 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

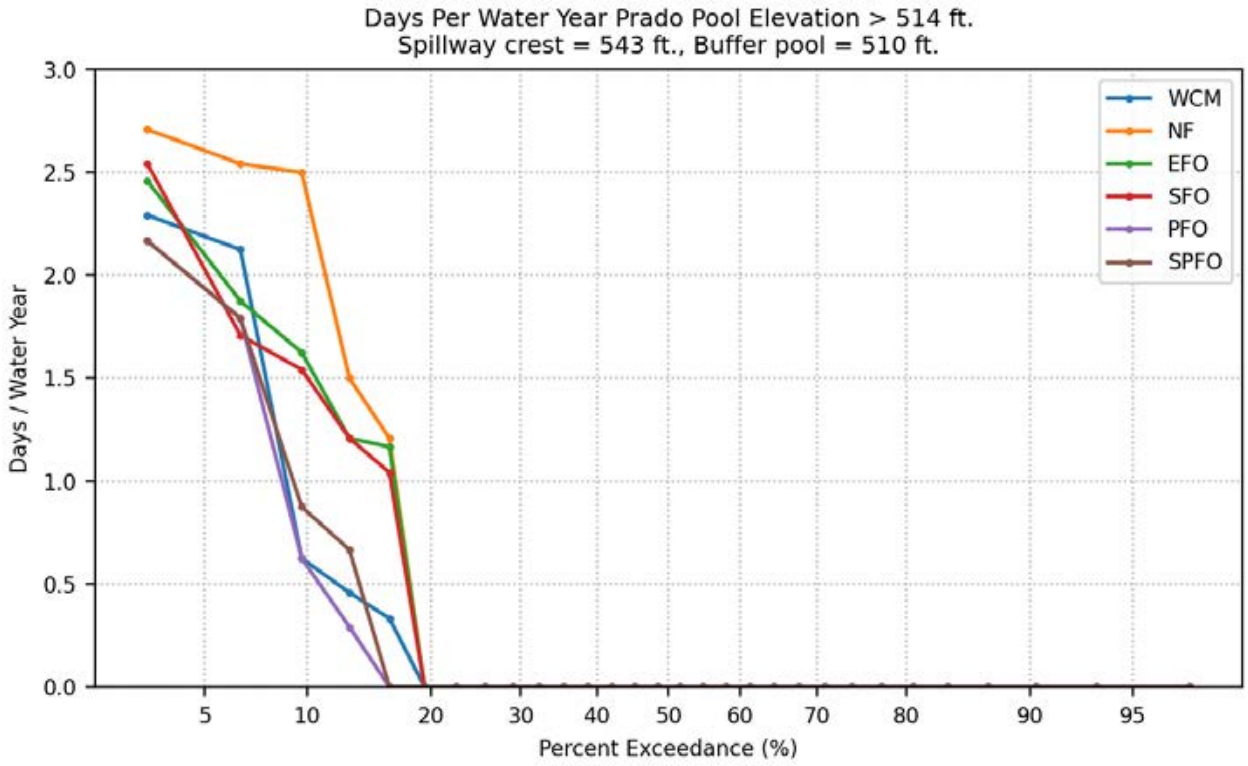

Days Per Water Year Elevation Change > 1-meter
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
35.0
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

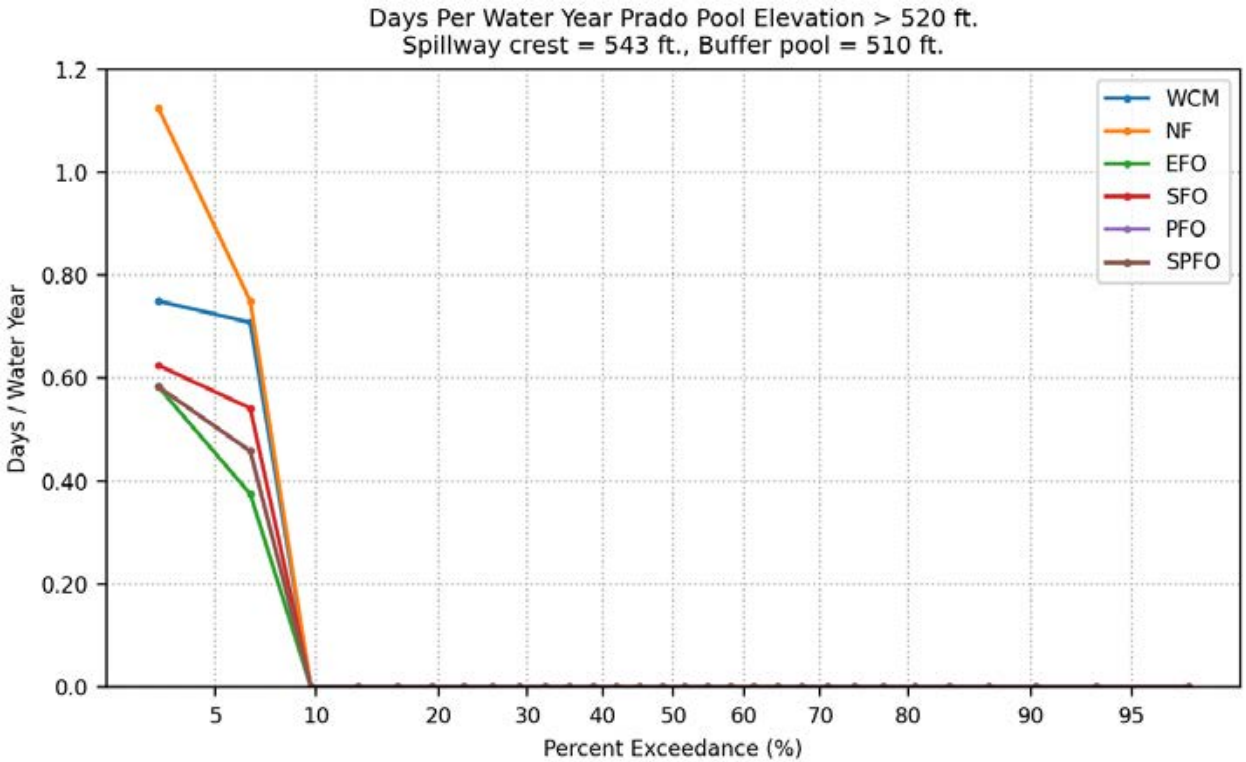

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

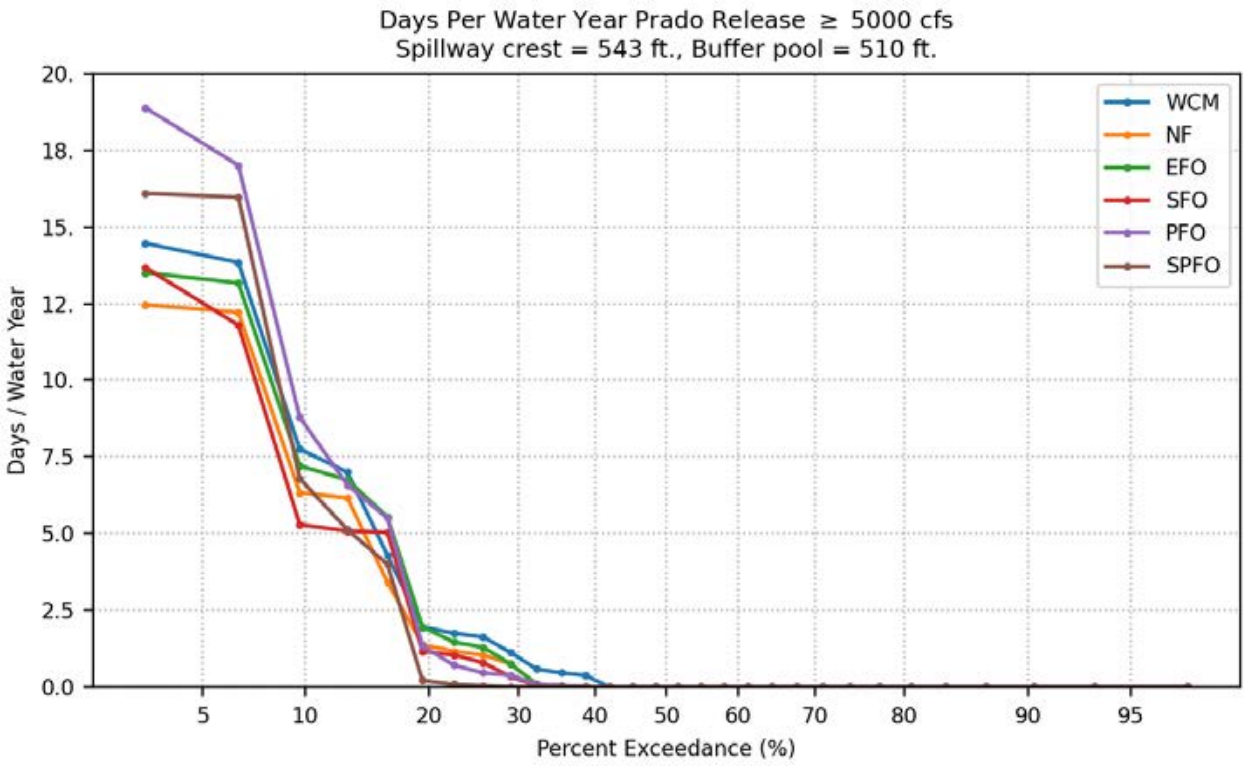

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

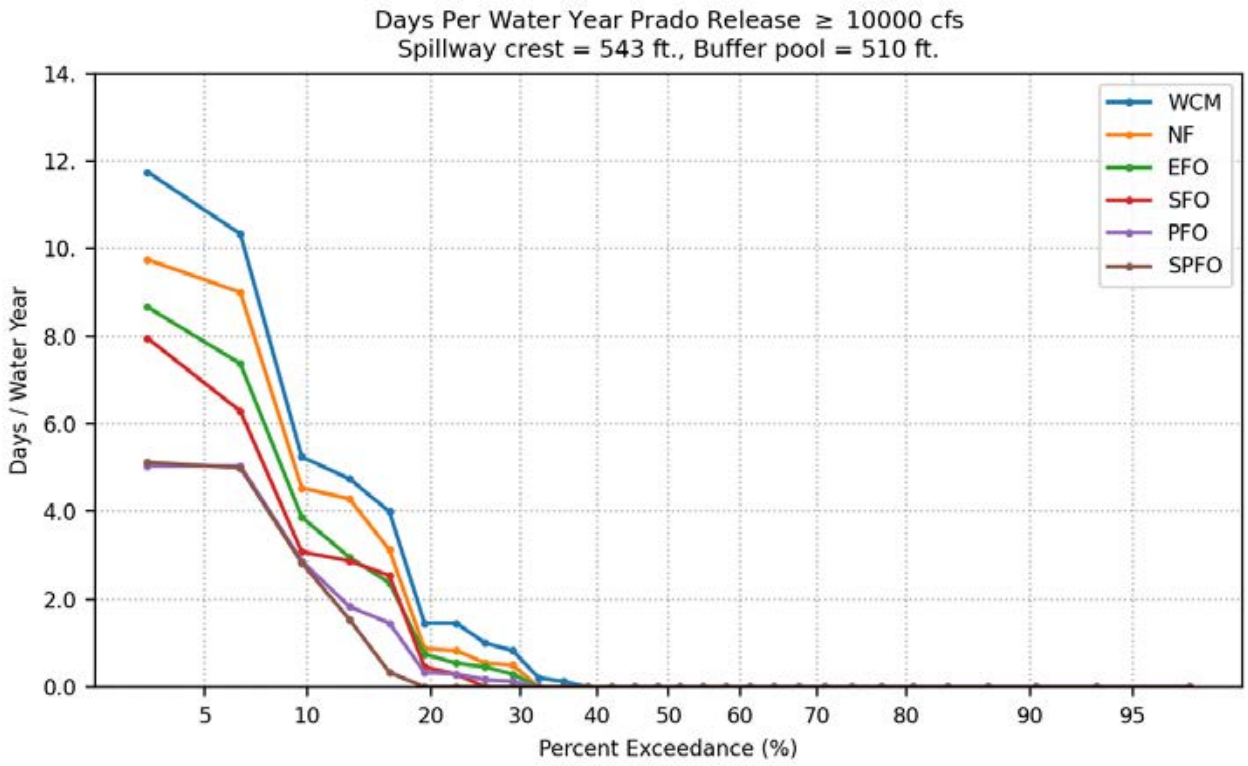

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

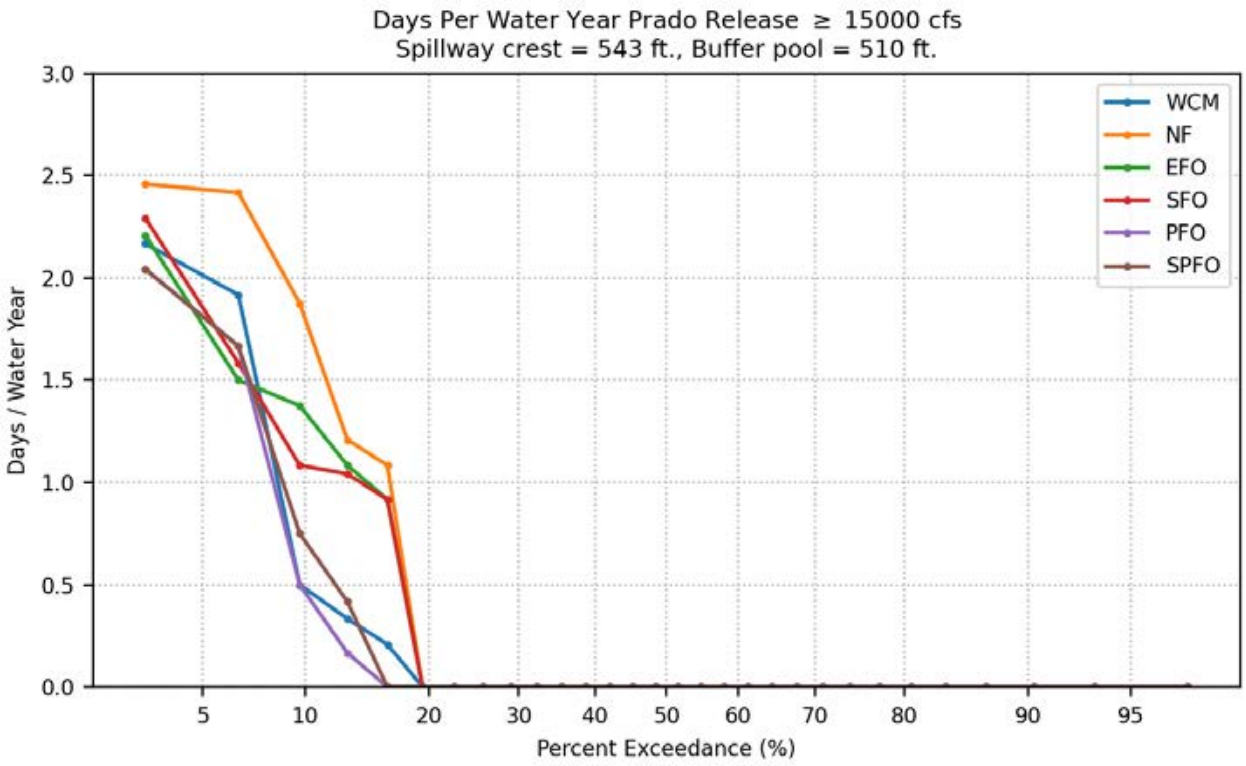

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

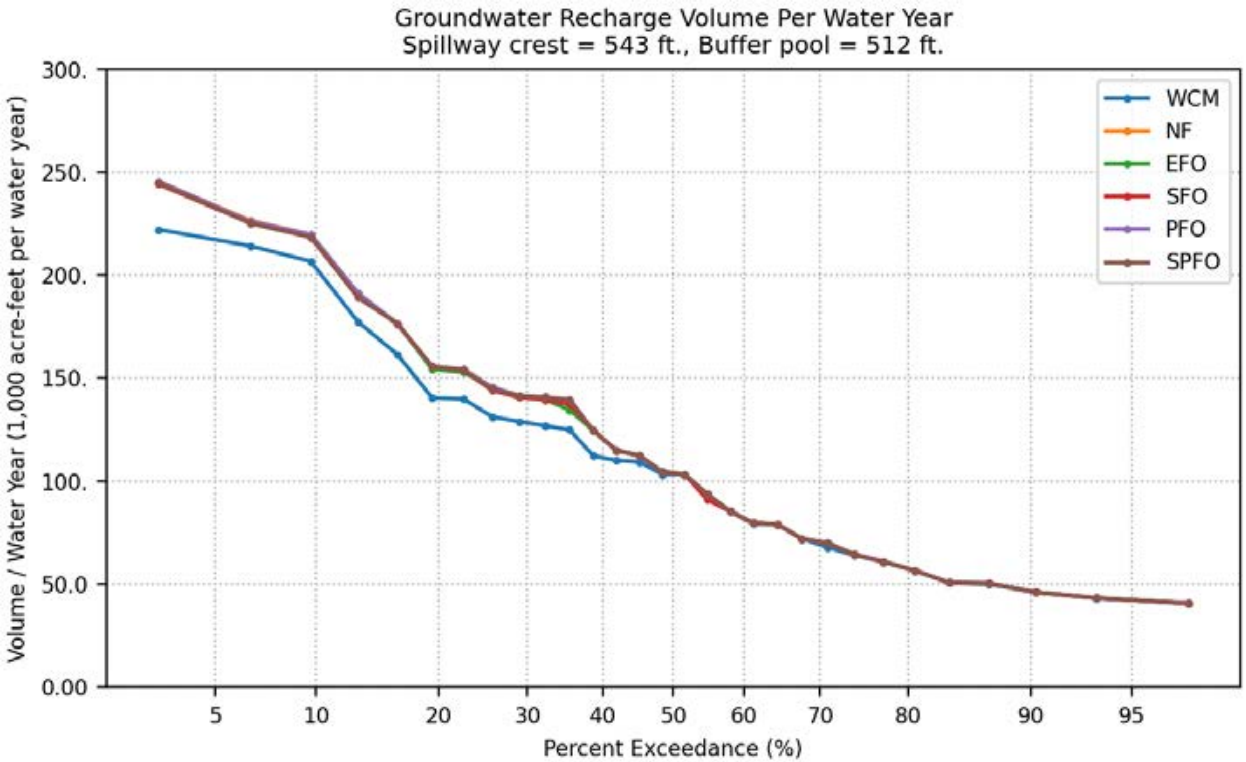

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

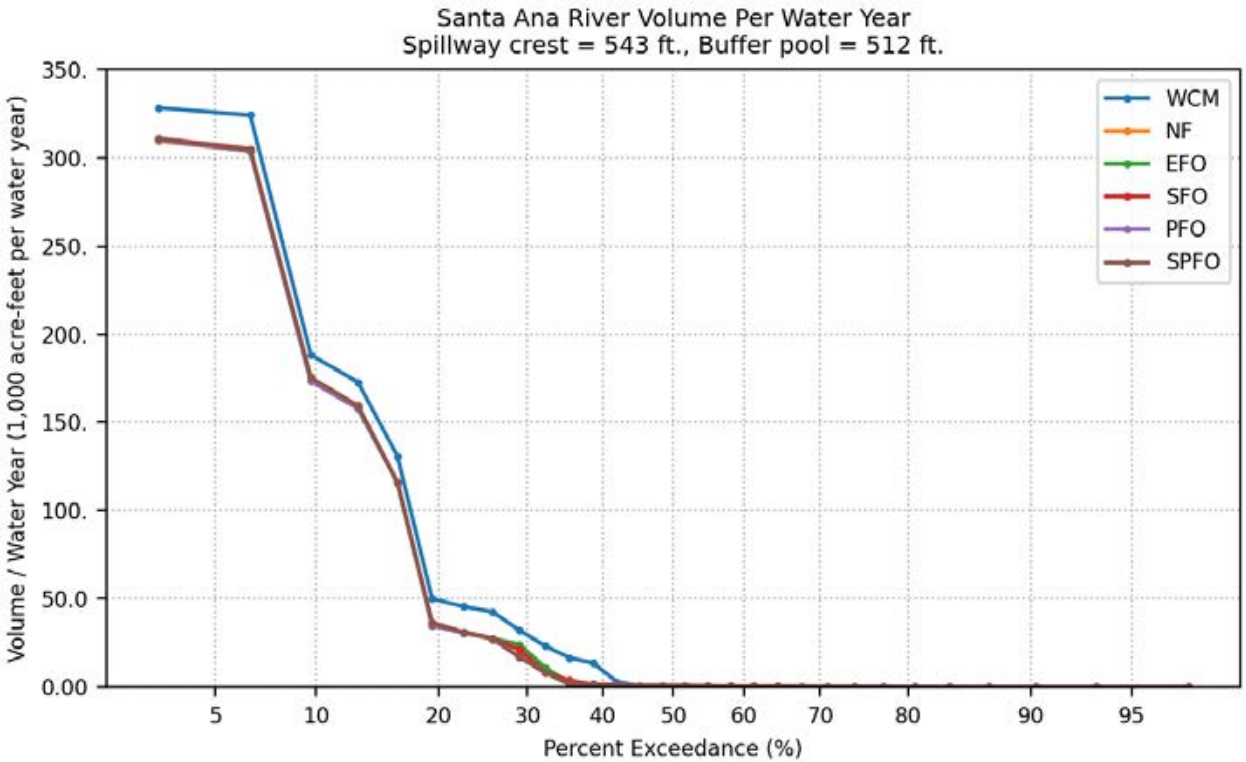

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
1.2
1.0
0.80
0.60
0.40
0.20
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

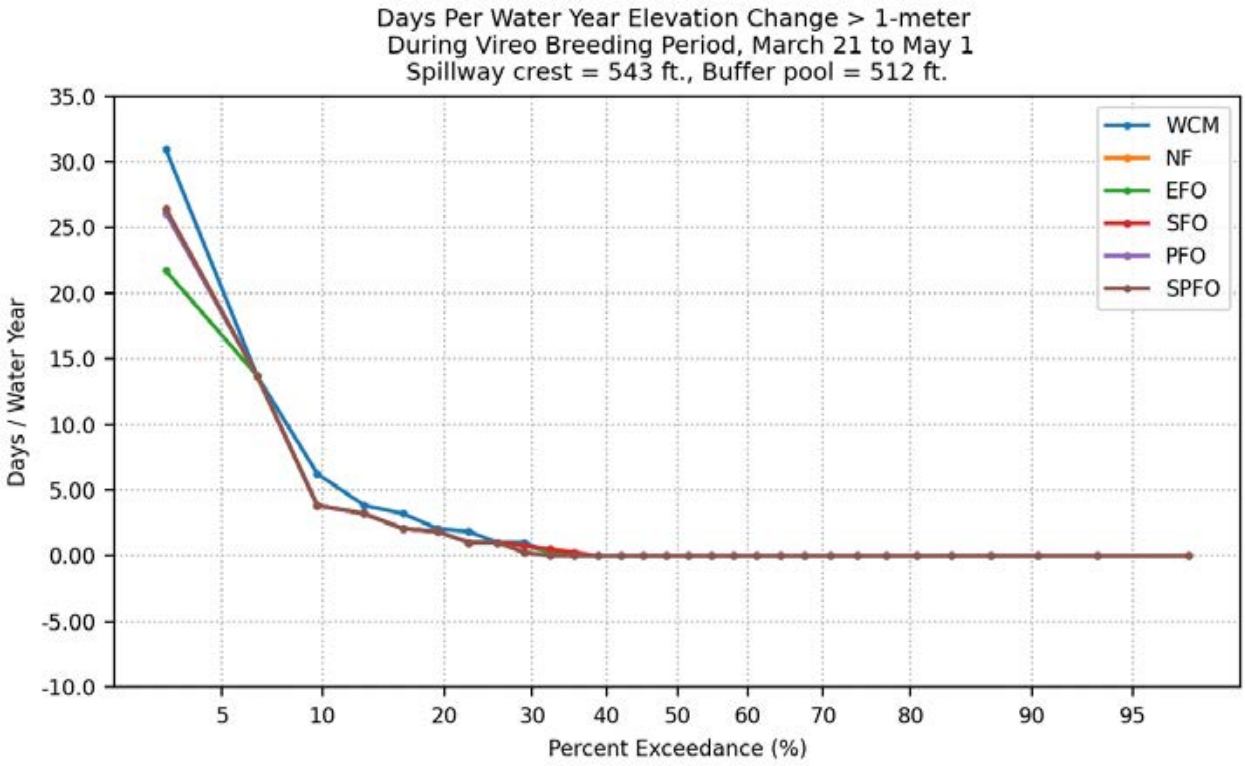

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
20.
18.
15.
12.
10.
7.5
5.0
2.5
0.0
5
10
20
30
40
50
60
70
80
90
95

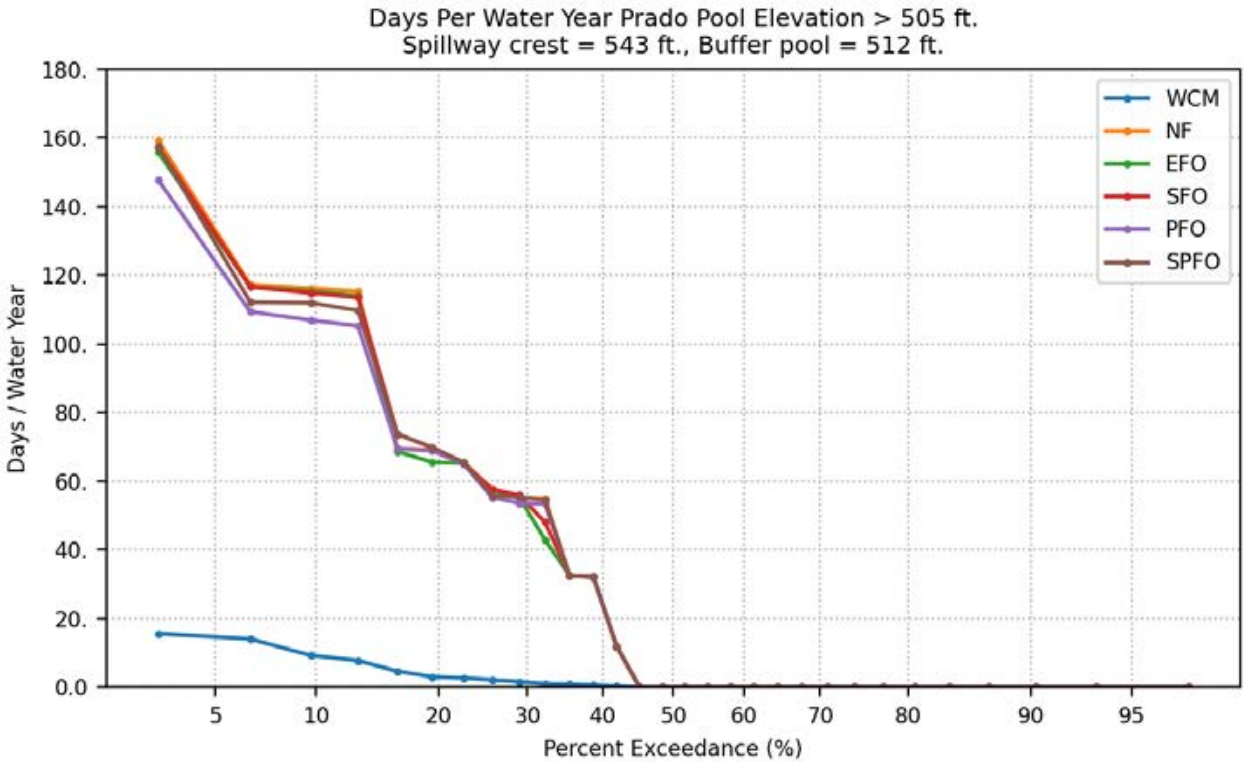

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

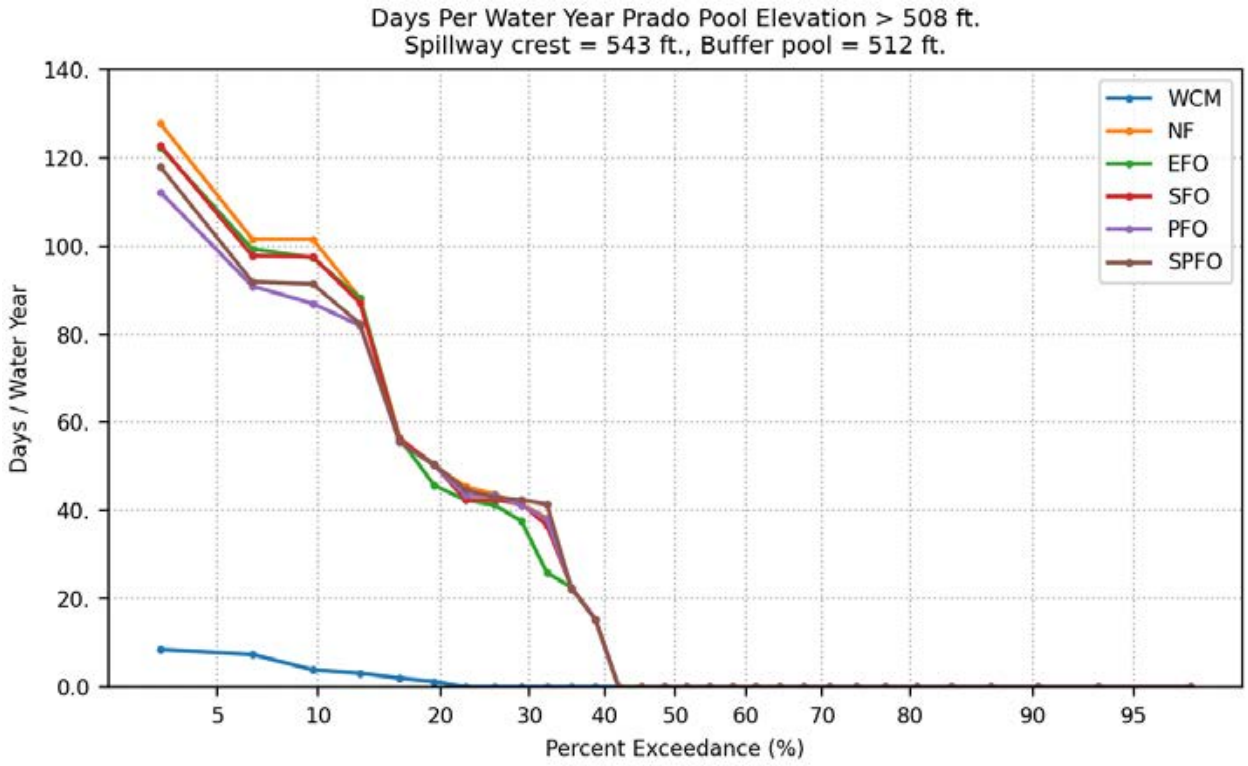

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

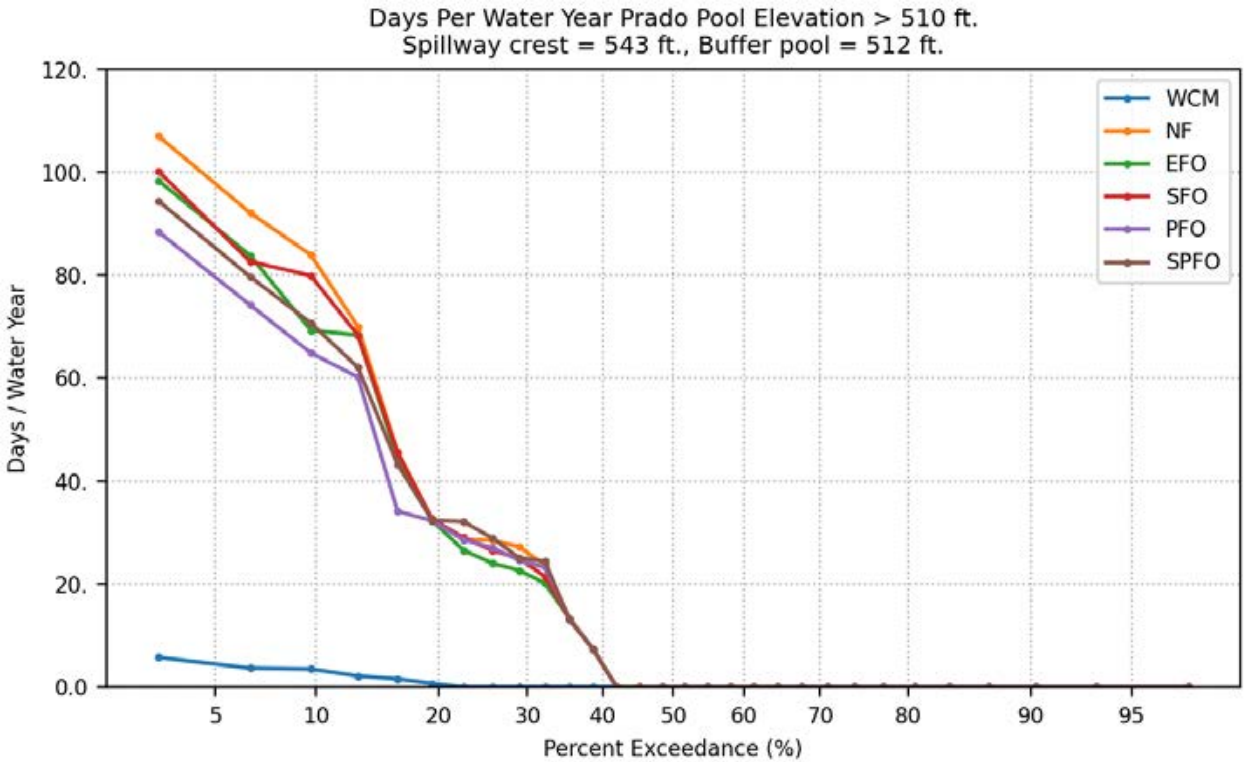

Groundwater Recharge Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 512 ft.
Volume / Water Year (1,000 acre-feet per water year)
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

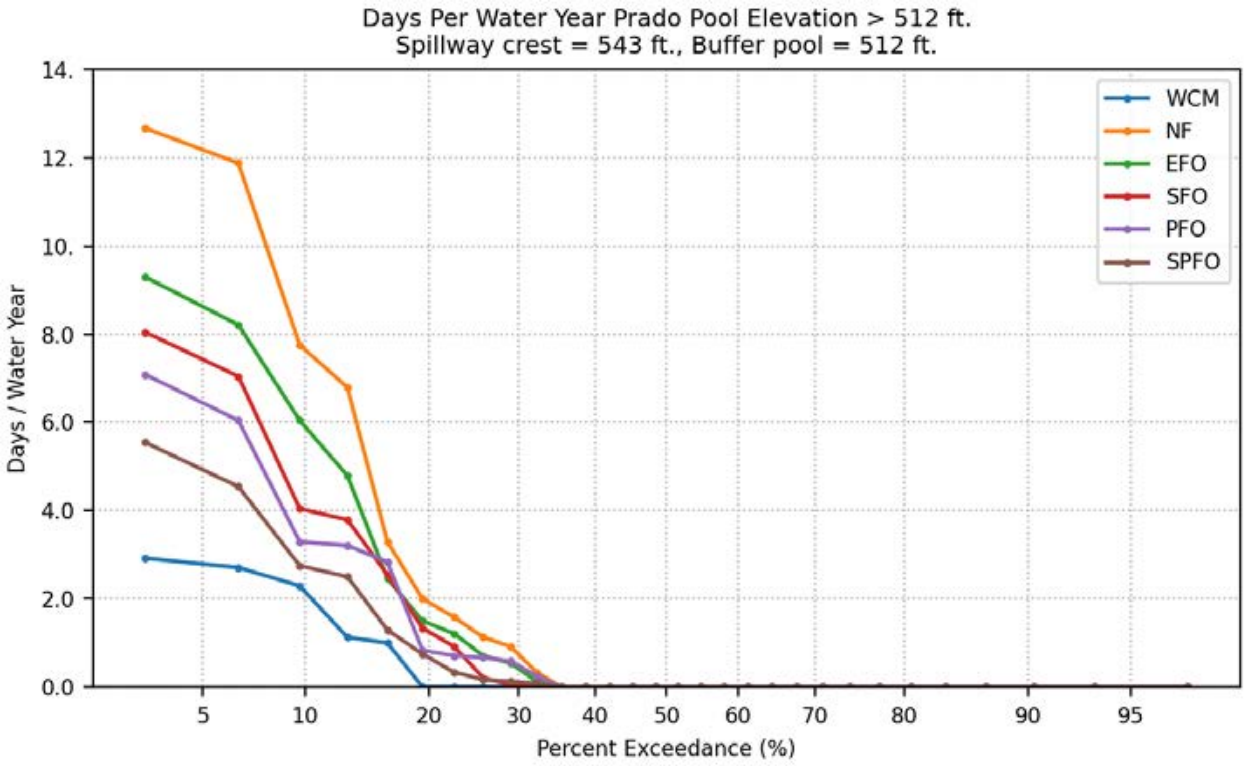

Santa Ana River Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 512 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

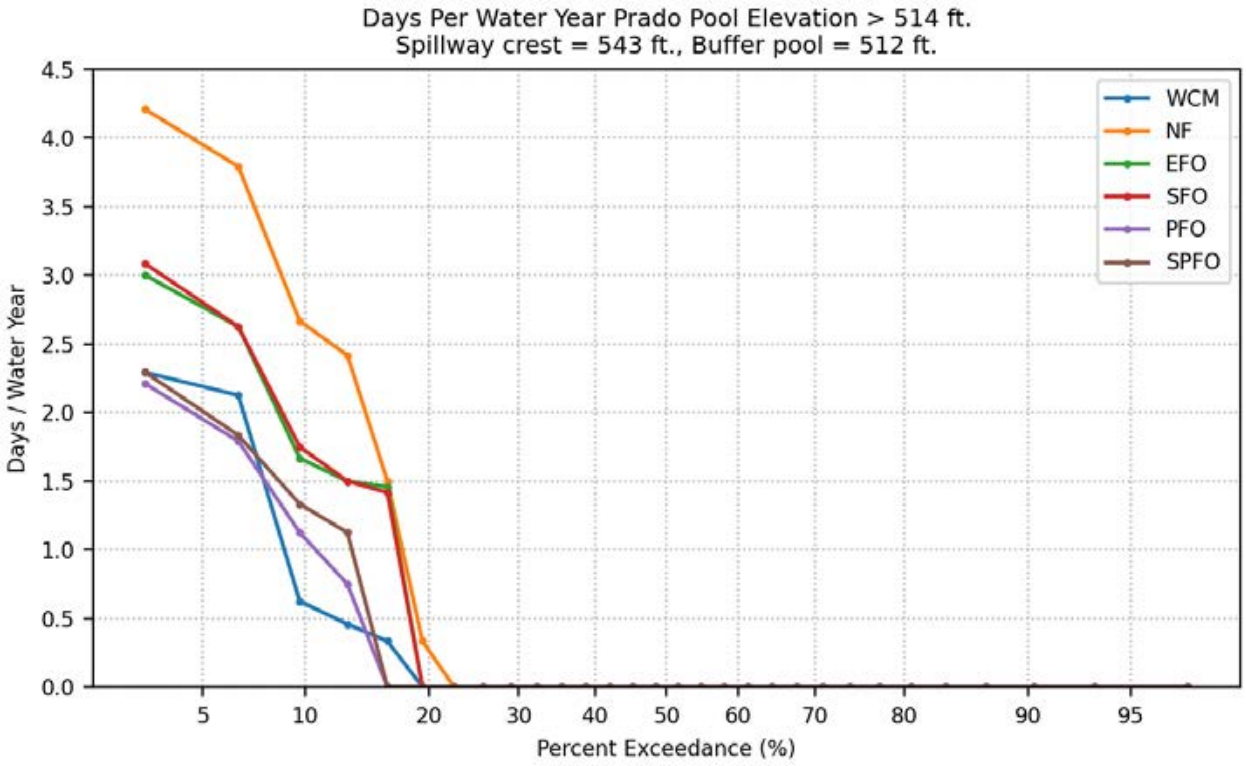

Days Per Water Year Elevation Change > 1-meter
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
35.0
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

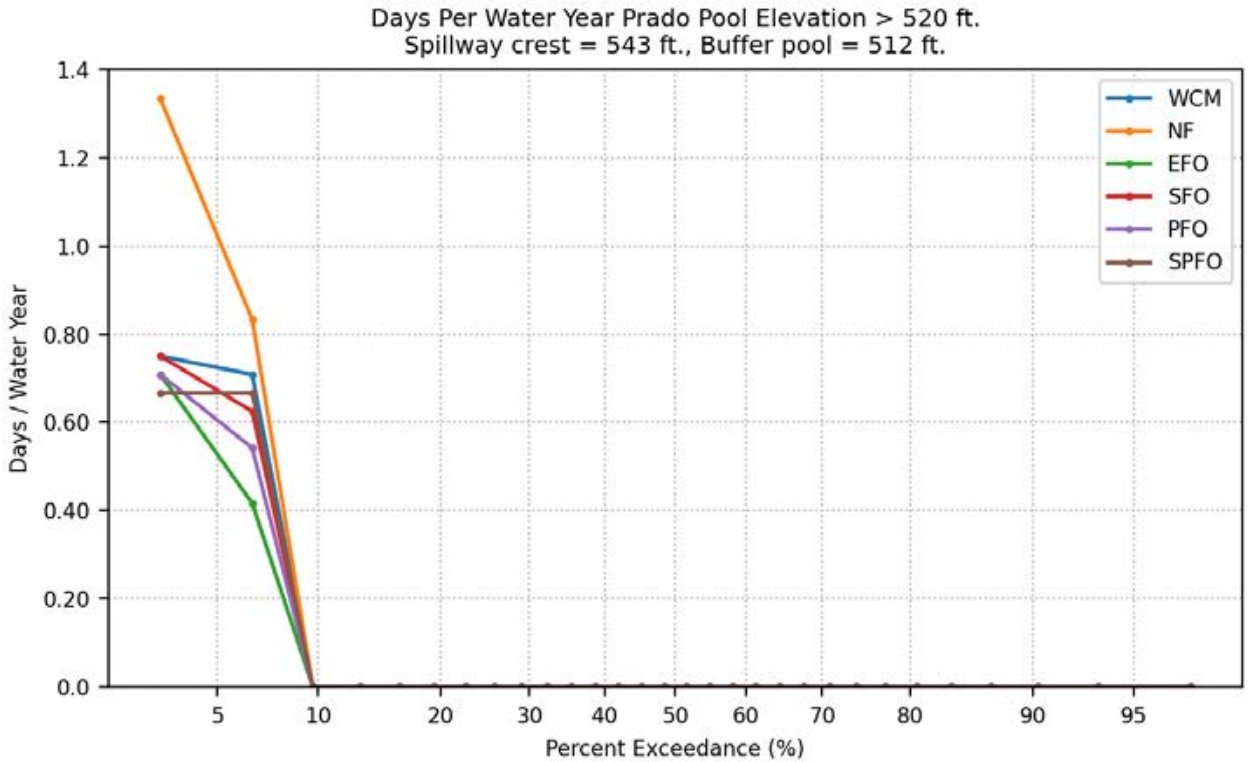

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
180.
160.
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

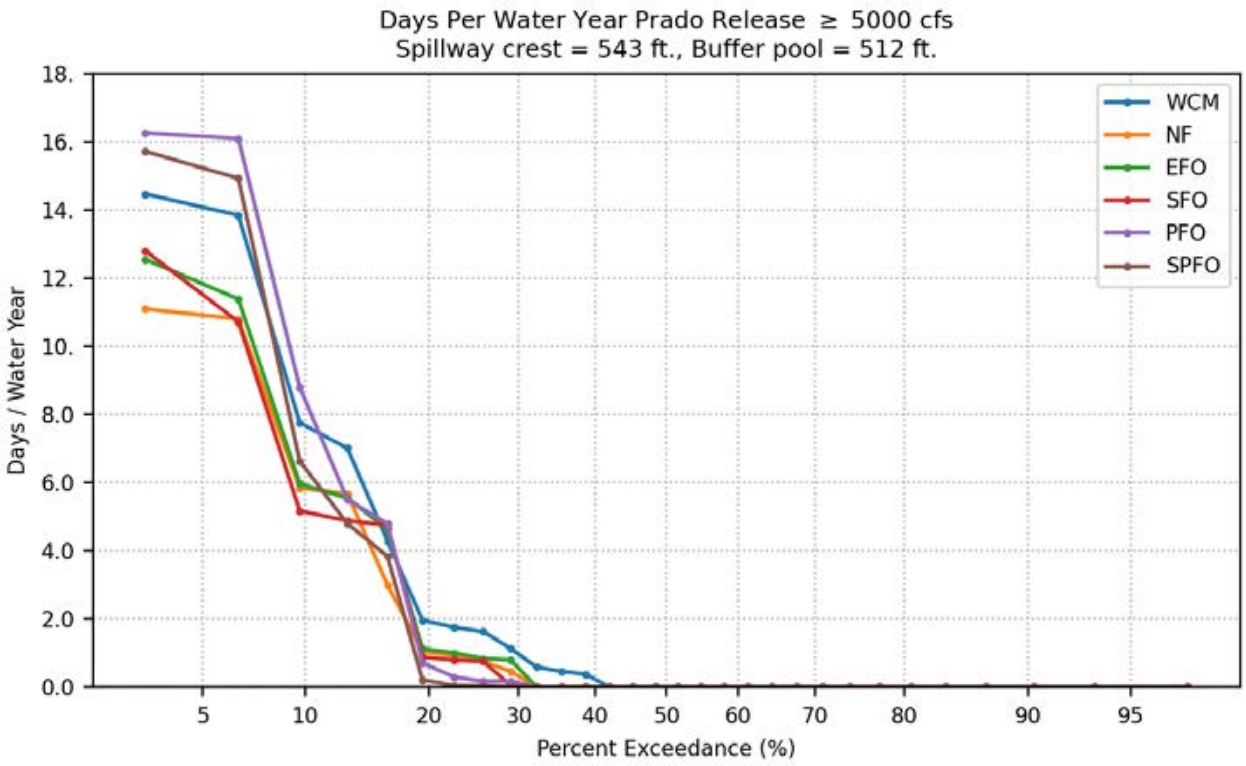

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

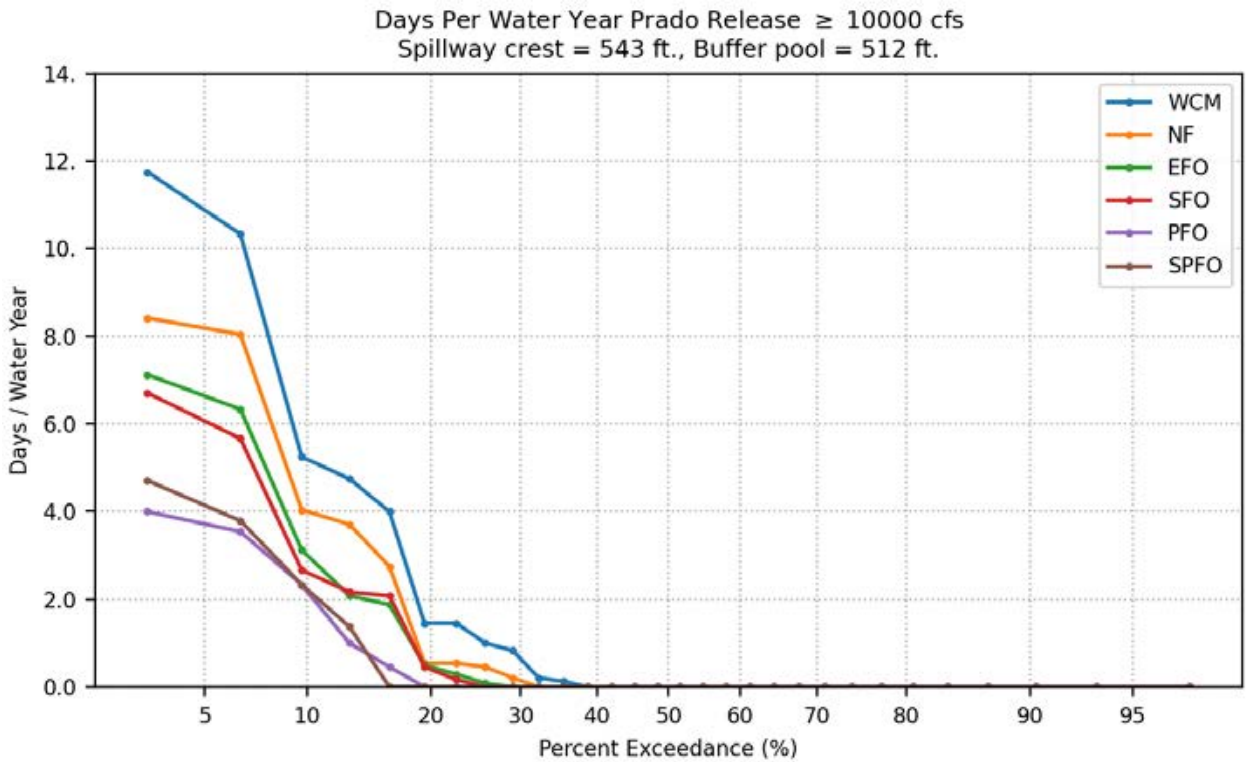

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

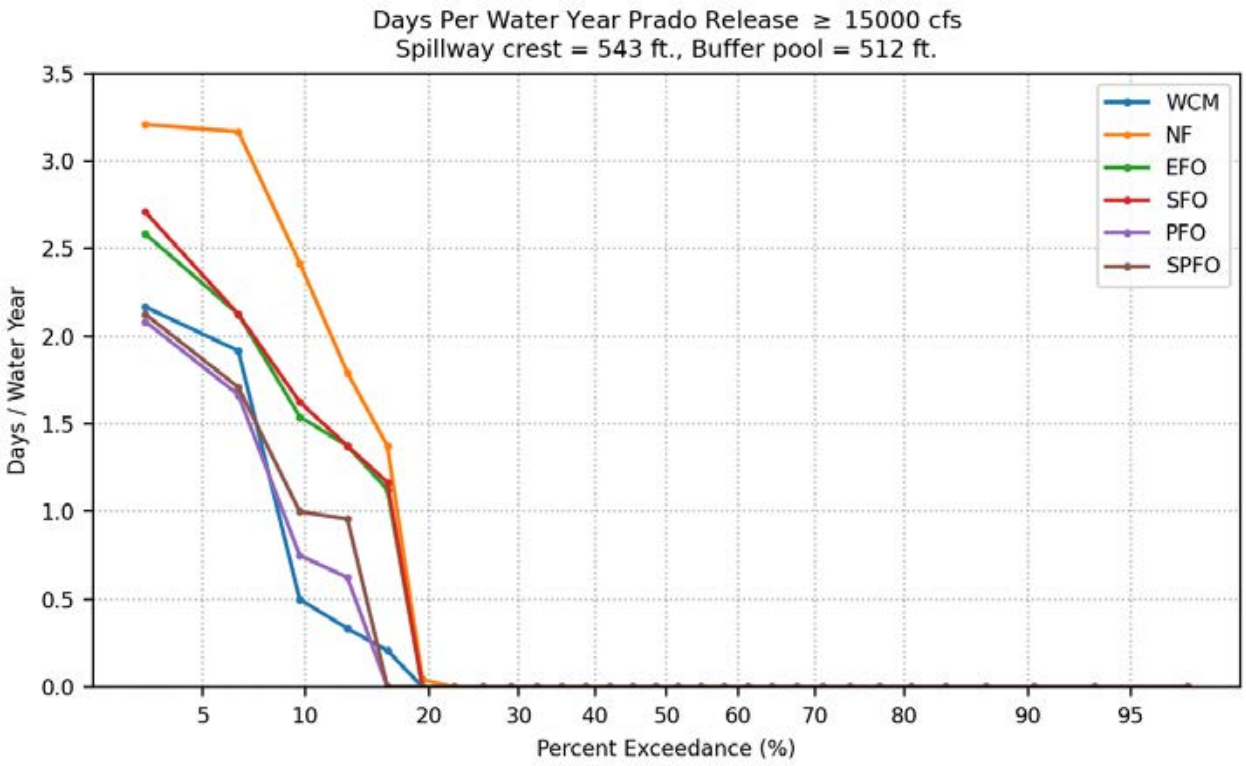

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

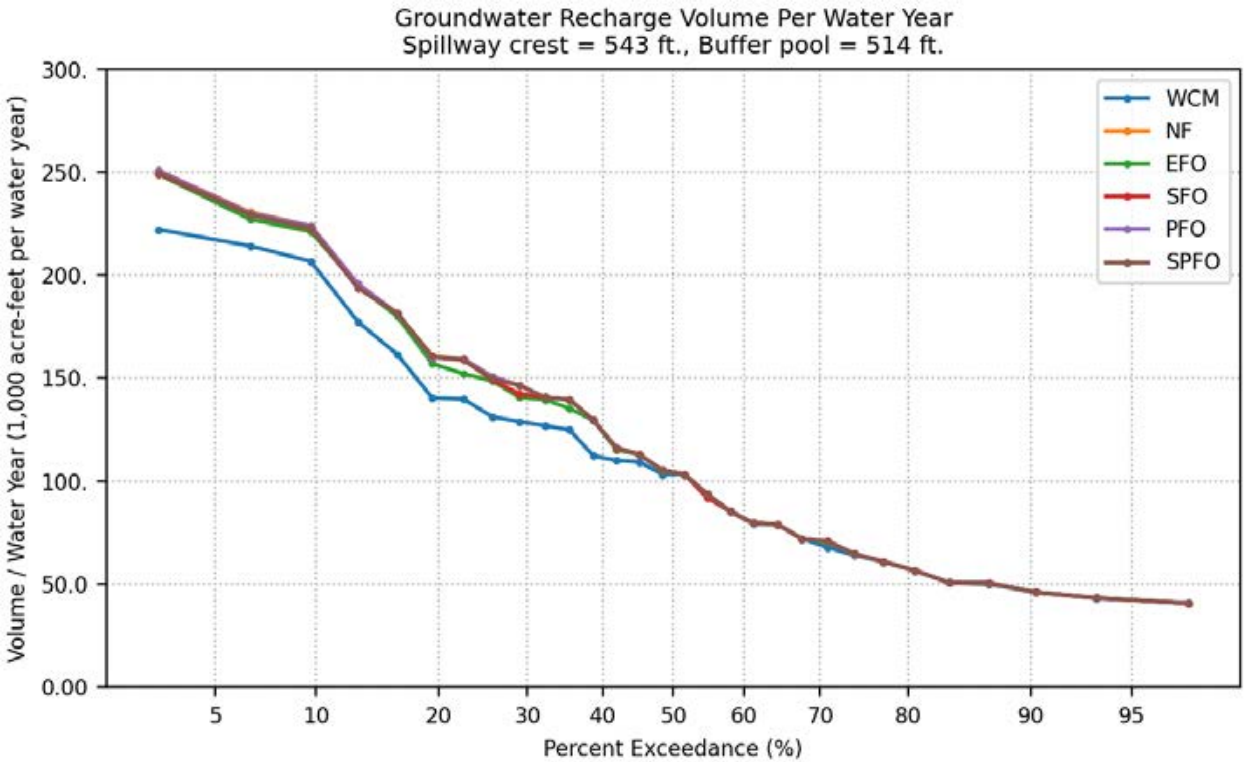

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5
10
20
30
40
50
60
70
80
90
95

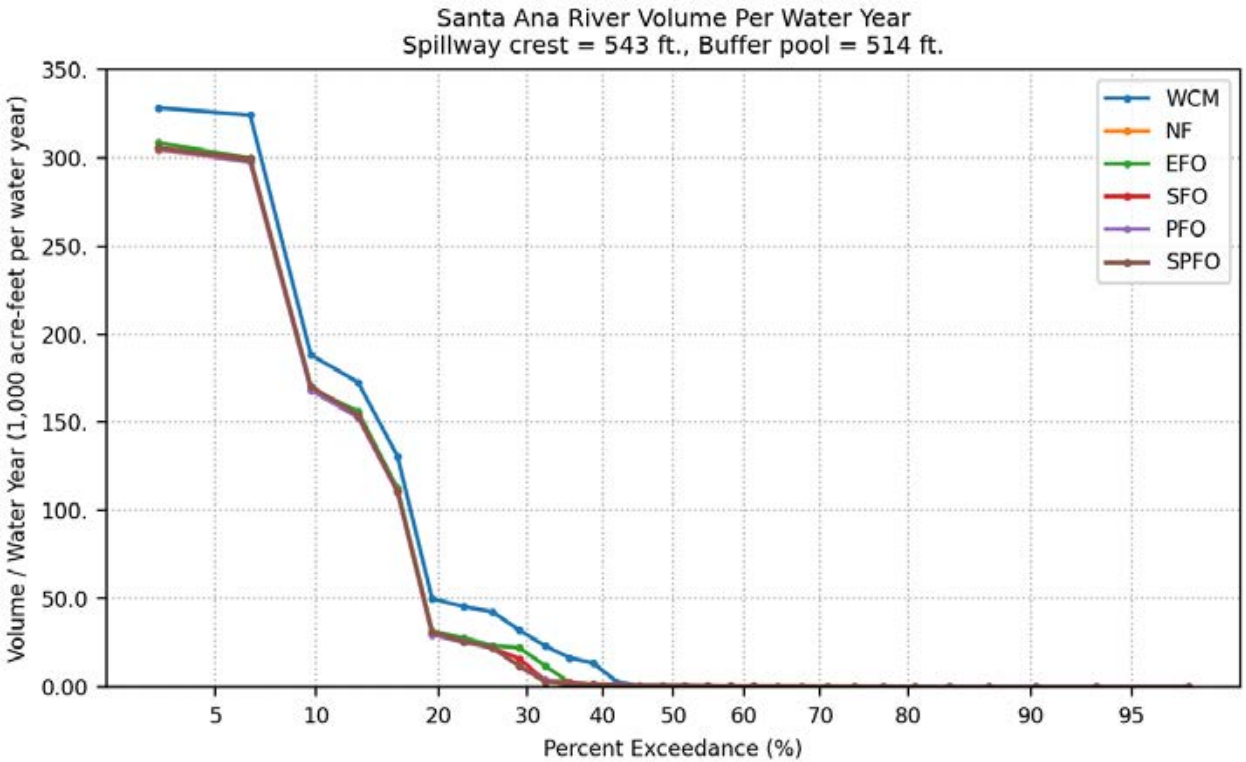

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
1.4
1.2
1.0
0.80
0.60
0.40
0.20
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

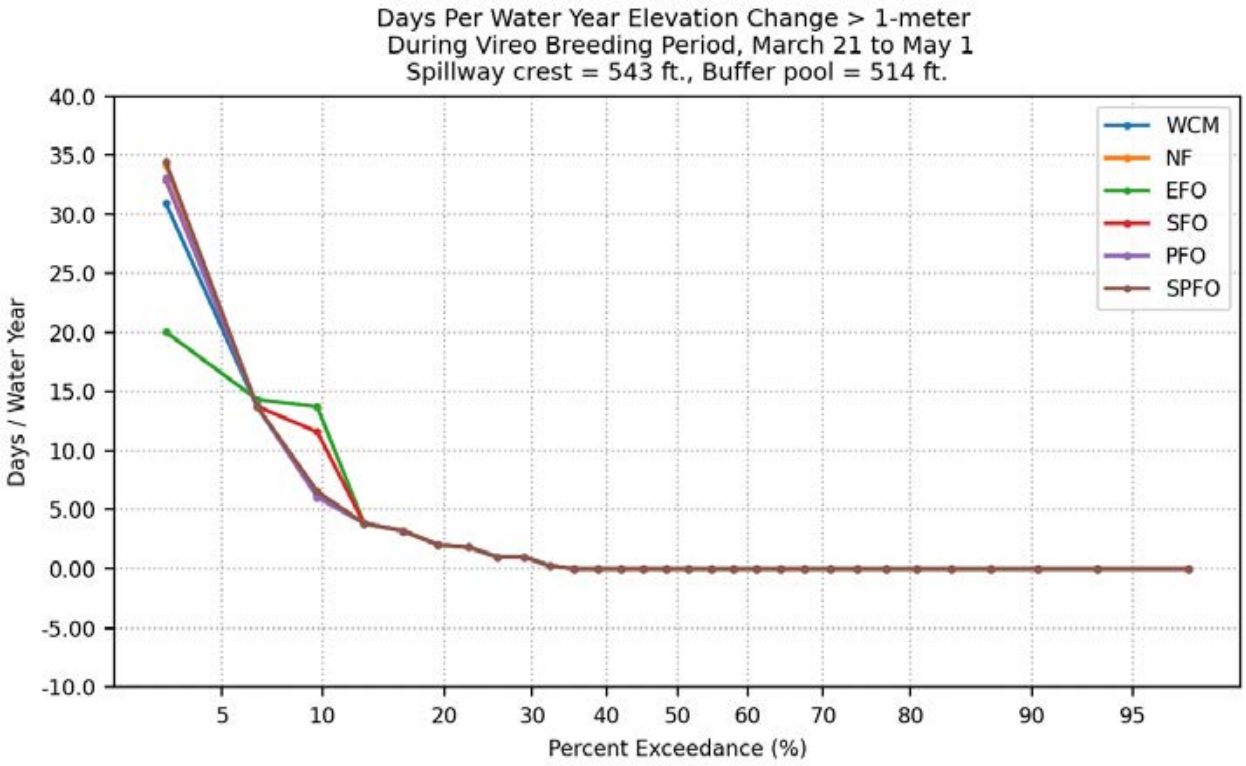

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
18.
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

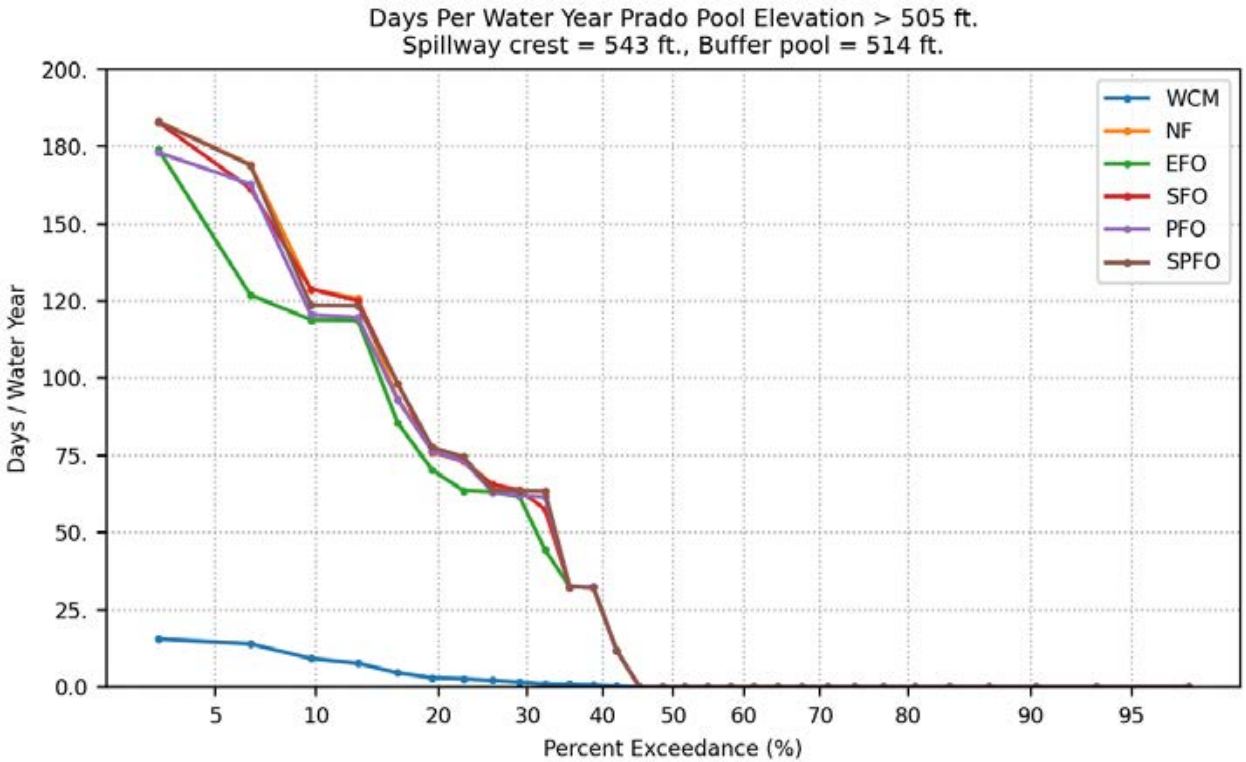

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
0.0
2.0
4.0
6.0
8.0
10.
12.
14.
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

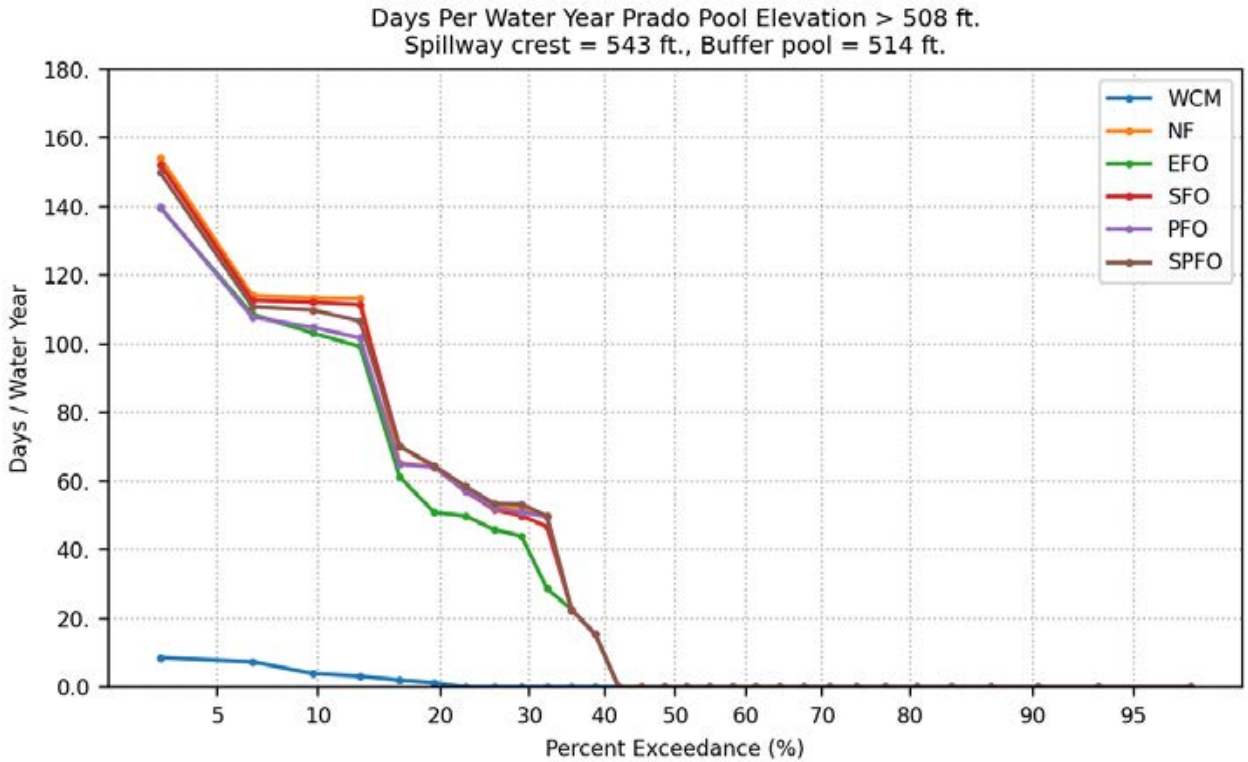

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
5
10
20
30
40
50
60
70
80
90
95

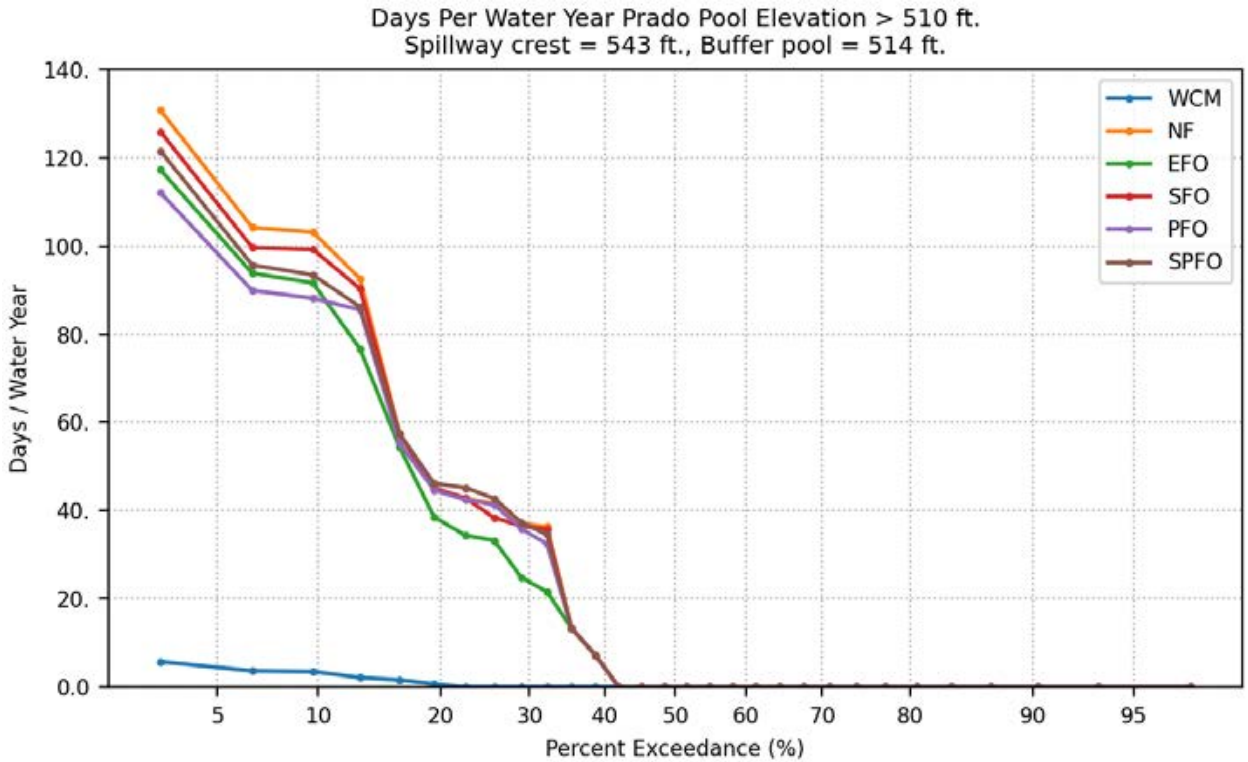

Groundwater Recharge Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 514 ft.
Volume / Water Year (1,000 acre-feet per water year)
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

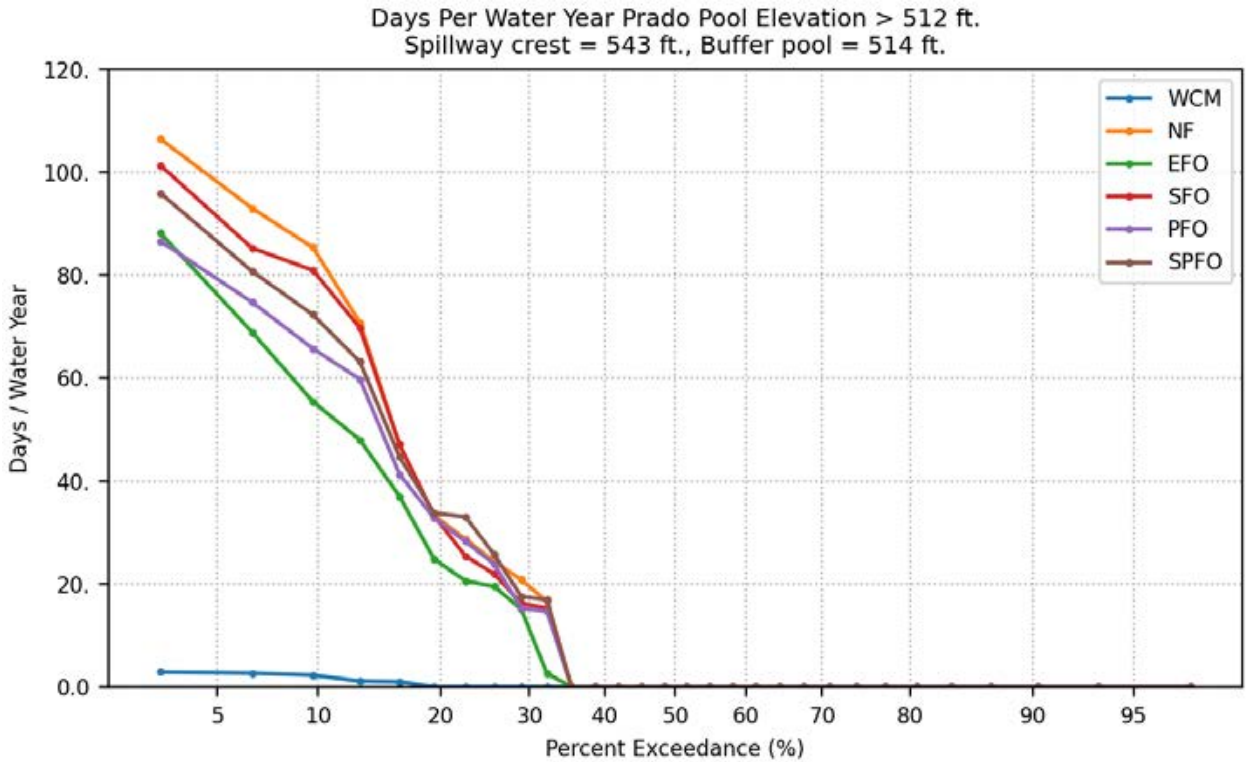

Santa Ana River Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 514 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

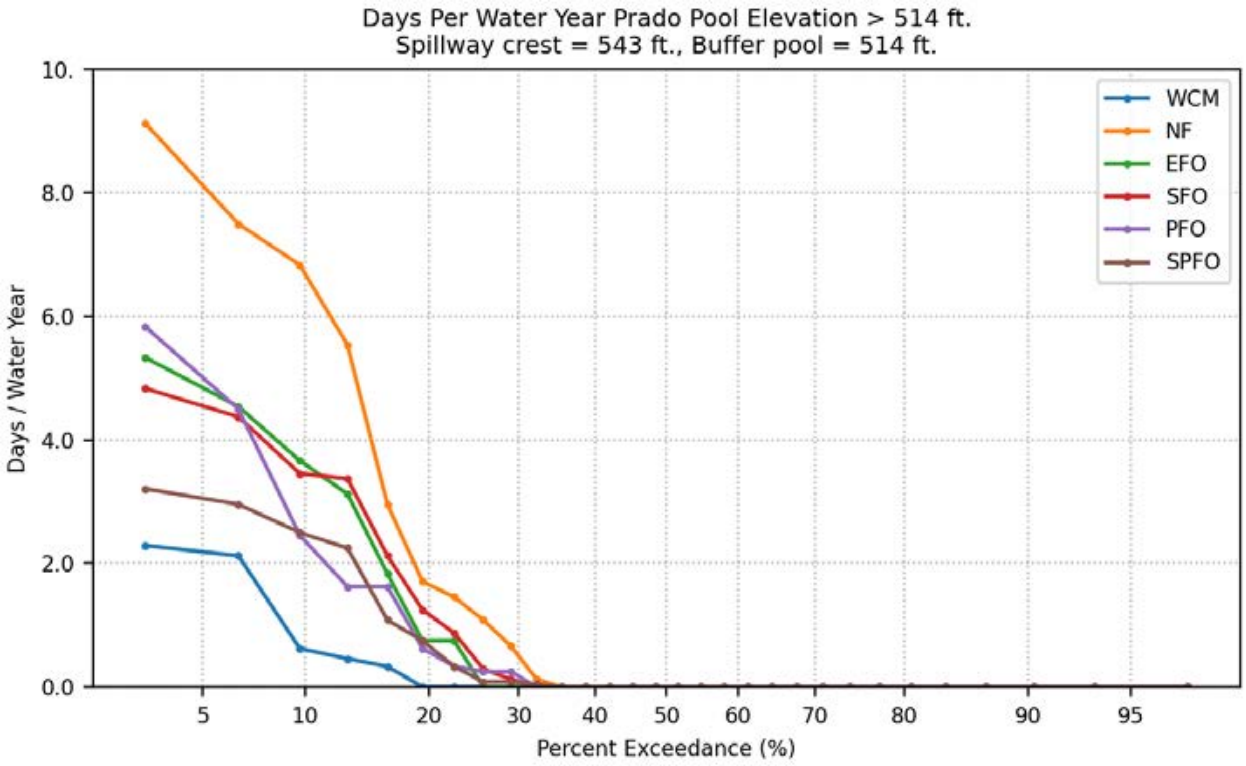

Days Per Water Year Elevation Change > 1-meter
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95

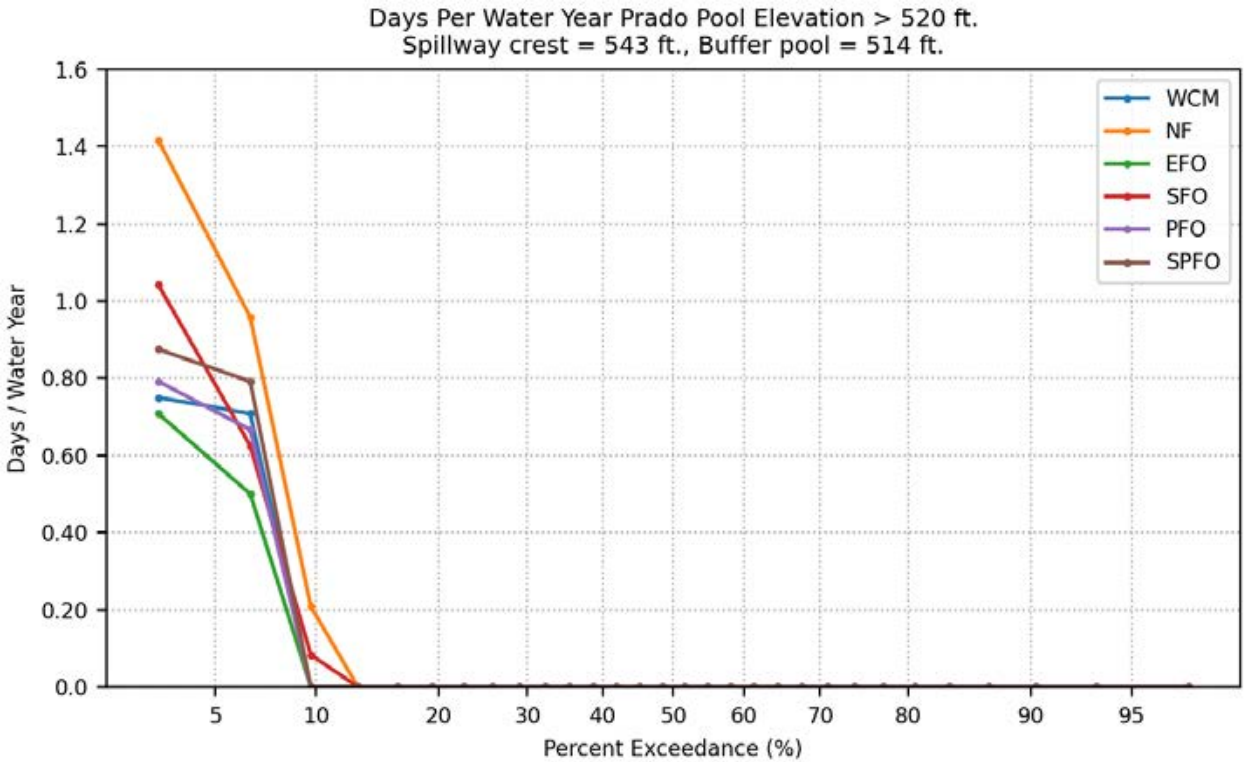

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
200.
180.
150.
120.
100.
75.
50.
25.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

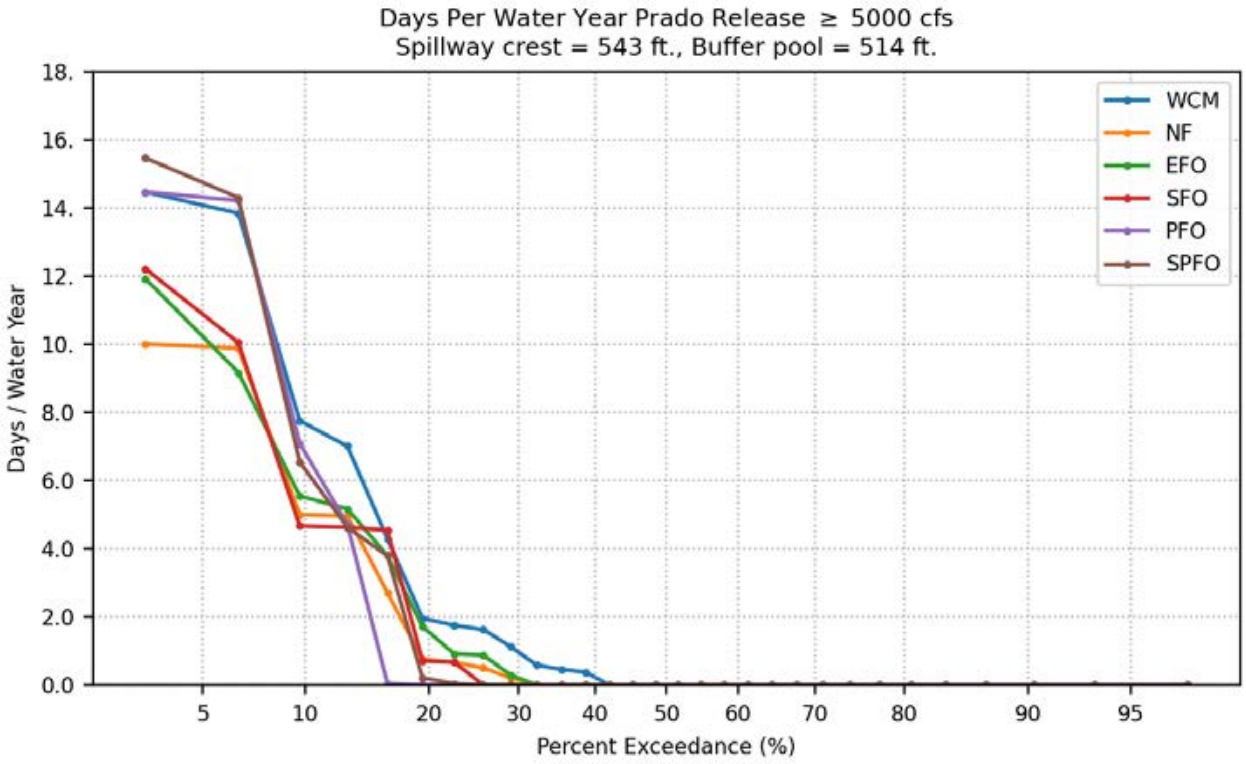

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
180.
160.
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

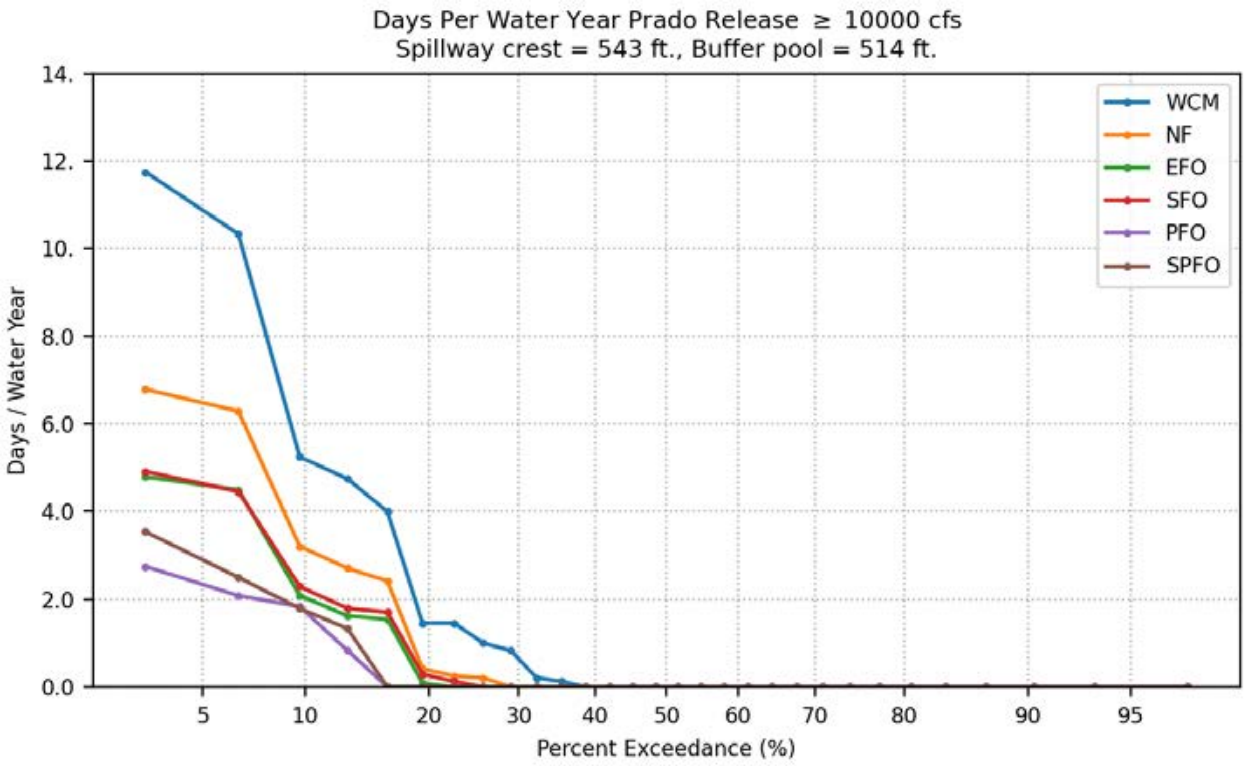

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

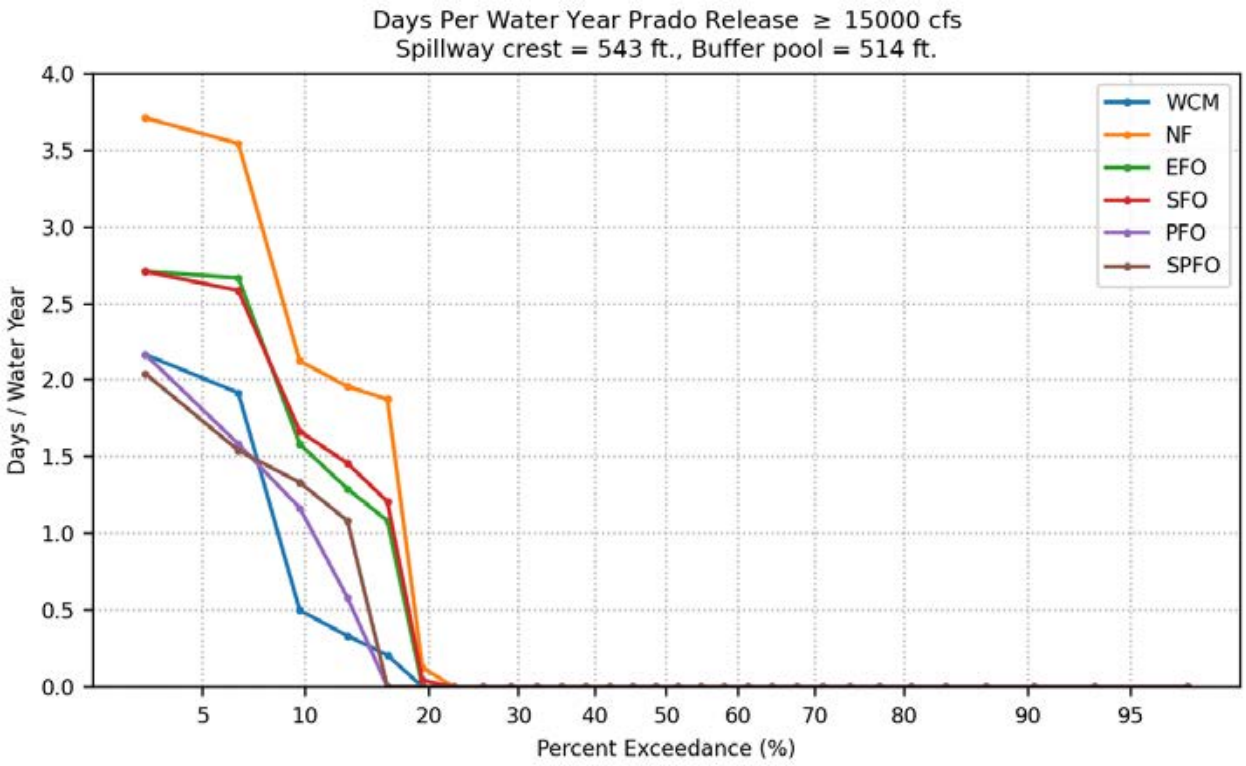

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

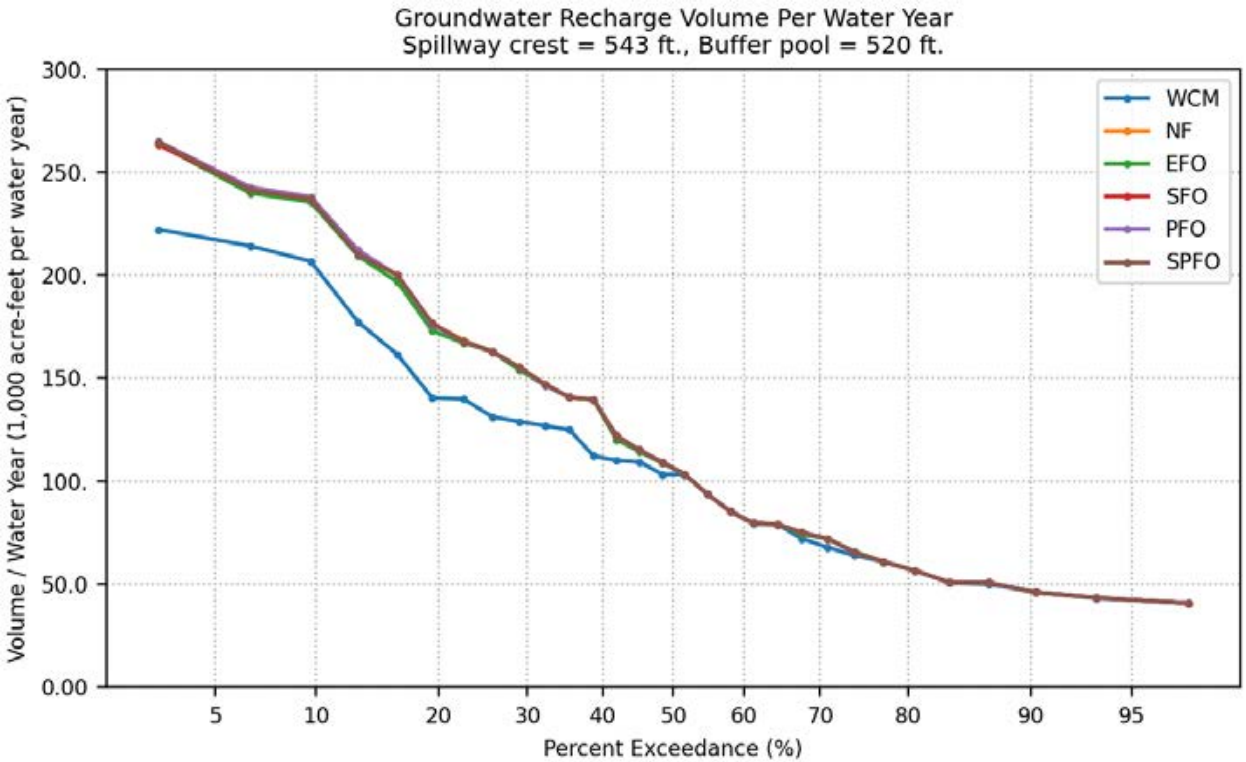

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

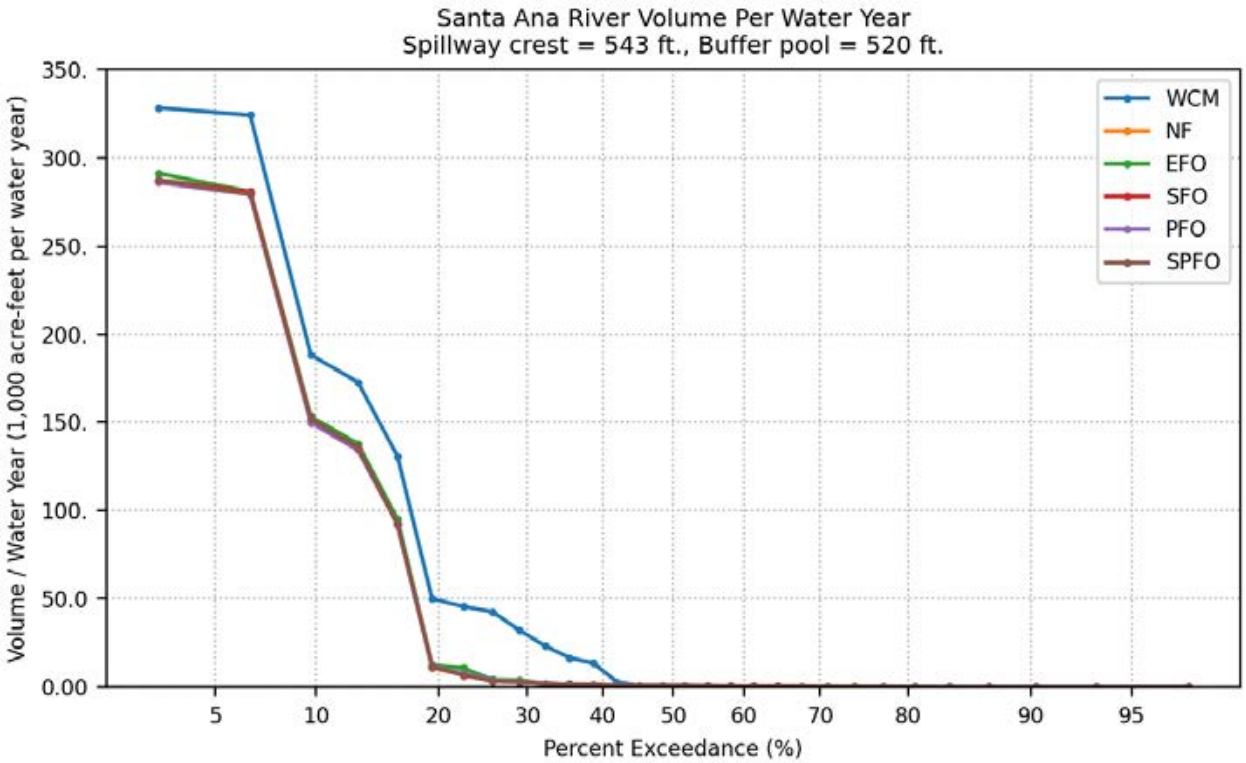

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
1.6
1.4
1.2
1.0
0.80
0.60
0.40
0.20
0.0
5
10
20
30
40
50
60
70
80
90
95

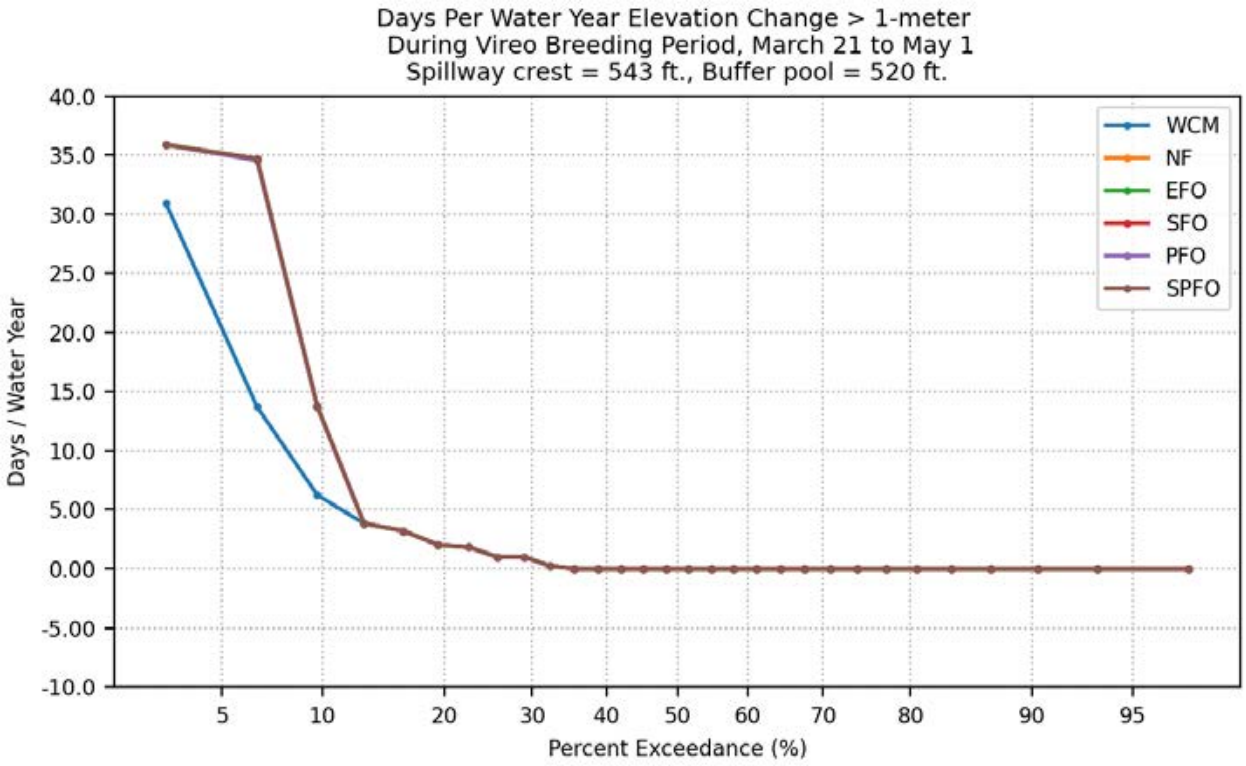

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
18.
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

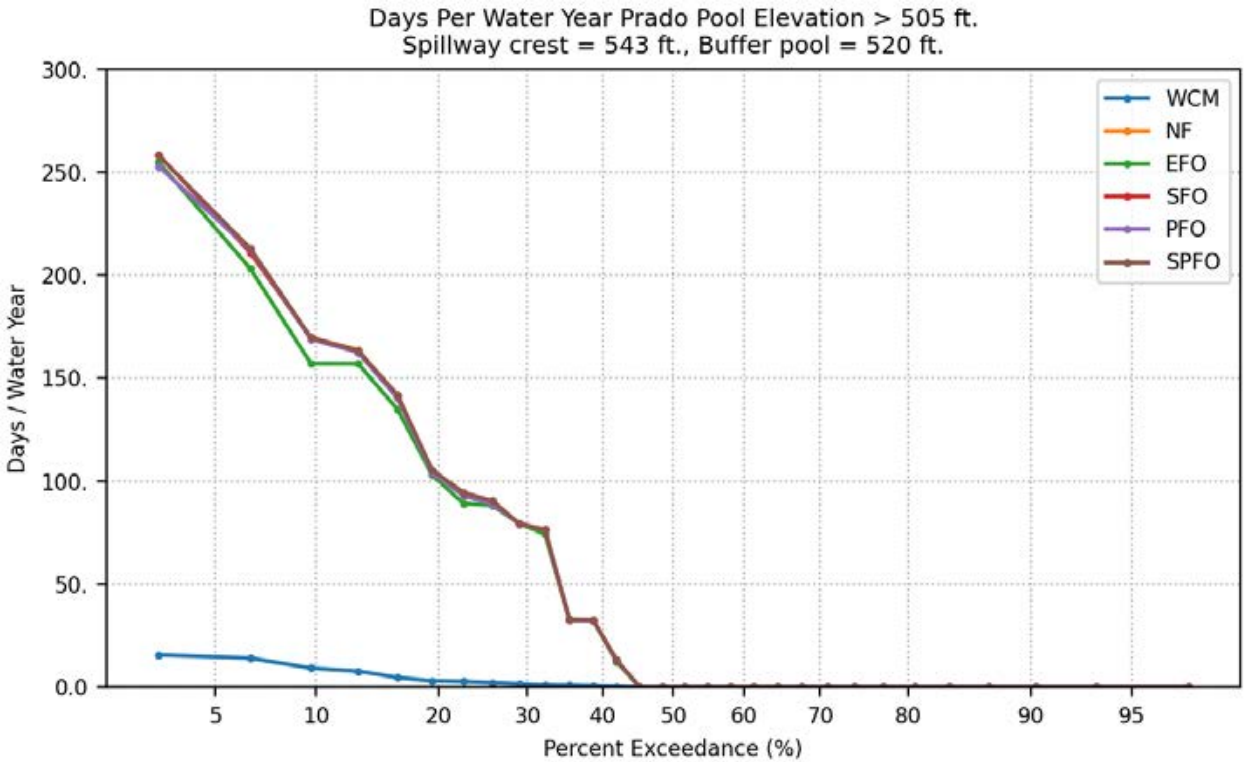

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

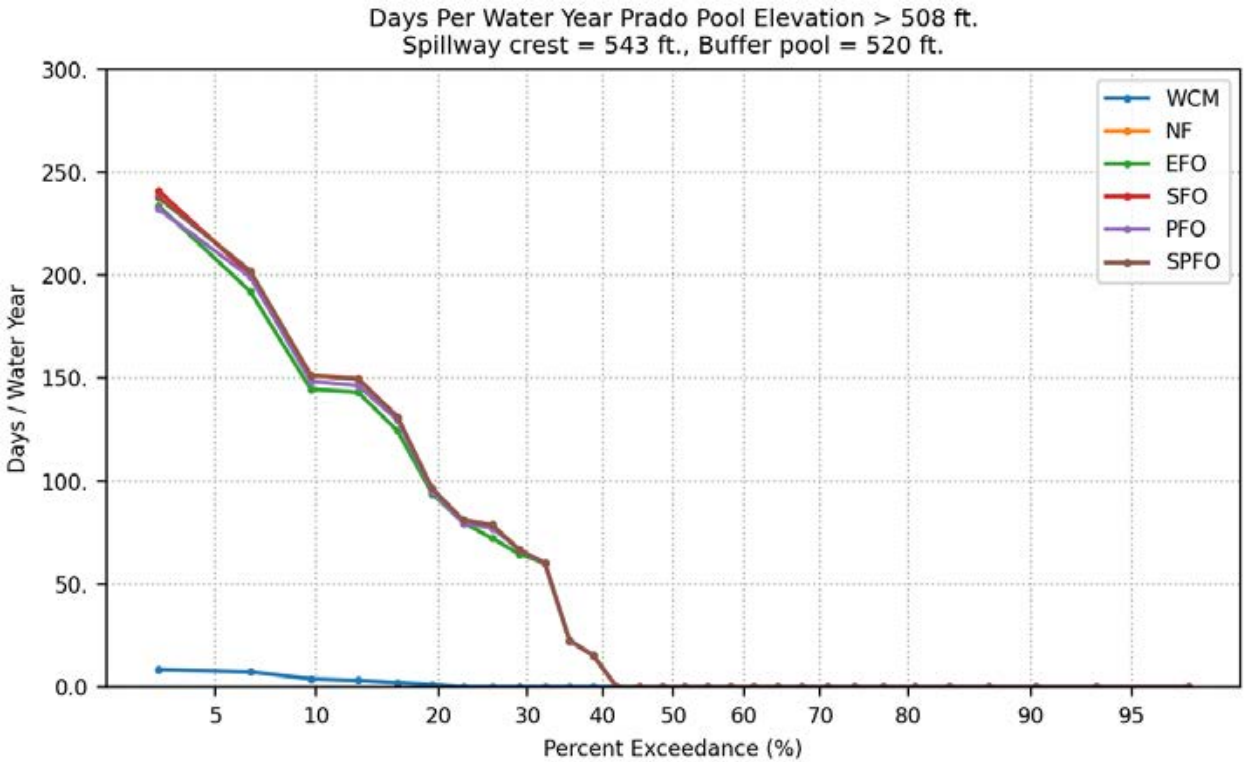

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
20
30
40
50
60
70
80
90
95

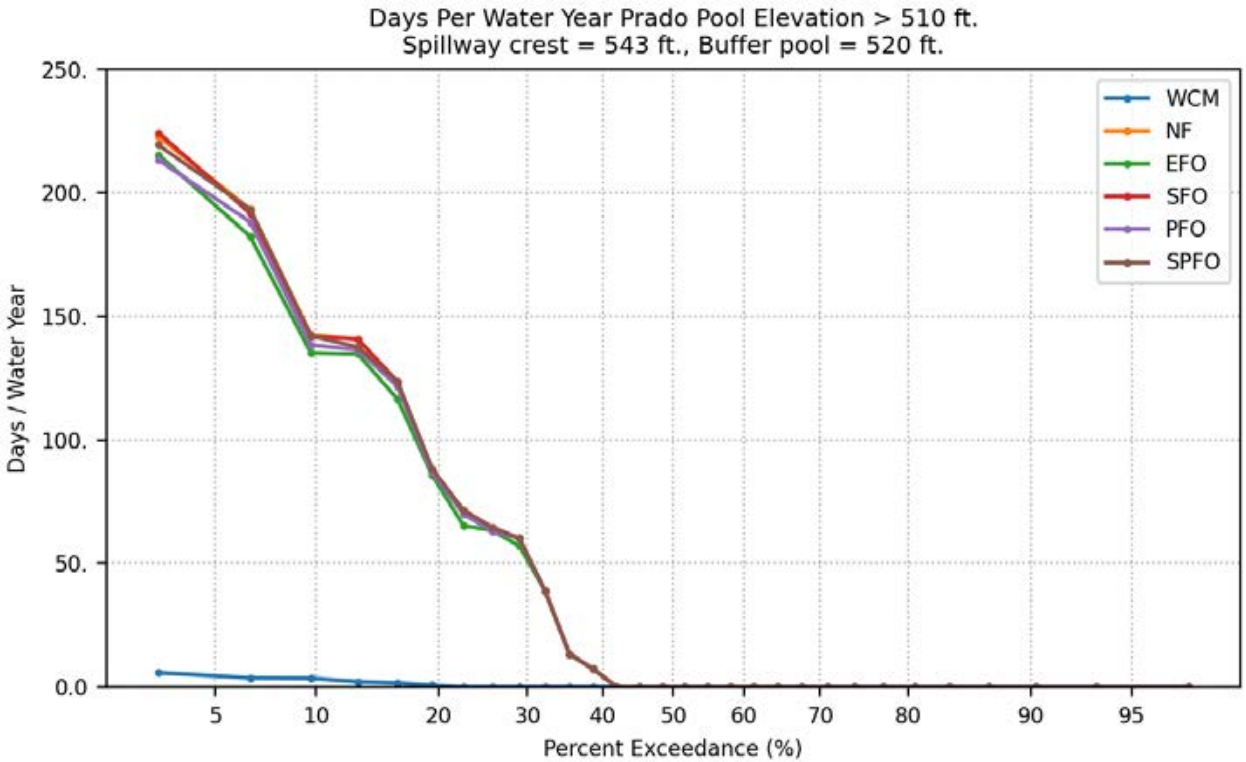

Groundwater Recharge Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 520 ft.
Volume / Water Year (1,000 acre-feet per water year)
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

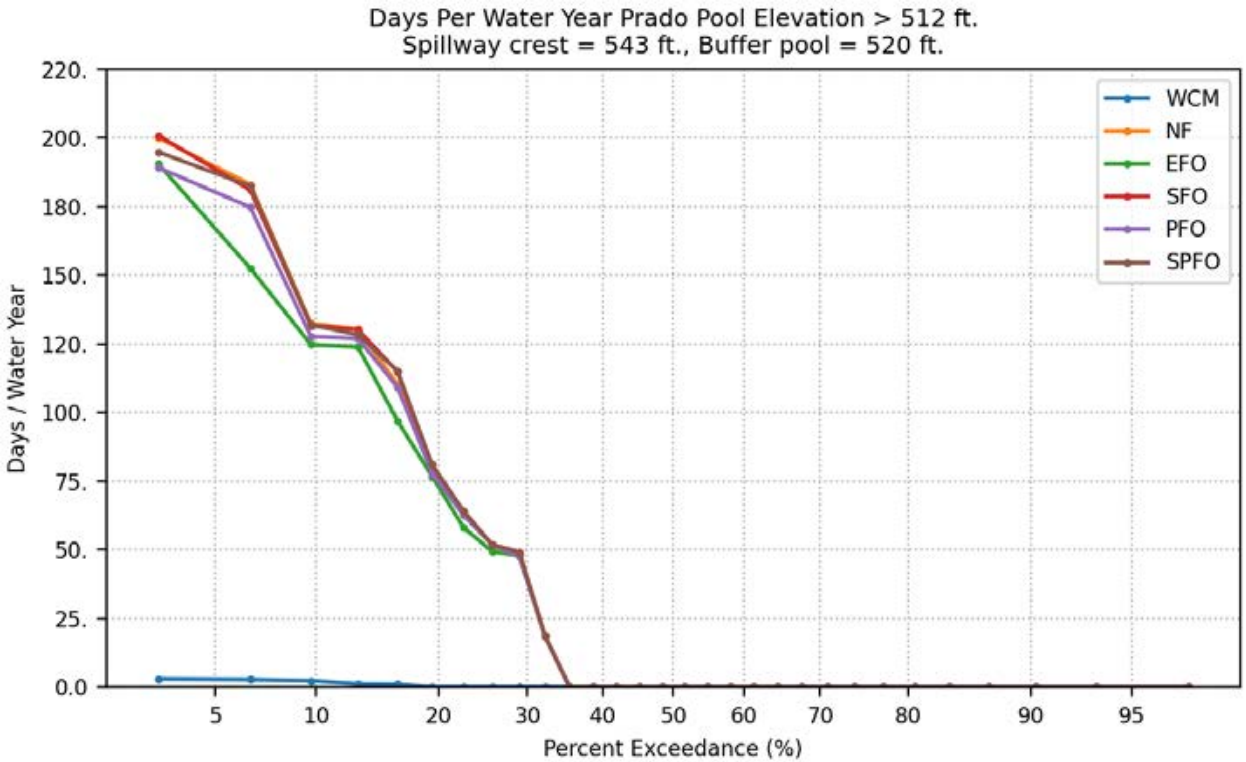

Santa Ana River Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 520 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

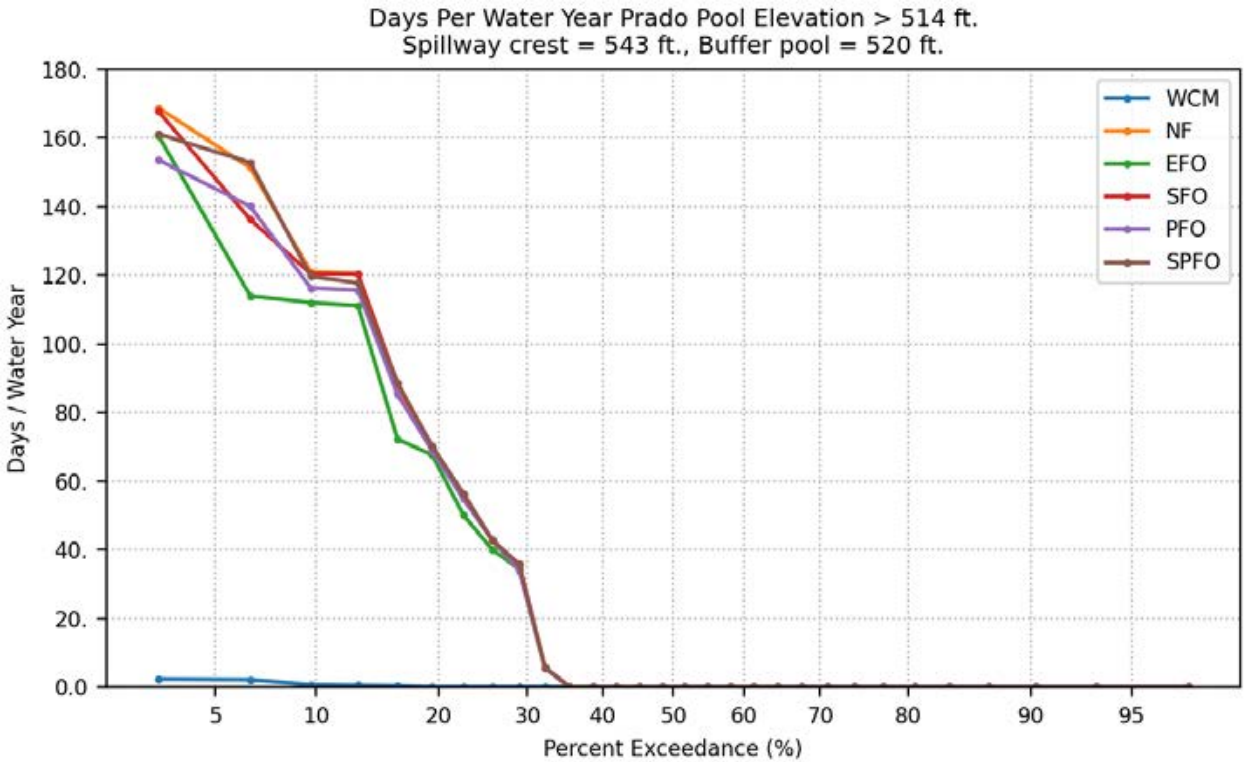

Days Per Water Year Elevation Change > 1-meter
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 543 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95

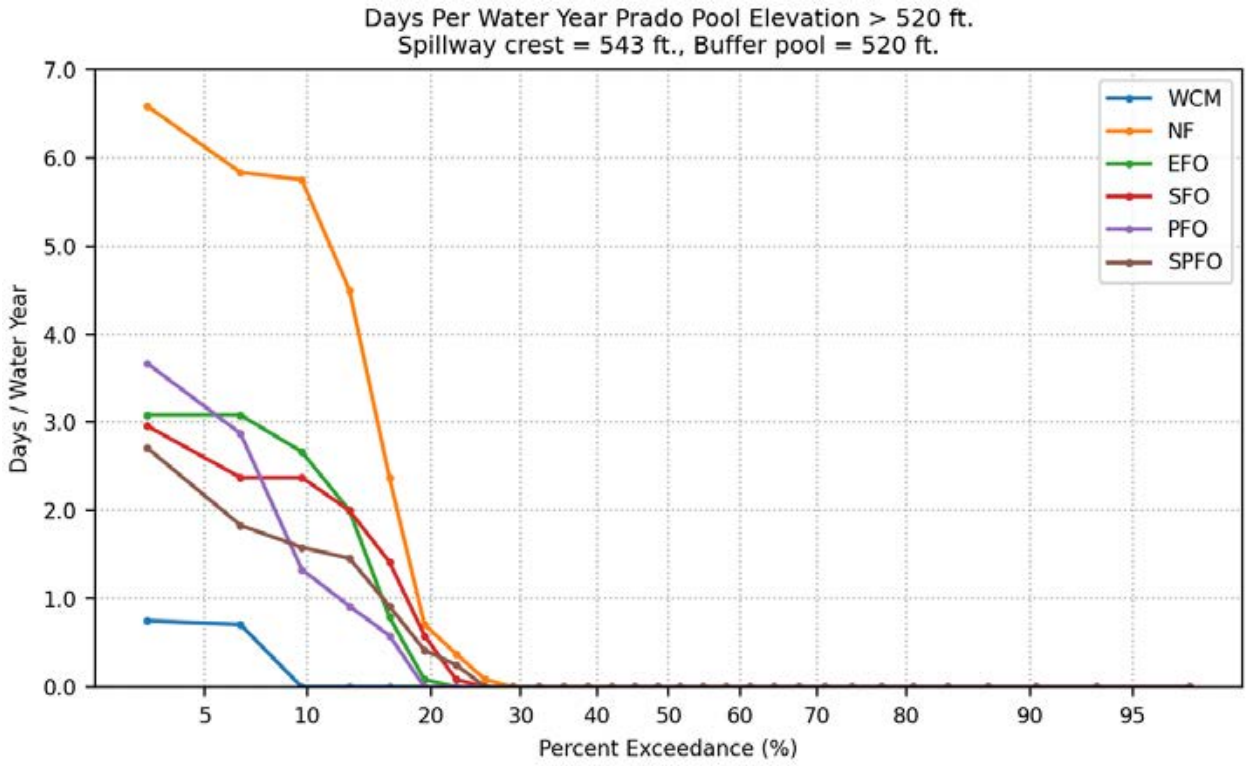

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 543 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
300.
250.
200.
150.
100.
50.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

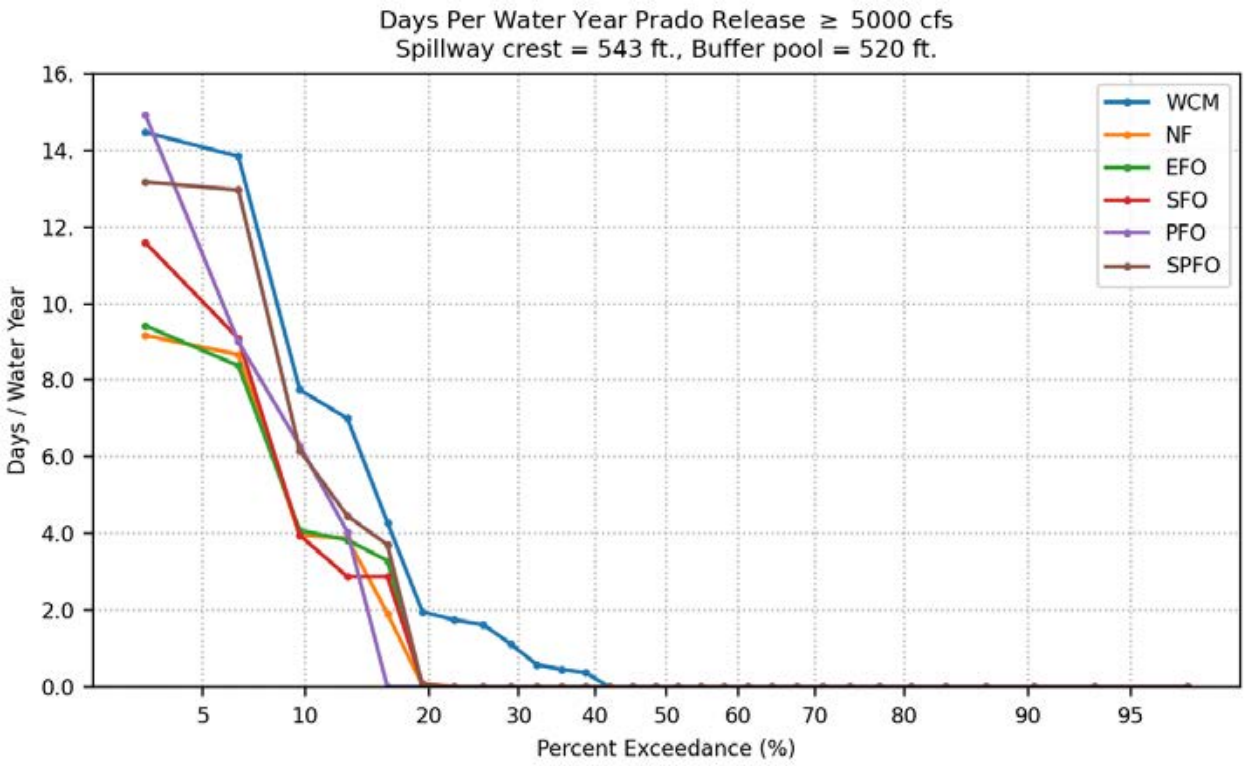

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 543 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
300.
250.
200.
150.
100.
50.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

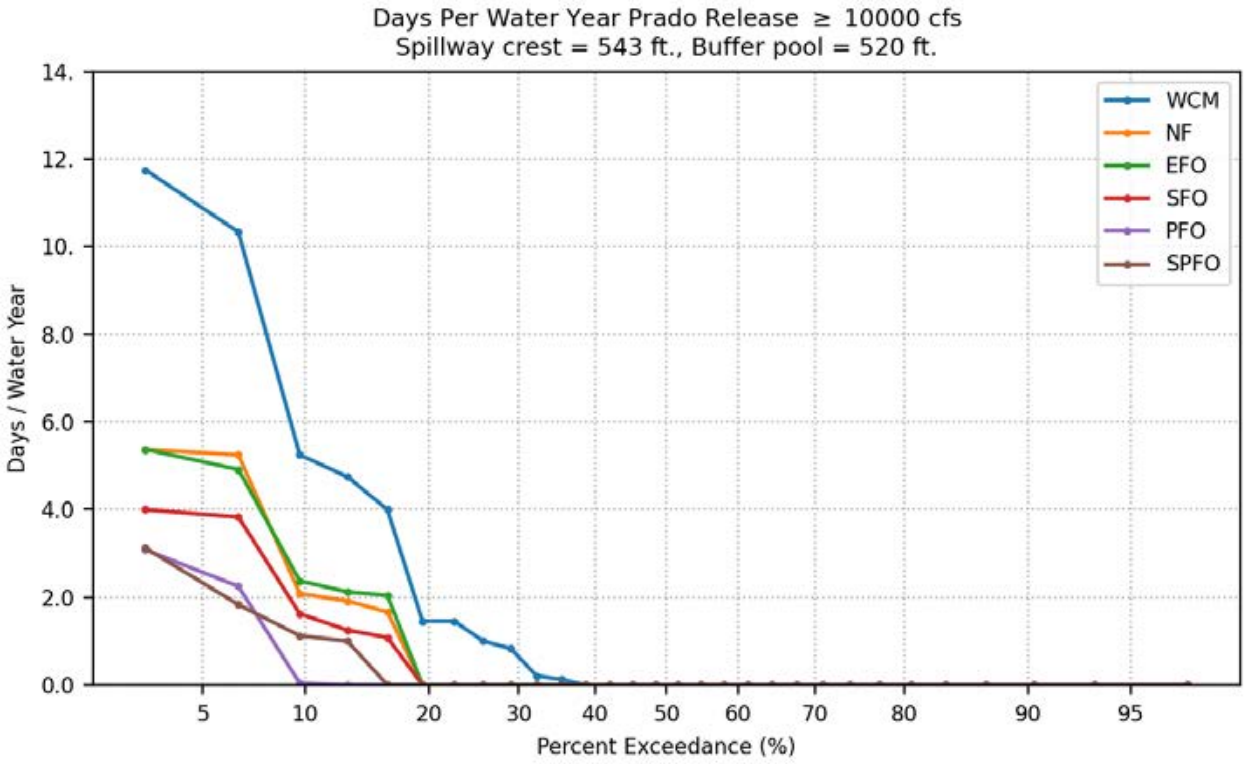

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 543 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
250.
200.
150.
100.
50.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

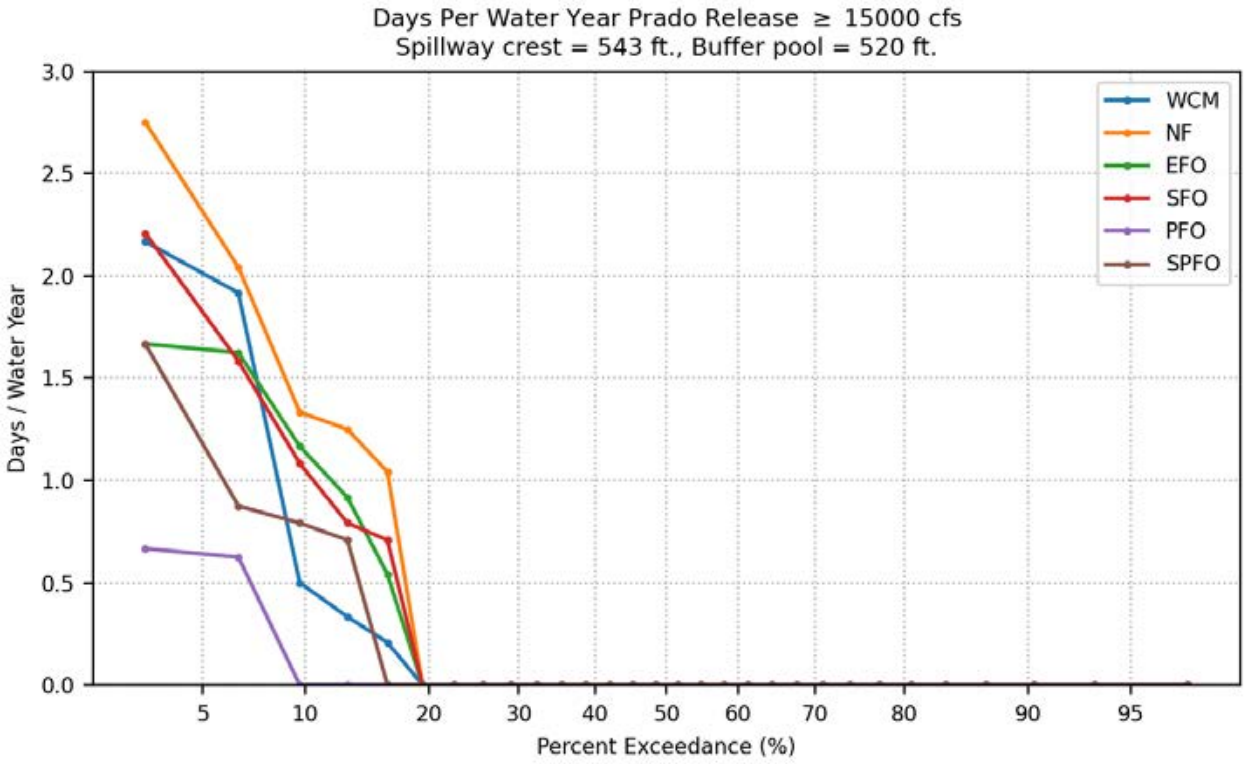

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 543 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
220.
200.
180.
150.
120.
100.
75.
50.
25.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

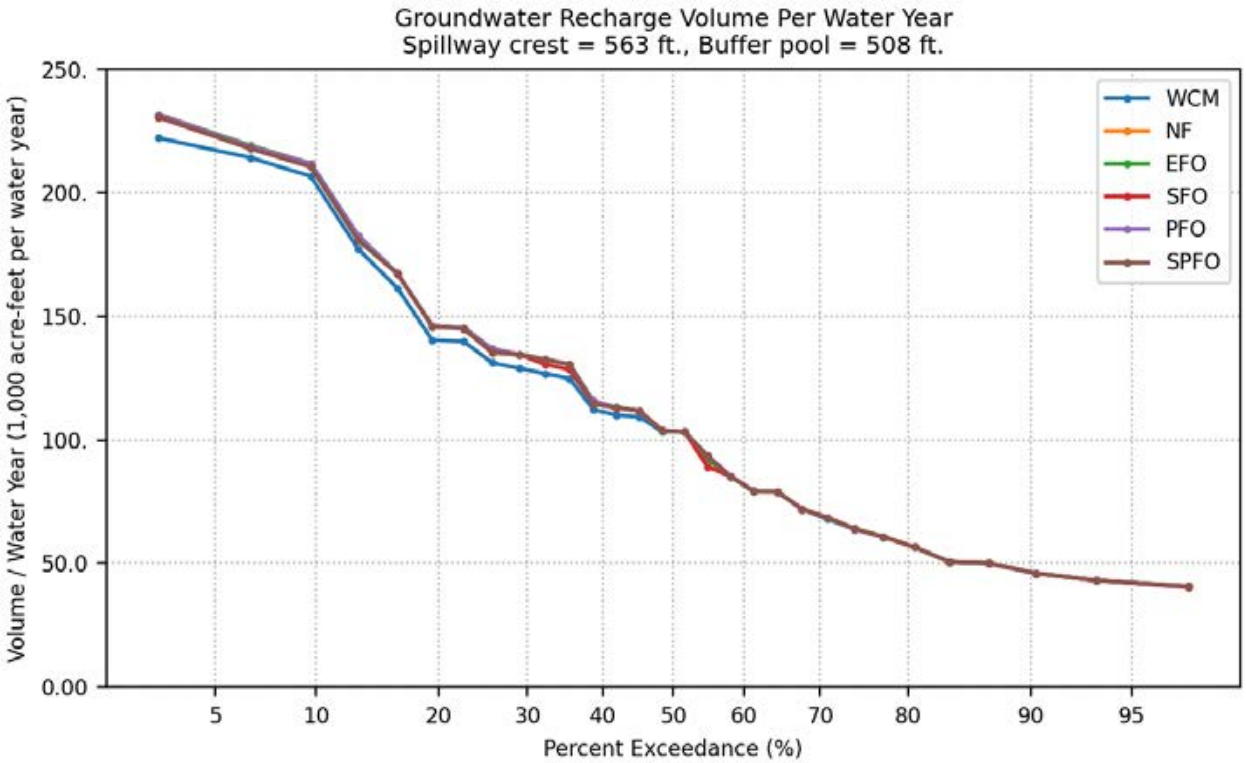

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 543 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
180.
160.
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

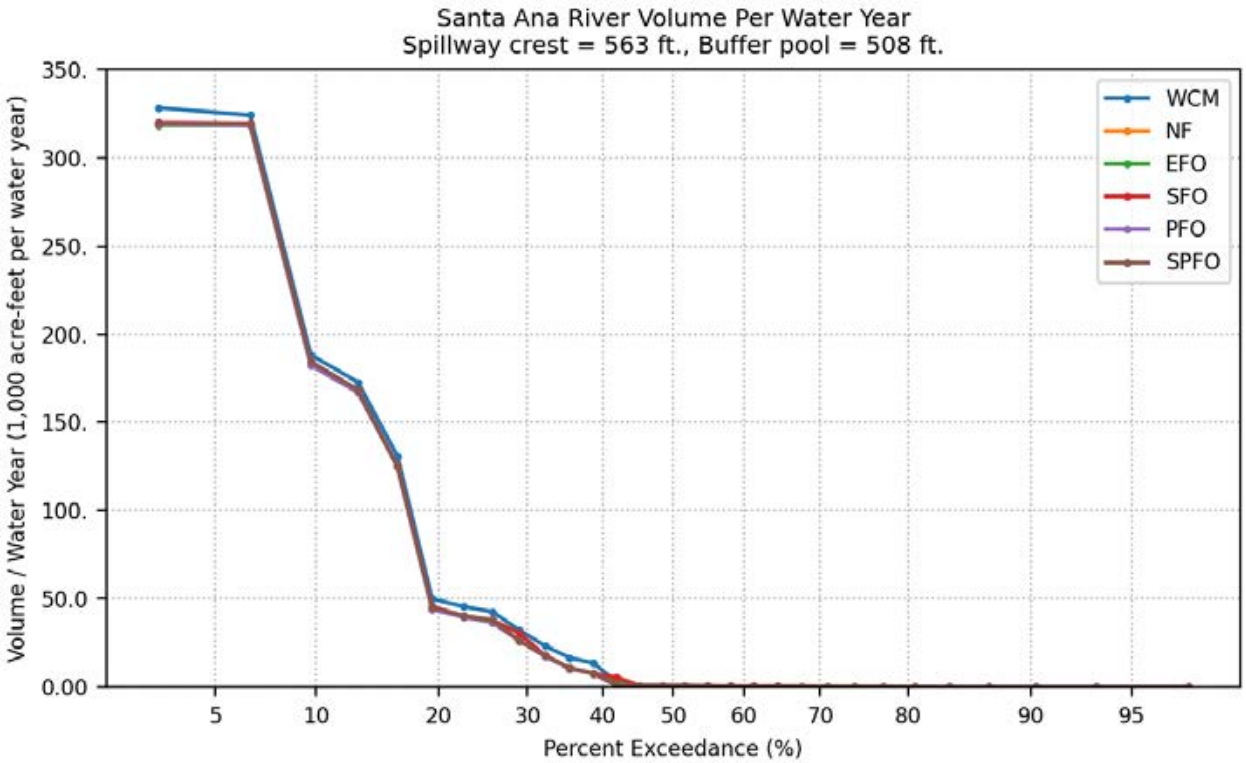

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 543 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

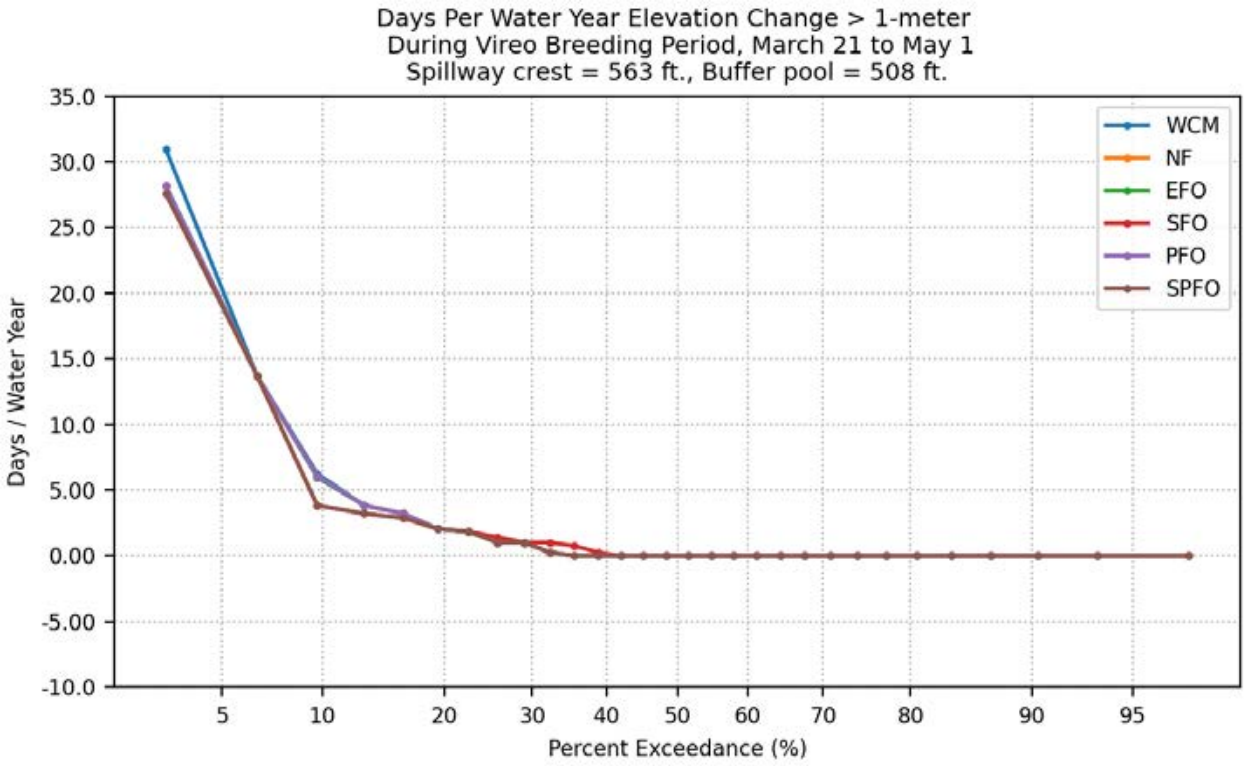

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 543 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

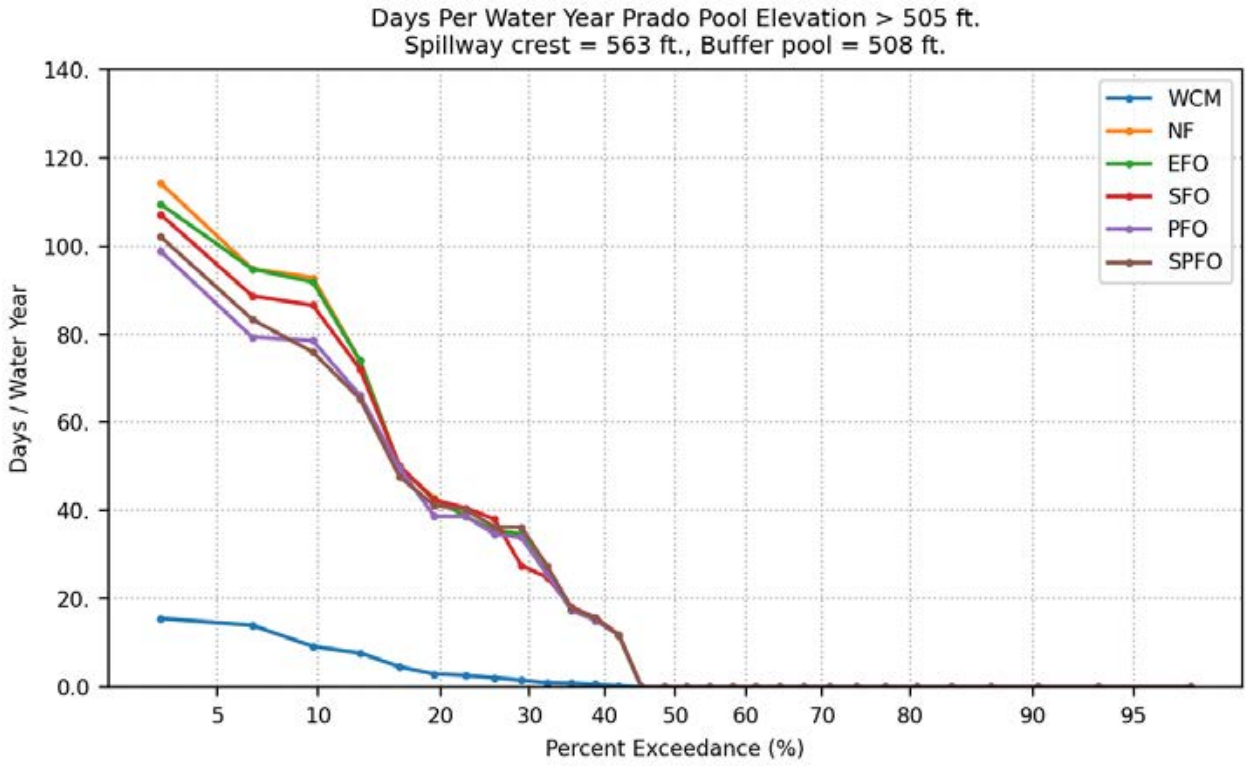

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 543 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

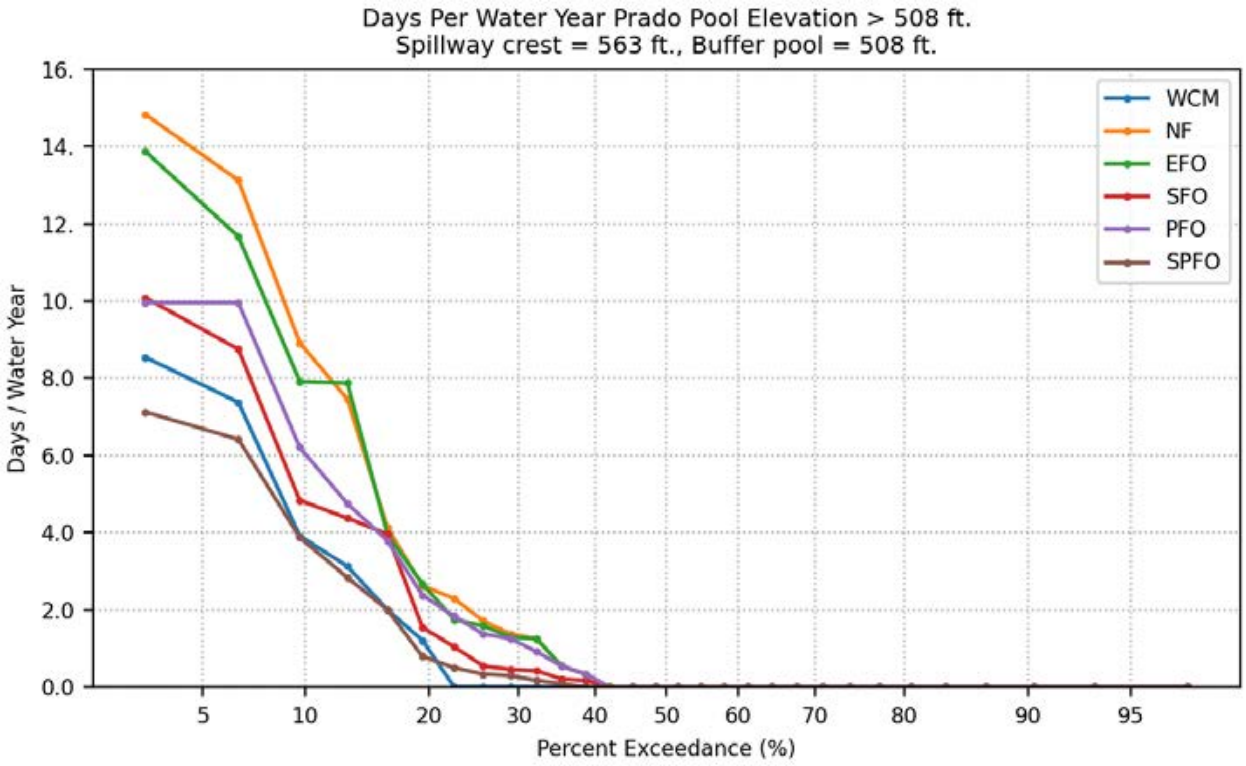

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 543 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
0.0
0.5
1.0
1.5
2.0
2.5
3.0
5
10
20
30
40
50
60
70
80
90
95

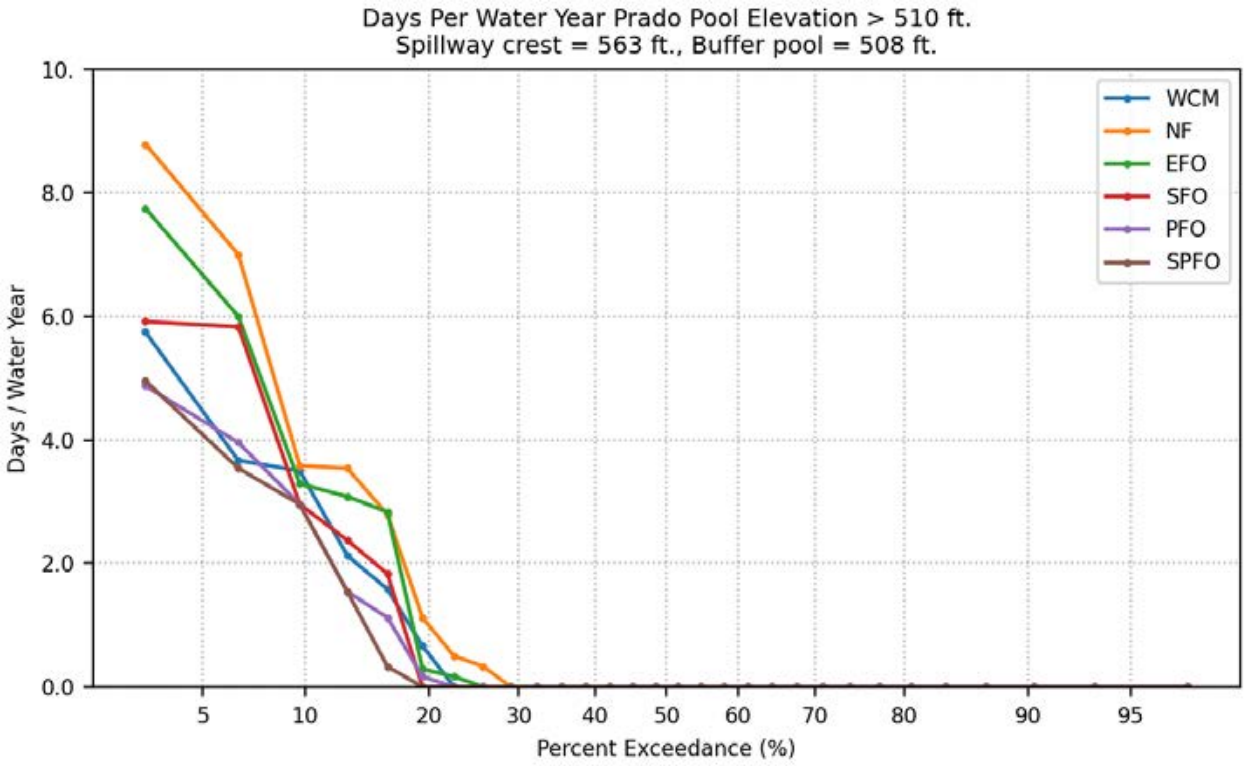

Groundwater Recharge Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 508 ft.
Volume / Water Year (1,000 acre-feet per water year)
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

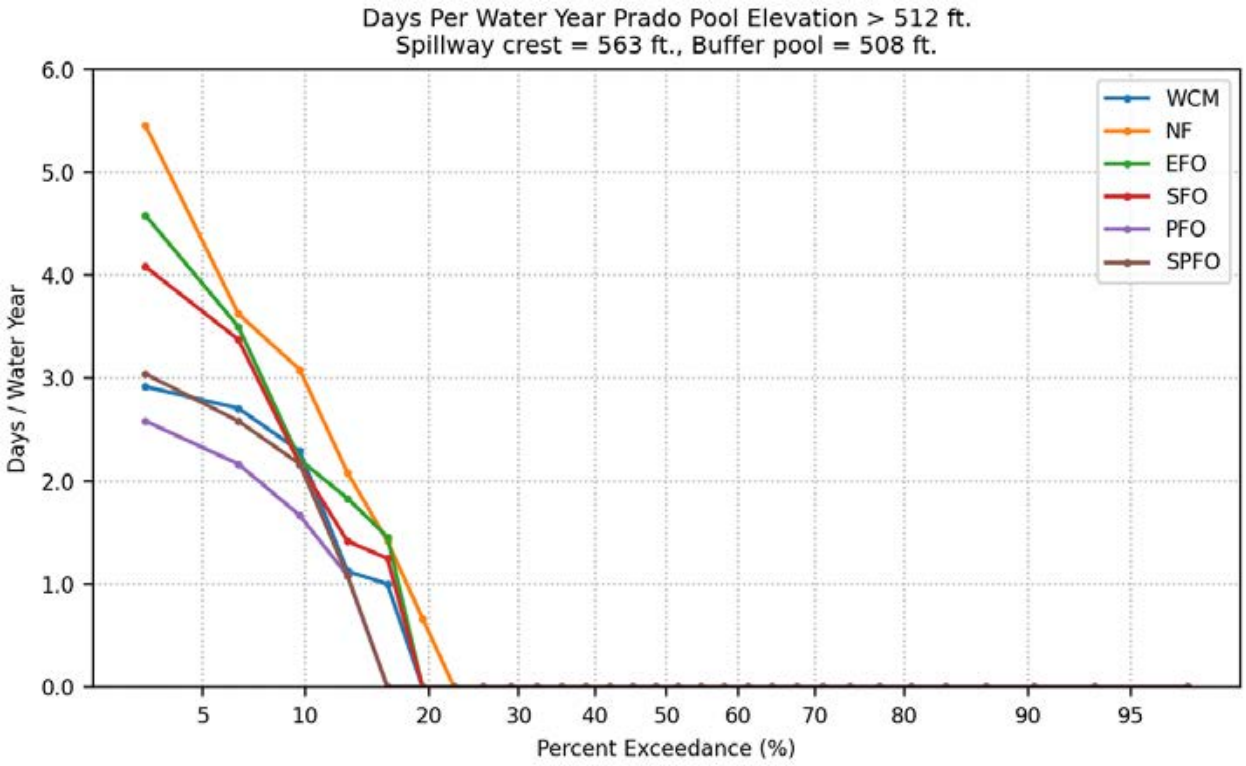

Santa Ana River Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 508 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

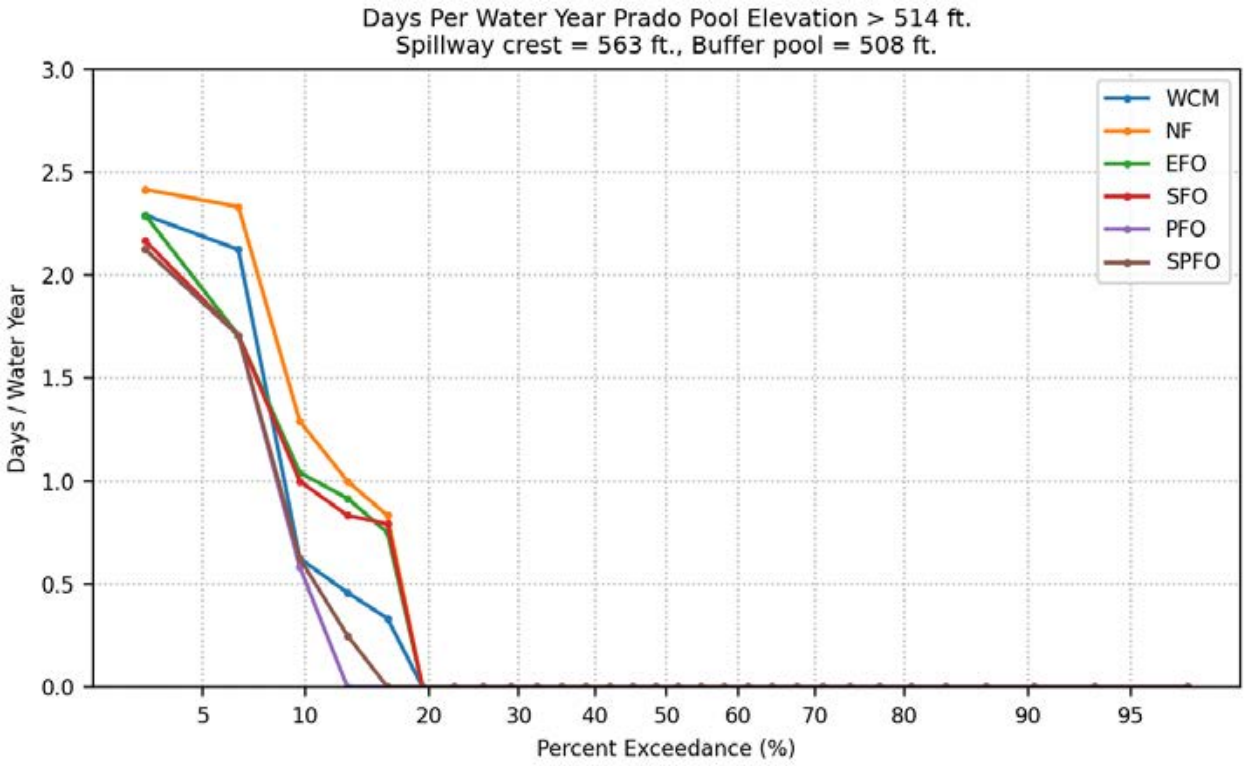

Days Per Water Year Elevation Change > 1-meter
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
35.0
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

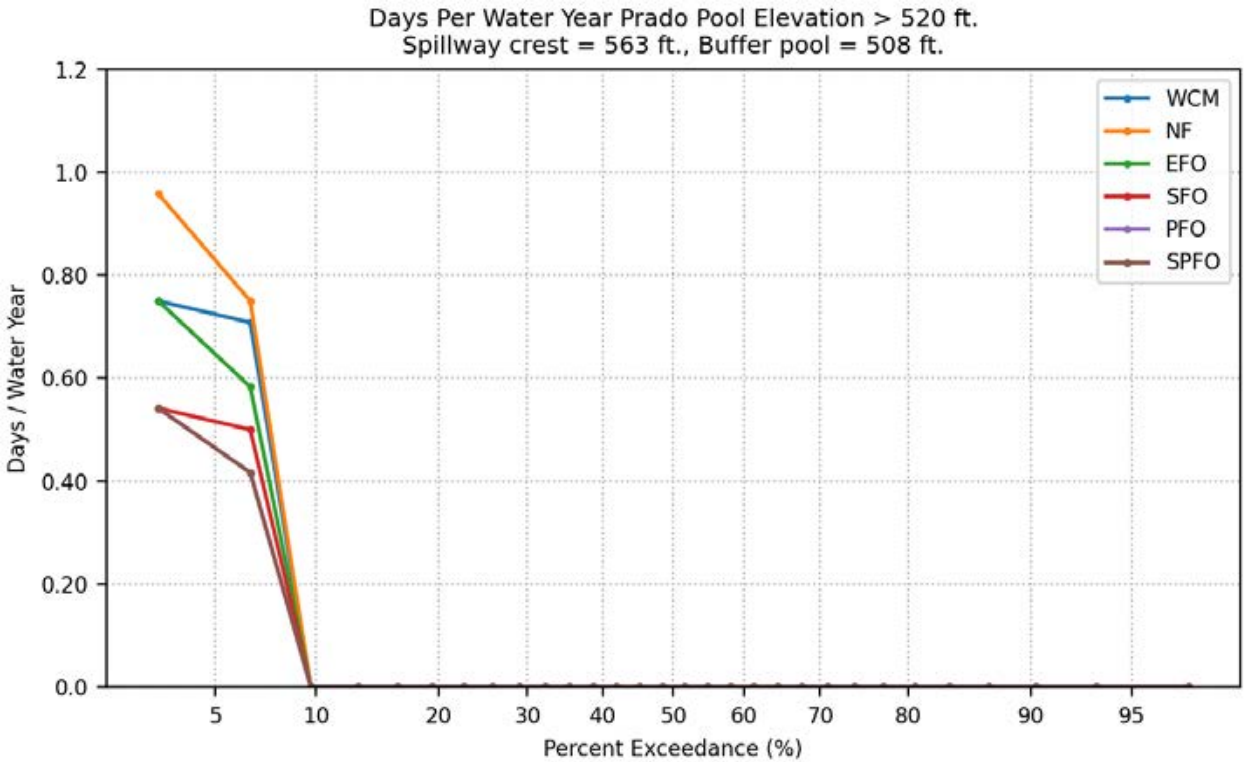

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

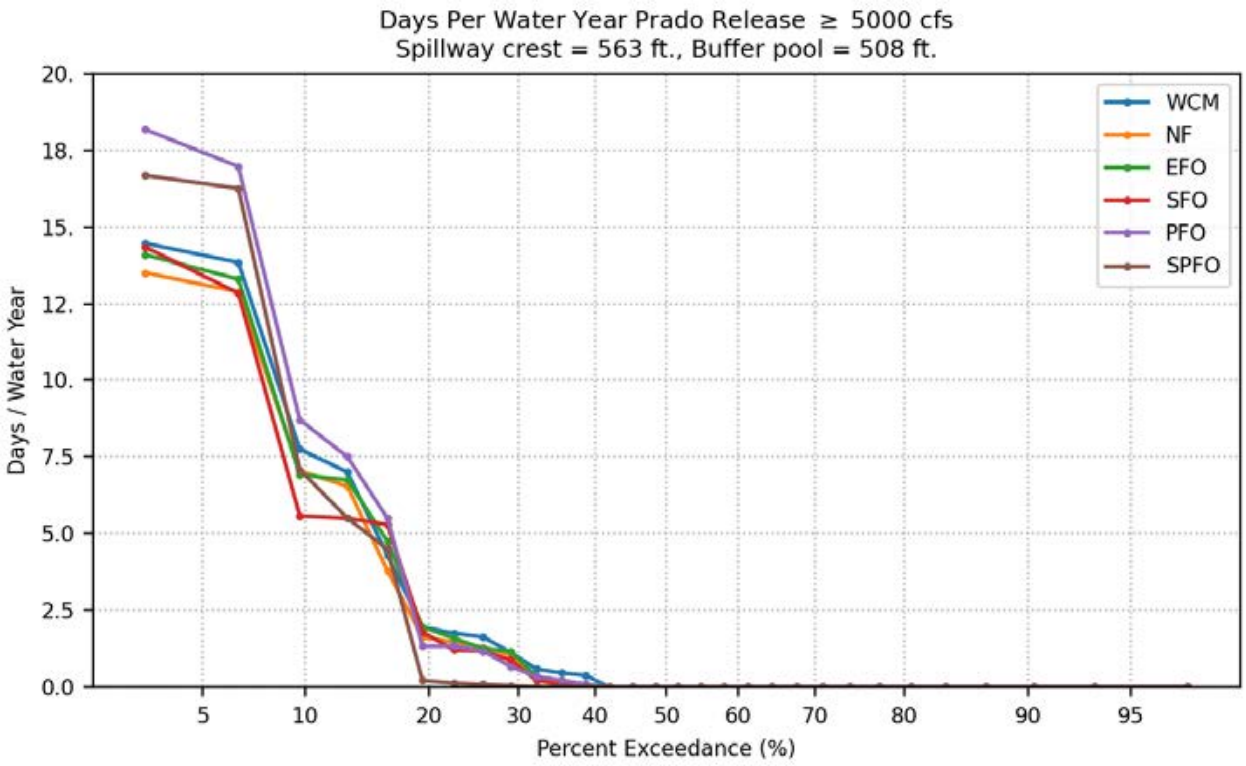

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

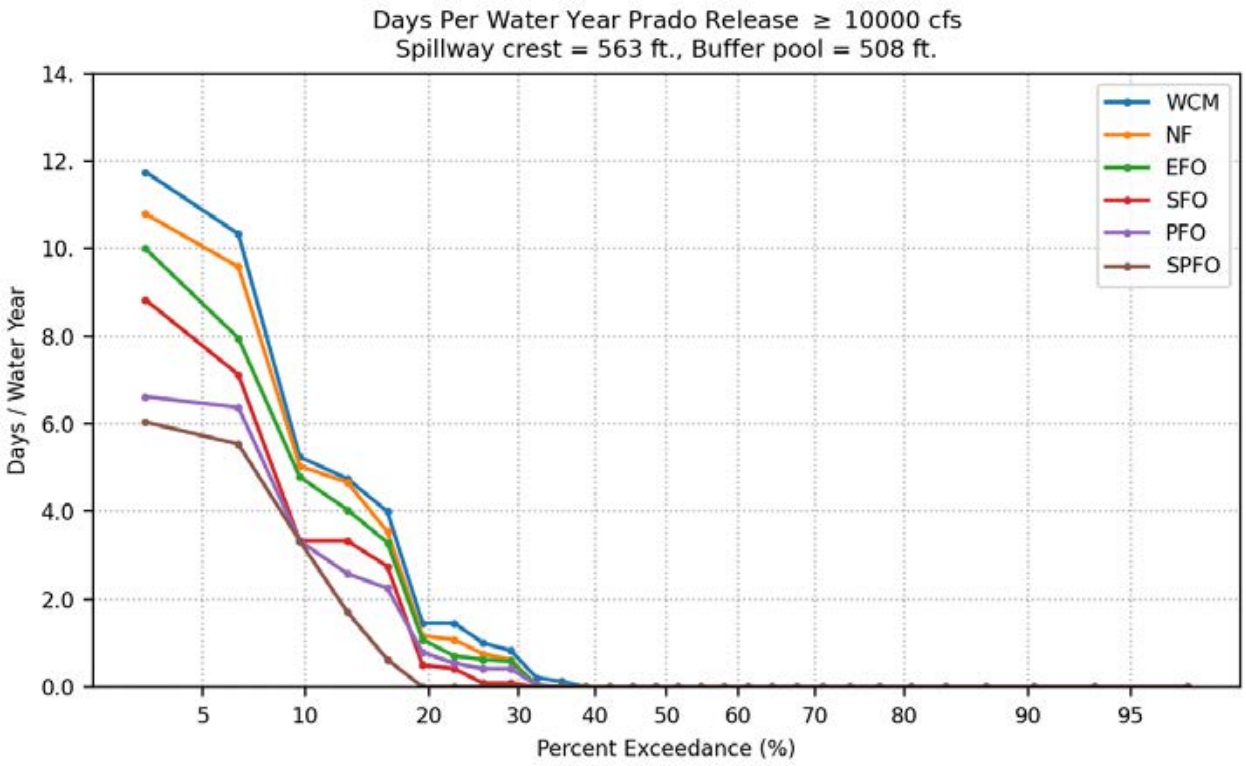

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

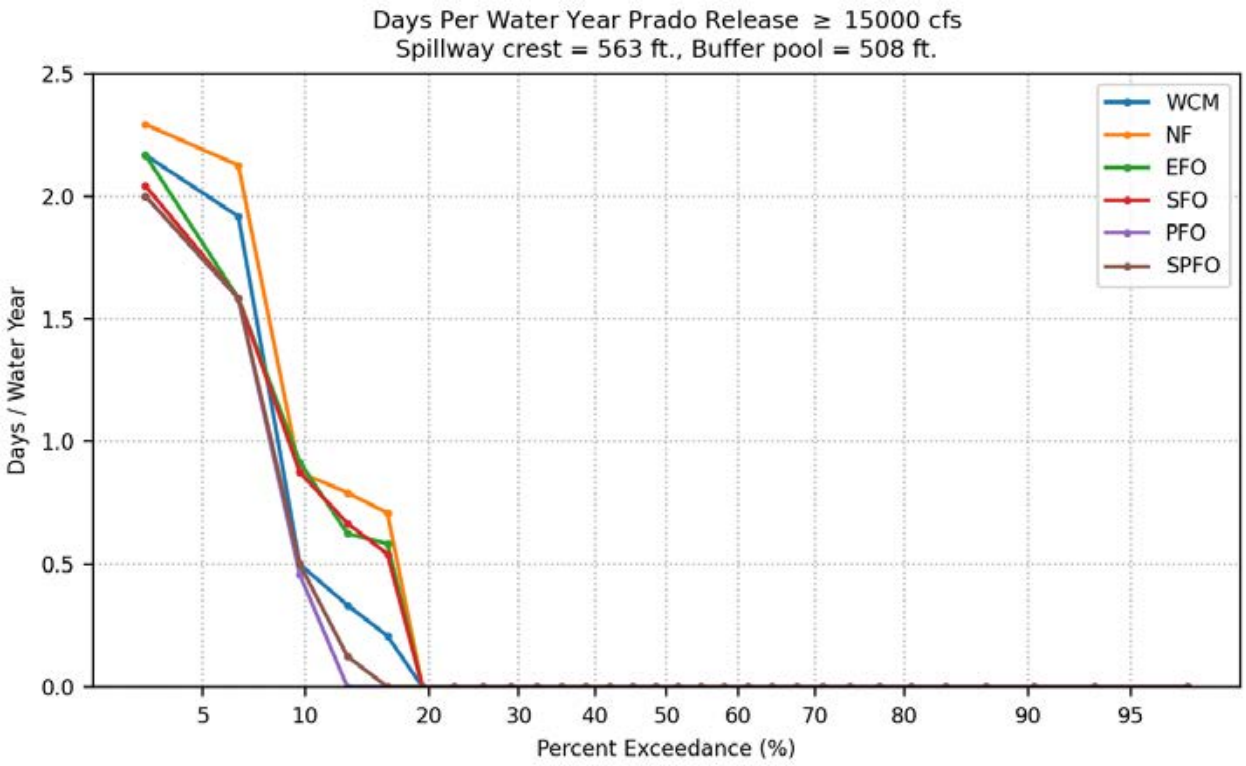

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

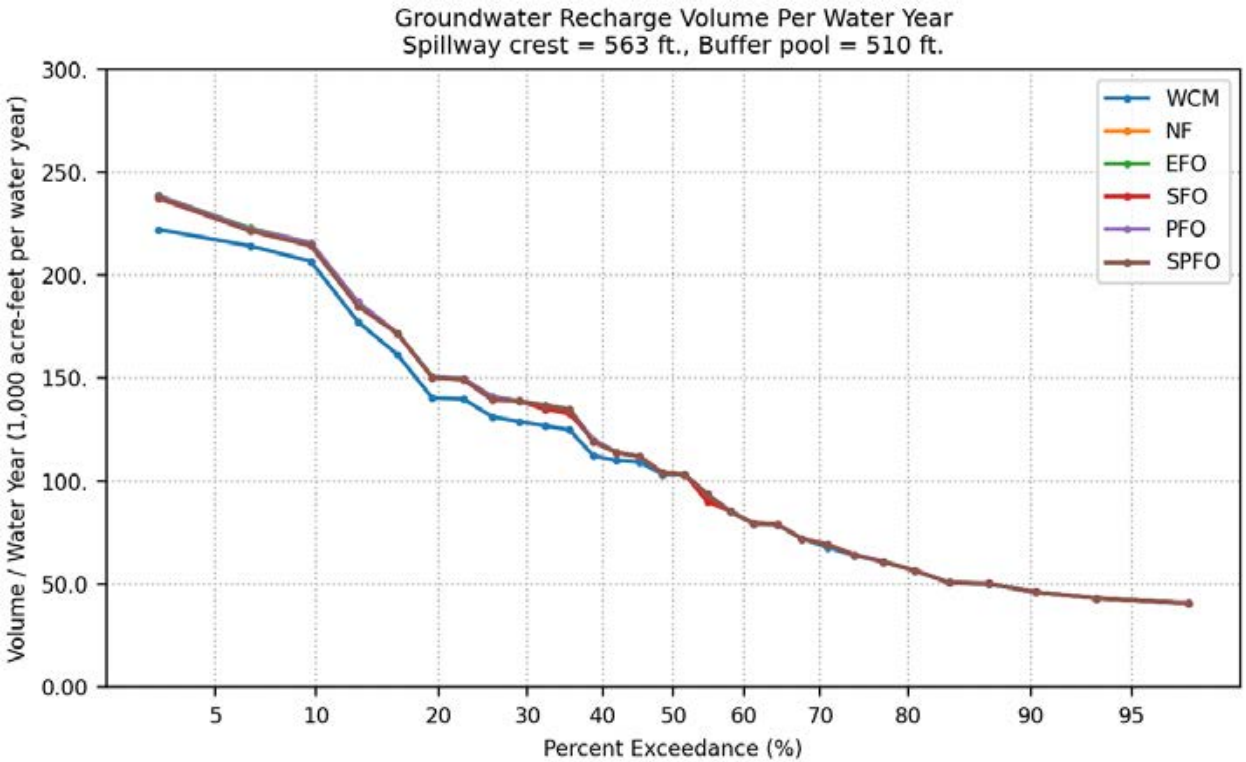

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

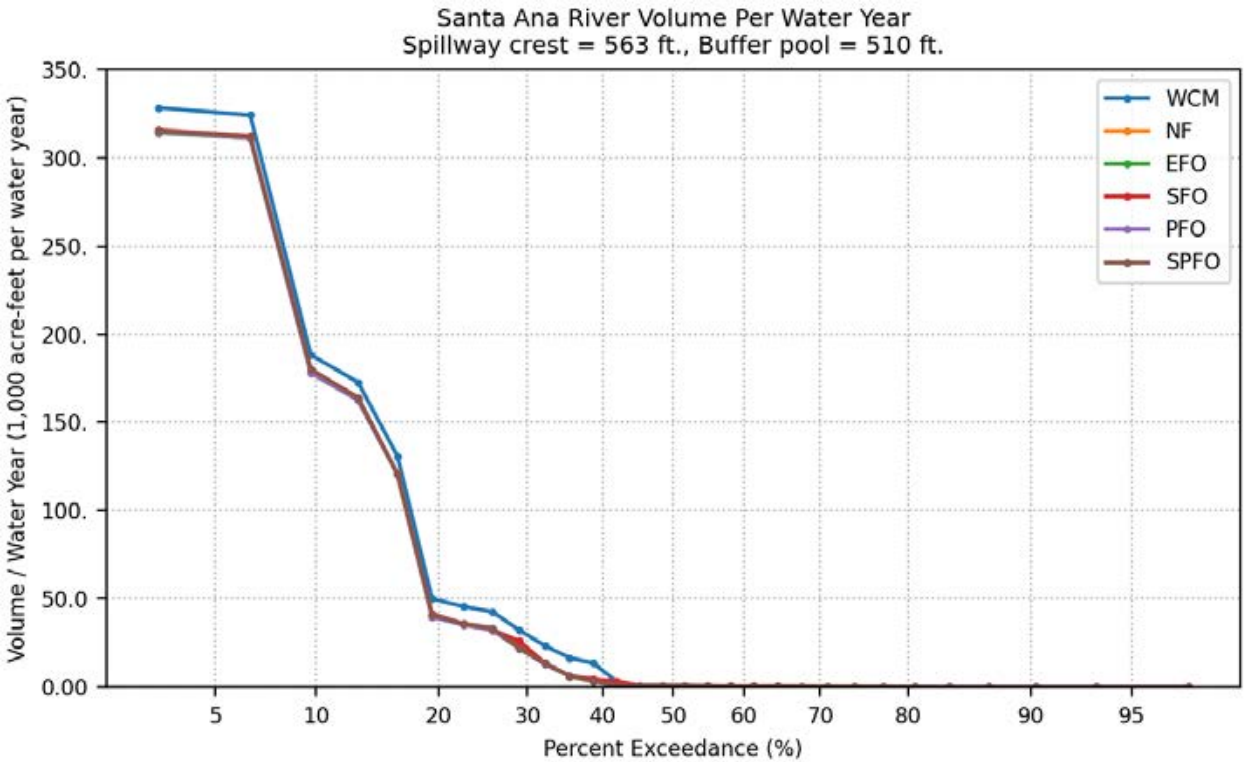

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
1.2
1.0
0.80
0.60
0.40
0.20
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

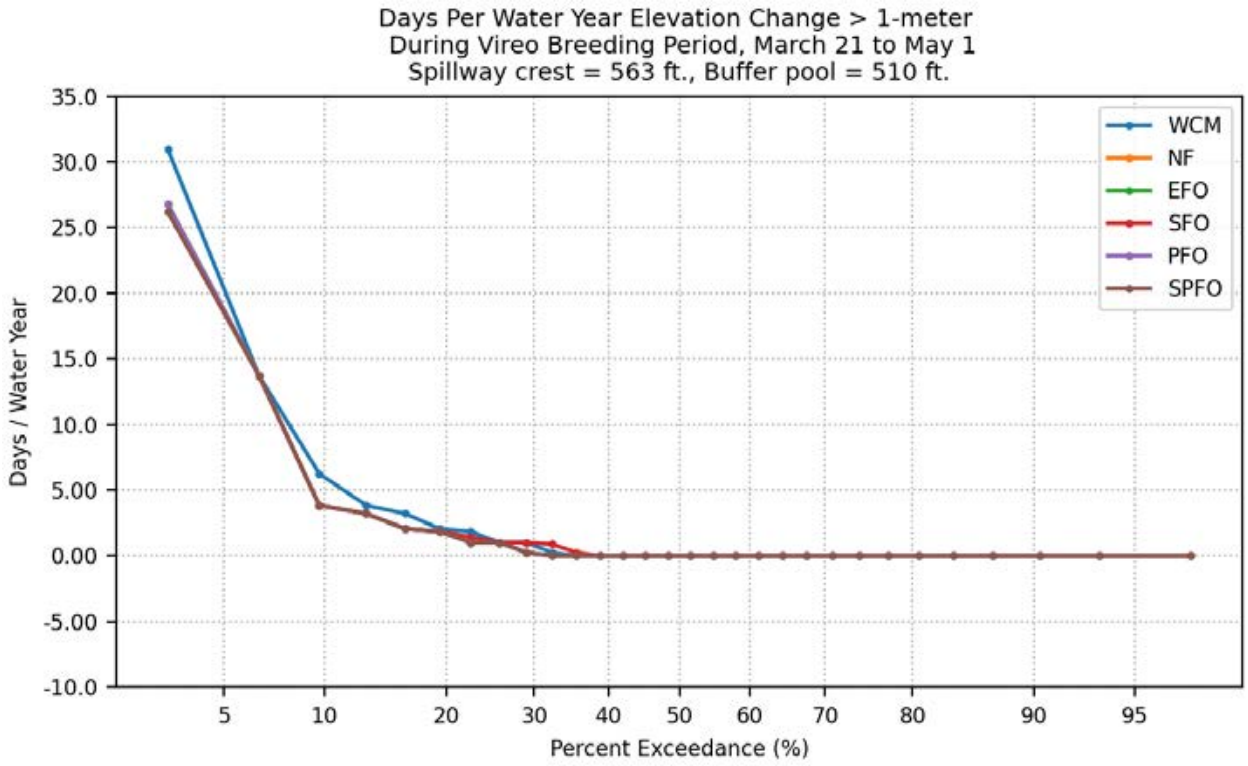

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
20.
18.
15.
12.
10.
7.5
5.0
2.5
0.0
5
10
20
30
40
50
60
70
80
90
95

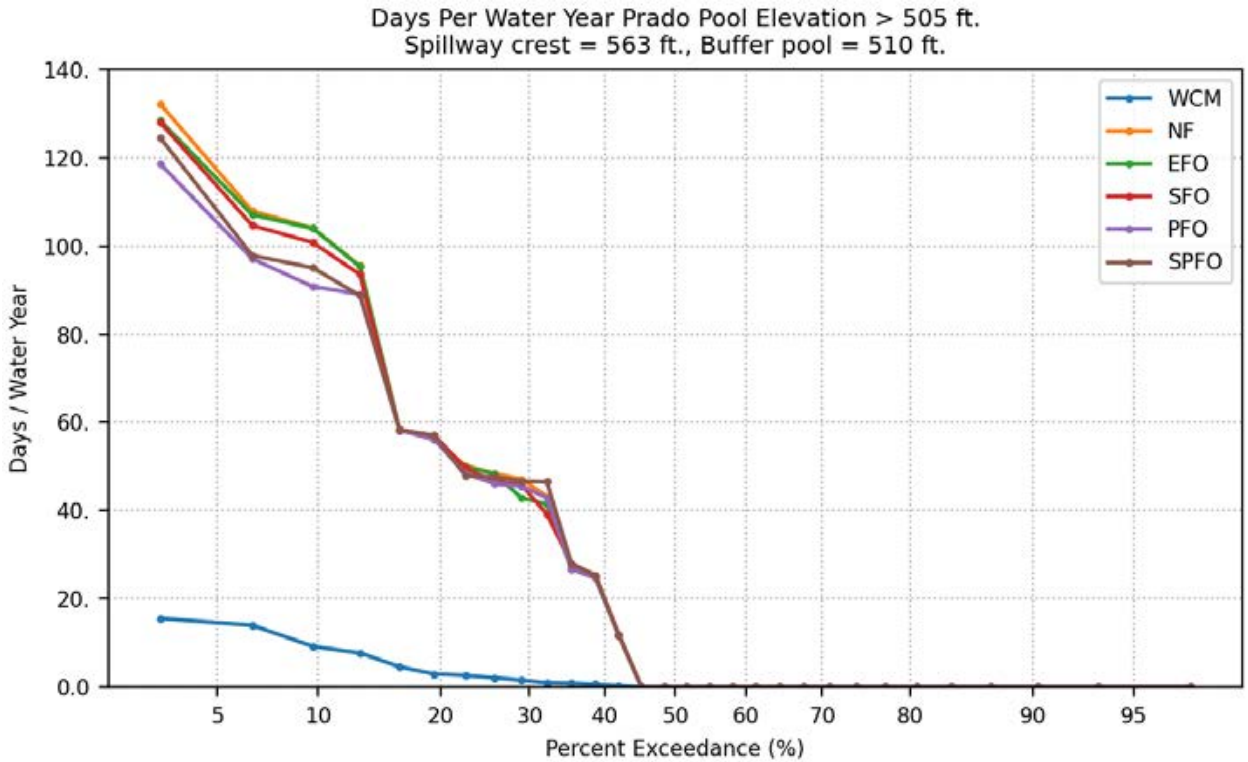

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

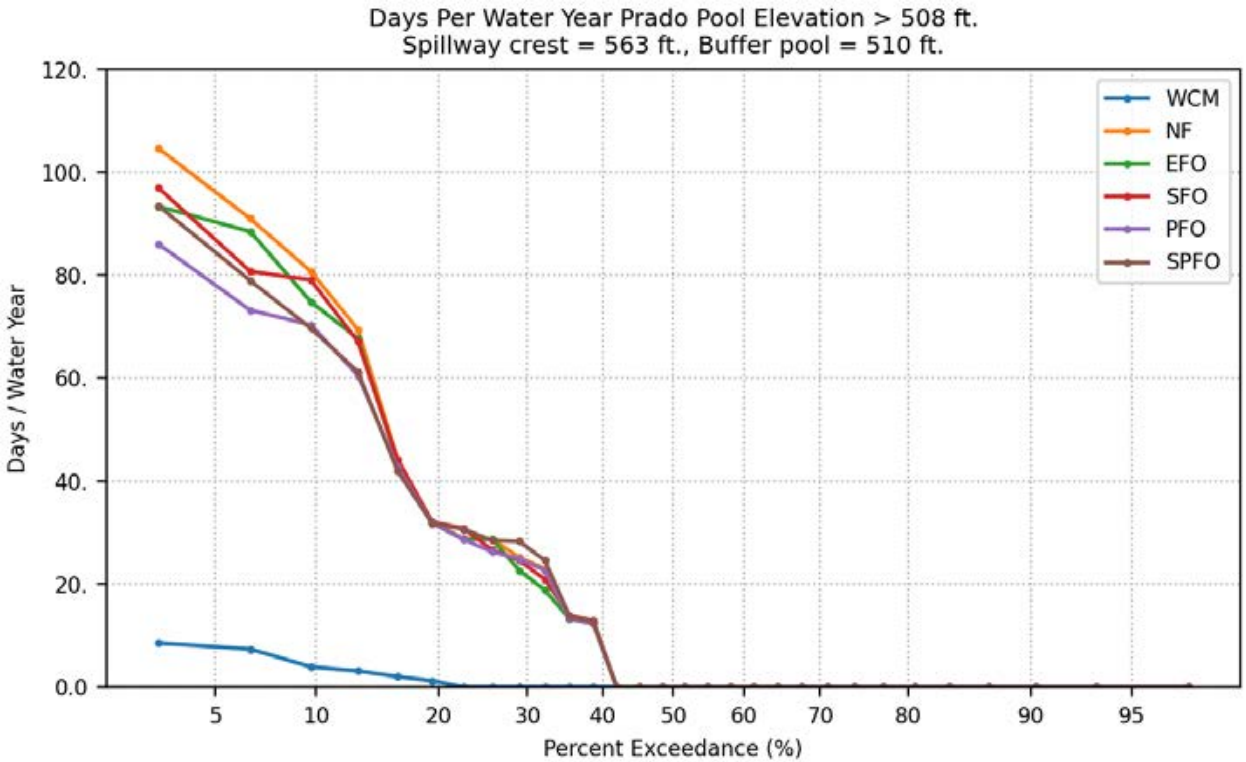

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
0.0
0.5
1.0
1.5
2.0
2.5
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

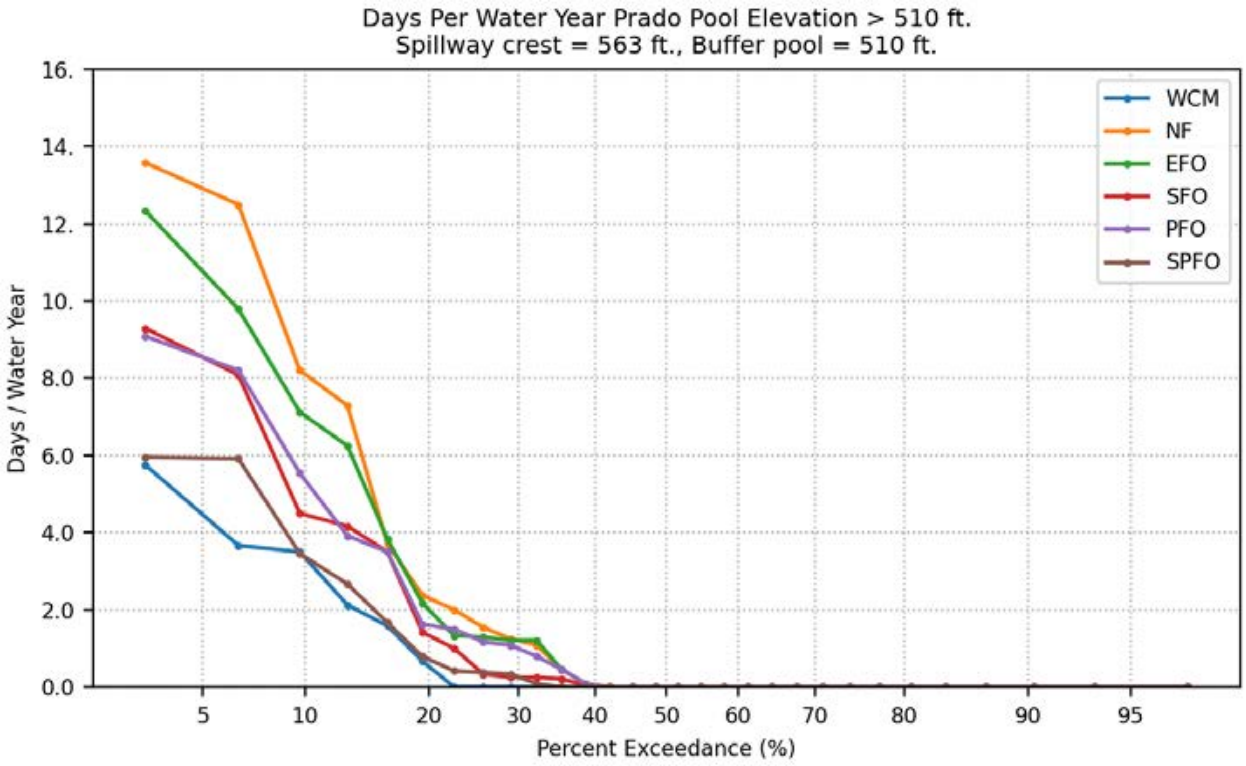

Groundwater Recharge Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 510 ft.
Volume / Water Year (1,000 acre-feet per water year)
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

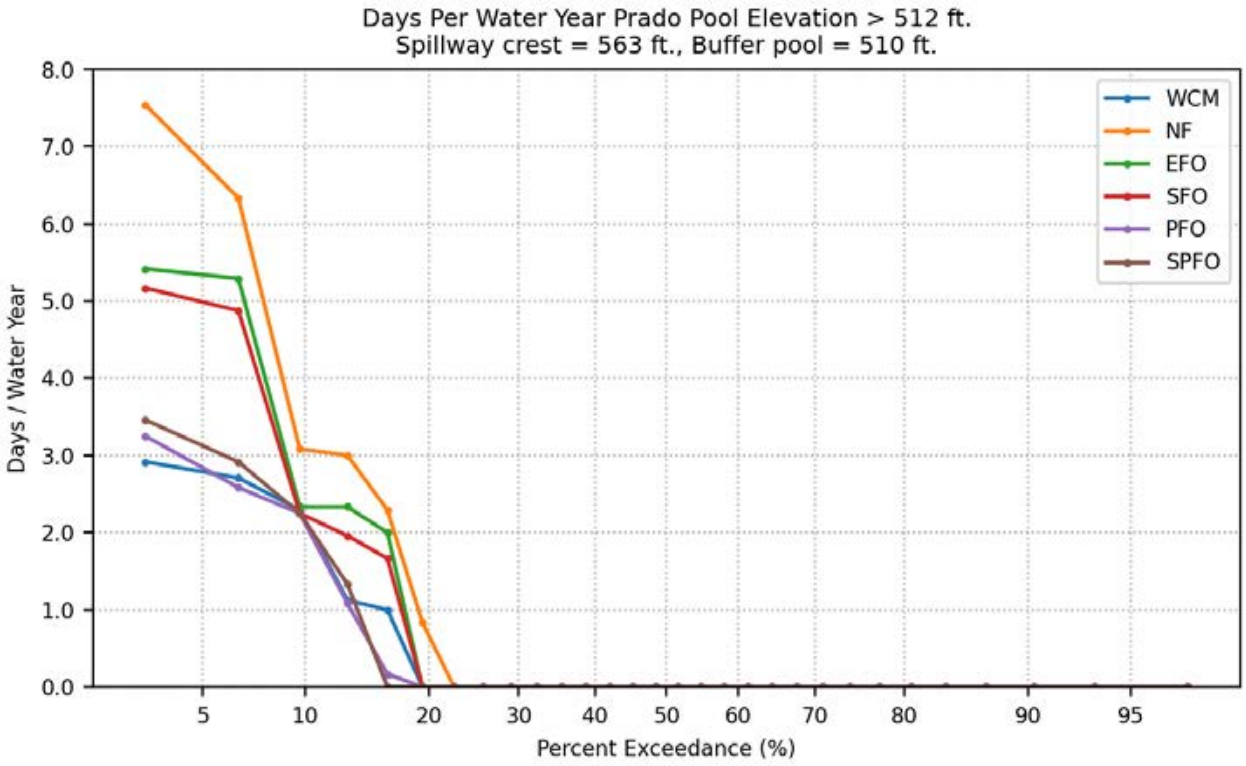

Santa Ana River Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 510 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

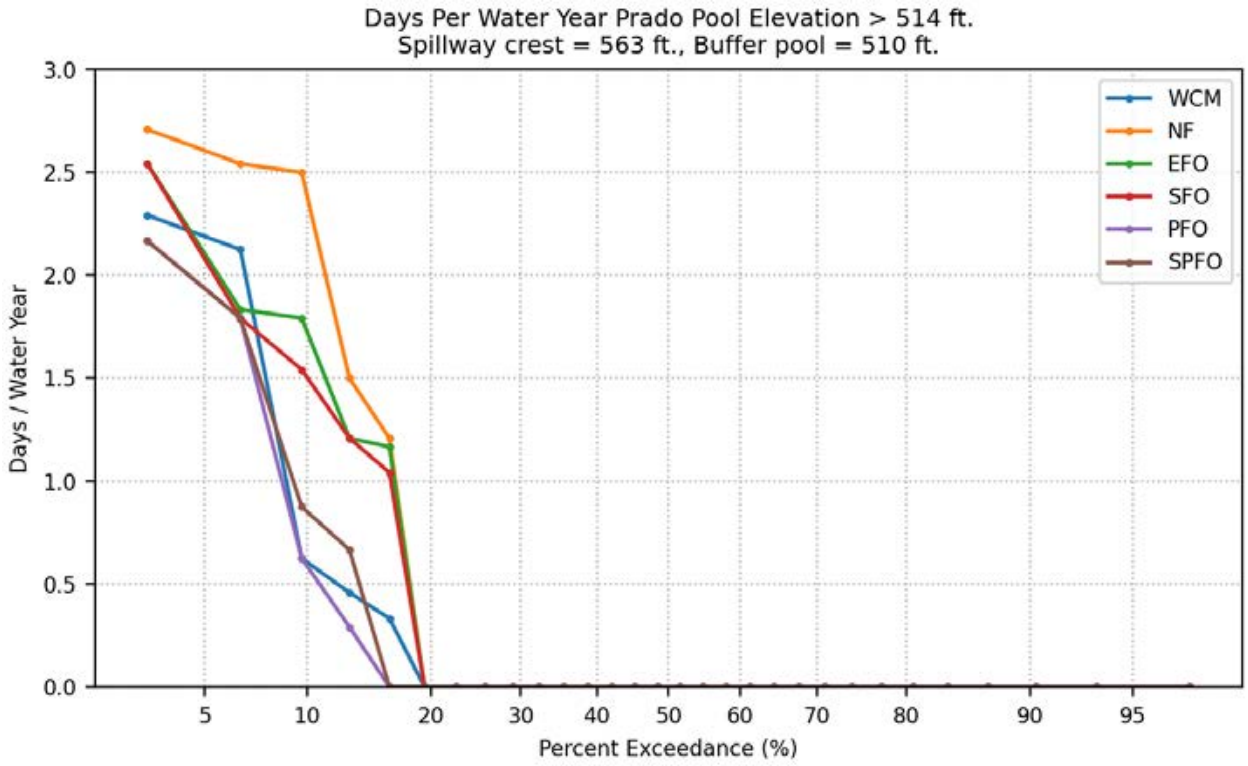

Days Per Water Year Elevation Change > 1-meter
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
35.0
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

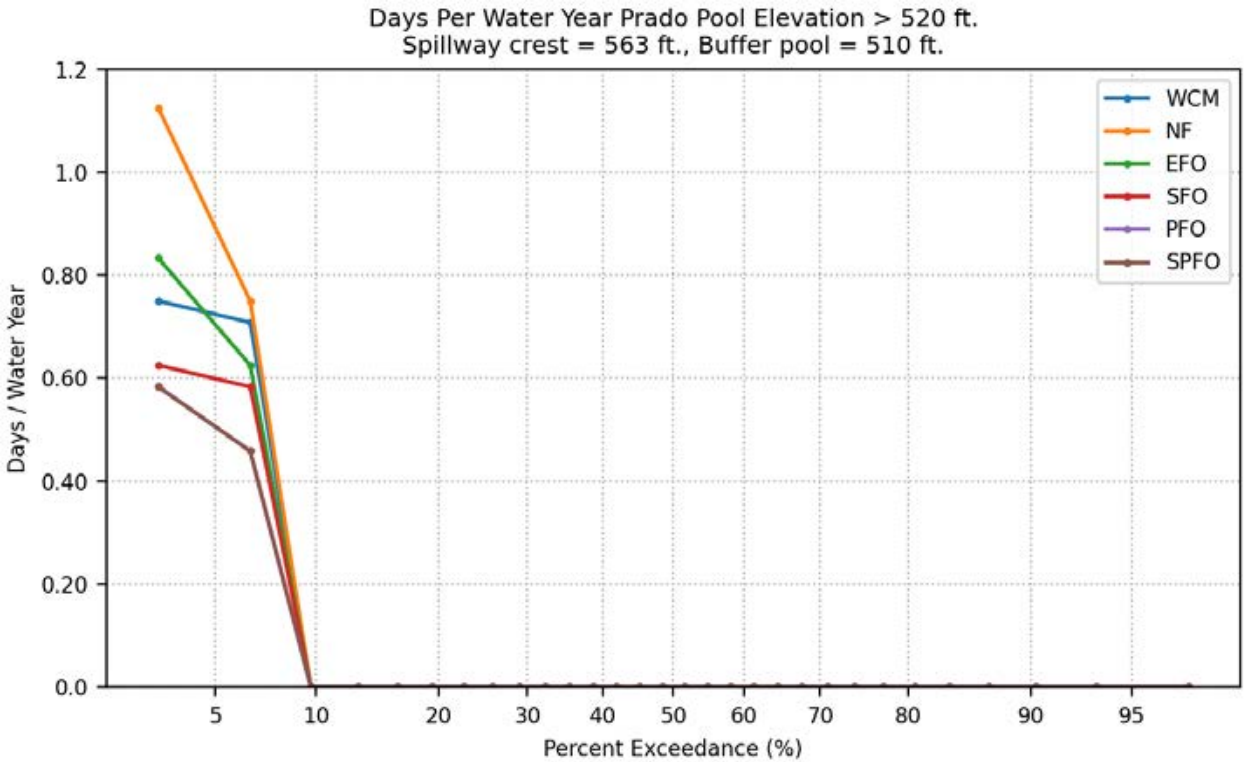

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

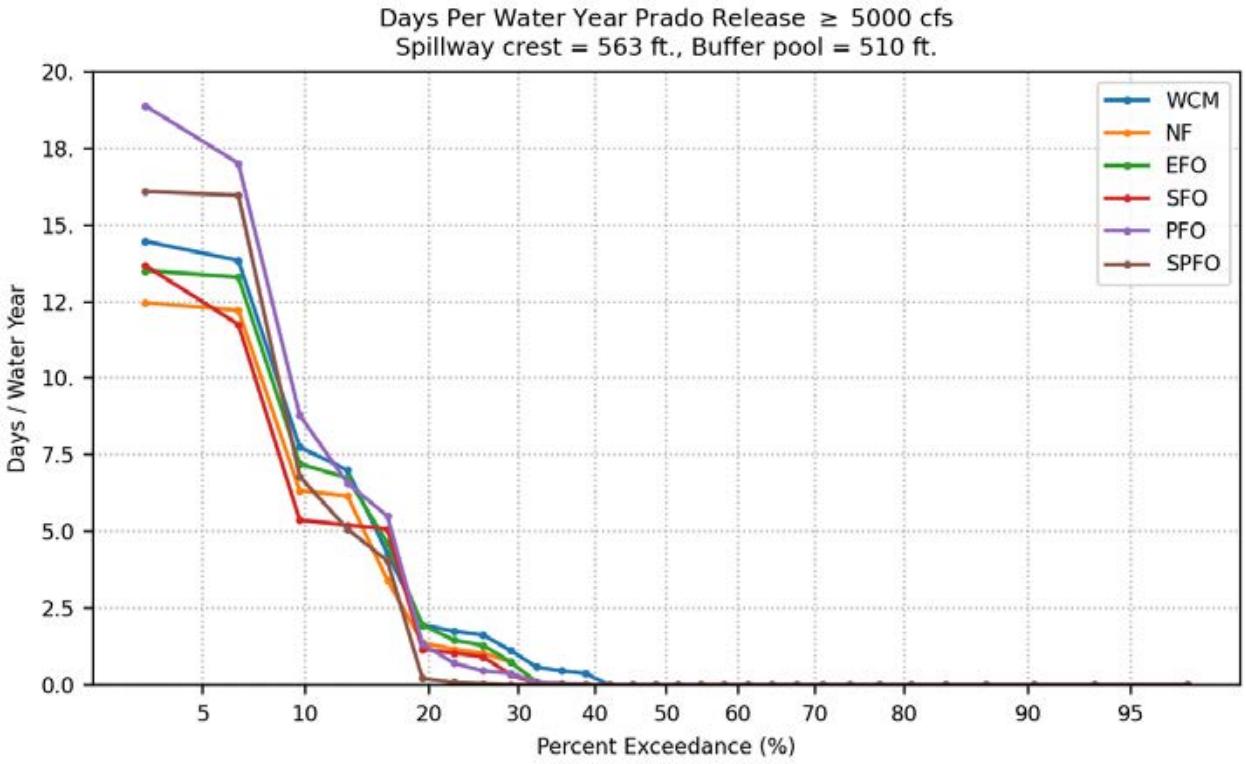

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

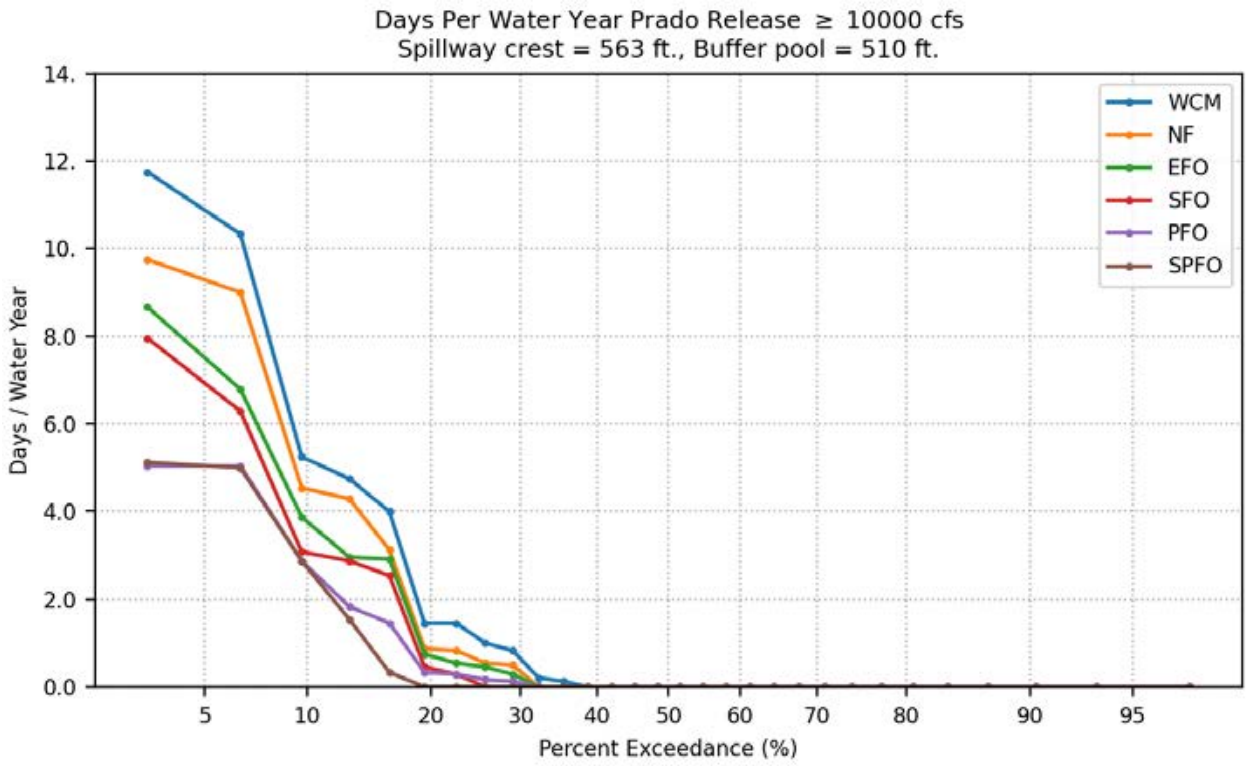

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

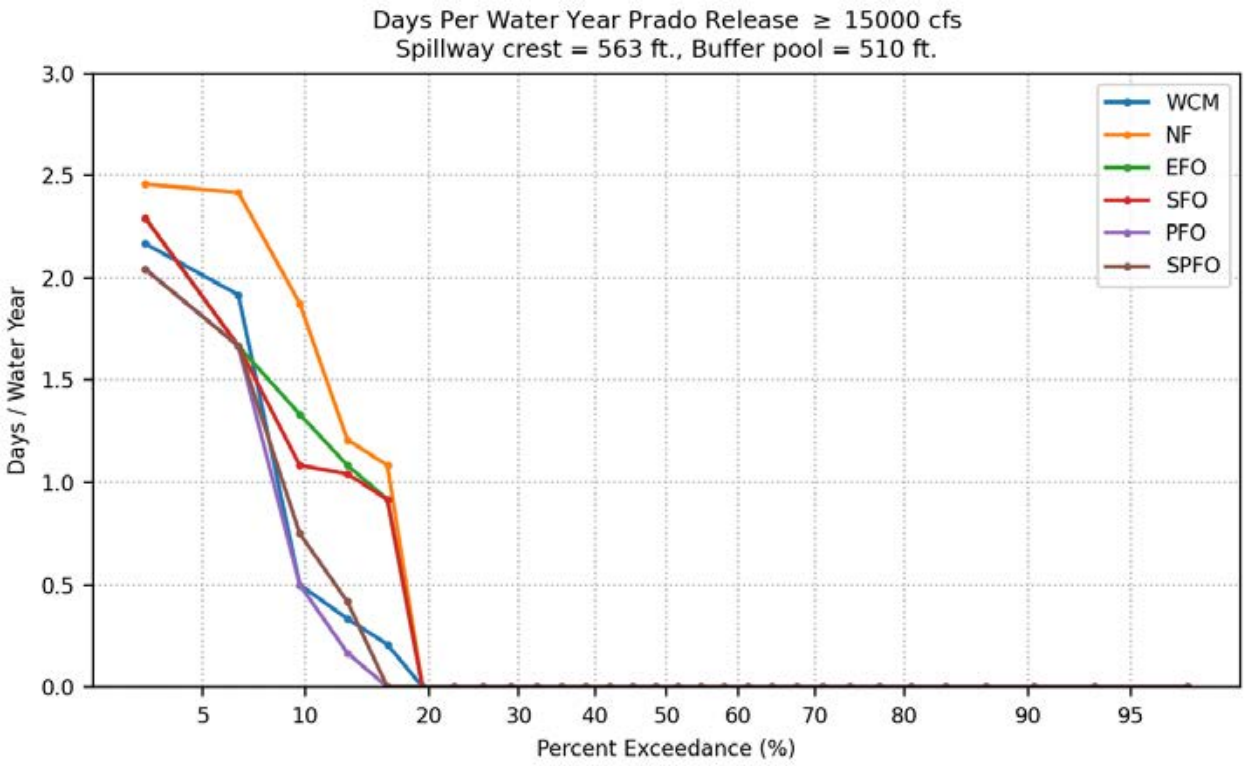

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
5
10
20
30
40
50
60
70
80
90
95

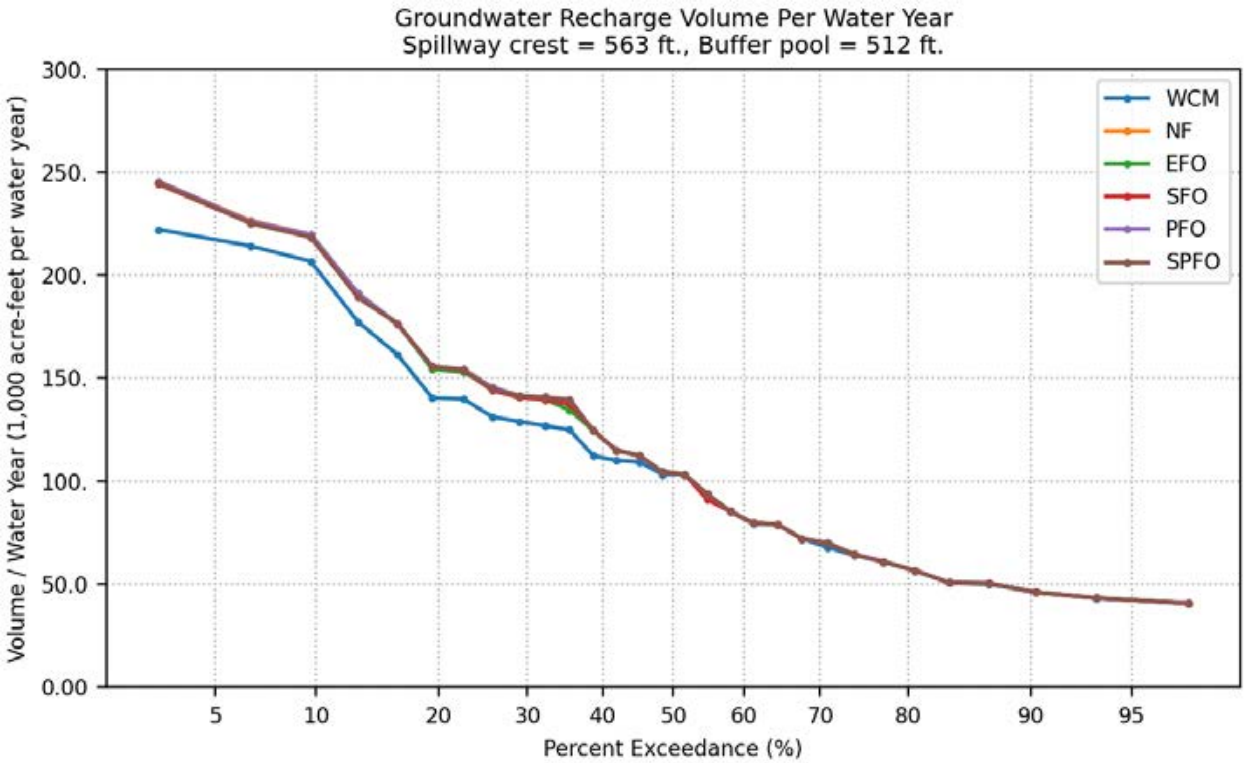

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

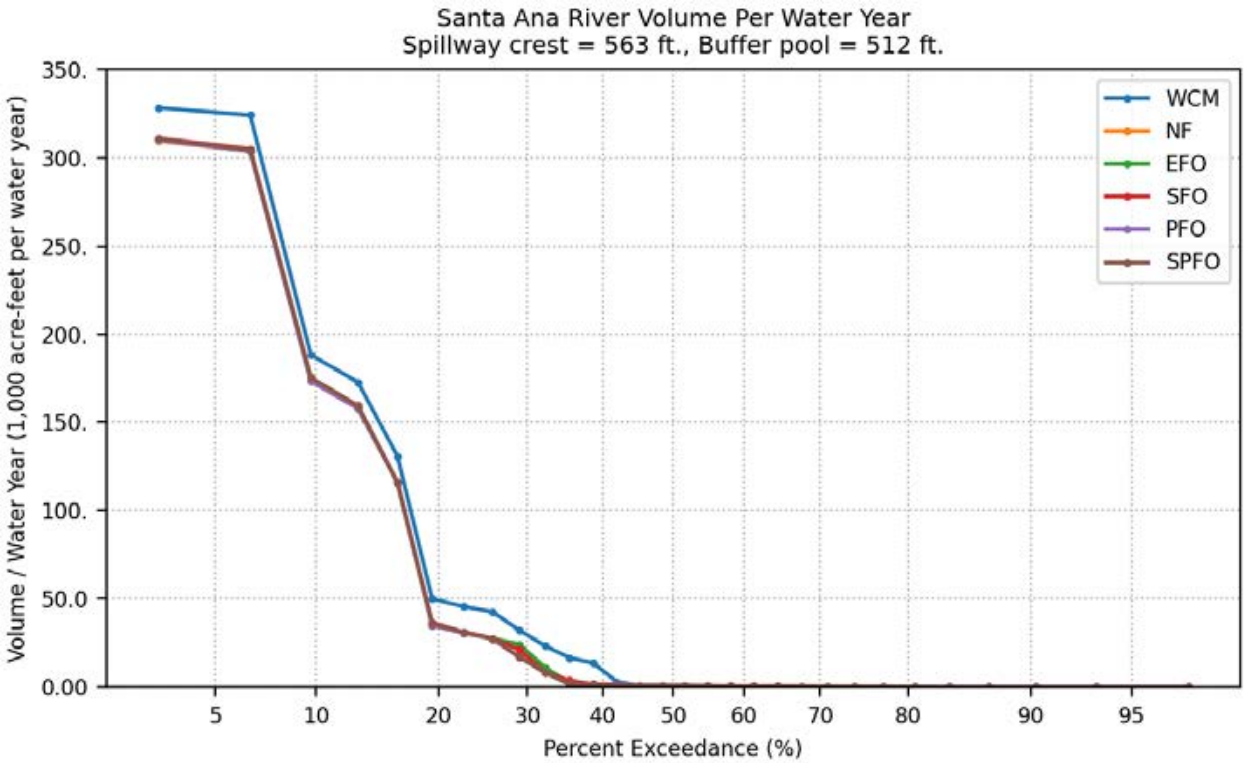

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
1.2
1.0
0.80
0.60
0.40
0.20
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

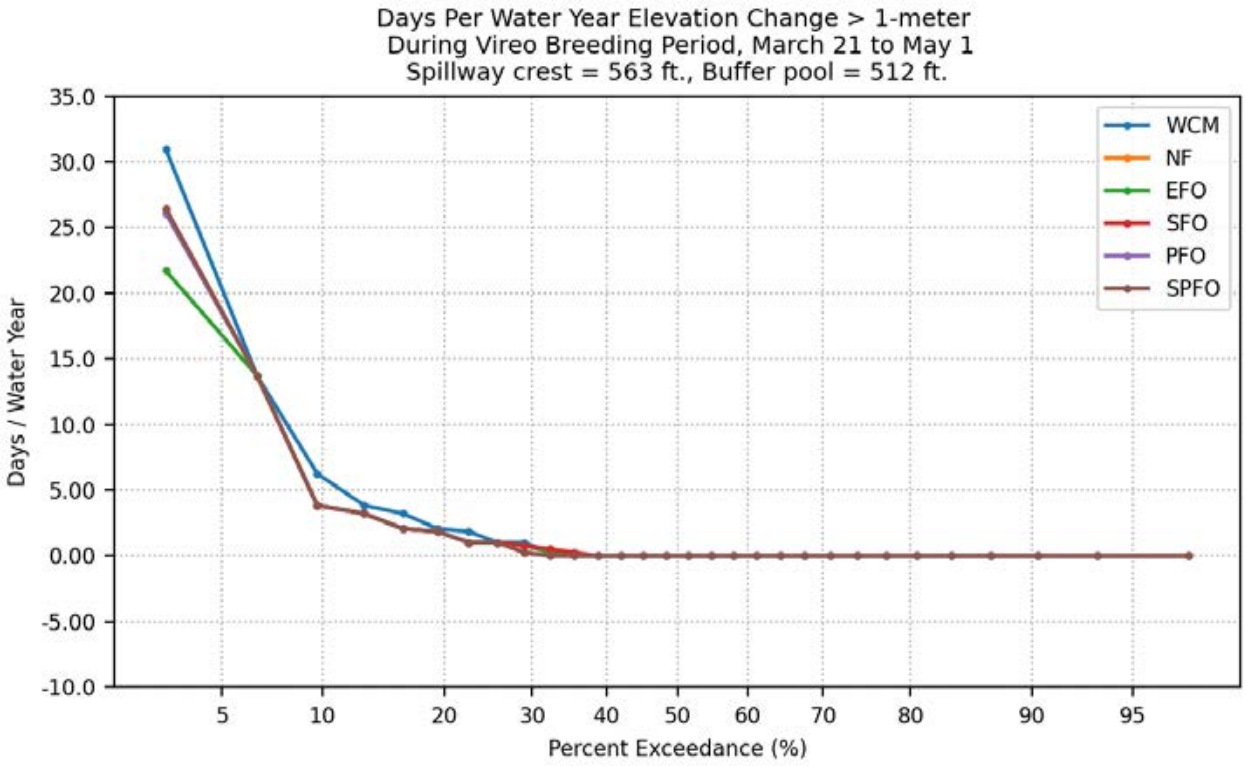

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
20.
18.
15.
12.
10.
7.5
5.0
2.5
0.0
5
10
20
30
40
50
60
70
80
90
95

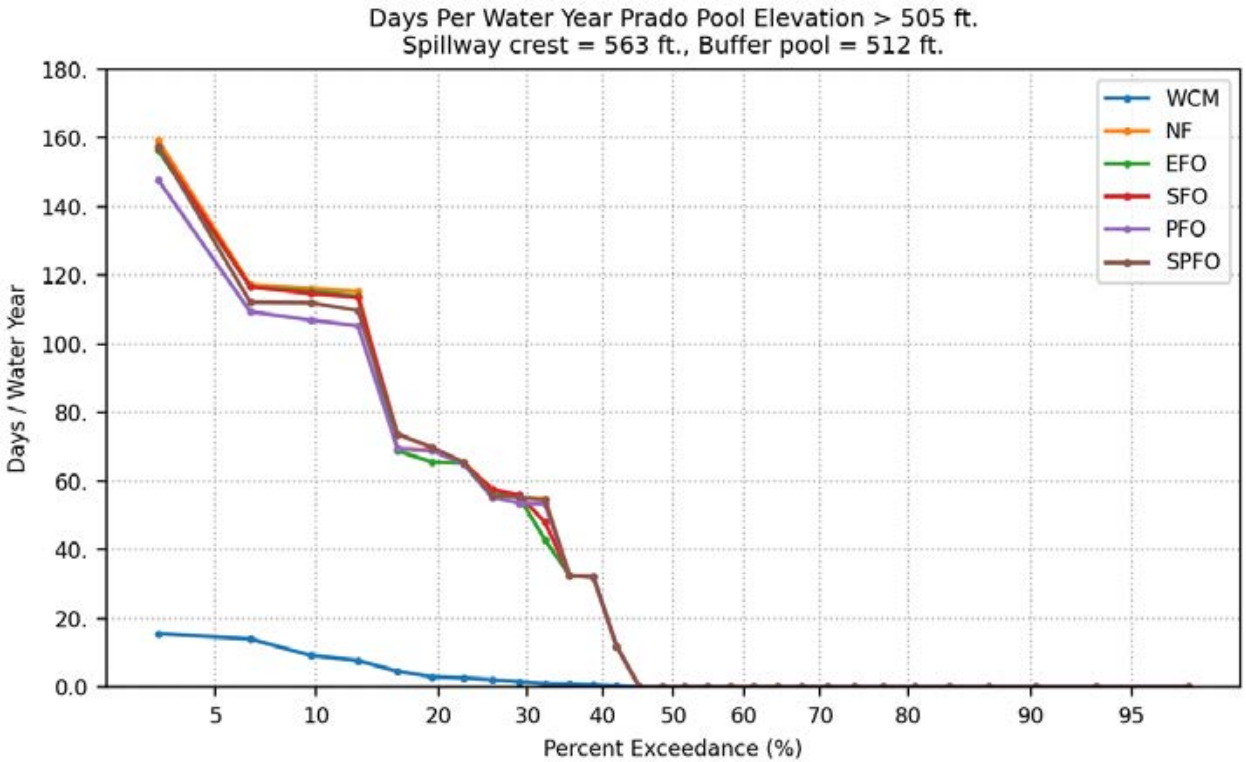

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

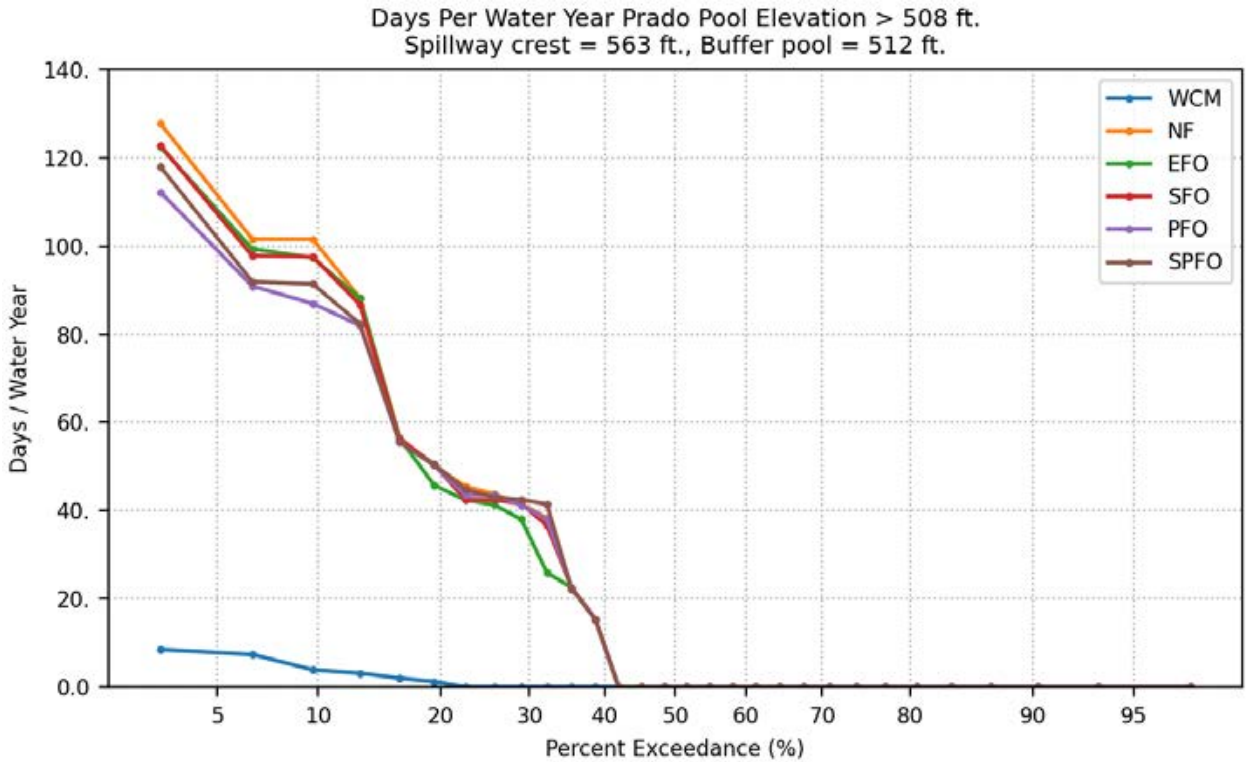

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

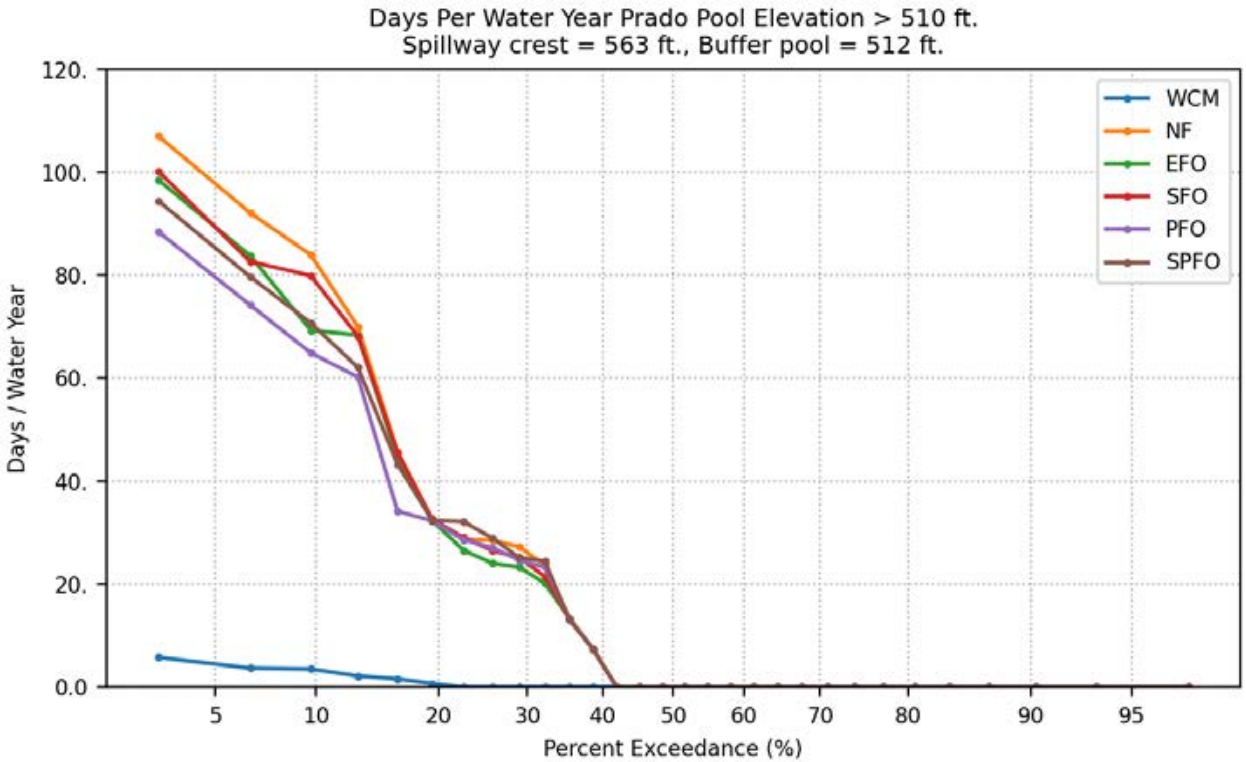

Groundwater Recharge Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 512 ft.
Volume / Water Year (1,000 acre-feet per water year)
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

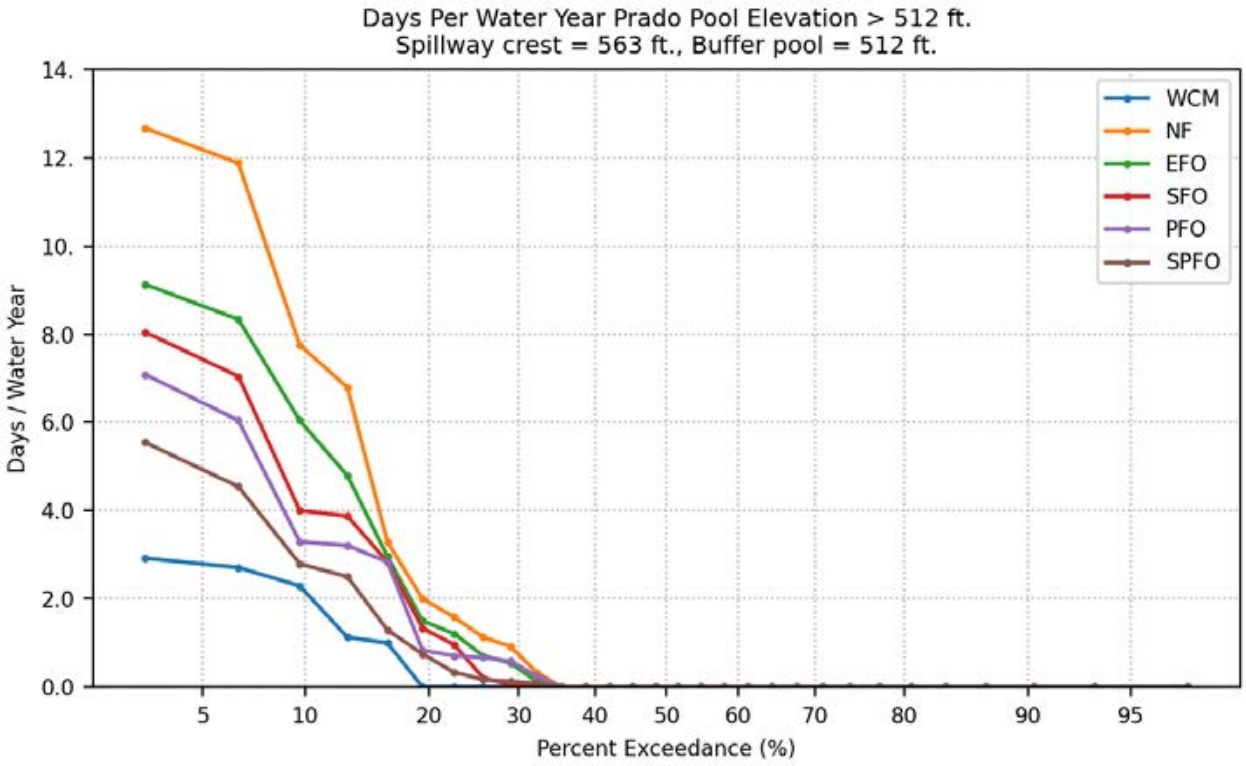

Santa Ana River Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 512 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

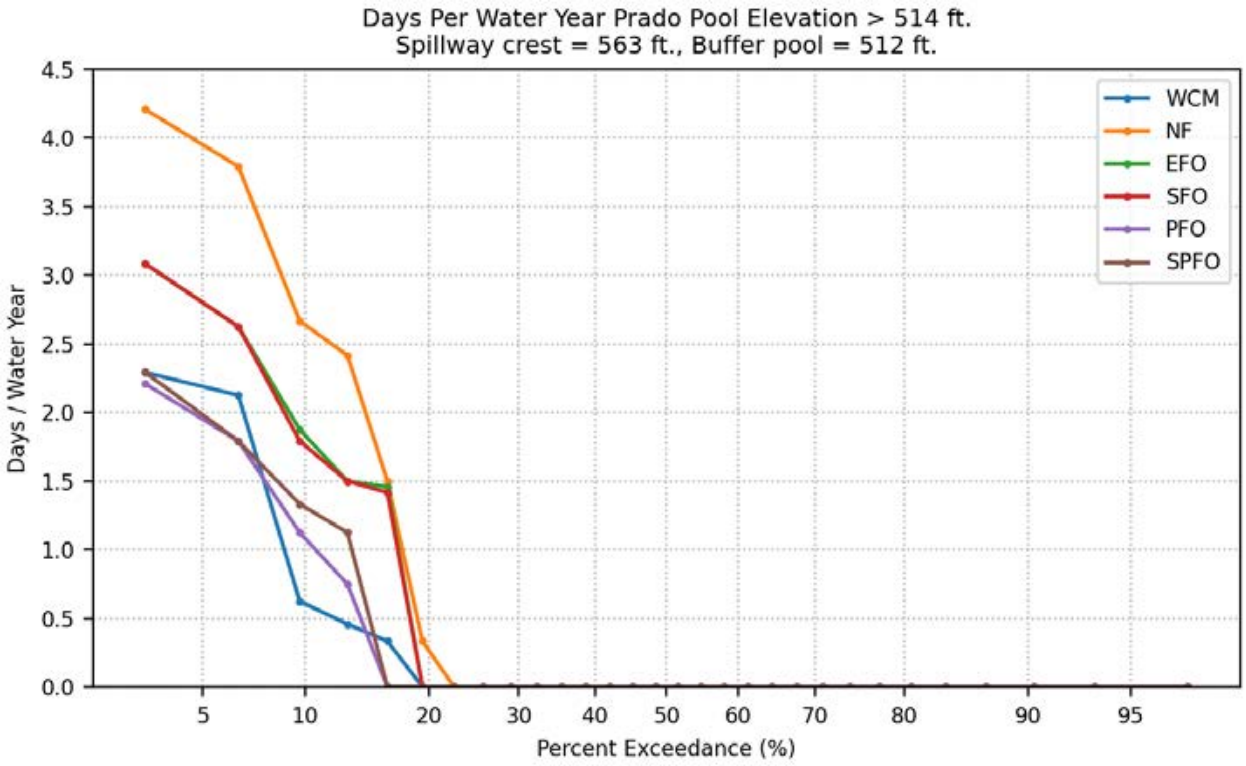

Days Per Water Year Elevation Change > 1-meter
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
35.0
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

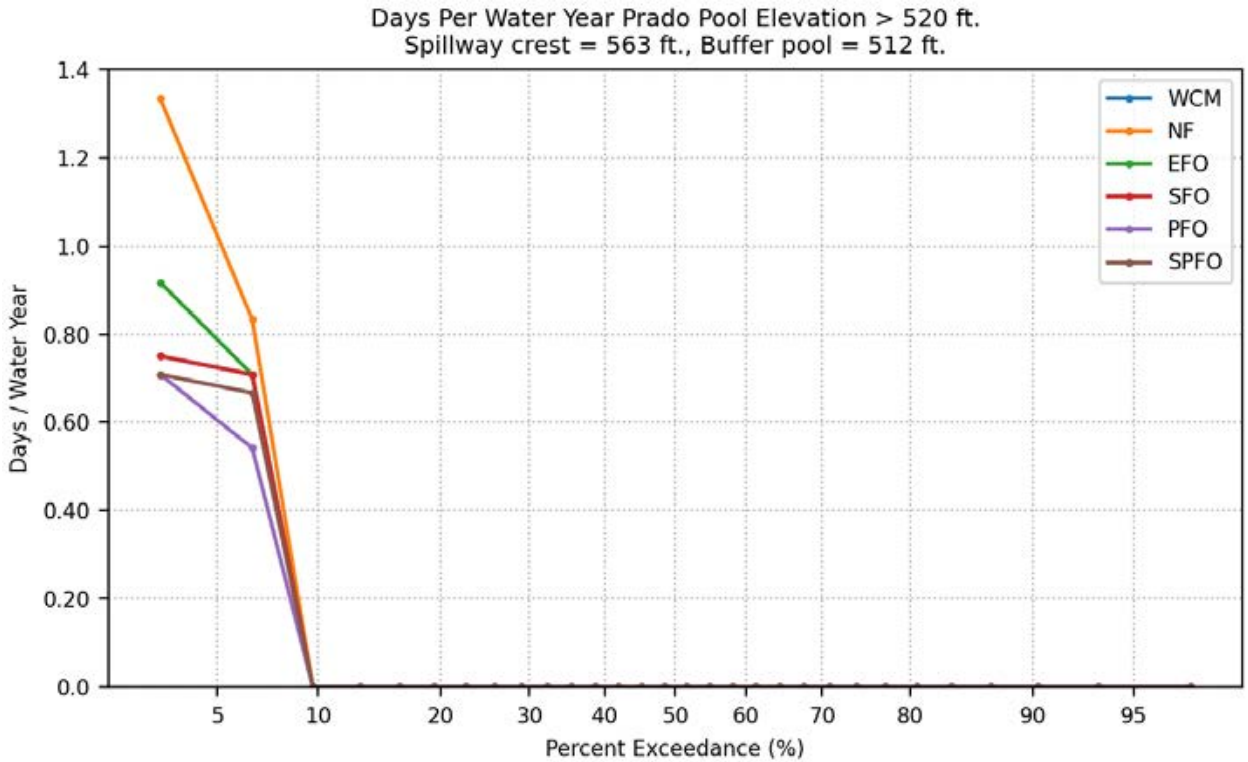

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
180.
160.
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

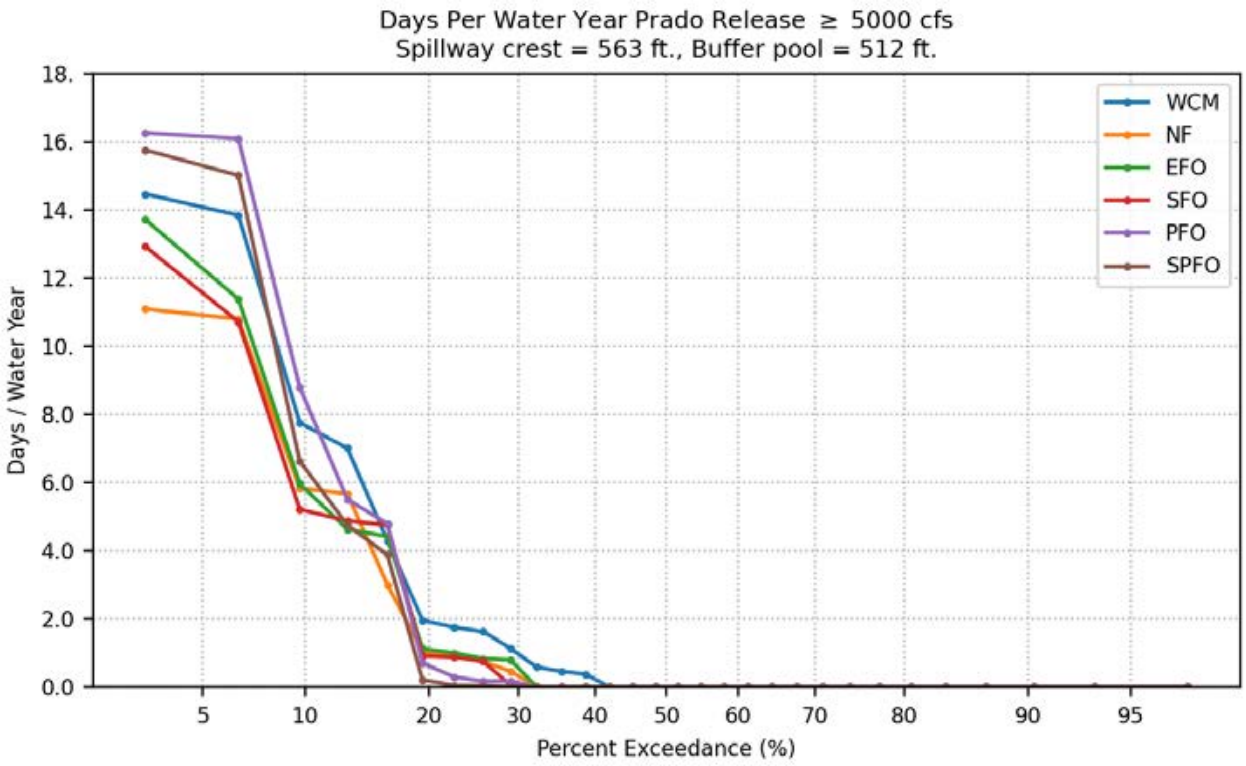

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

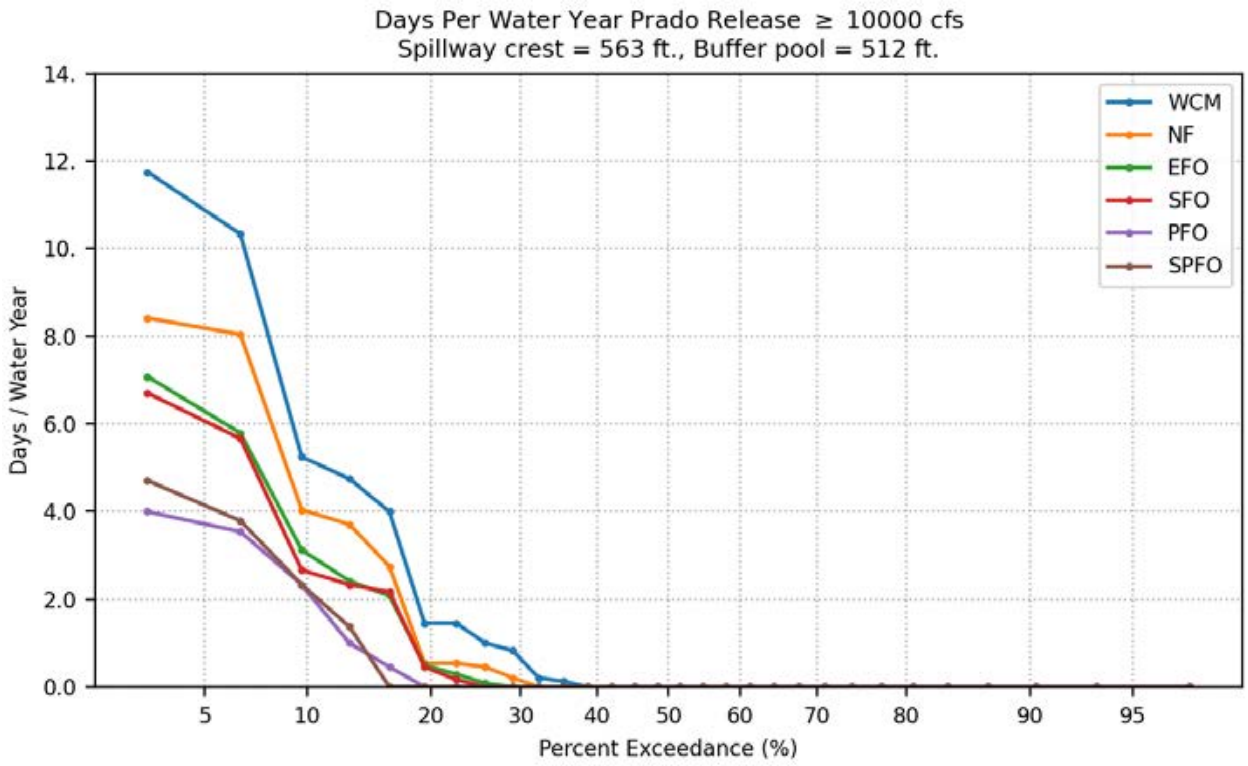

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

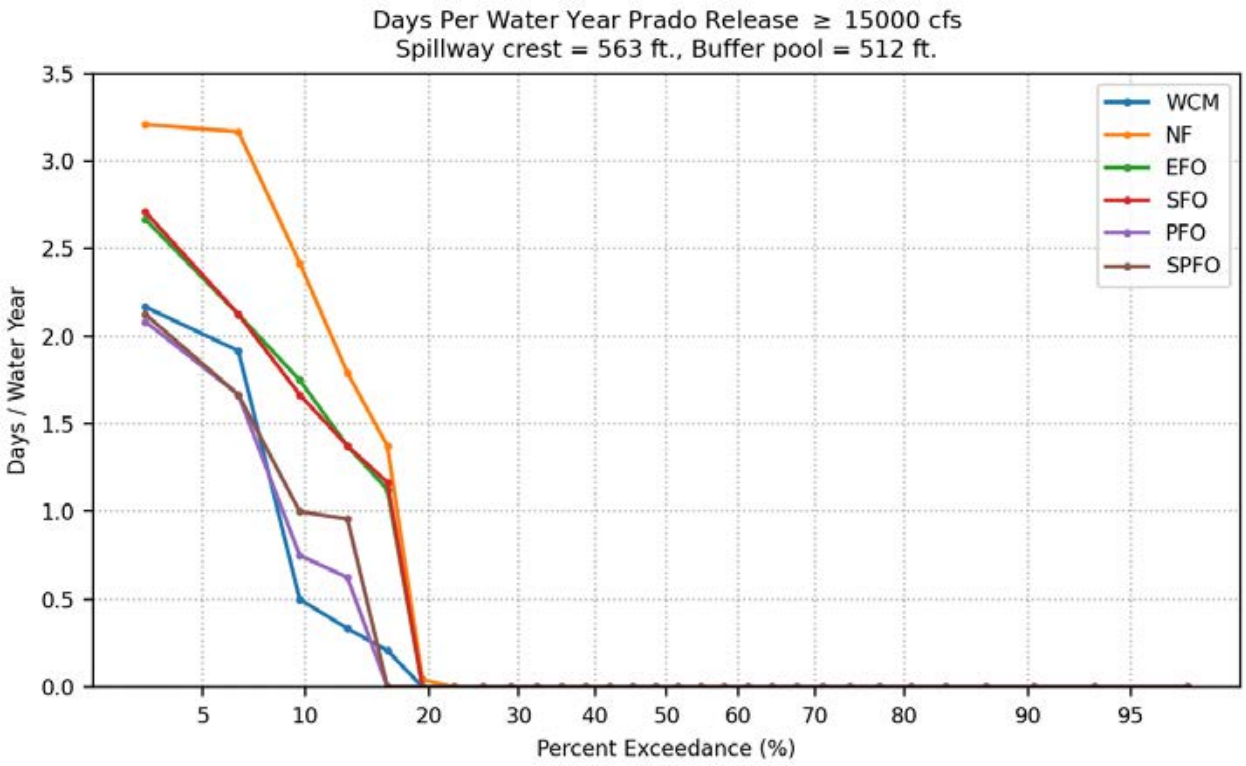

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

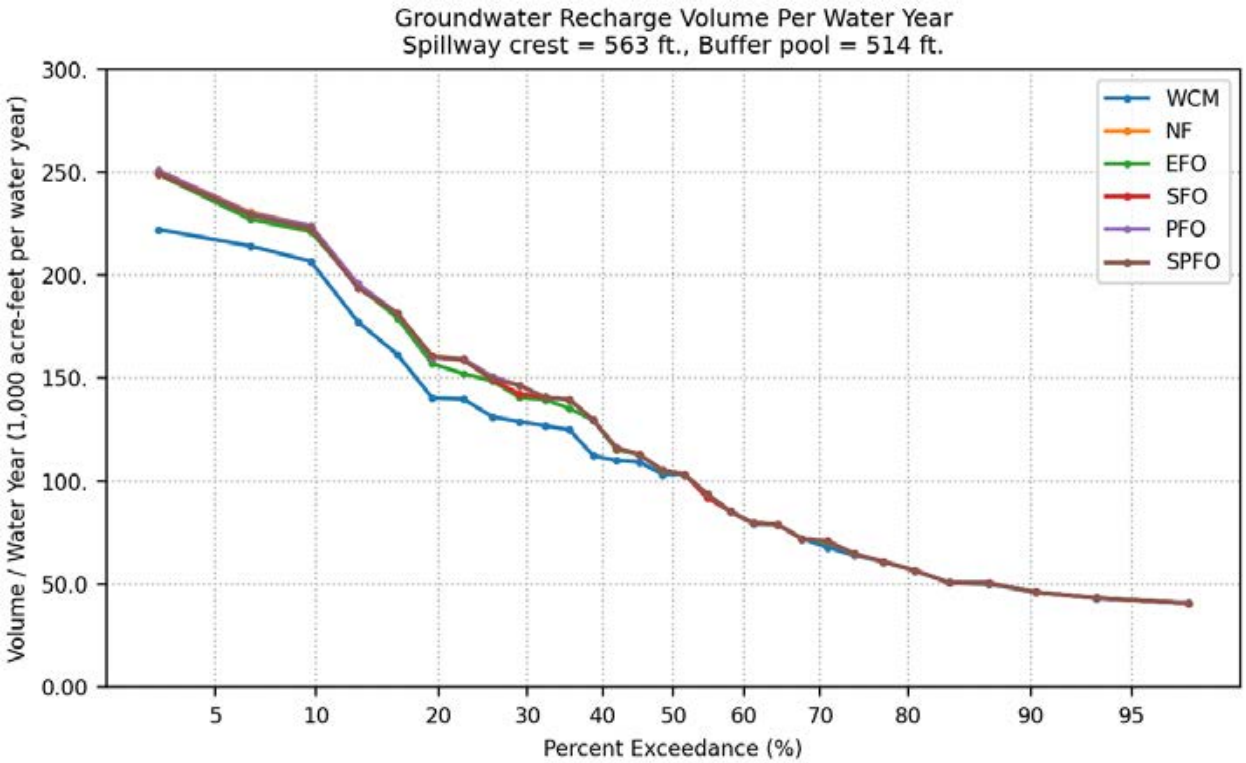

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5
10
20
30
40
50
60
70
80
90
95

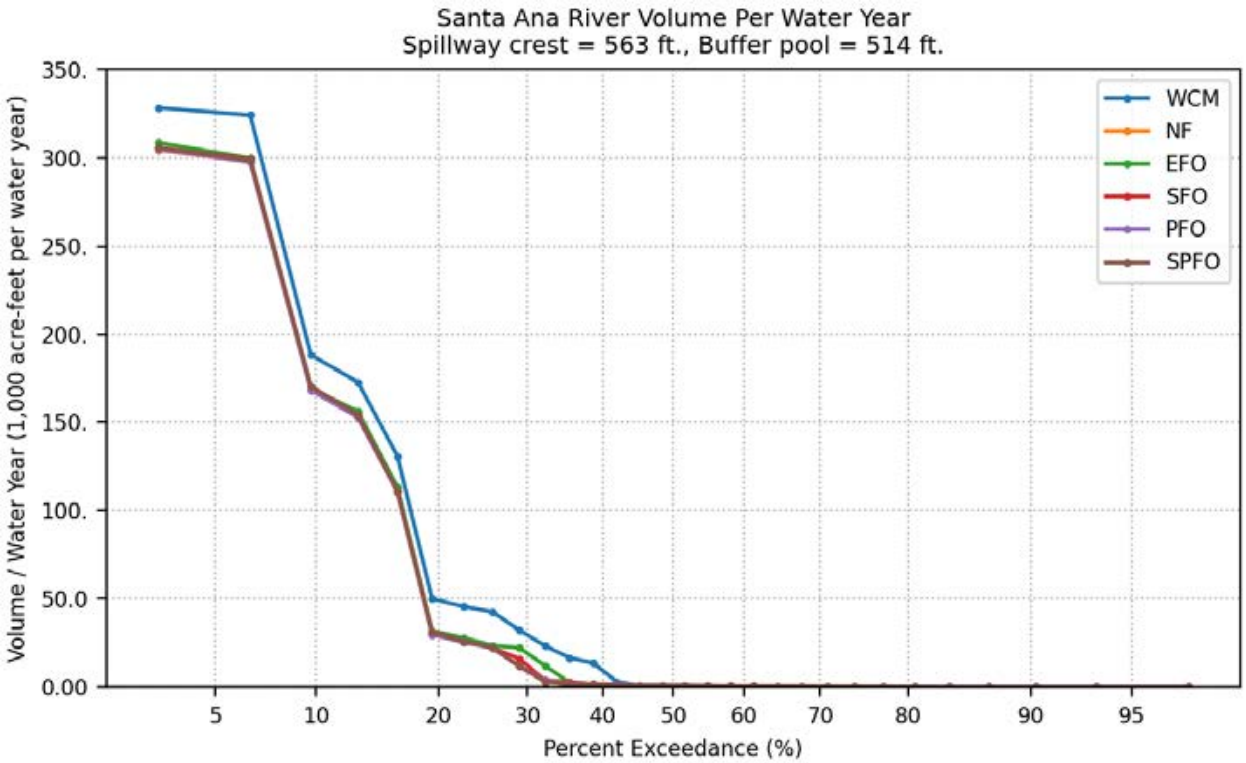

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
1.4
1.2
1.0
0.80
0.60
0.40
0.20
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

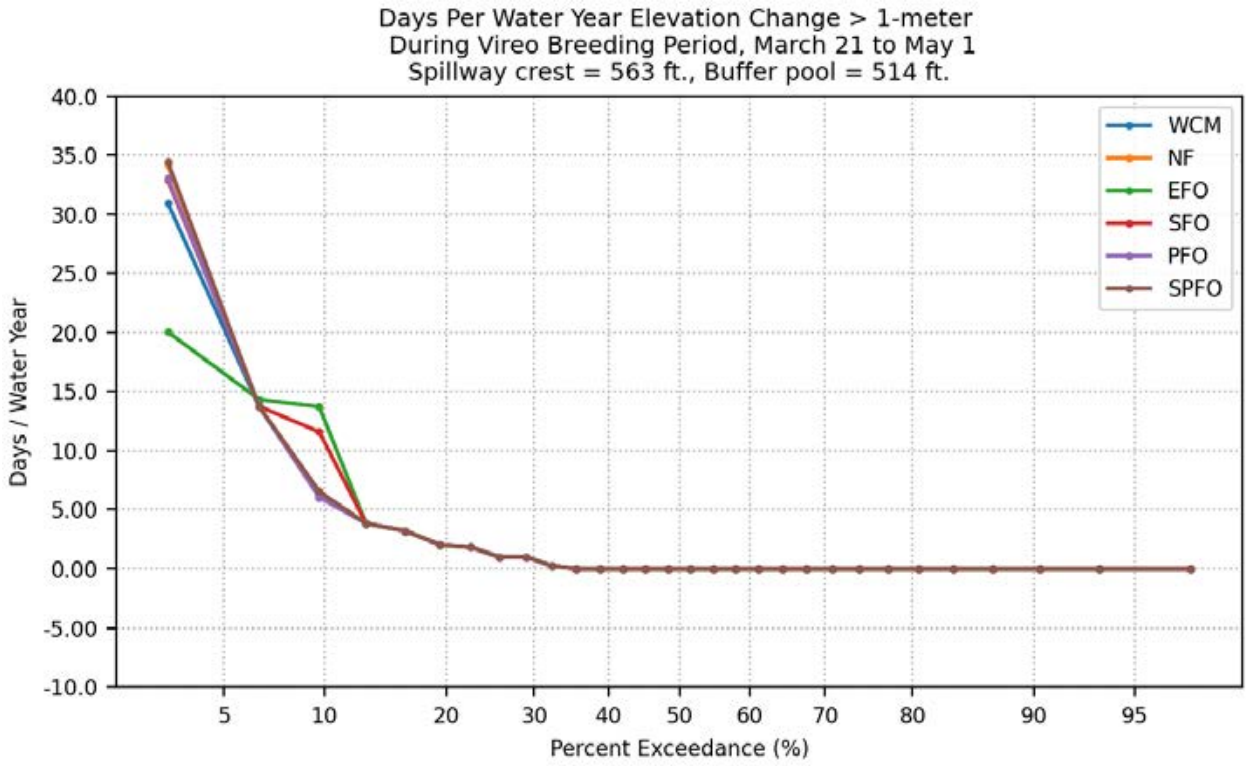

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
18.
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

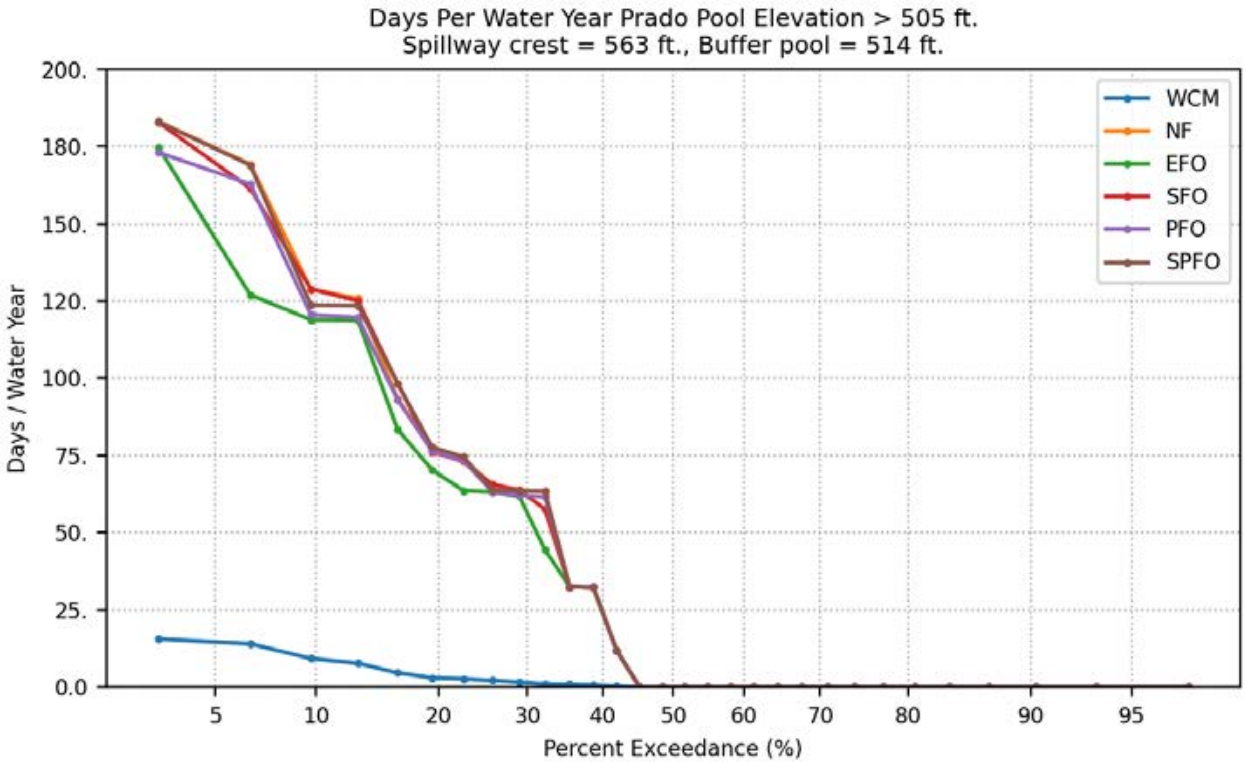

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

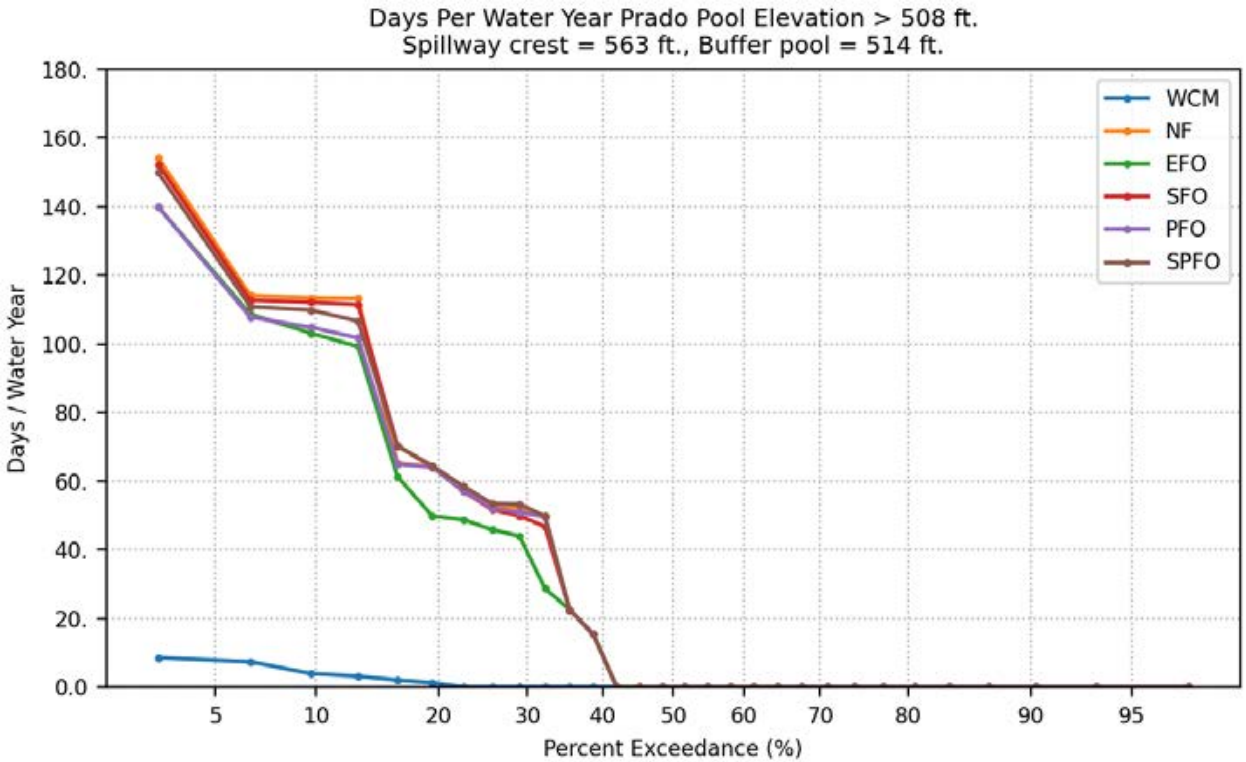

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
5
10
20
30
40
50
60
70
80
90
95

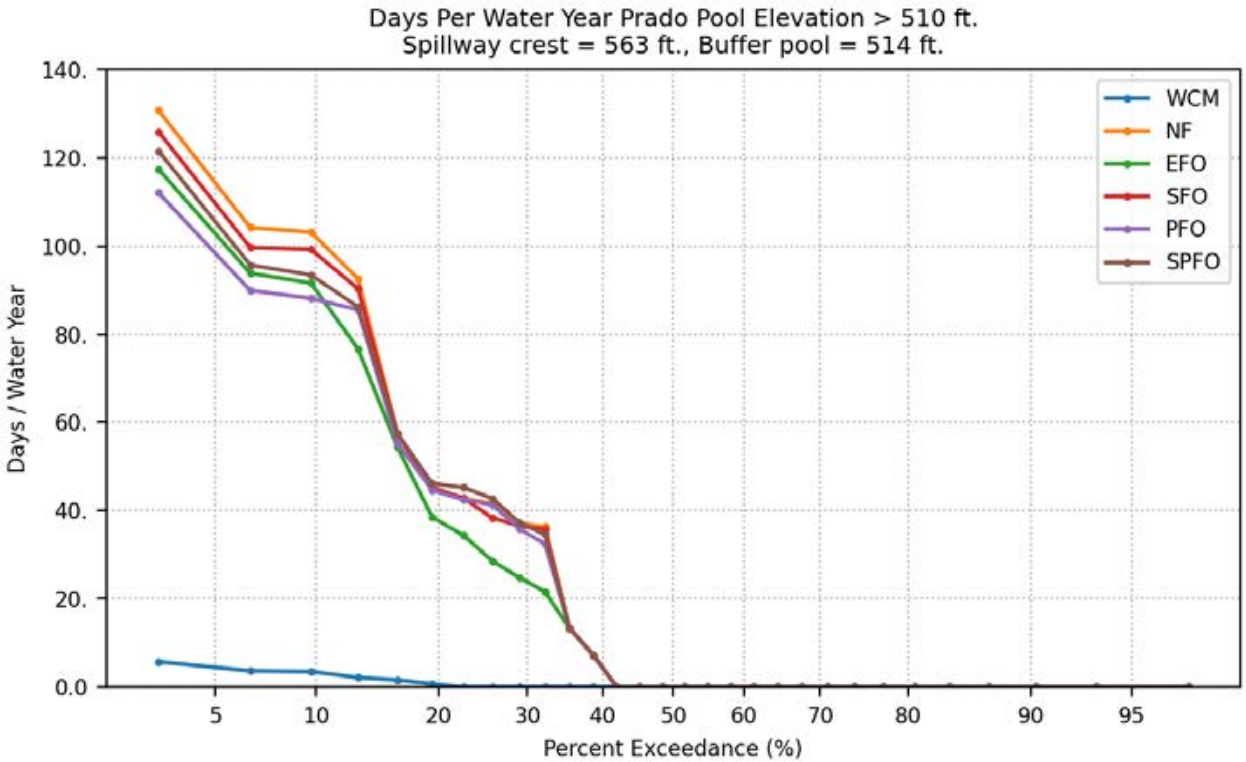

Groundwater Recharge Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 514 ft.
Volume / Water Year (1,000 acre-feet per water year)
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

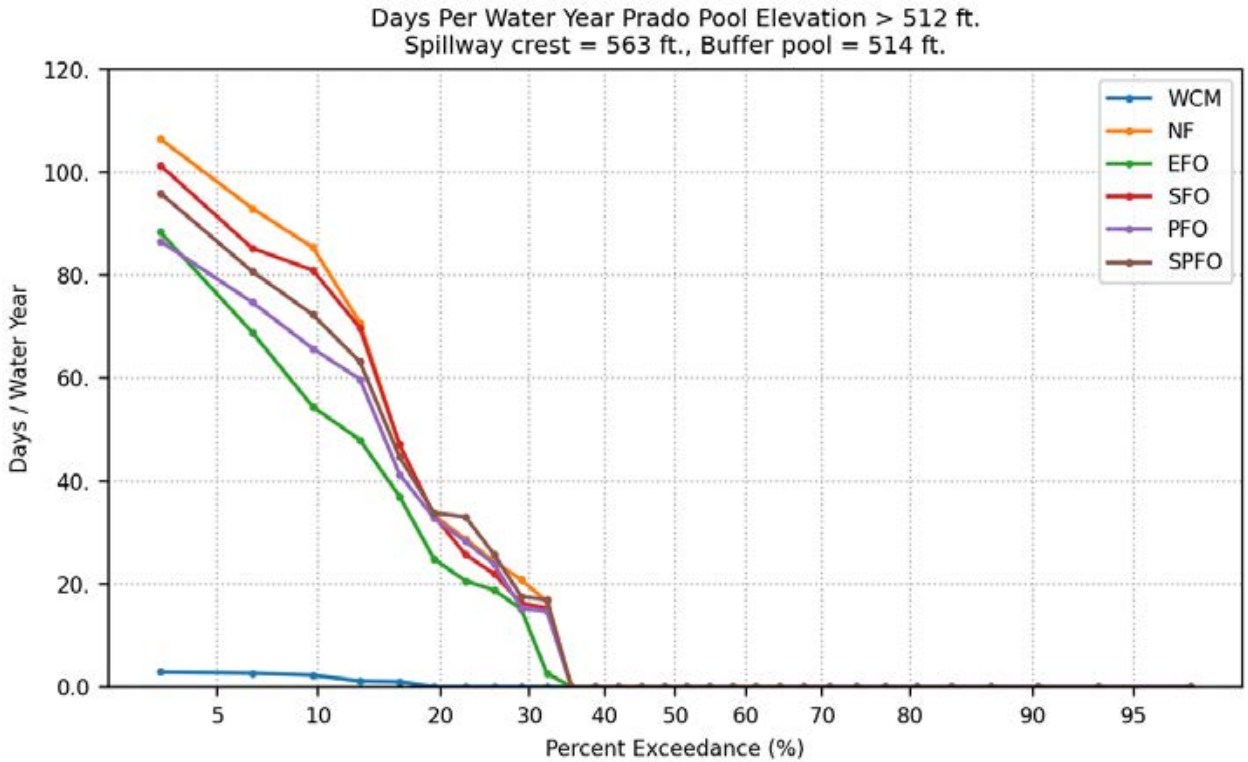

Santa Ana River Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 514 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

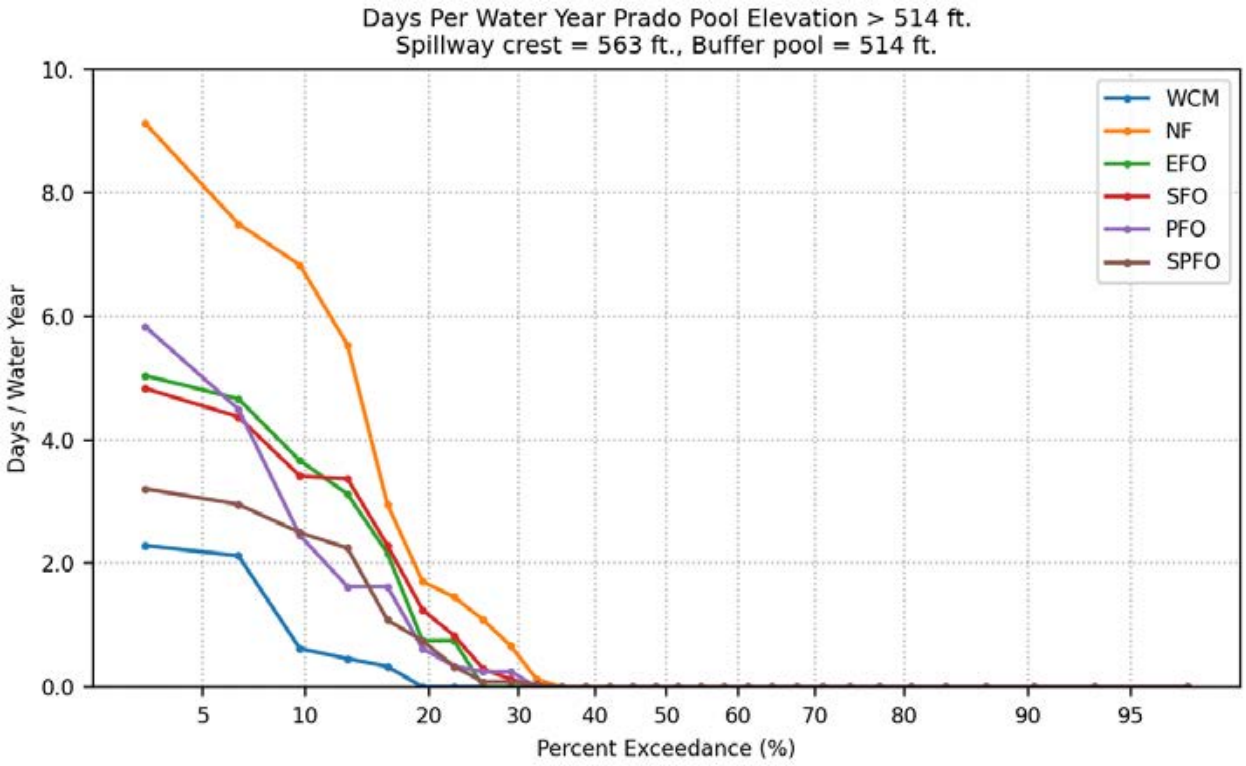

Days Per Water Year Elevation Change > 1-meter
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95

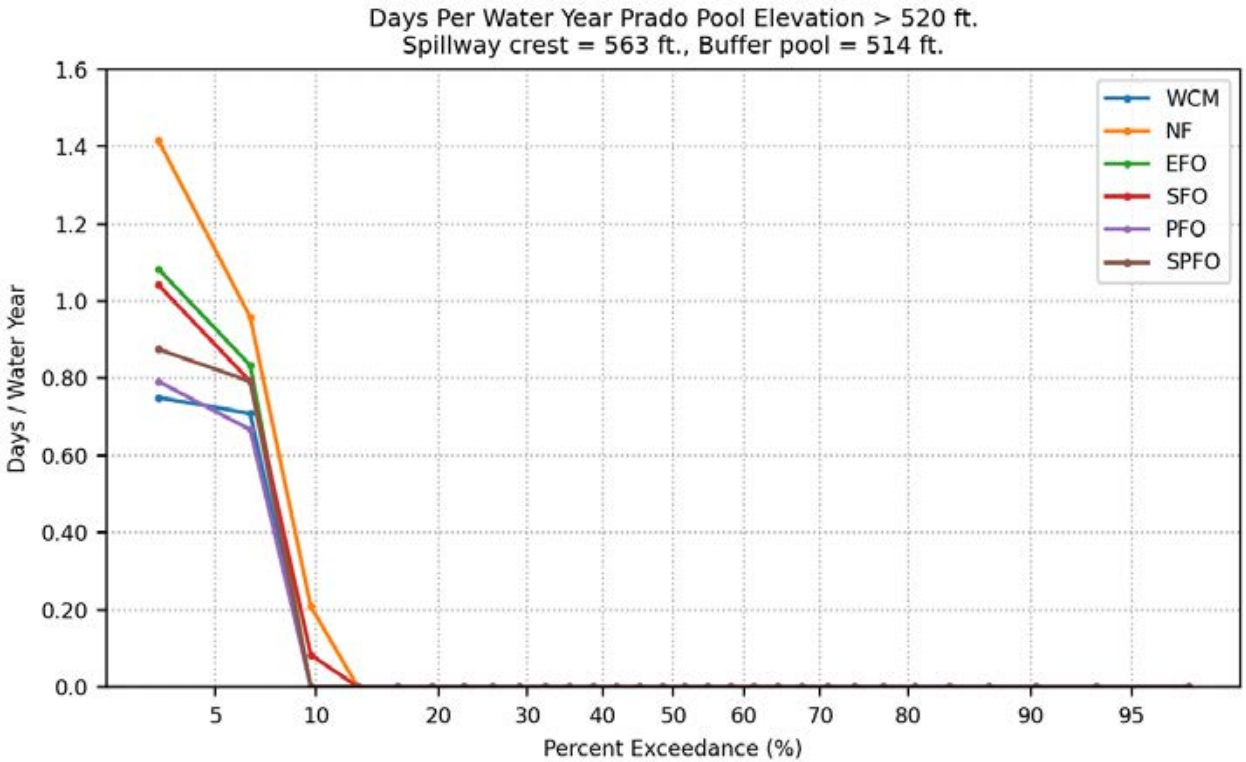

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
200.
180.
150.
120.
100.
75.
50.
25.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

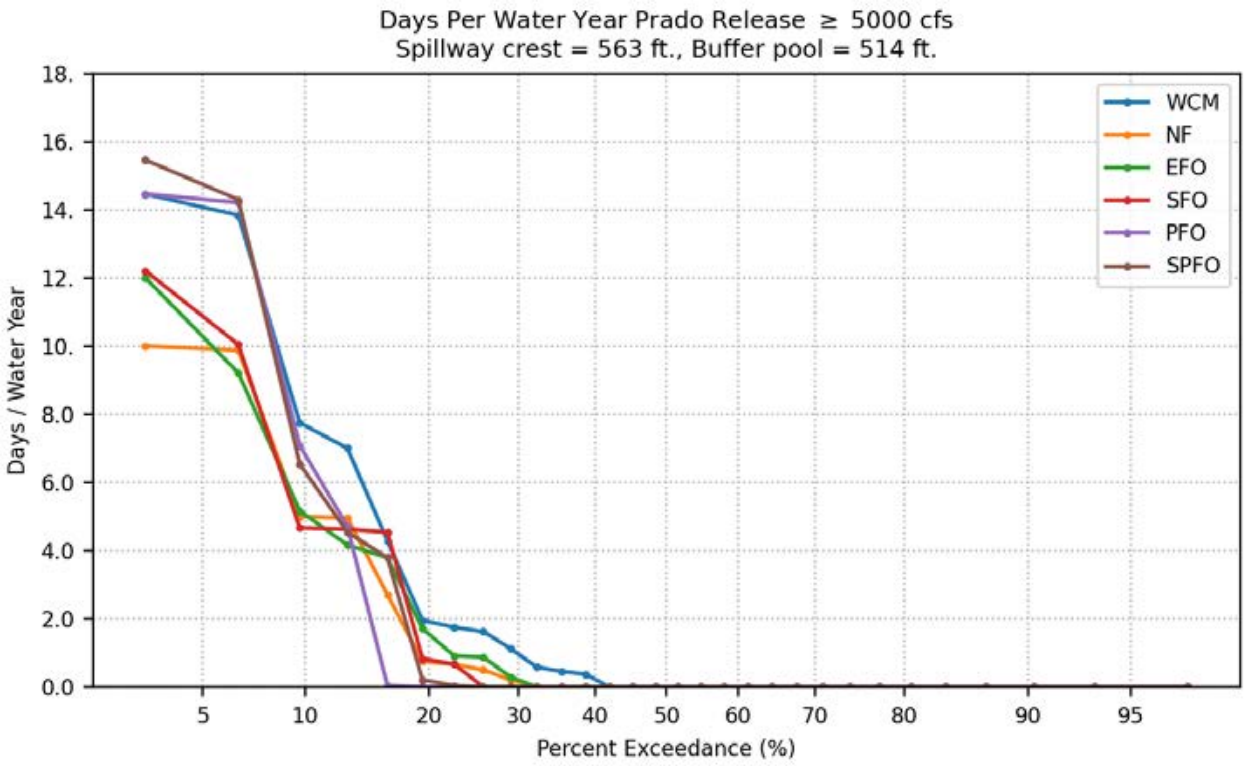

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
180.
160.
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

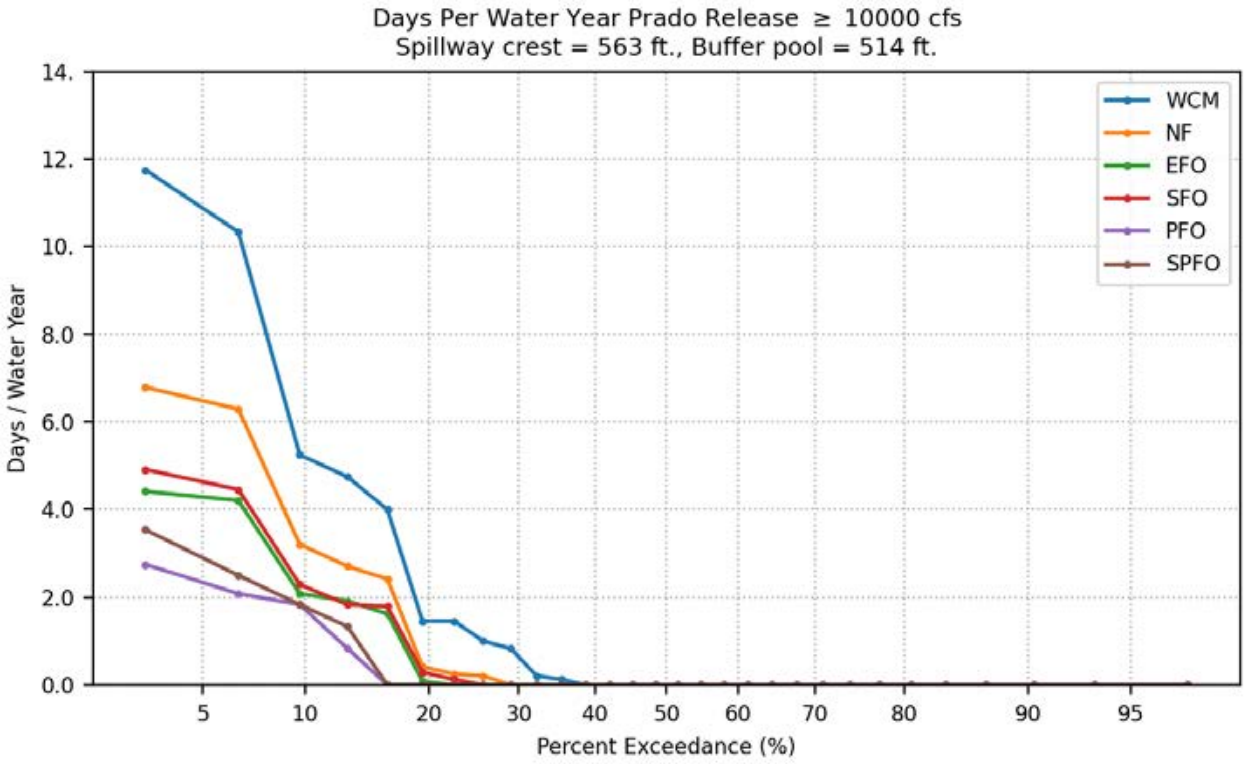

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

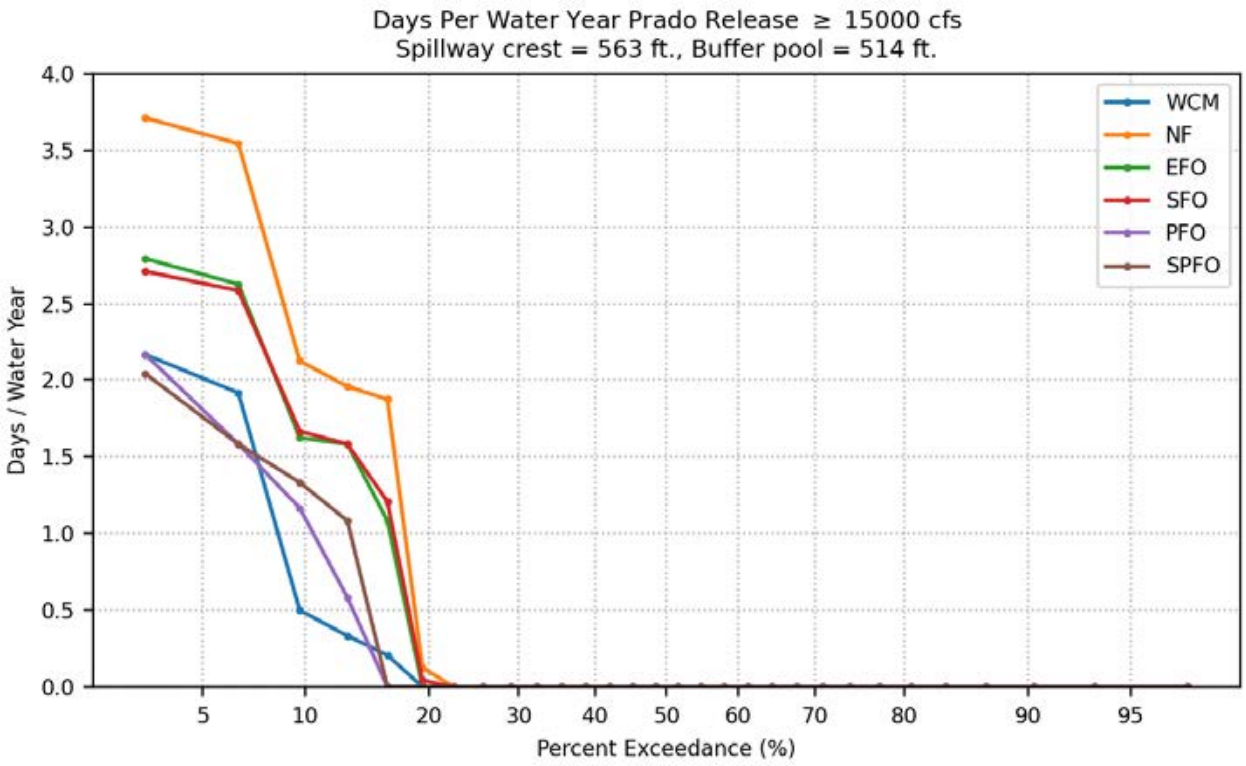

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

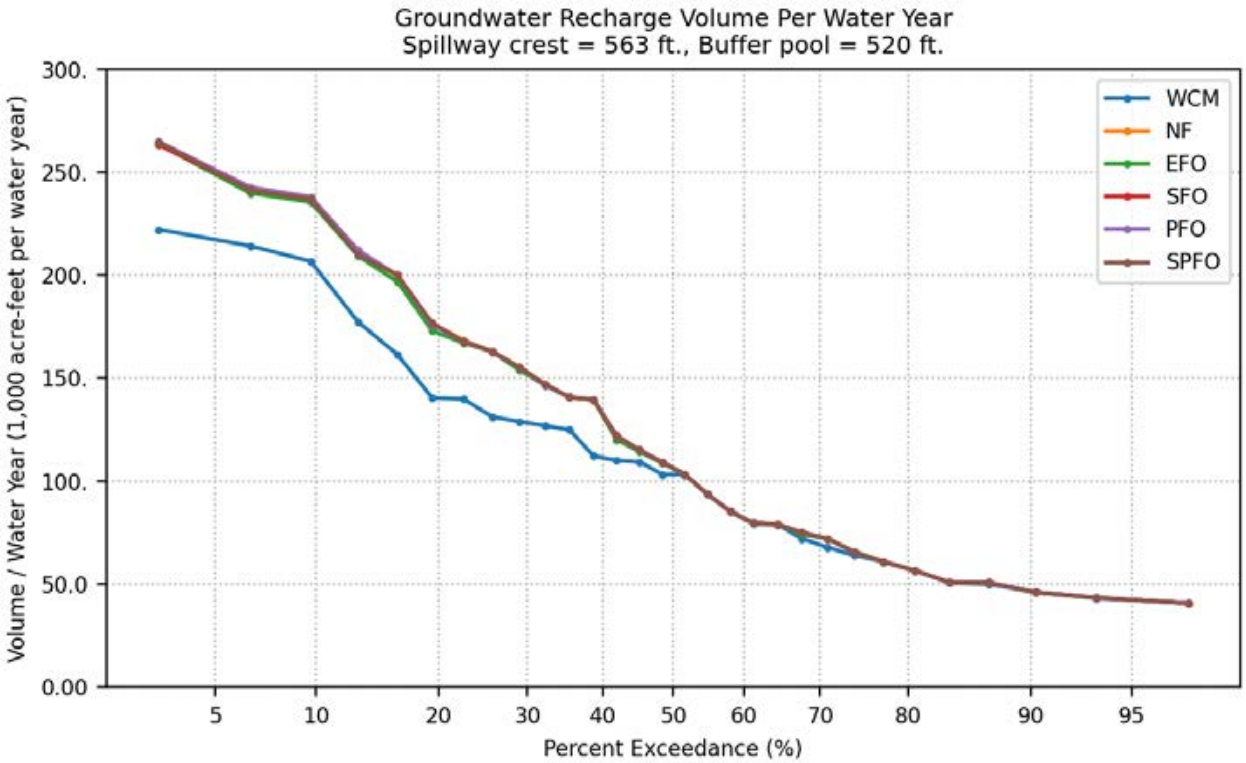

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

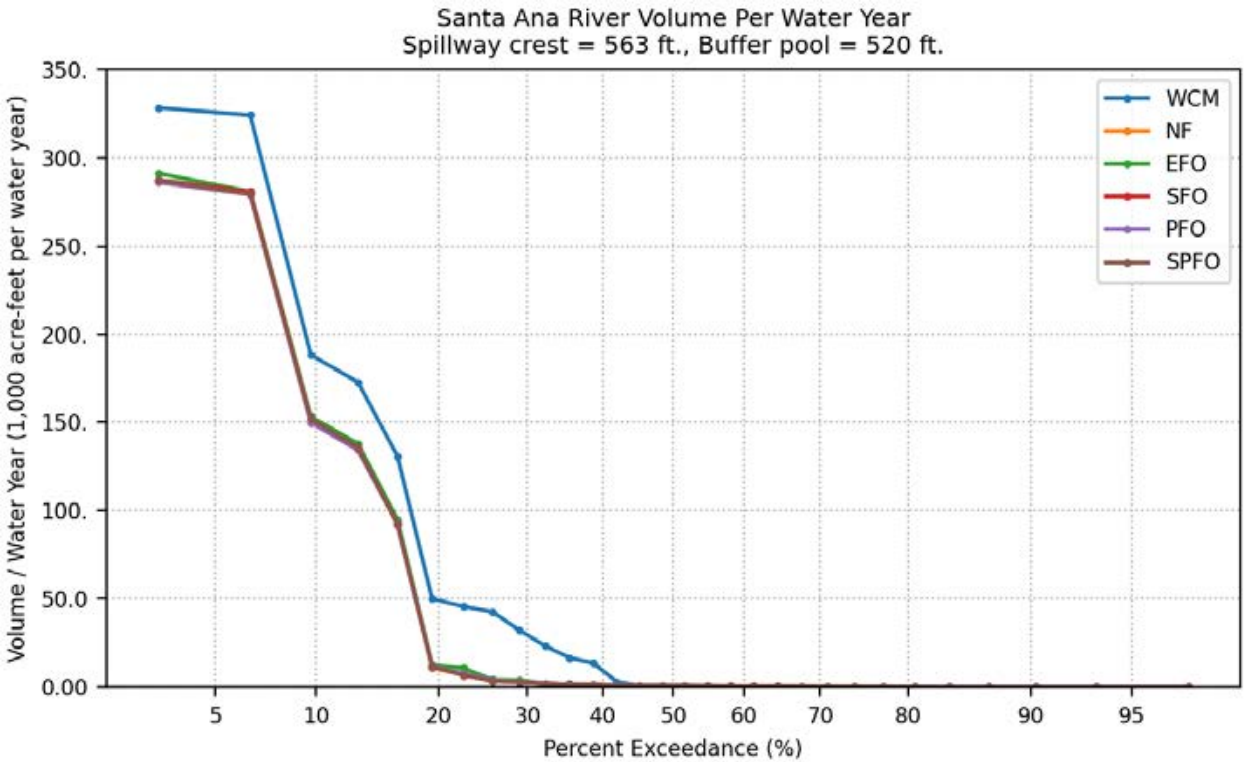

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
1.6
1.4
1.2
1.0
0.80
0.60
0.40
0.20
0.0
5
10
20
30
40
50
60
70
80
90
95

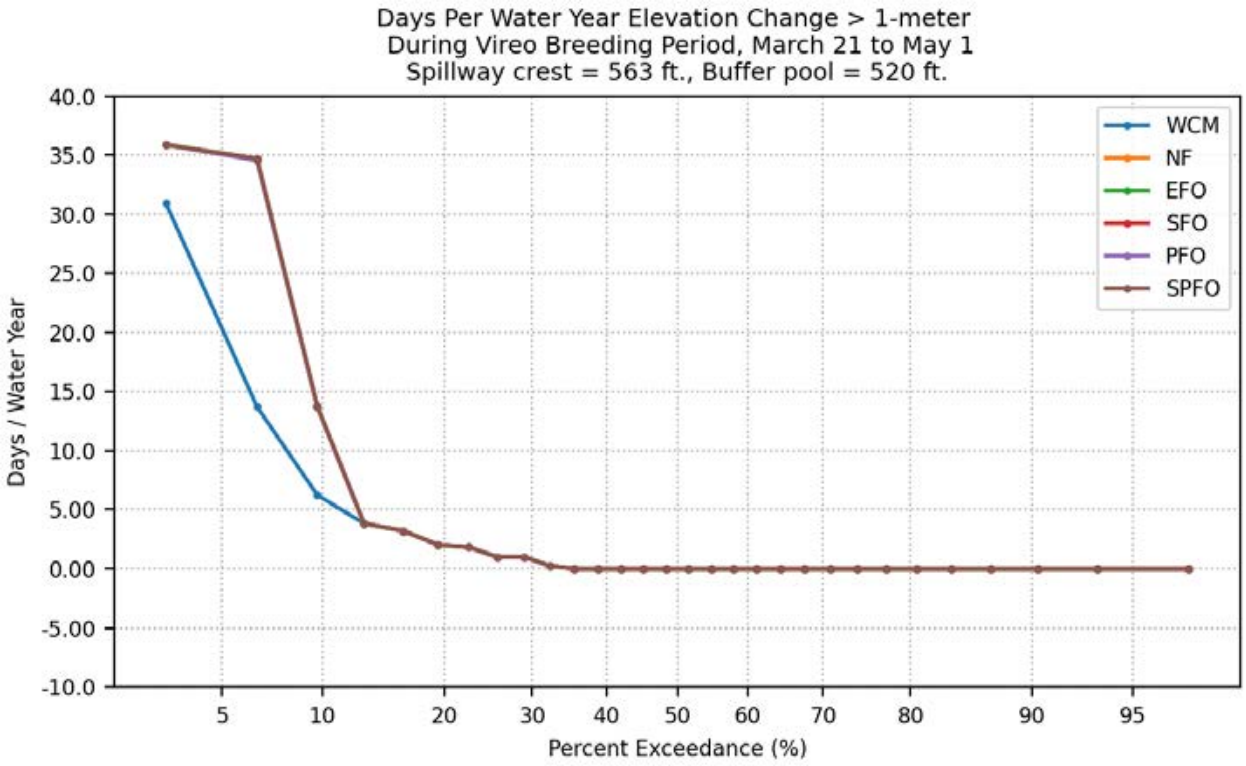

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
18.
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

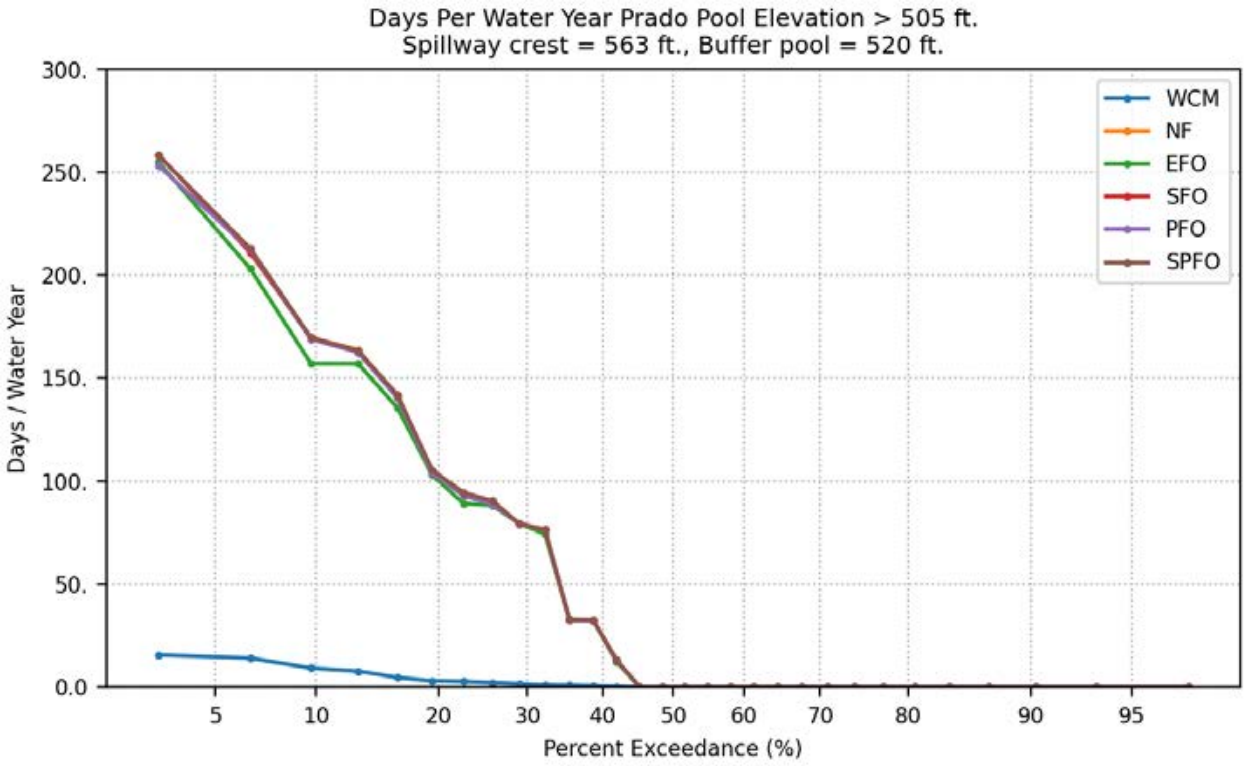

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

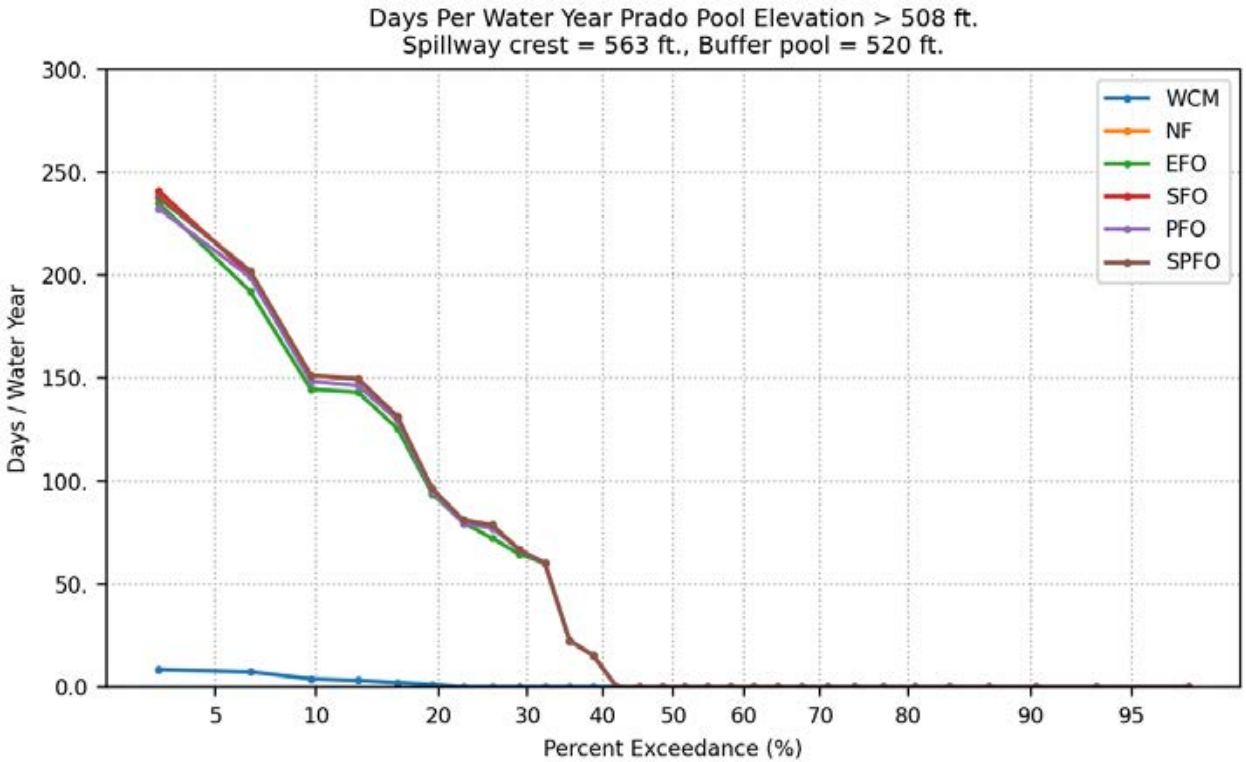

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
20
30
40
50
60
70
80
90
95

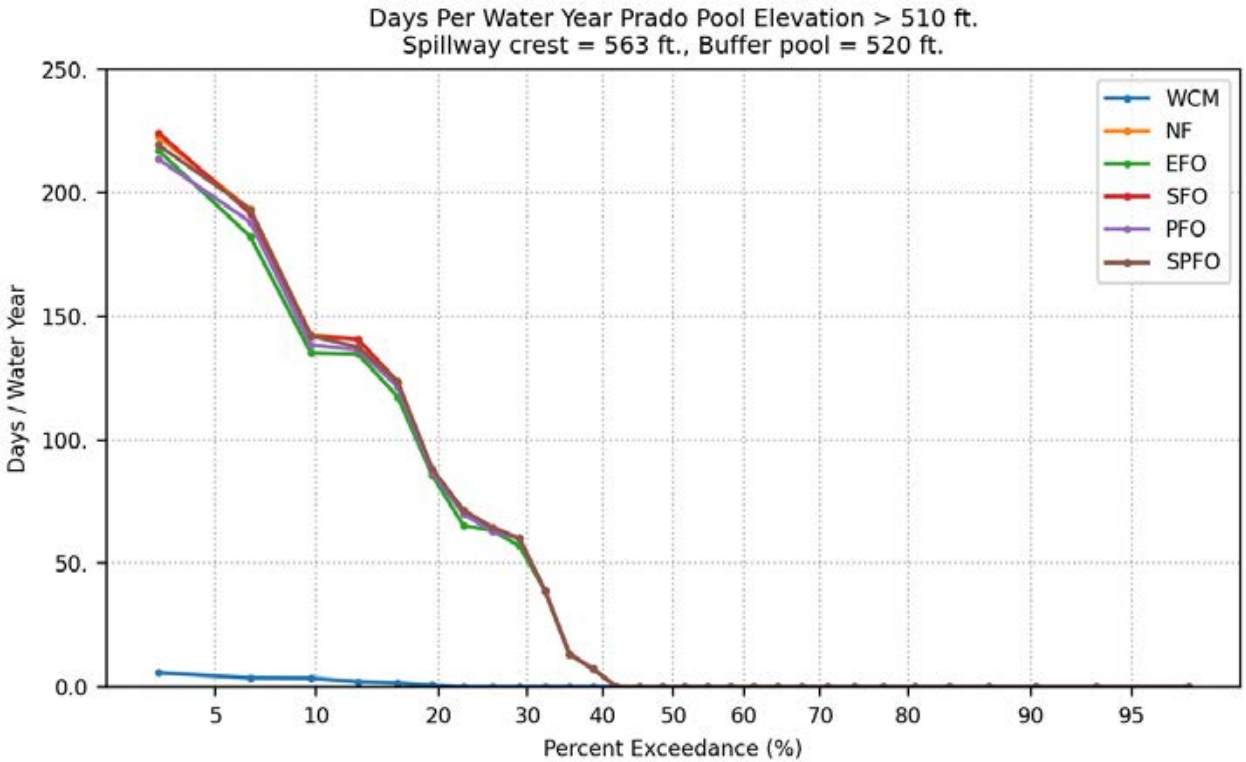

Groundwater Recharge Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 520 ft.
Volume / Water Year (1,000 acre-feet per water year)
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

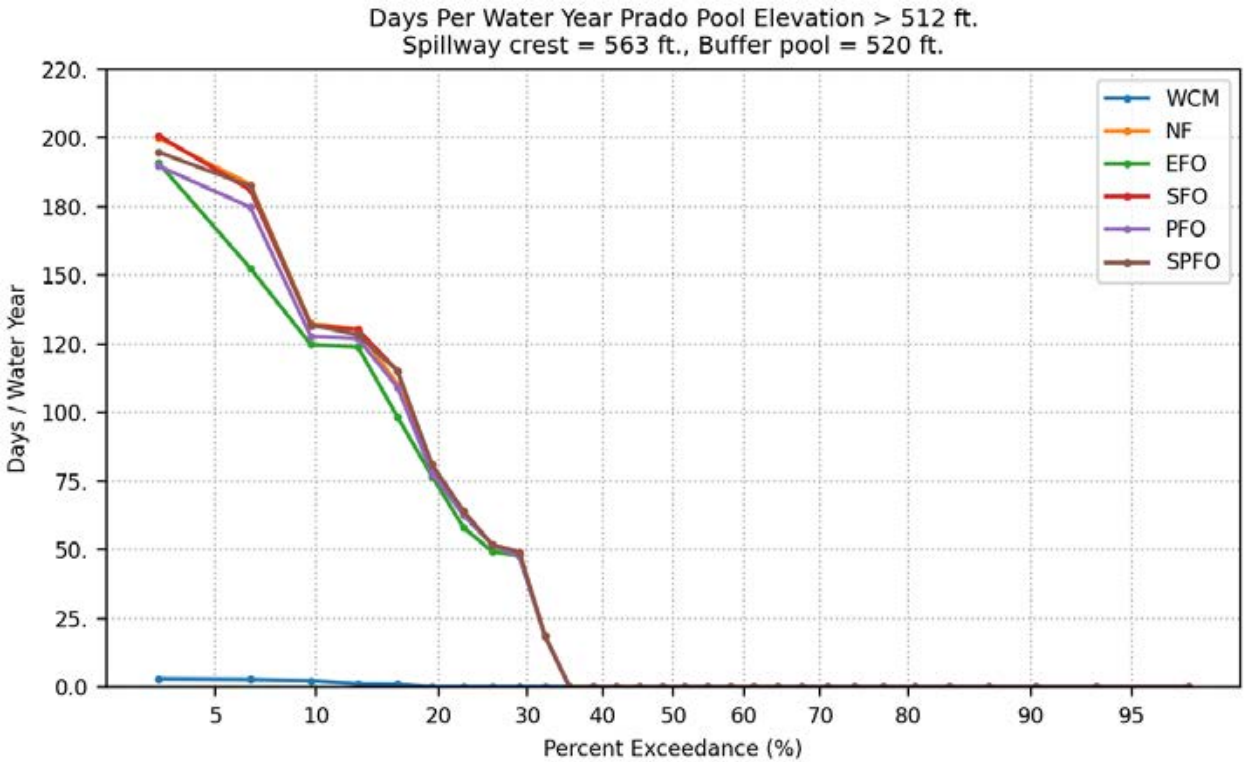

Santa Ana River Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 520 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

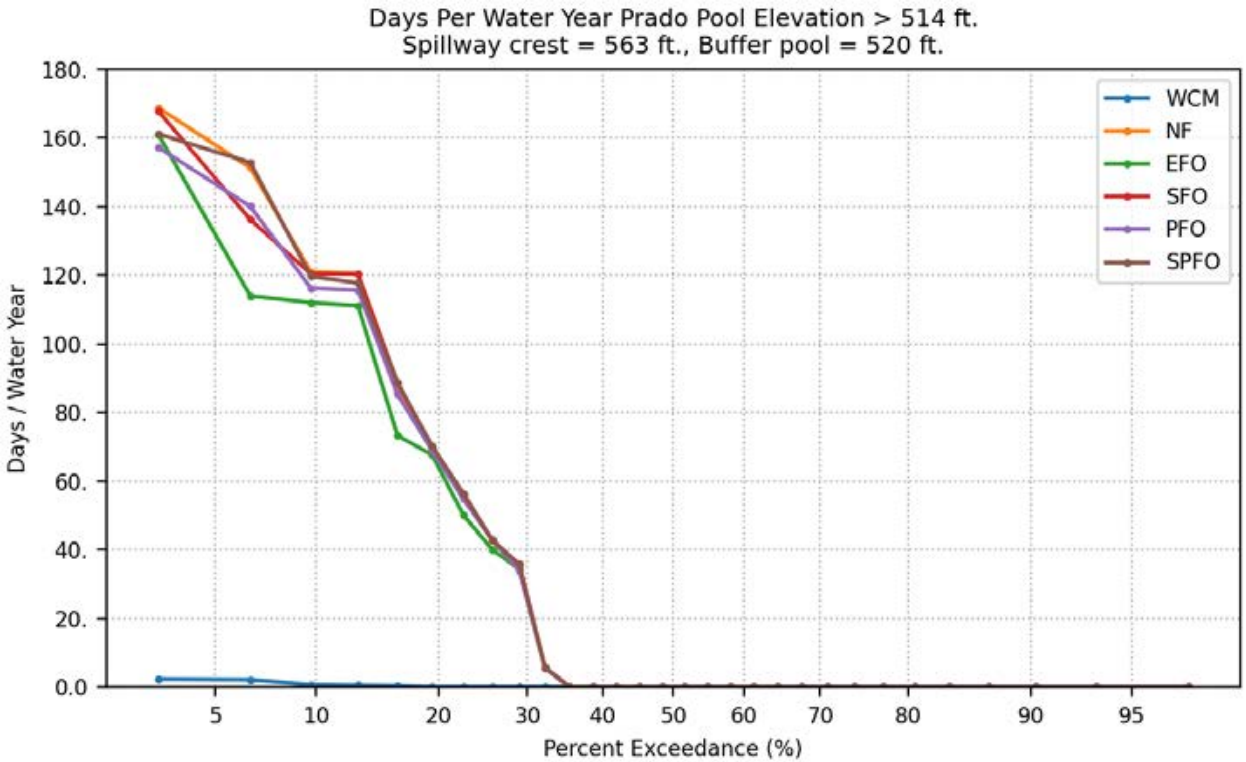

Days Per Water Year Elevation Change > 1-meter
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 563 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

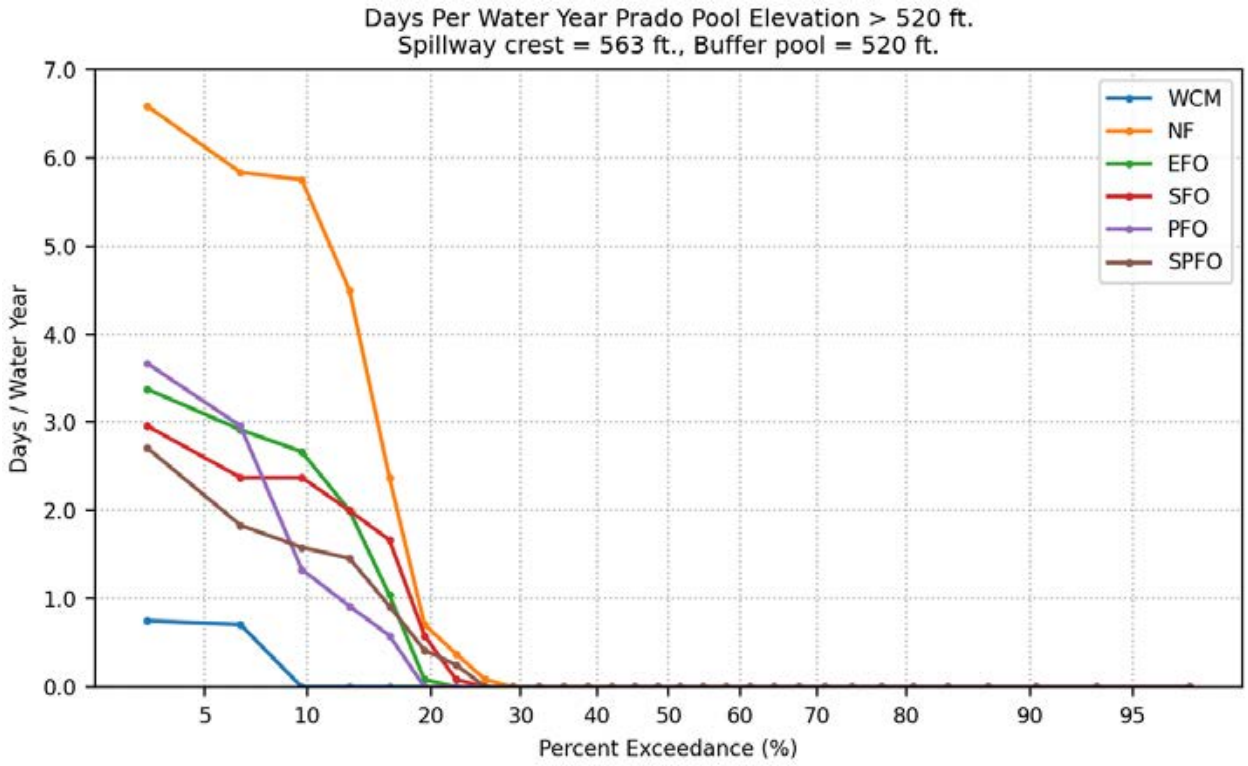

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 563 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
300.
250.
200.
150.
100.
50.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

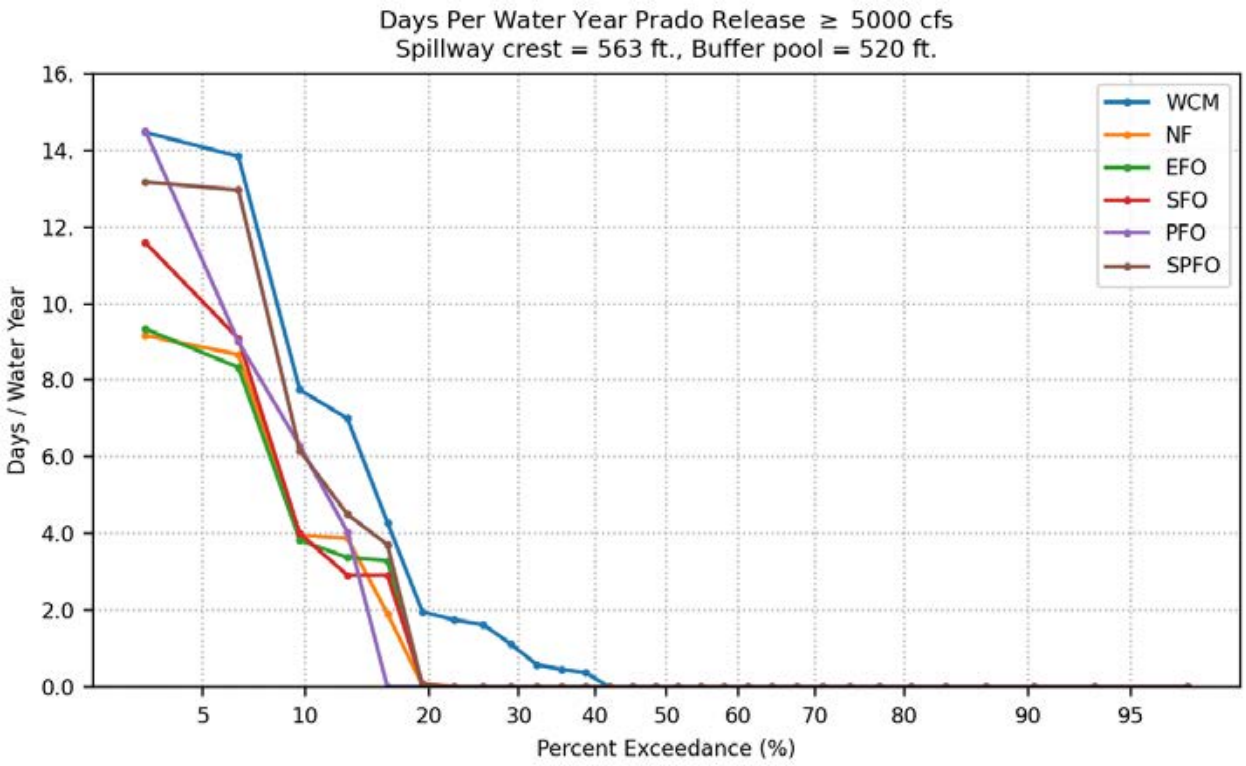

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 563 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
300.
250.
200.
150.
100.
50.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

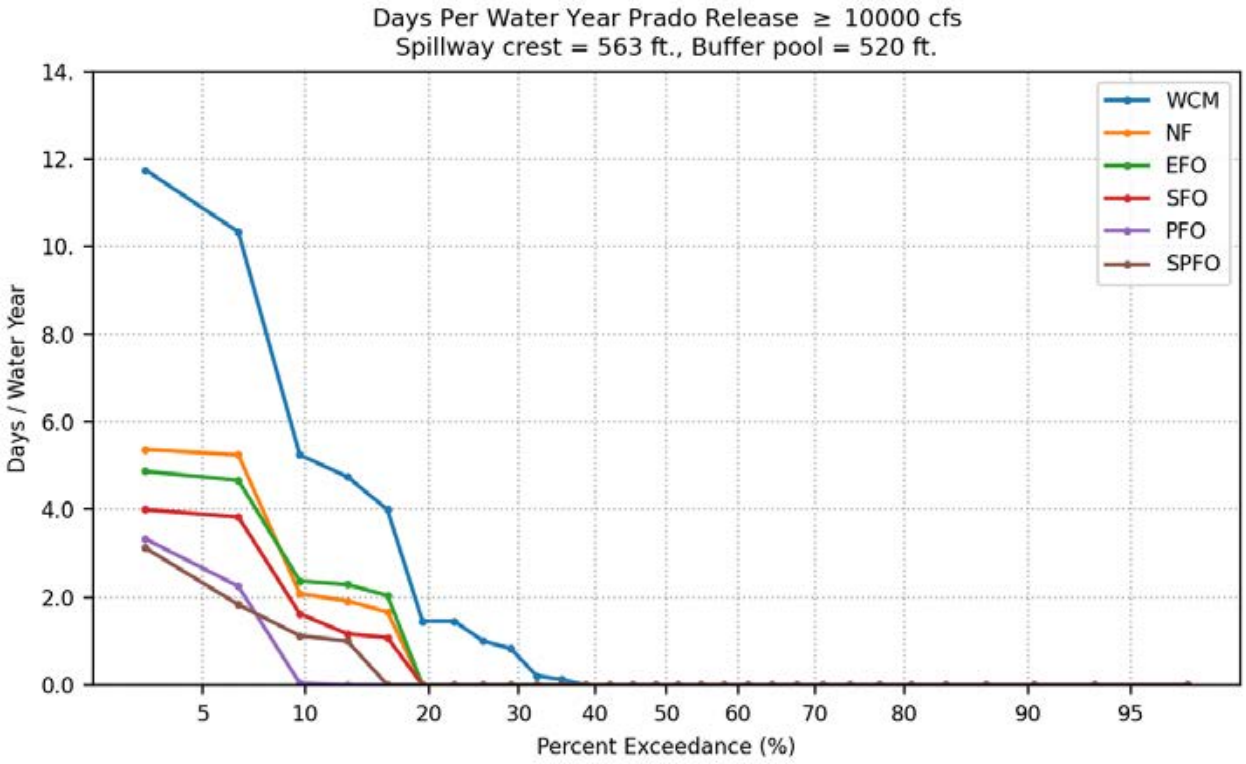

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 563 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
250.
200.
150.
100.
50.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

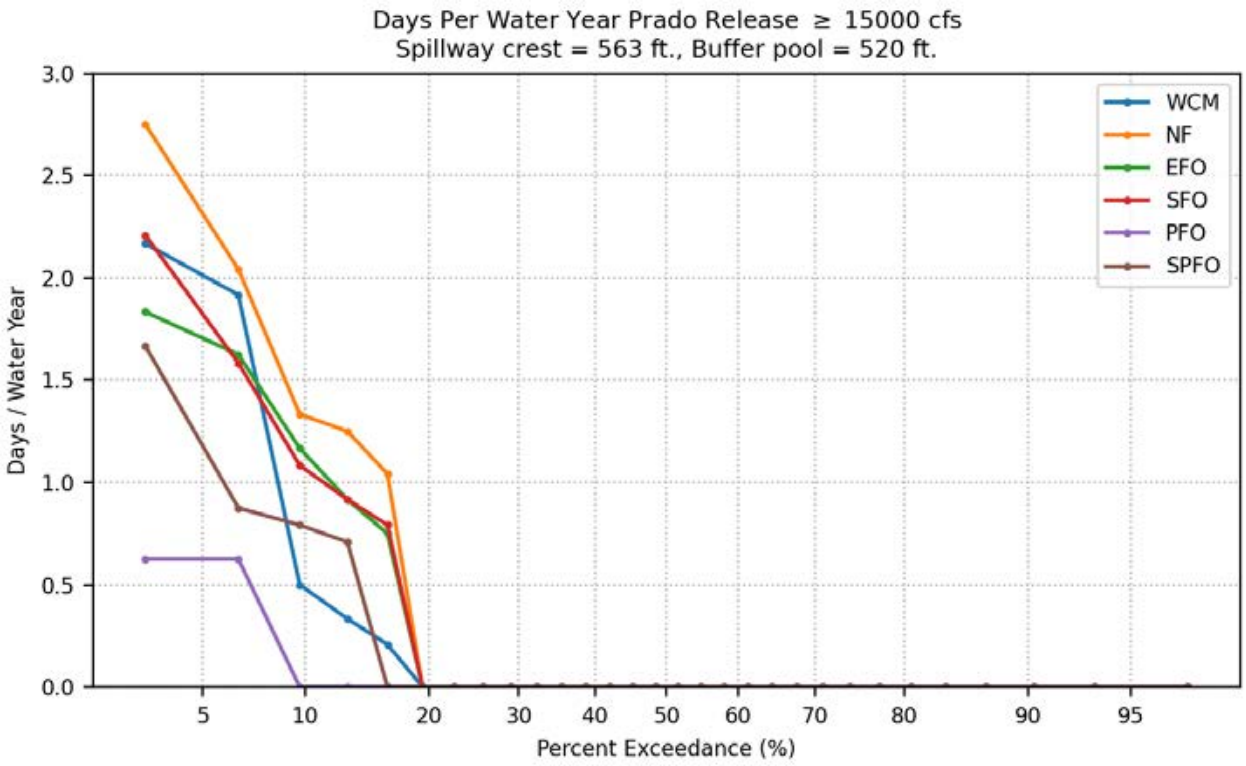

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 563 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
220.
200.
180.
150.
120.
100.
75.
50.
25.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO


Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 563 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
180.
160.
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO


Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 563 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO


Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 563 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95


Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 563 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

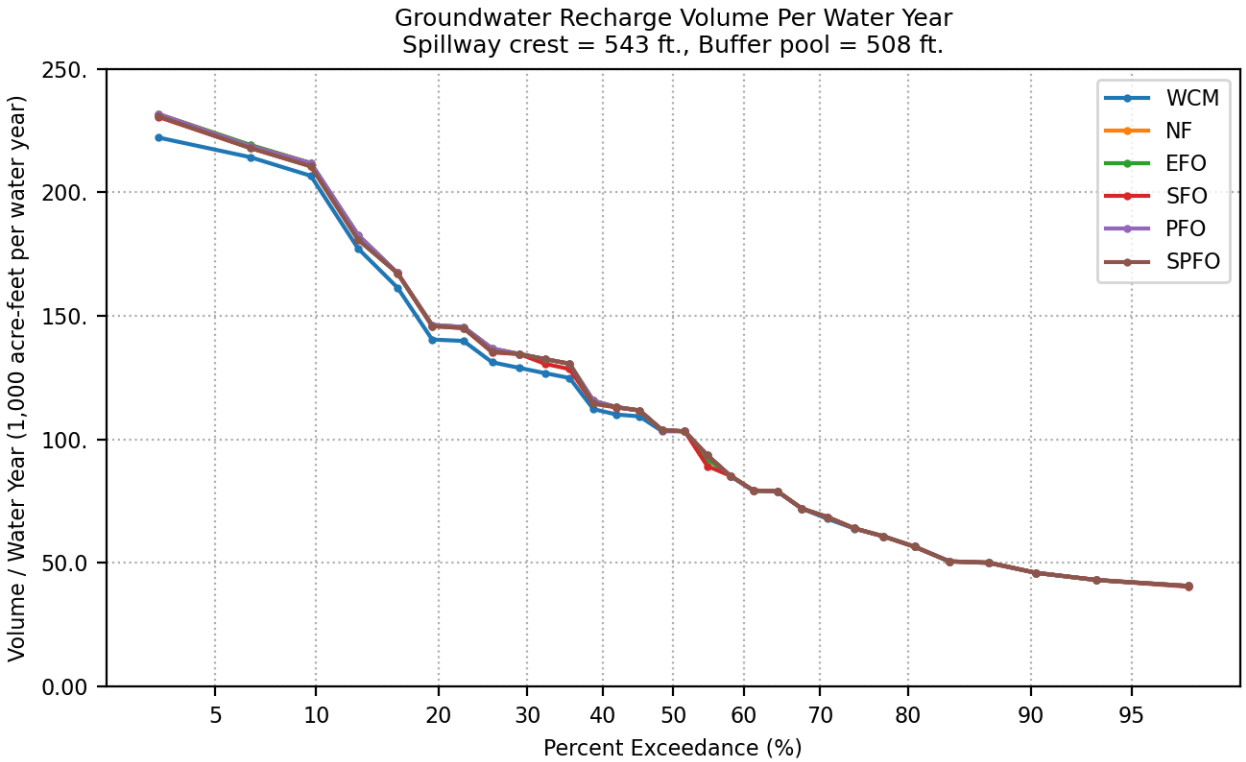

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 563 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

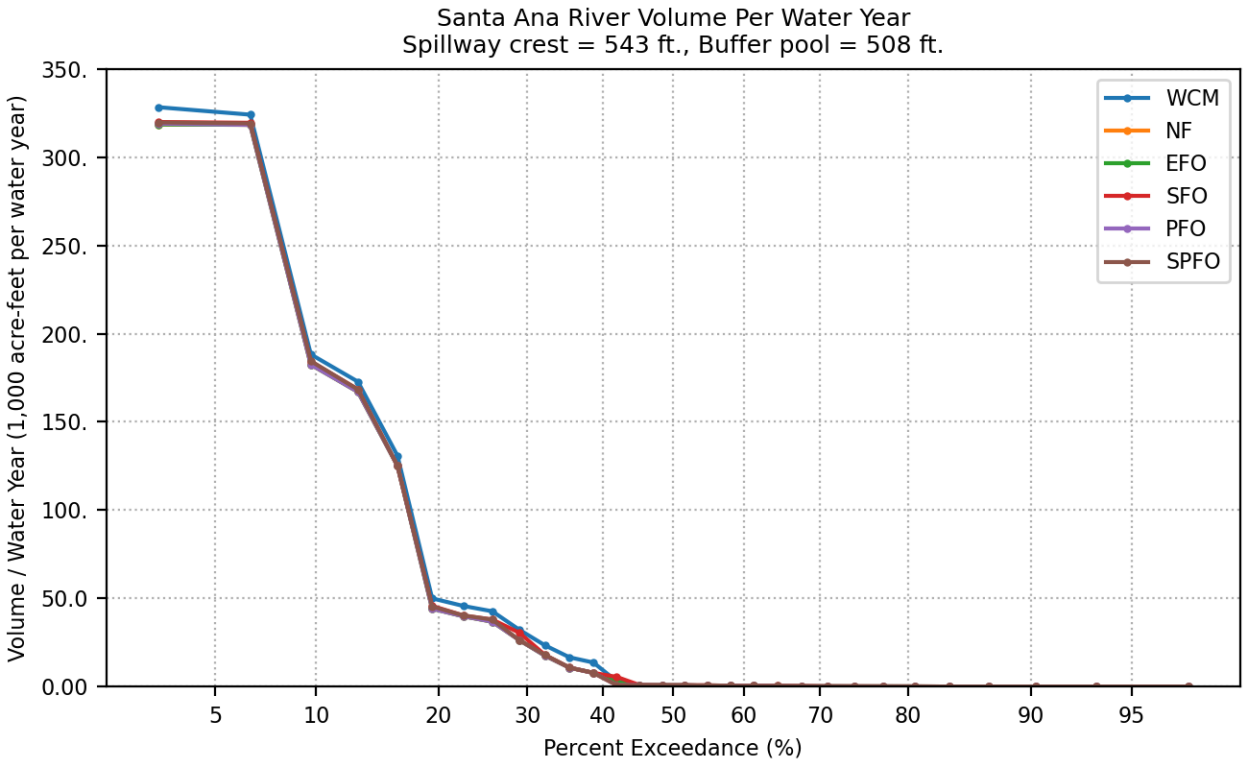
HEMP Metrics (No 520’)

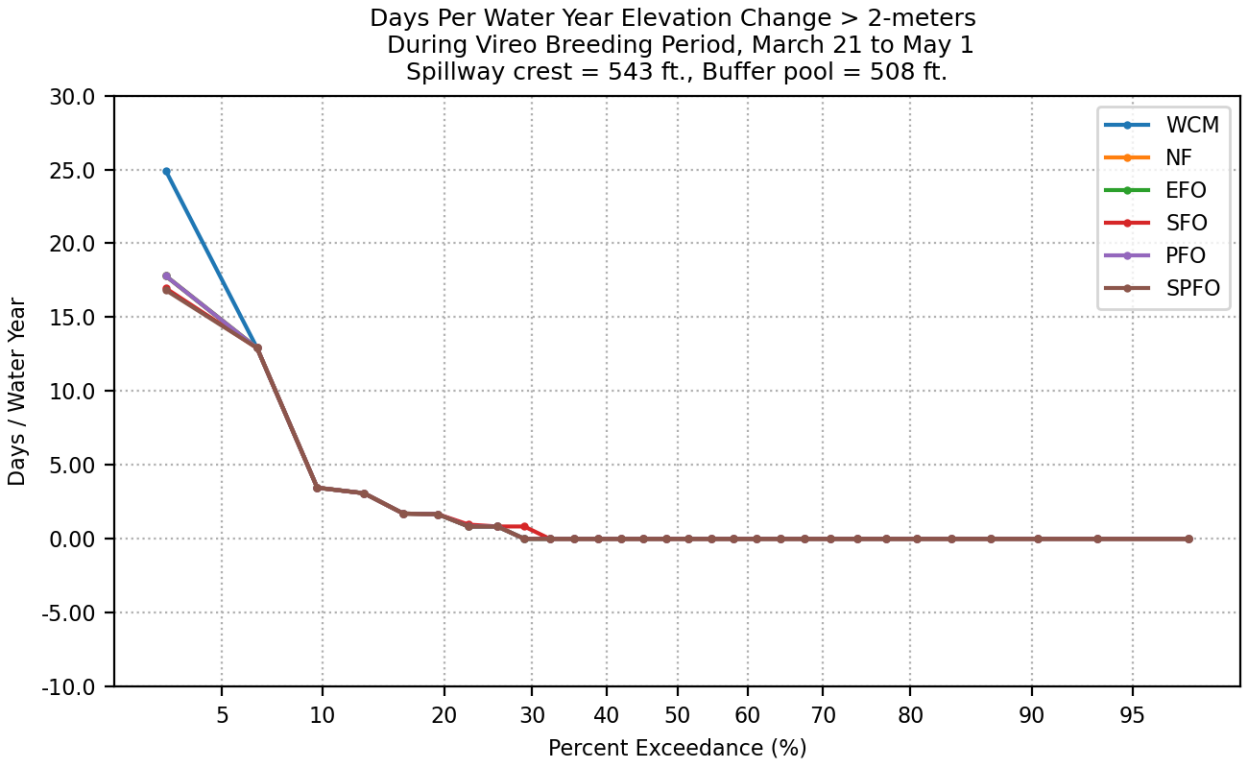
- Groundwater Recharge (KAF/yr)
- Discharge to Pacific Ocean (KAF/yr)
- >1 meter rise between 3/21 and 5/1 (days/yr)
- Pool elevation > 505’, 508’, 510’, 512’, 514’, 520’ (days/yr)
- Reservoir release > 5,000 cfs, 10,000 cfs, 15,000 cfs (days/yr)

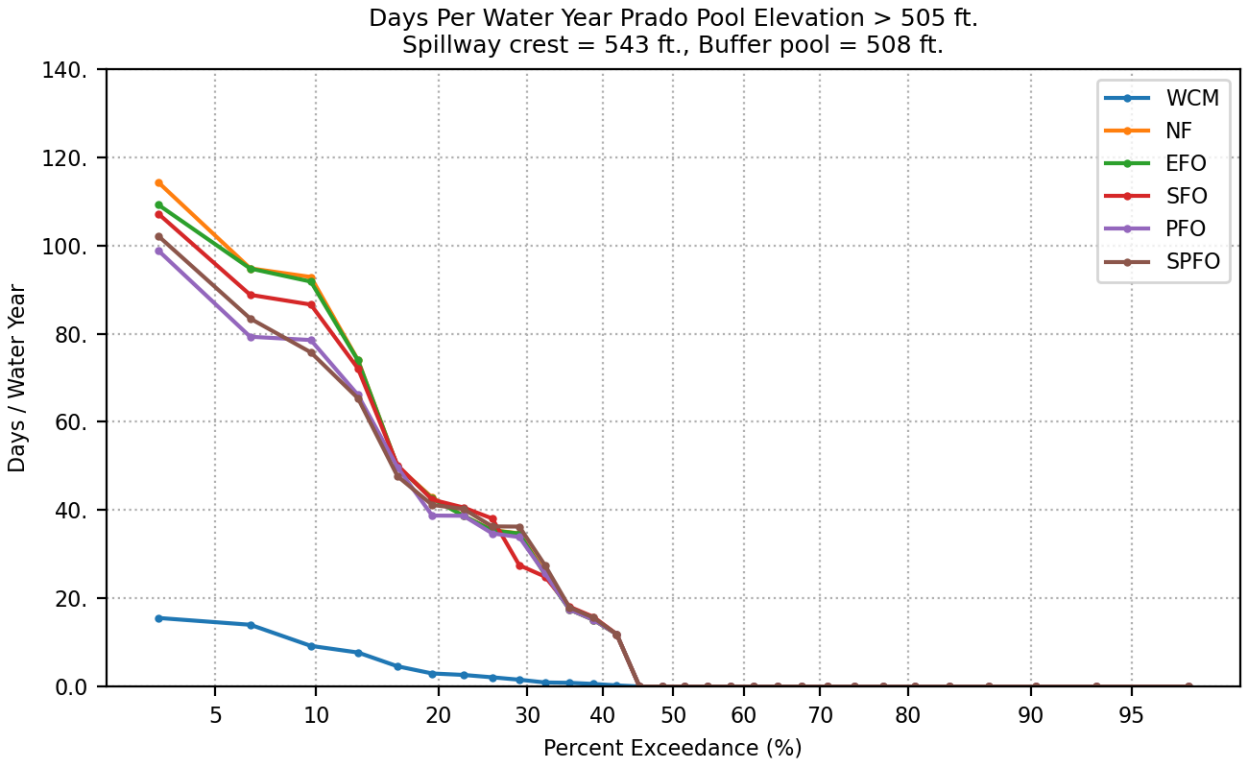
HEMP Metrics (No 520’)

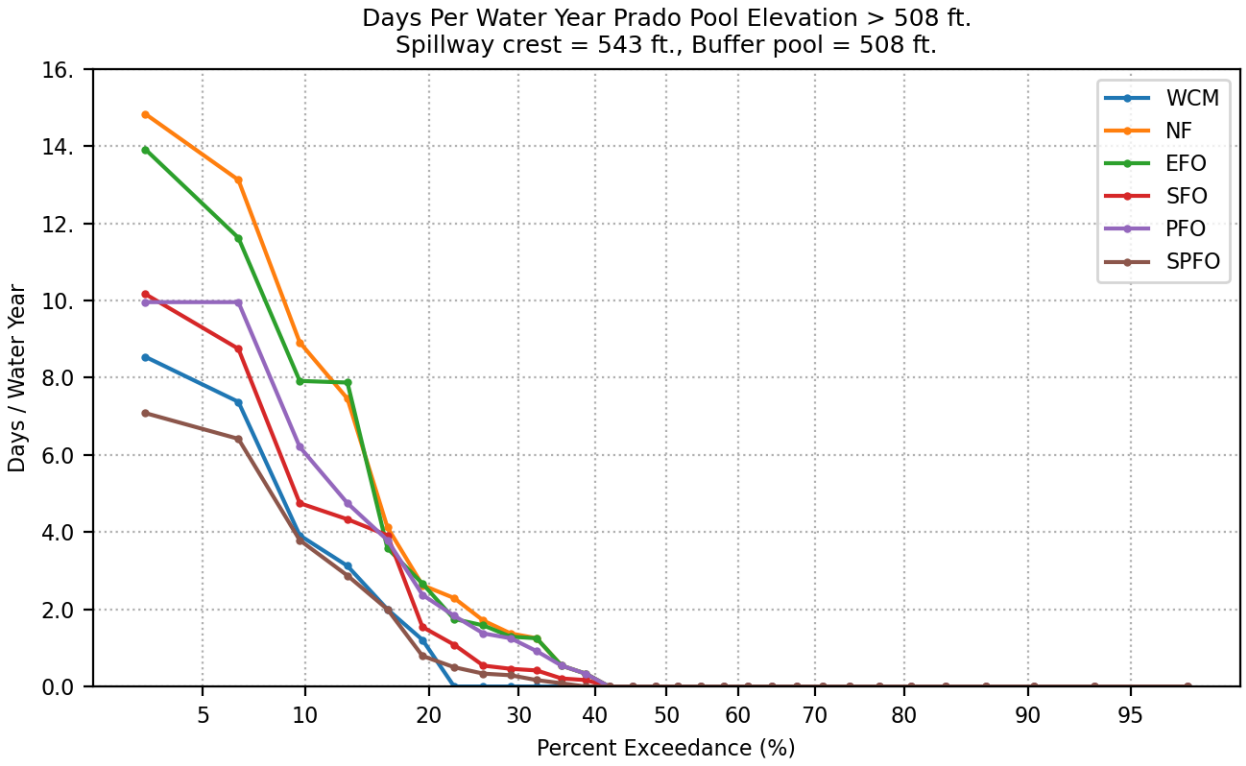
- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’, 510’, 512’, 514’
  - WCP alternatives in legend

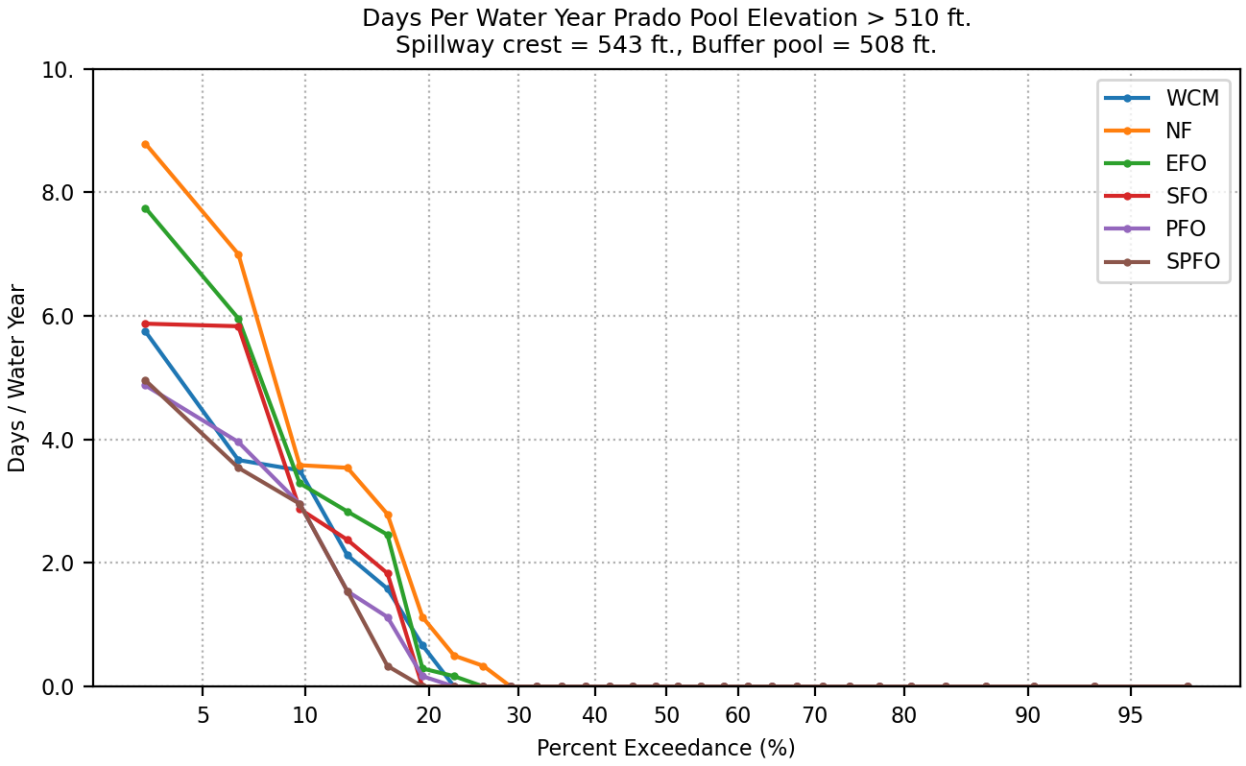

Groundwater Recharge Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 508 ft.
Volume / Water Year (1,000 acre-feet per water year)
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

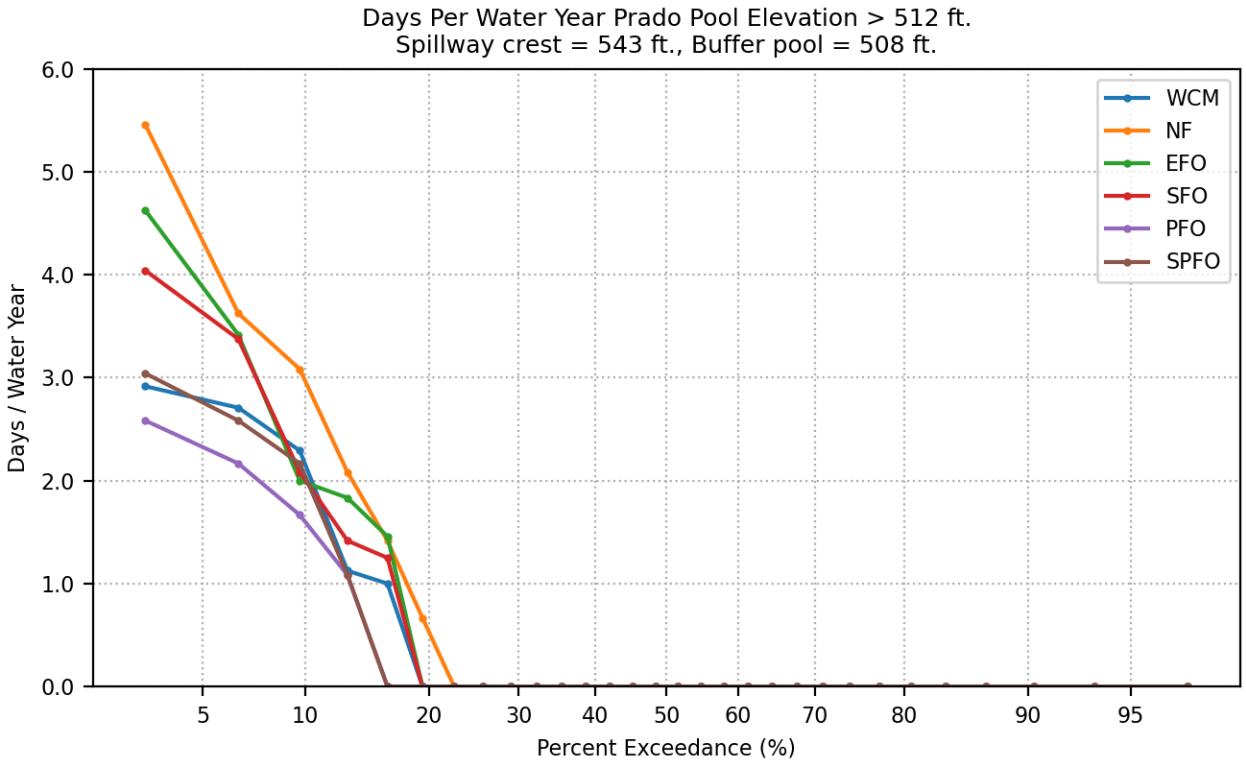

Santa Ana River Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 508 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

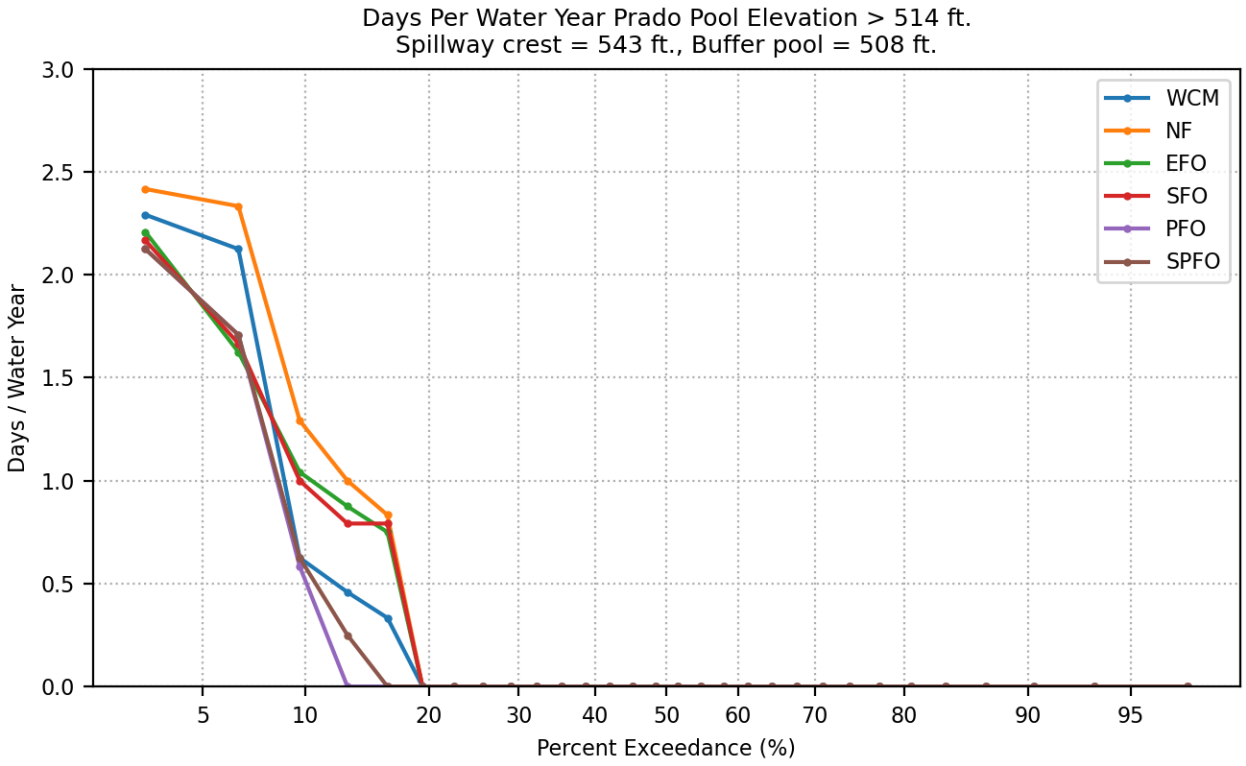

Days Per Water Year Elevation Change > 2-meters
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

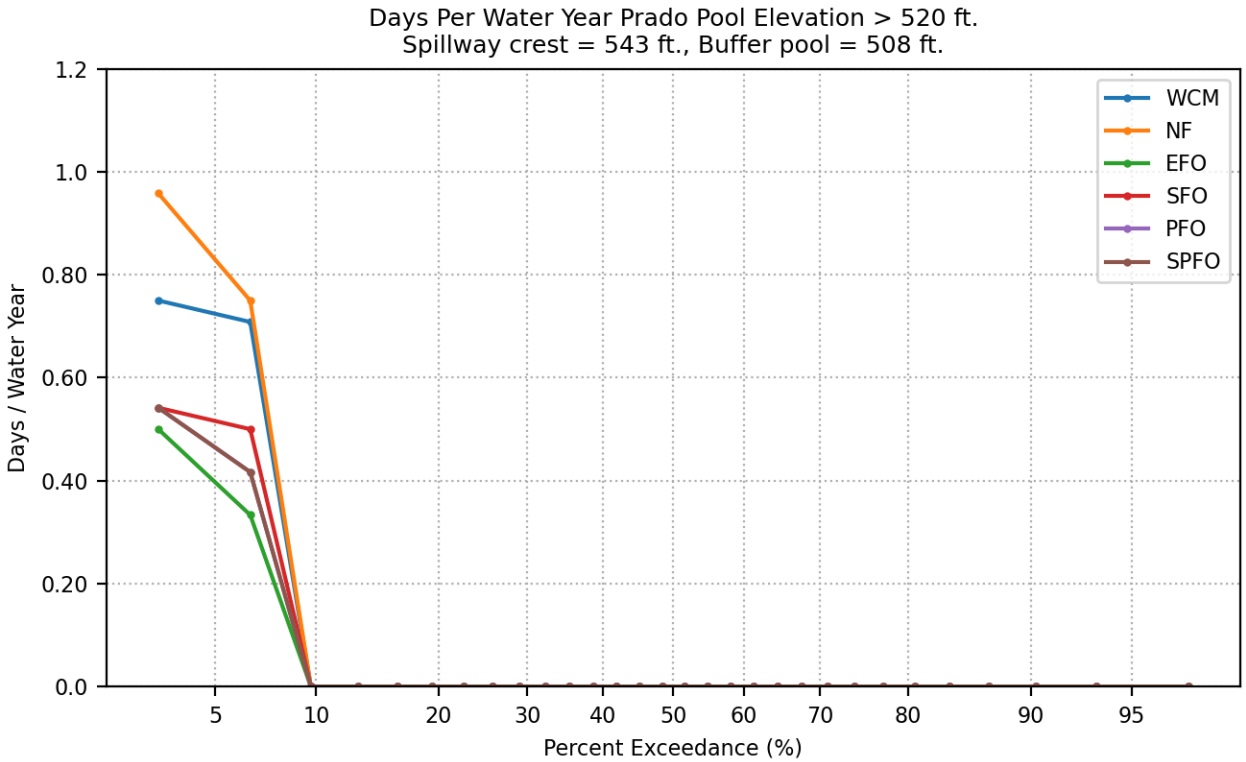

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

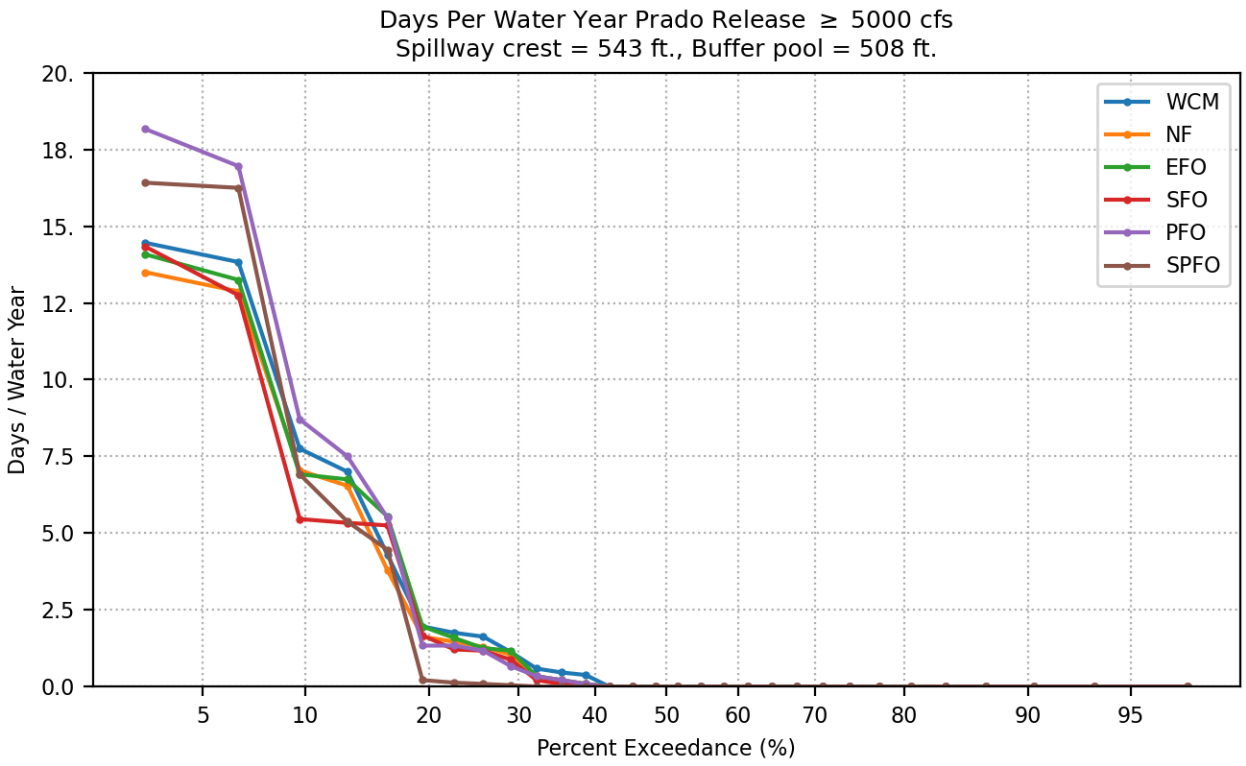

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

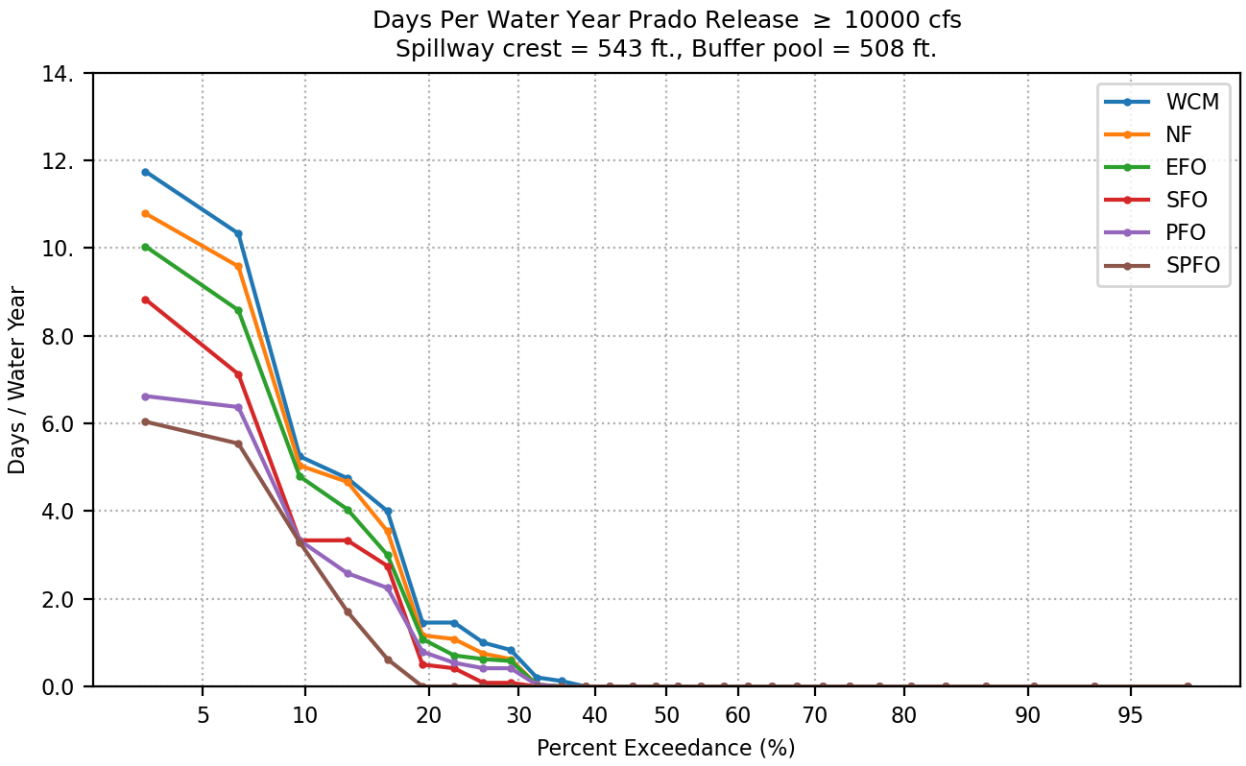

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

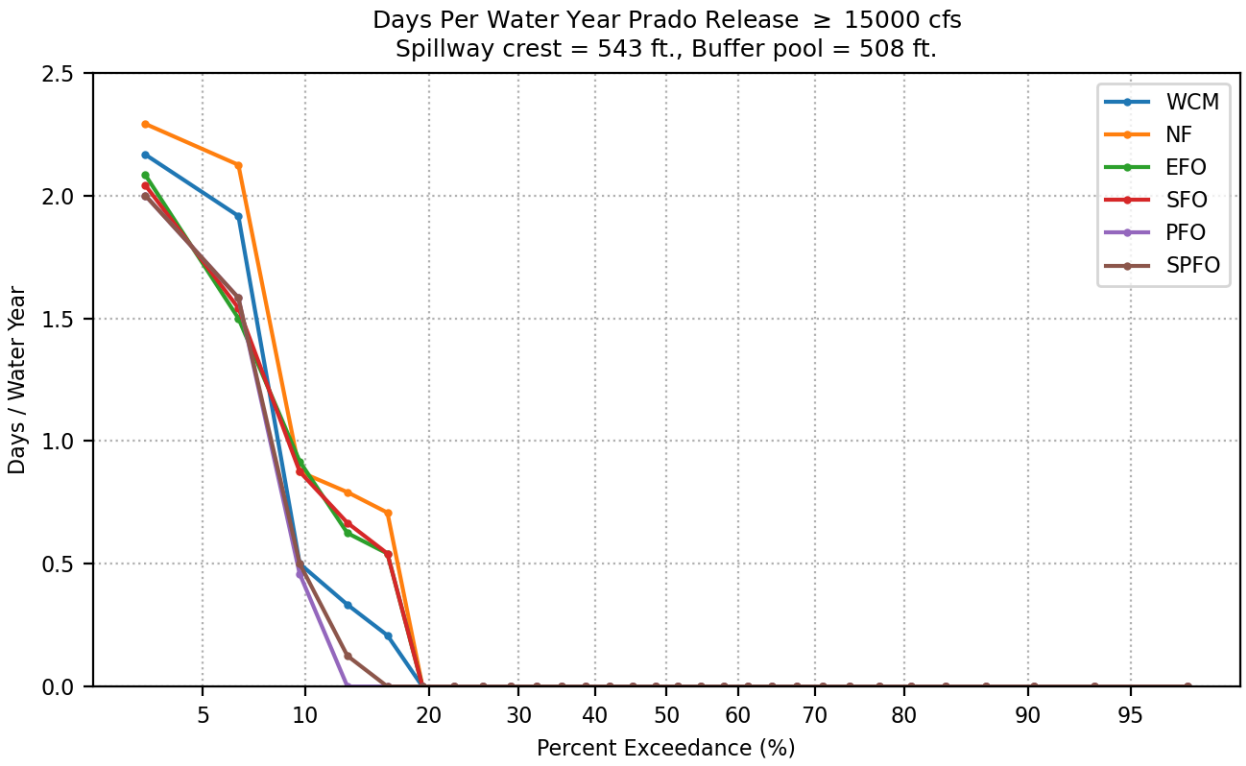

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

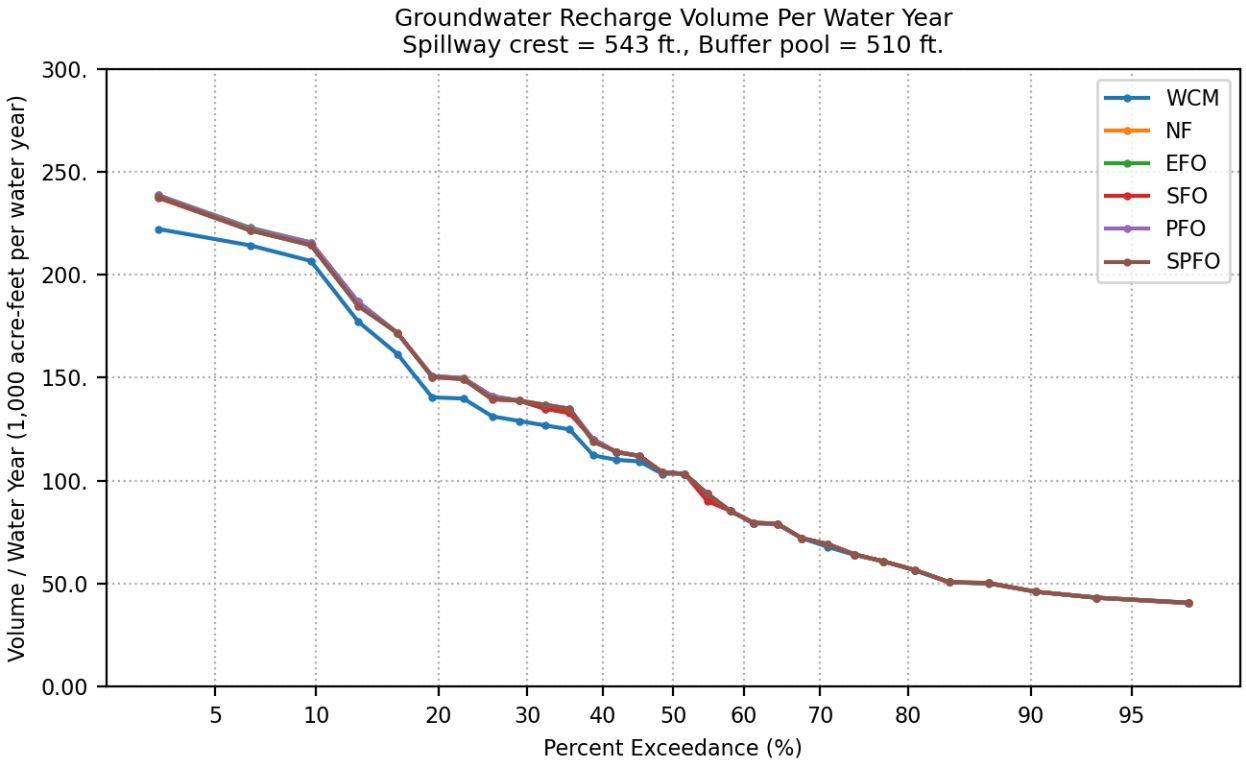

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

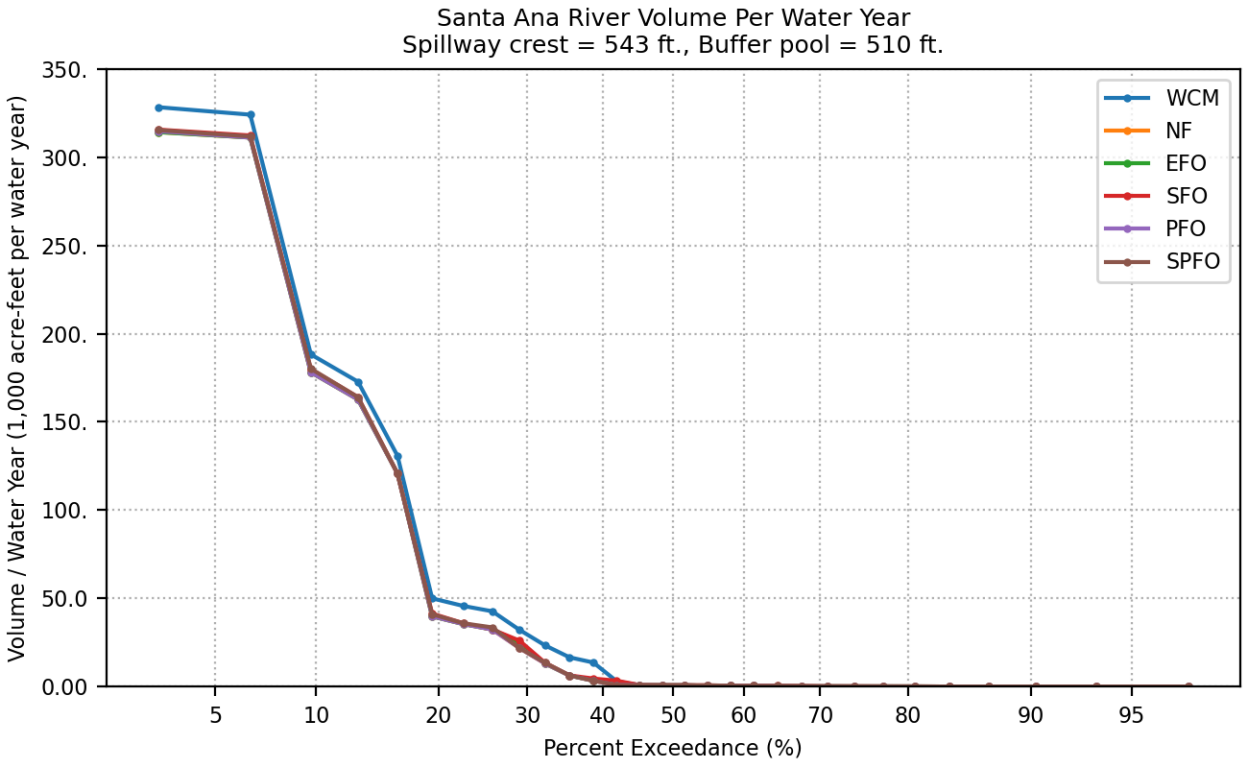

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
1.2
1.0
0.80
0.60
0.40
0.20
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

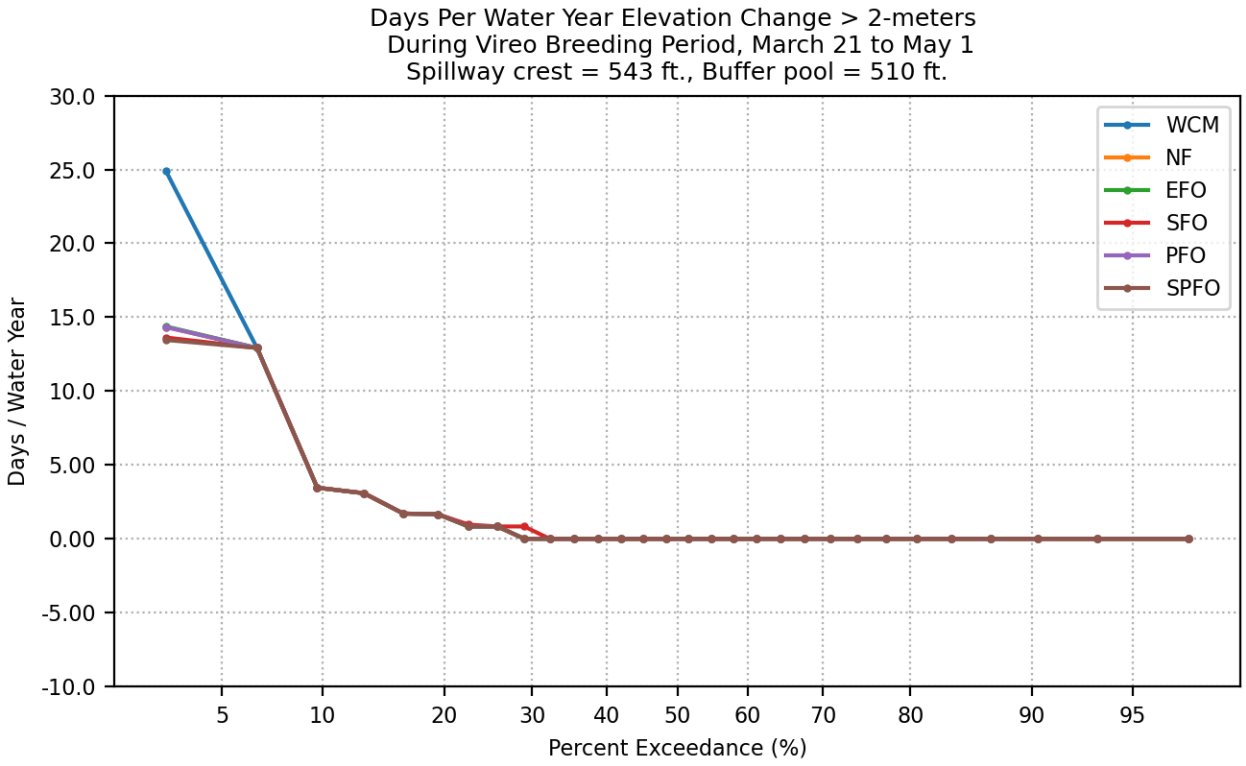

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
20.
18.
15.
12.
10.
7.5
5.0
2.5
0.0
5
10
20
30
40
50
60
70
80
90
95

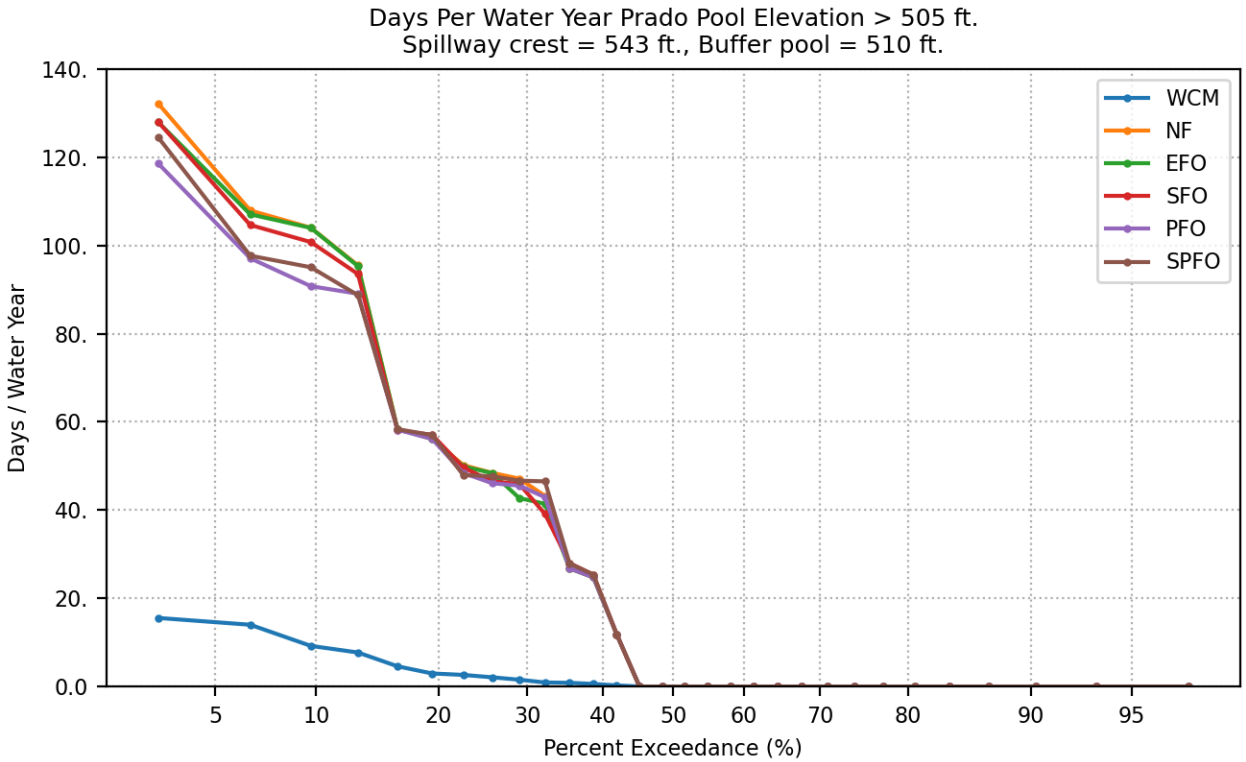

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
0.0
2.0
4.0
6.0
8.0
10.
12.
14.
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

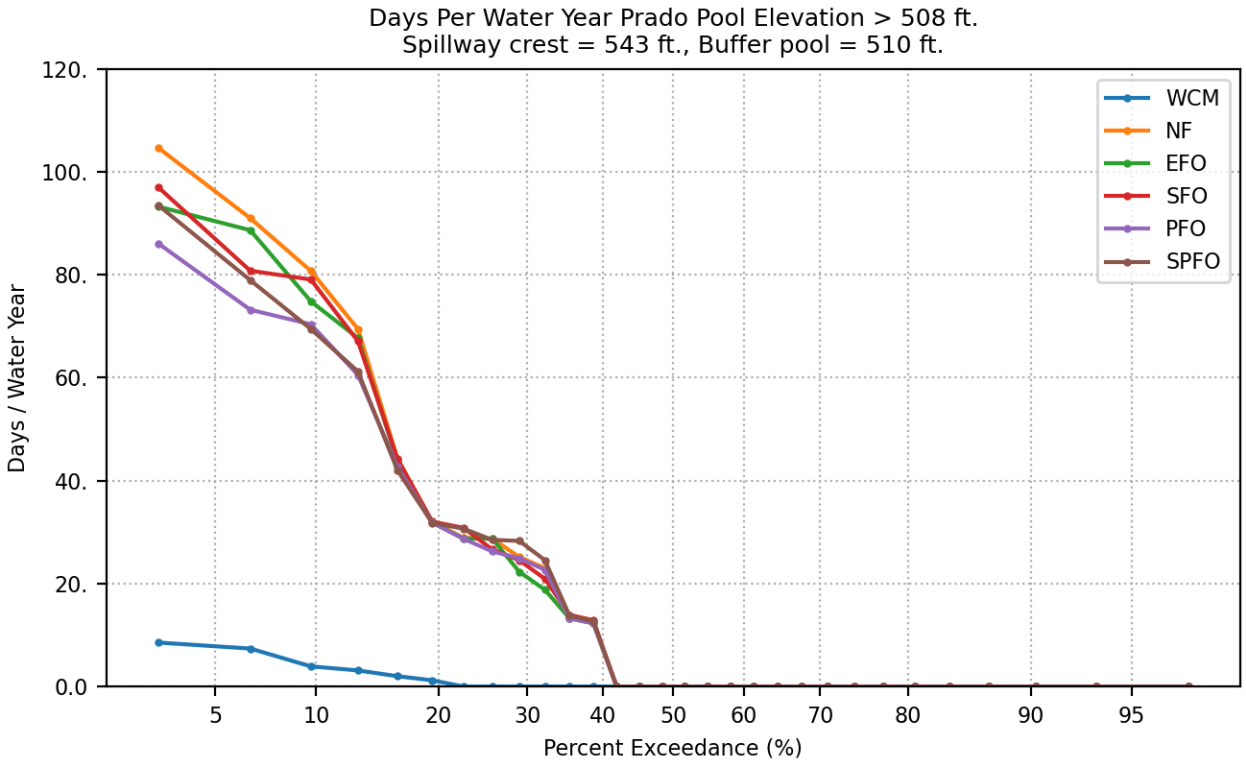

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
0.0
0.5
1.0
1.5
2.0
2.5
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

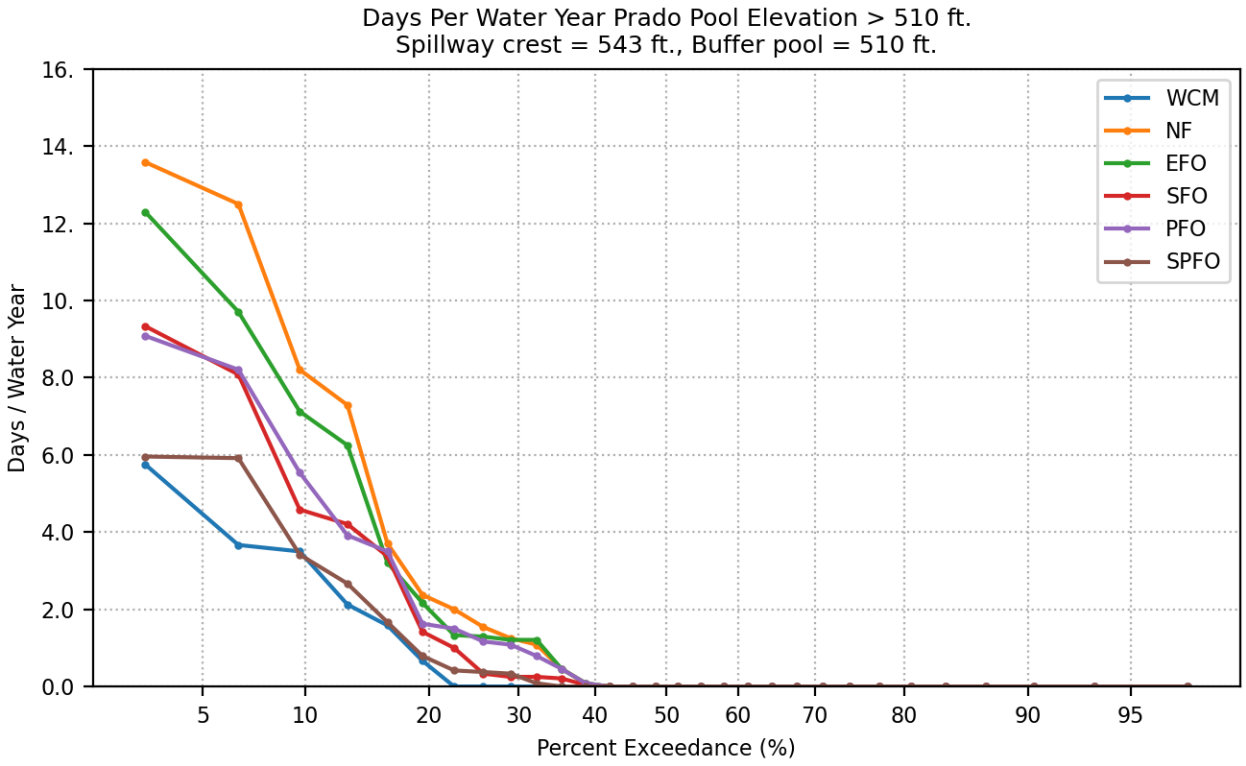

Groundwater Recharge Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 510 ft.
Volume / Water Year (1,000 acre-feet per water year)
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

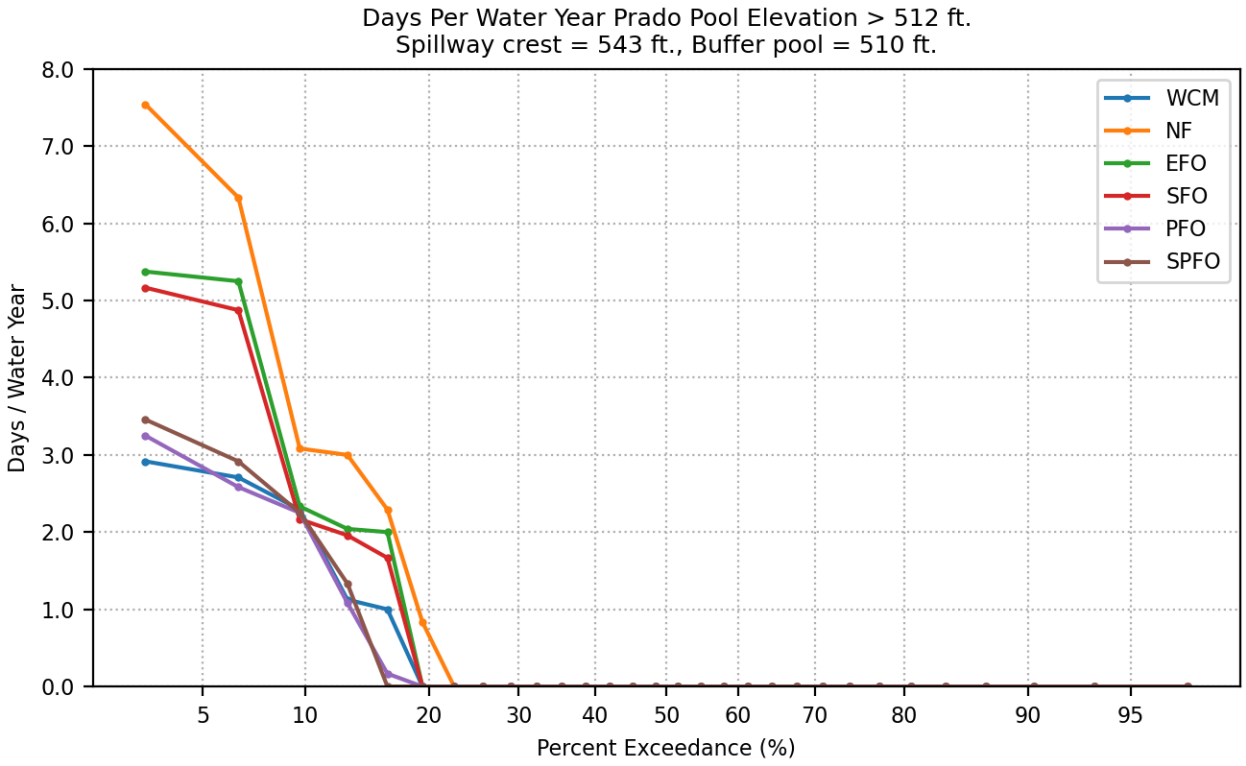

Santa Ana River Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 510 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

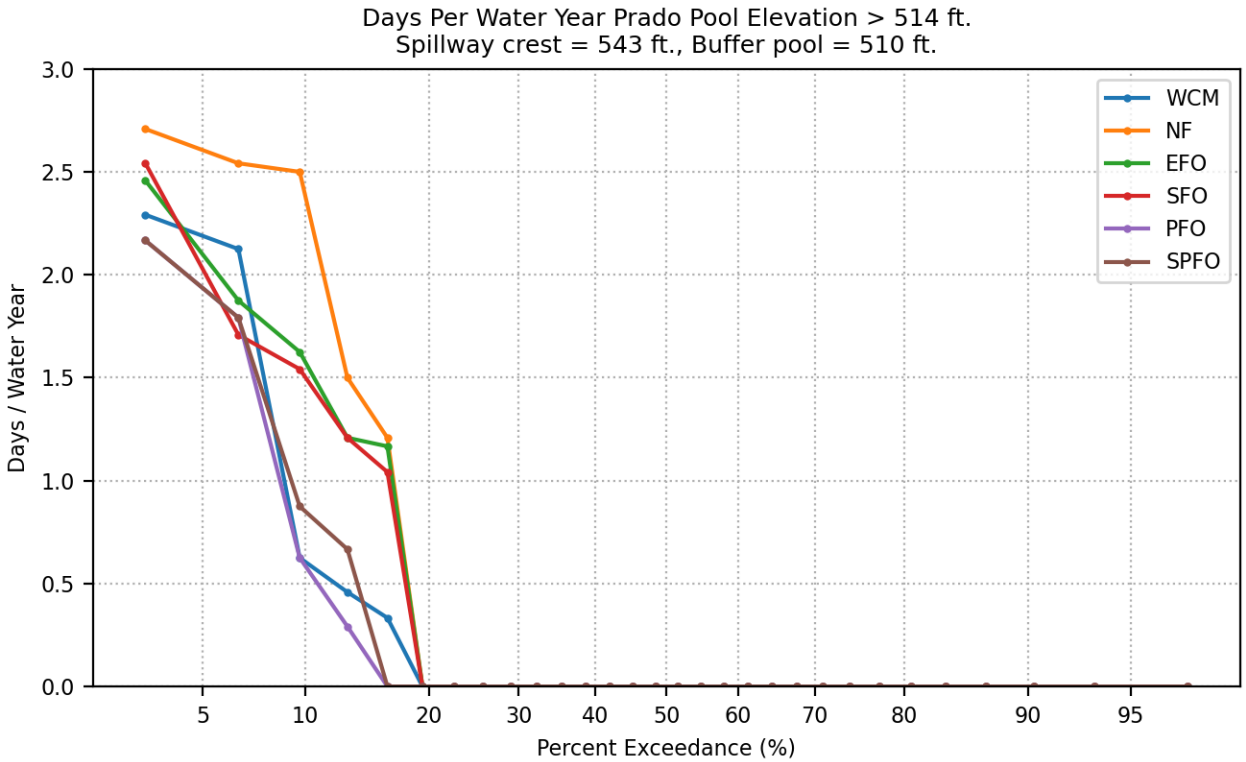

Days Per Water Year Elevation Change > 2-meters
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

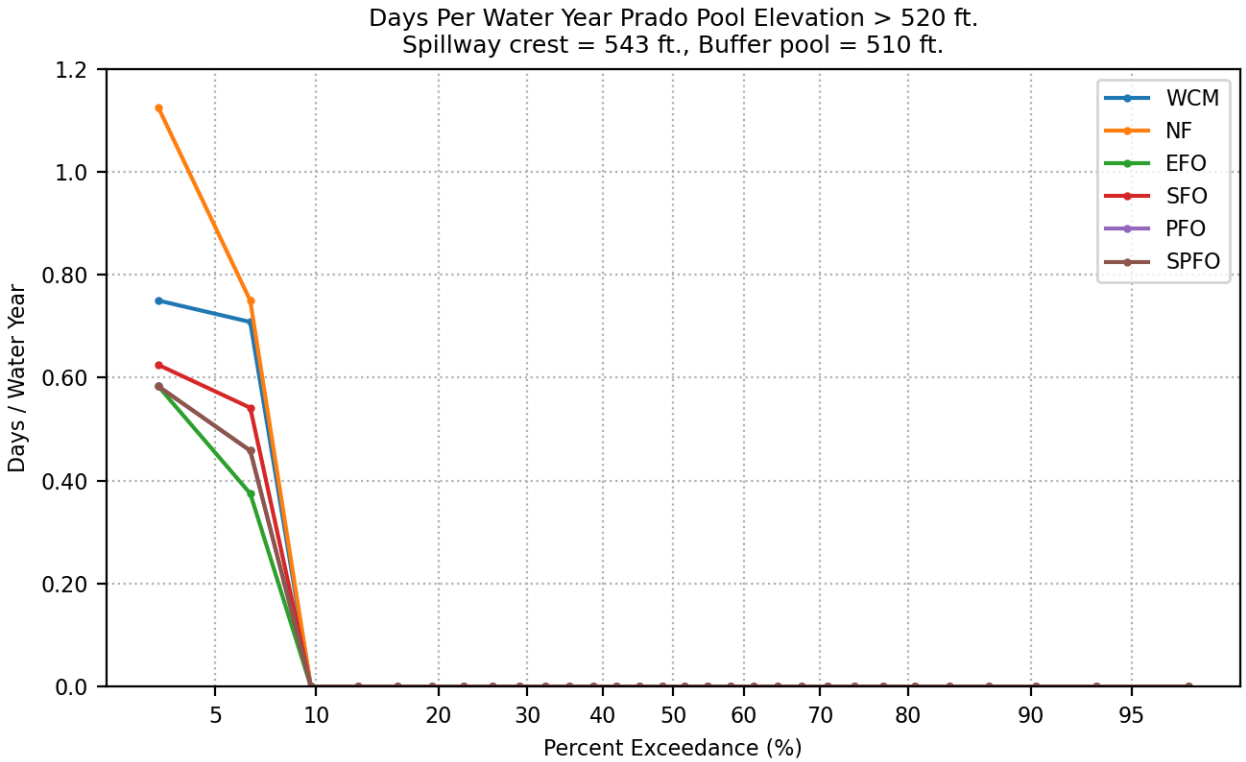

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

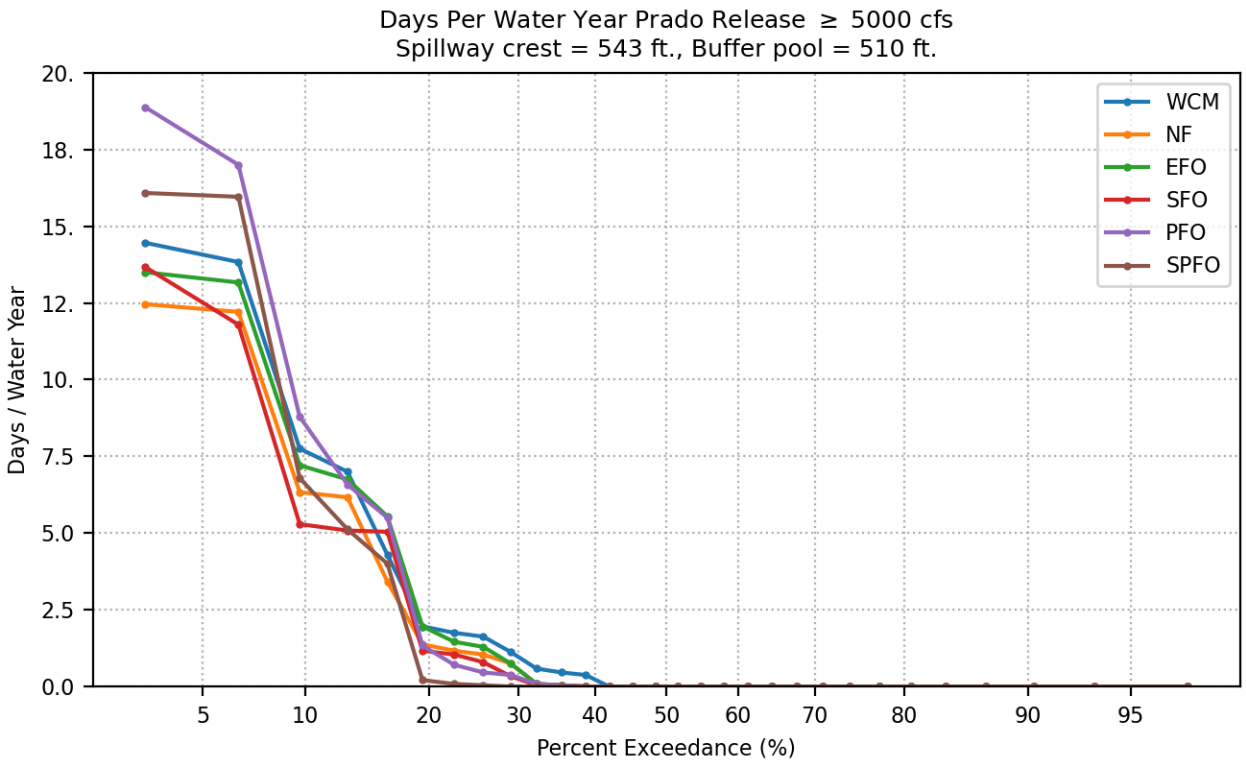

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

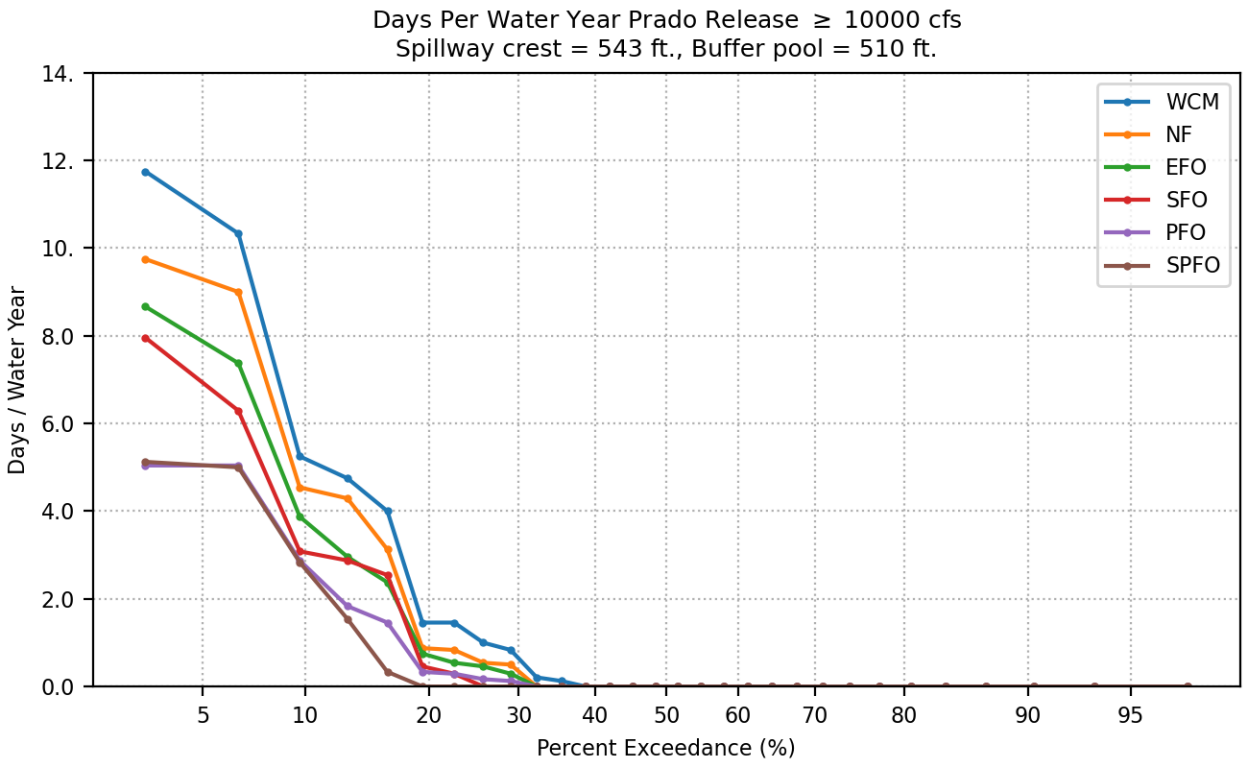

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

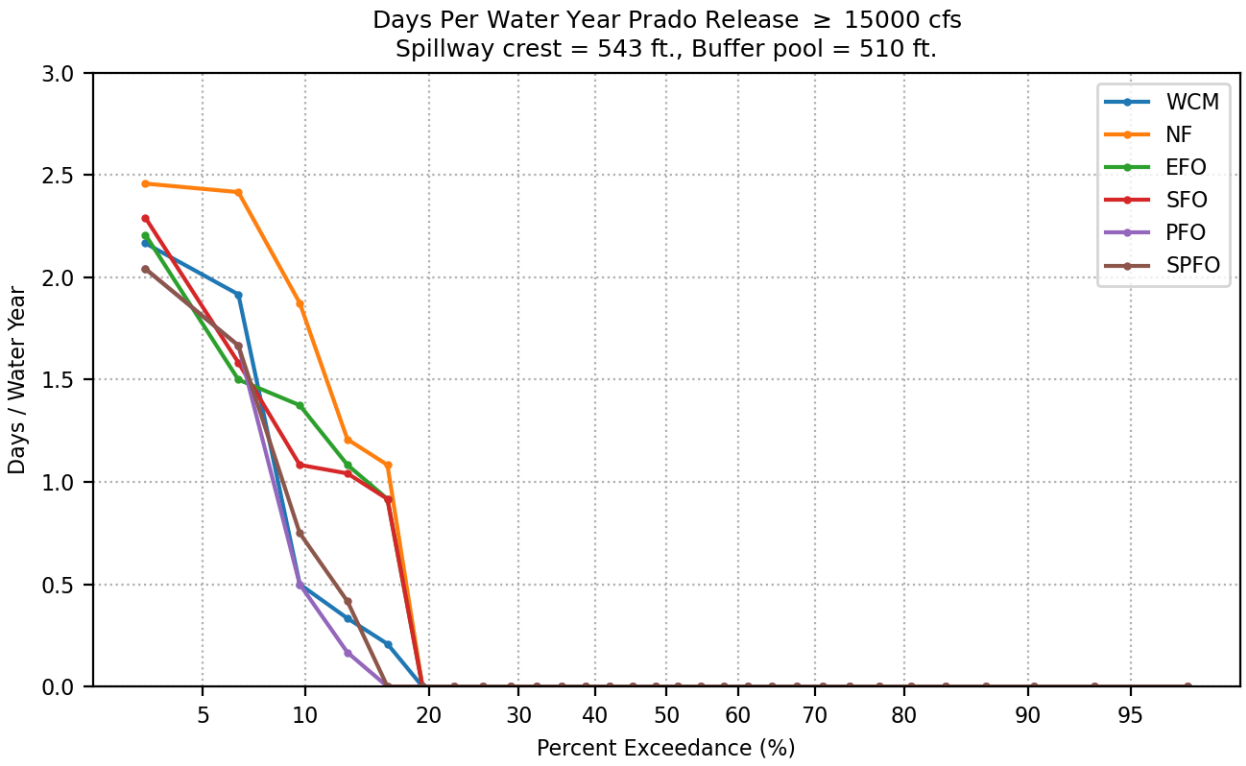

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

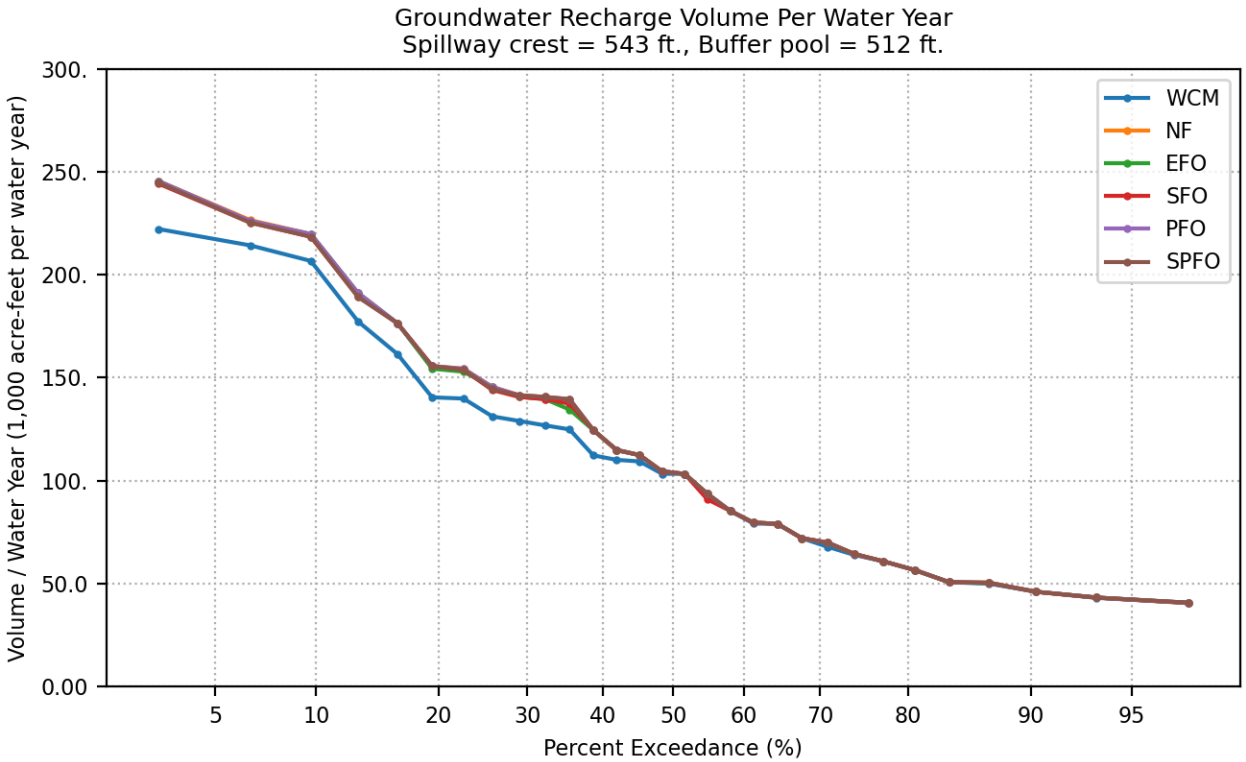

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

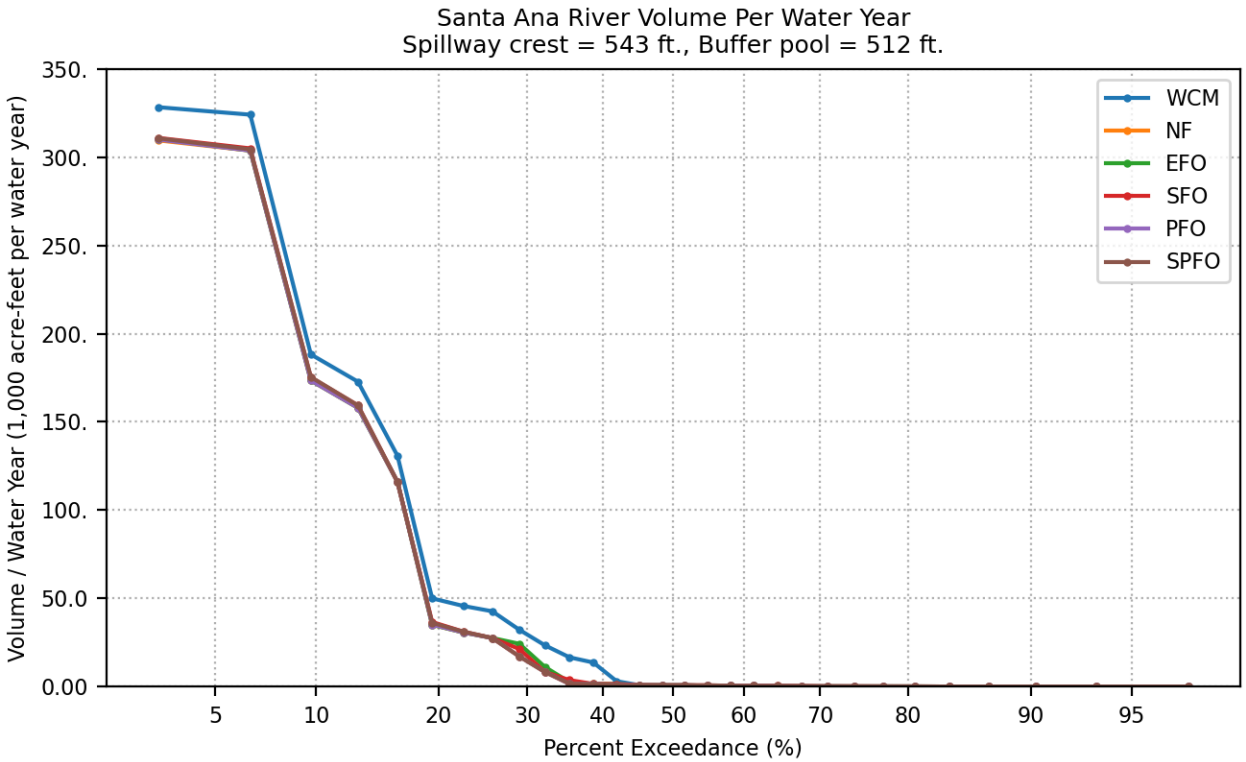

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
1.2
1.0
0.80
0.60
0.40
0.20
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

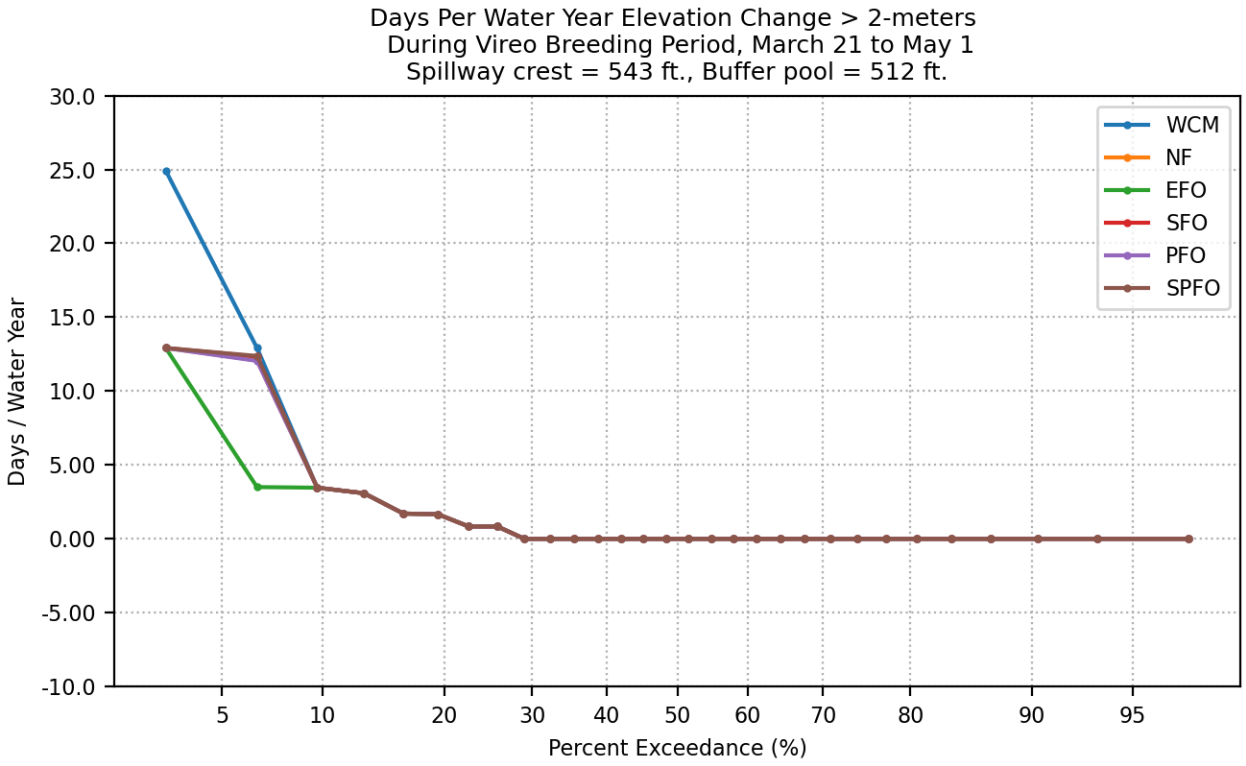

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
20.
18.
15.
12.
10.
7.5
5.0
2.5
0.0
5
10
20
30
40
50
60
70
80
90
95

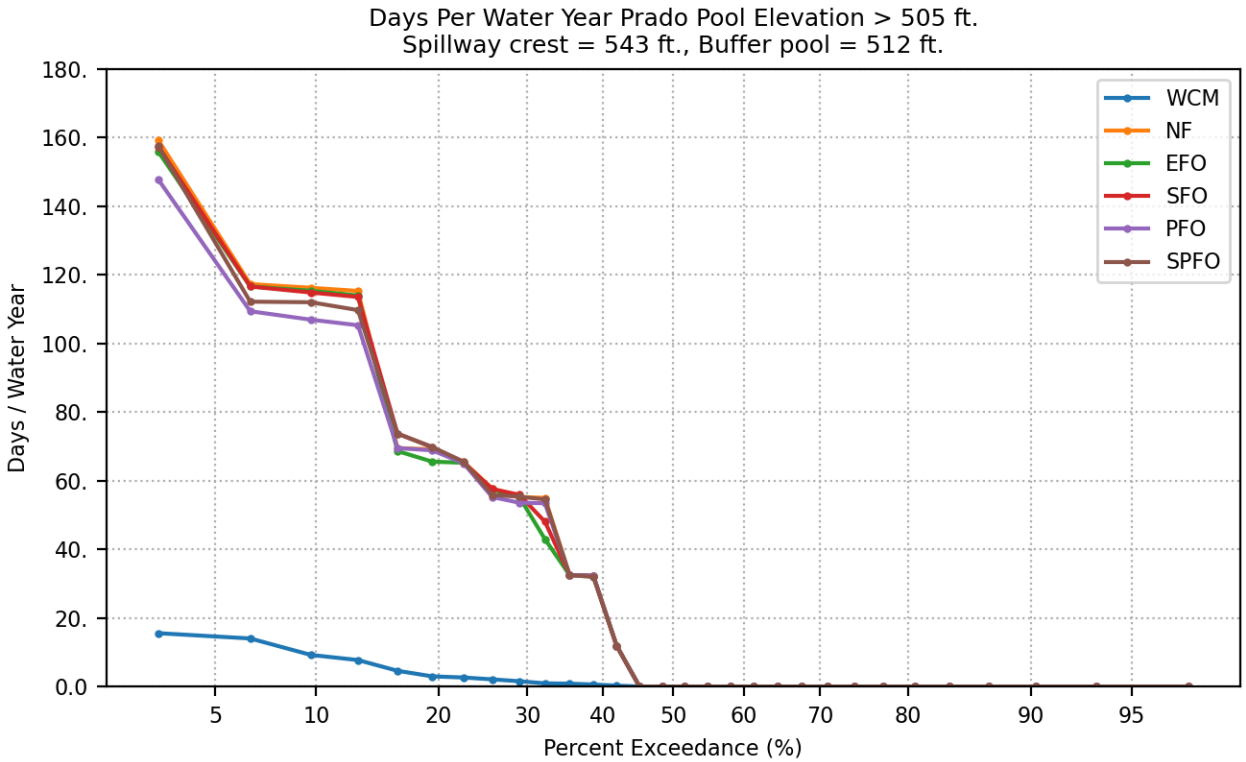

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
0.0
2.0
4.0
6.0
8.0
10.
12.
14.
5
10
20
30
40
50
60
70
80
90
95

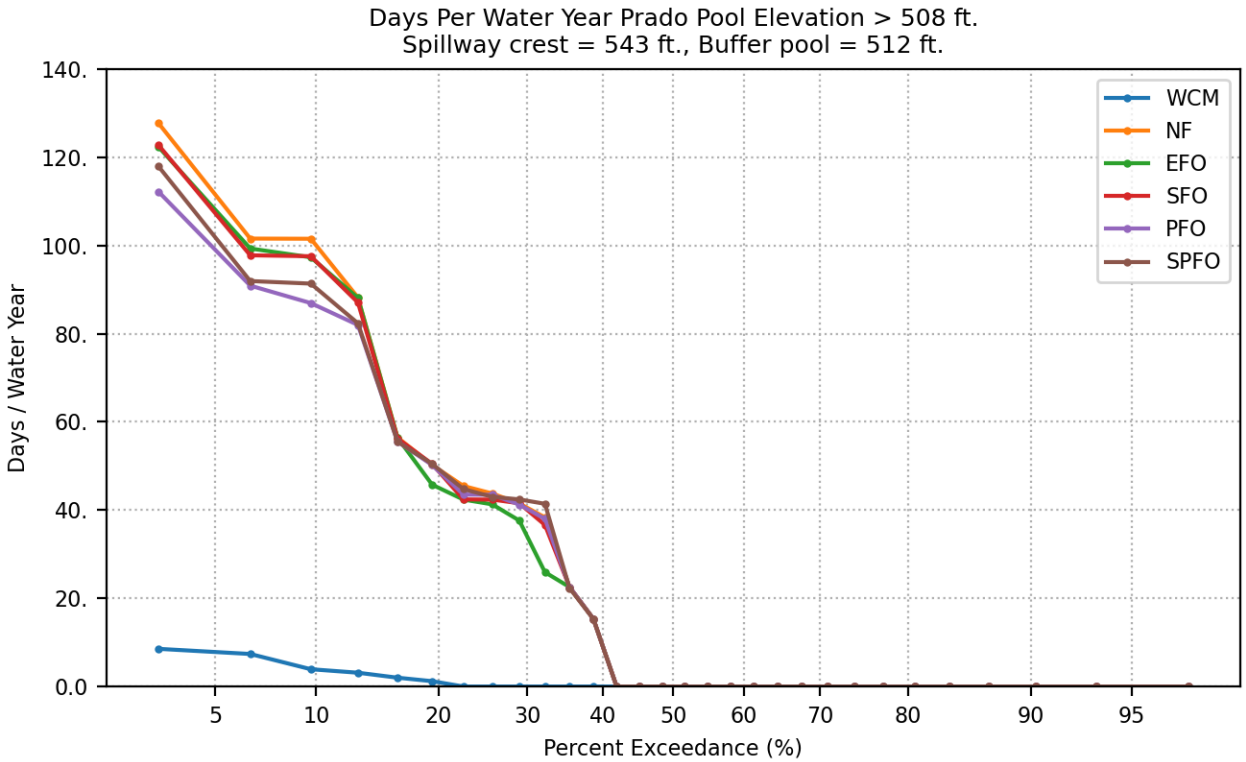

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

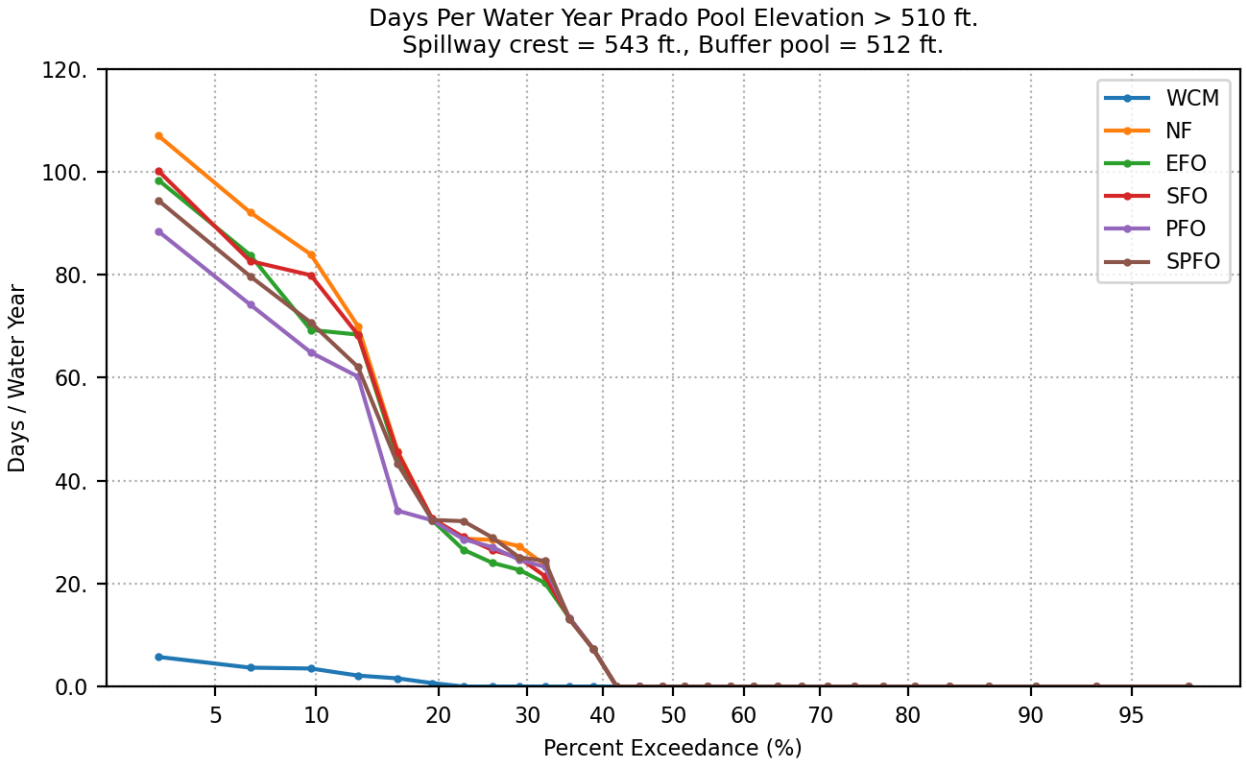

Groundwater Recharge Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 512 ft.
Volume / Water Year (1,000 acre-feet per water year)
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

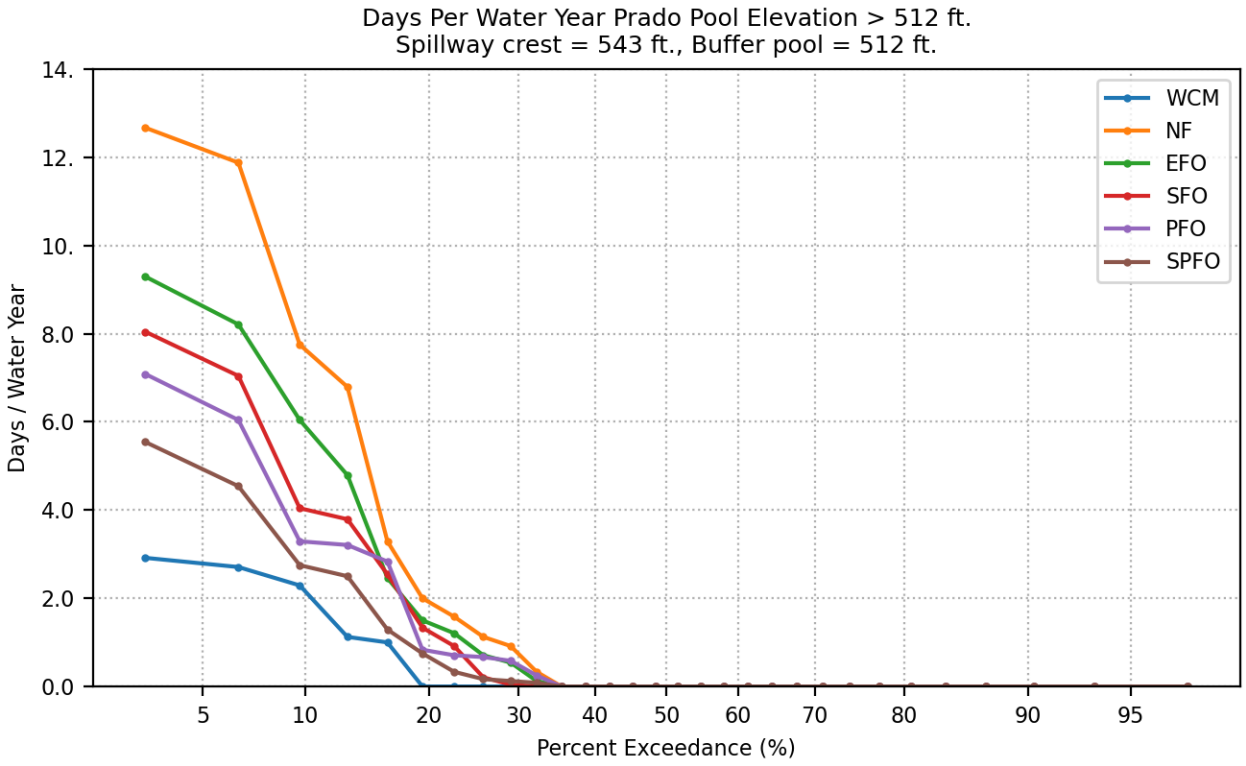

Santa Ana River Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 512 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

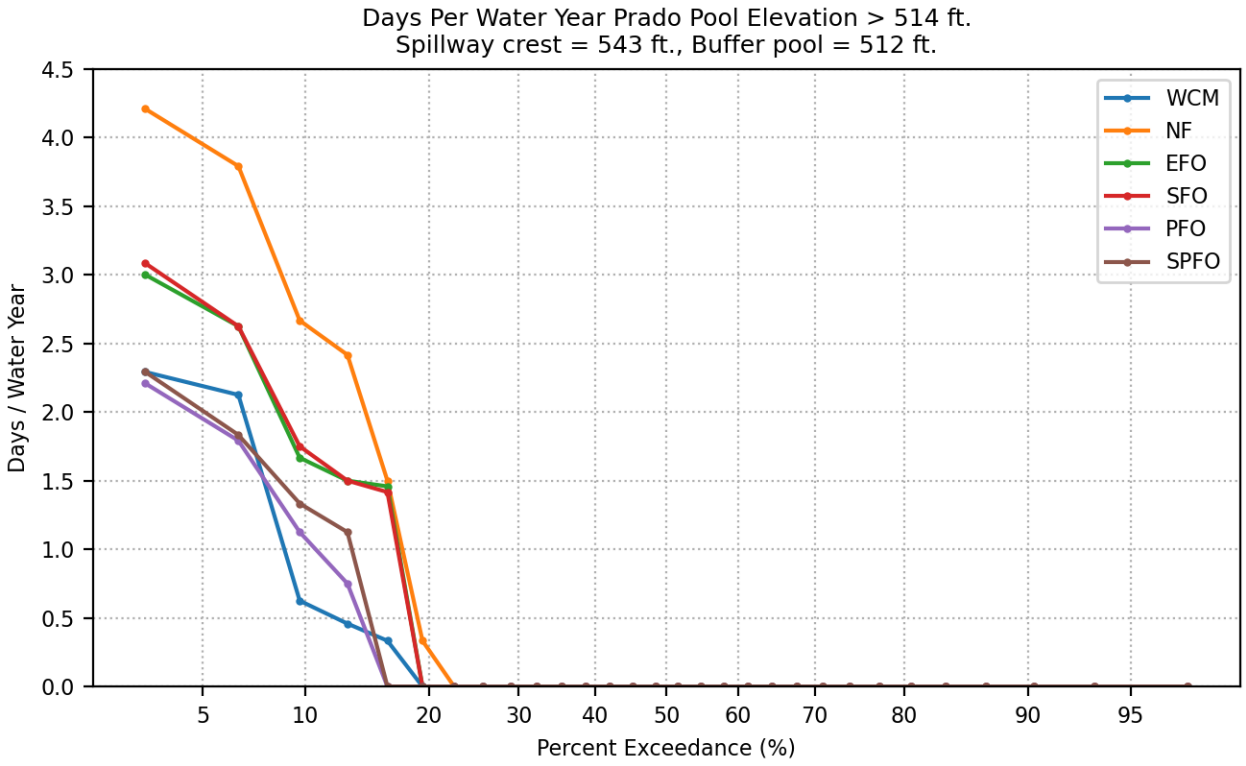

Days Per Water Year Elevation Change > 2-meters
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

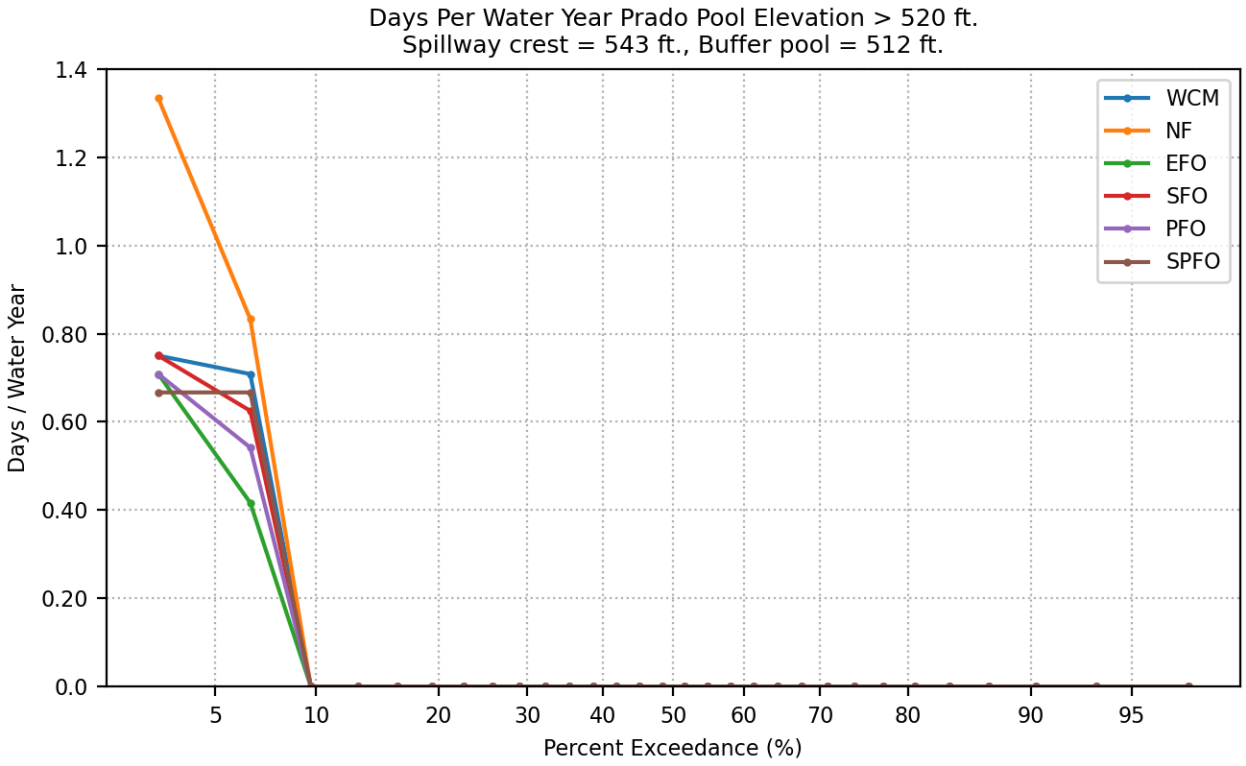

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
180.
160.
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

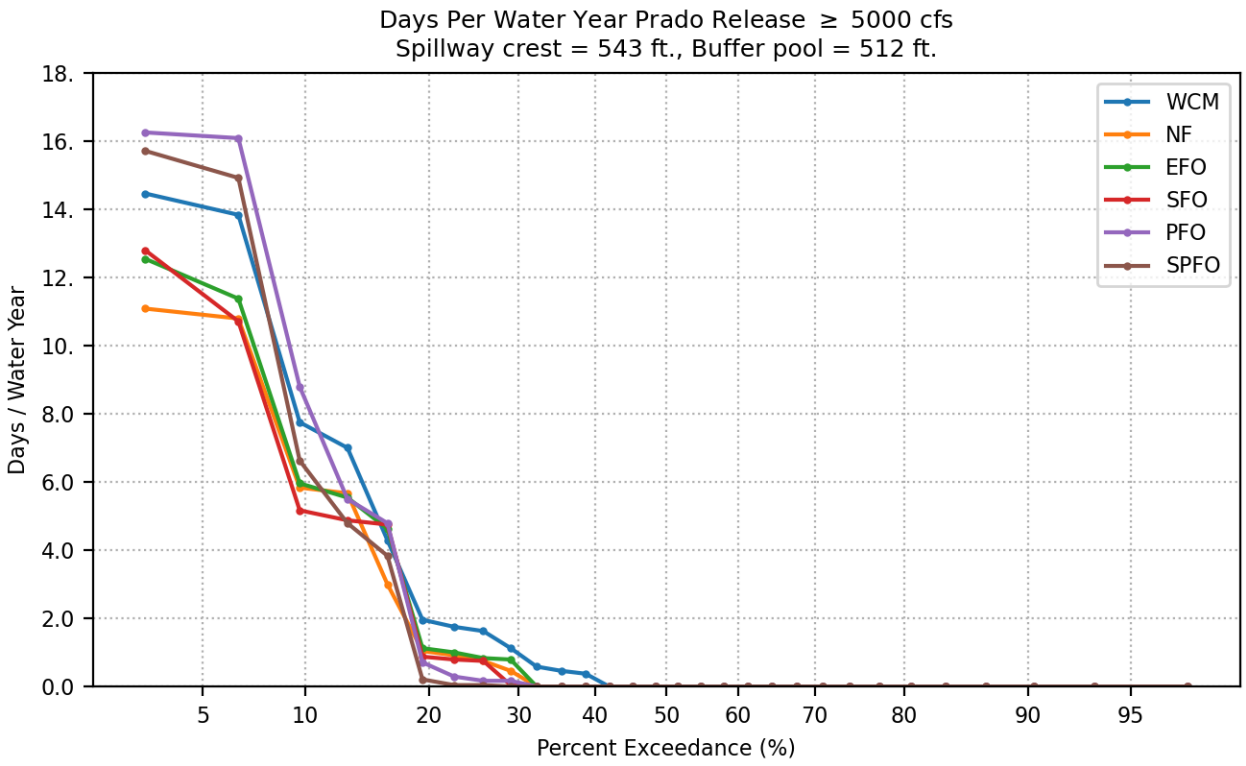

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

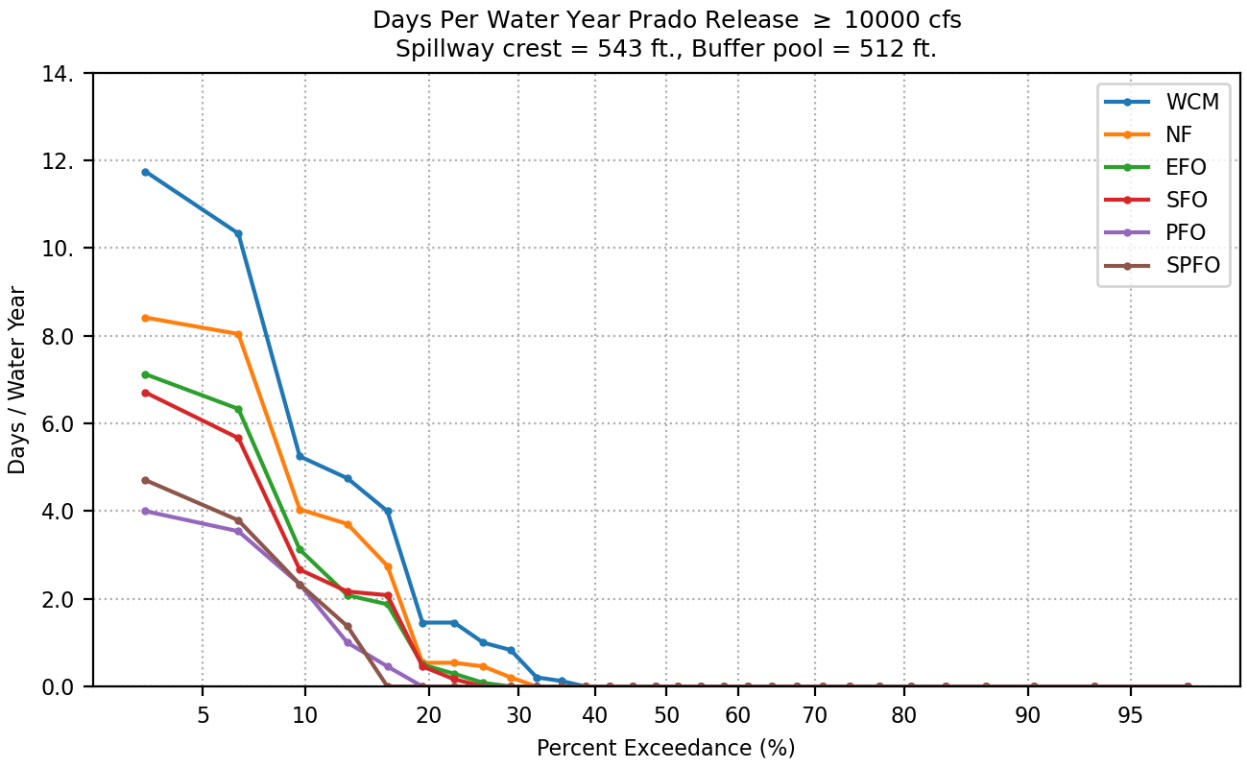

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

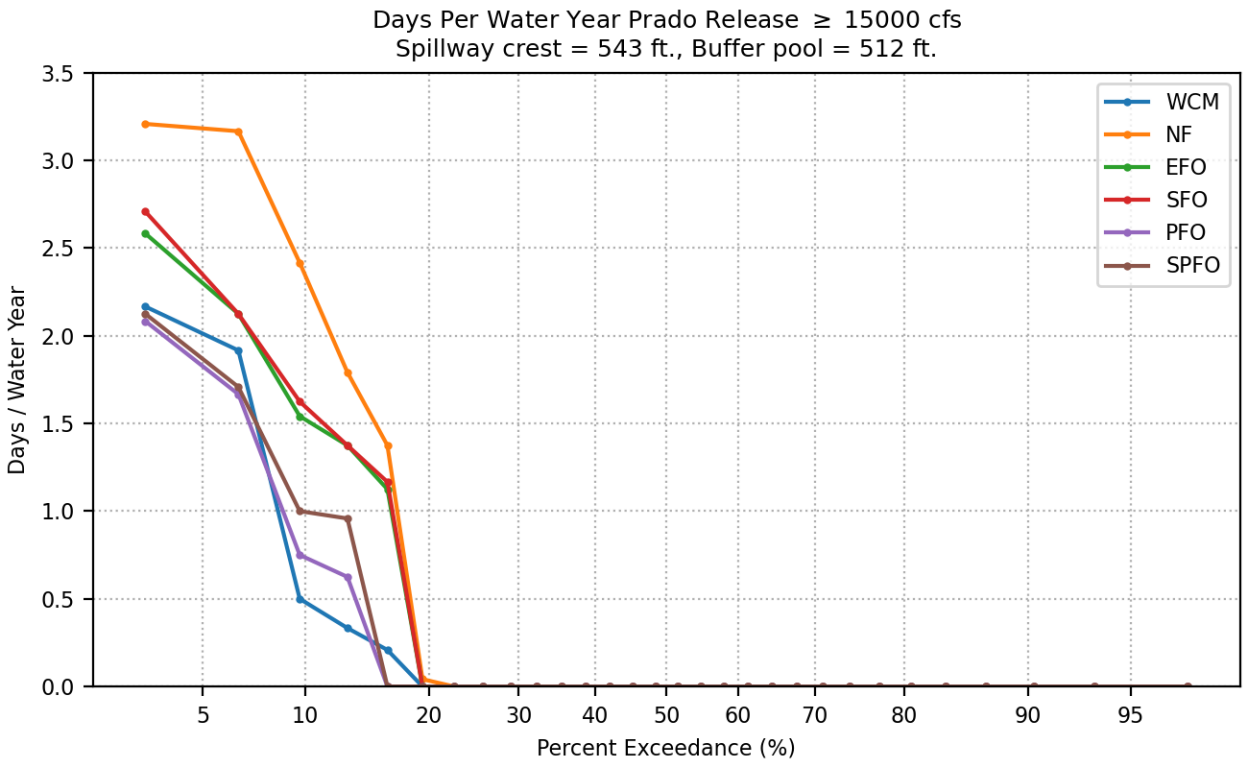

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
0.0
2.0
4.0
6.0
8.0
10.
12.
14.
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

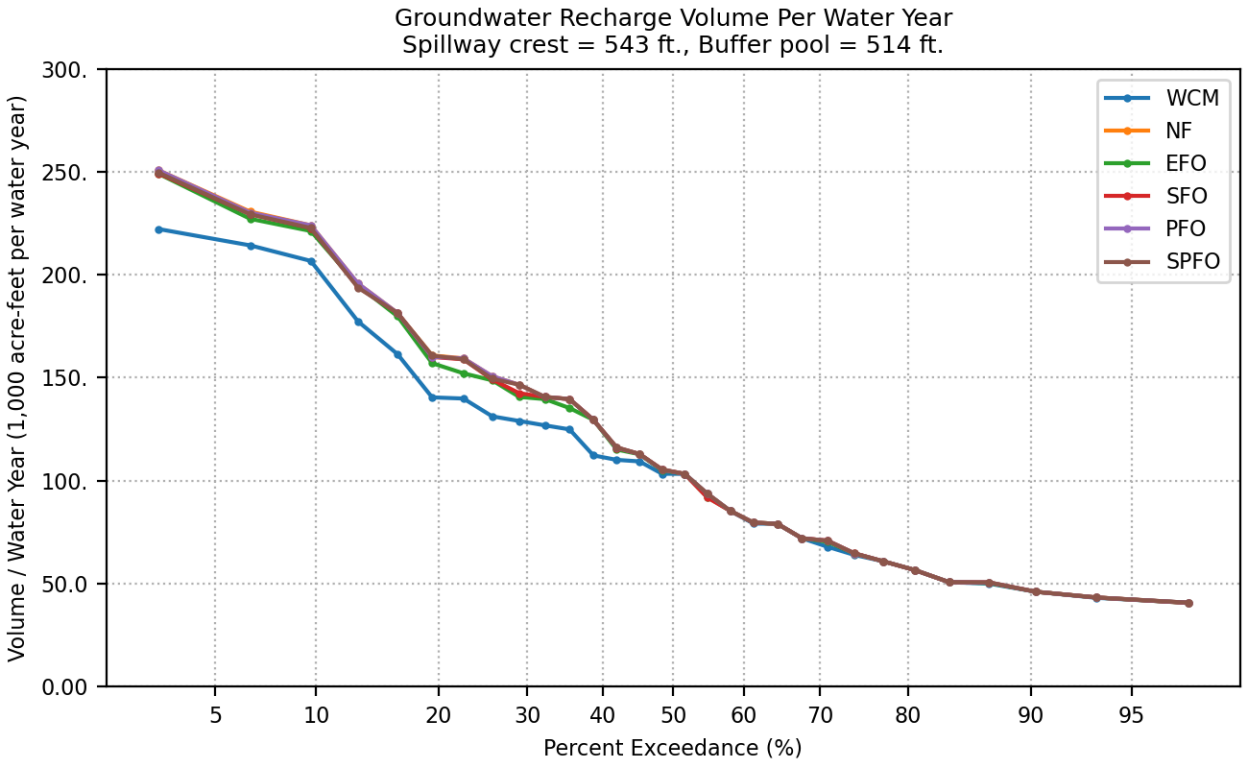

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5
10
20
30
40
50
60
70
80
90
95

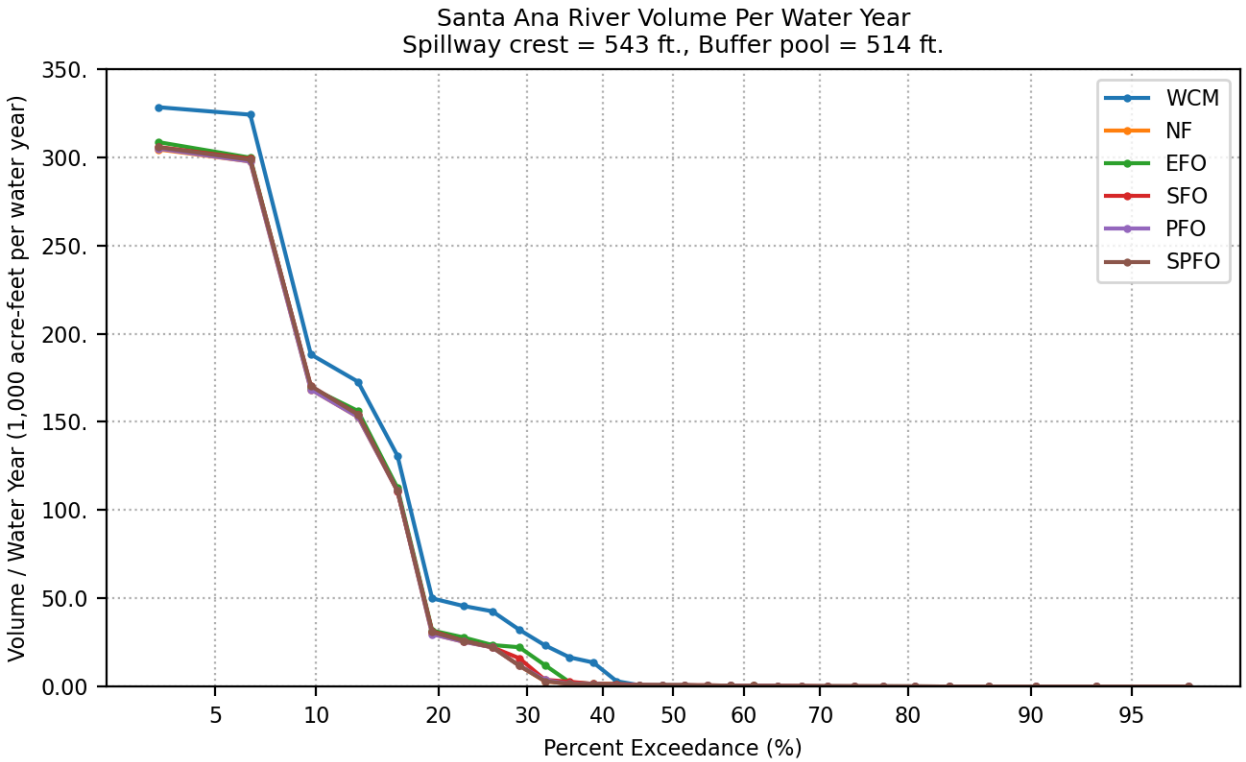

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
1.4
1.2
1.0
0.80
0.60
0.40
0.20
0.0
5
10
20
30
40
50
60
70
80
90
95

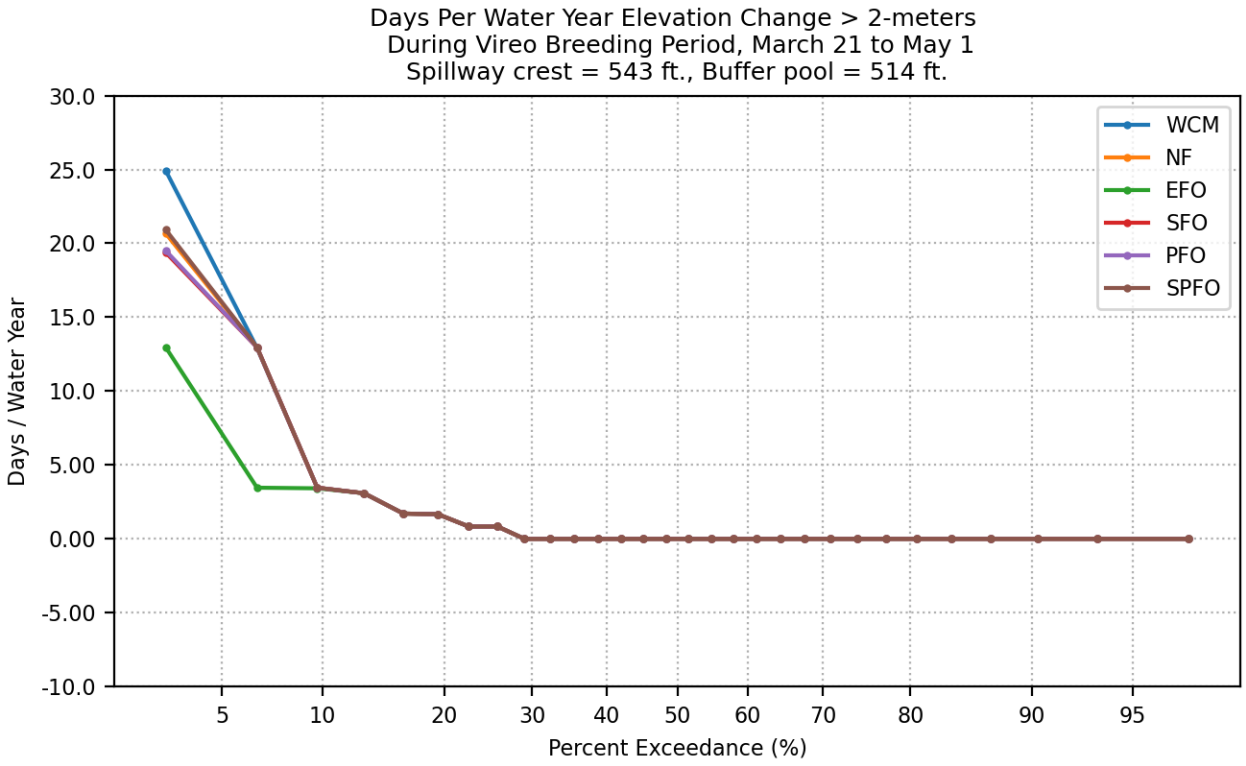

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
18.
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

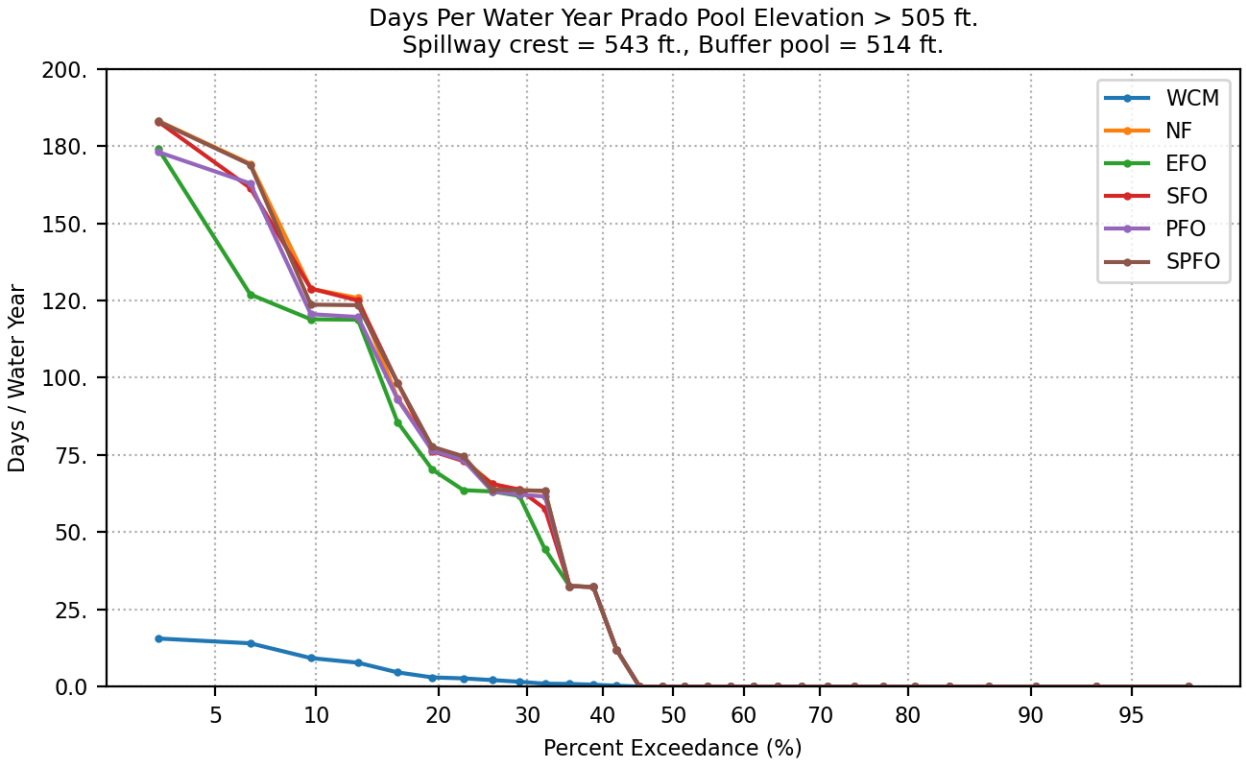

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
0.0
2.0
4.0
6.0
8.0
10.
12.
14.
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

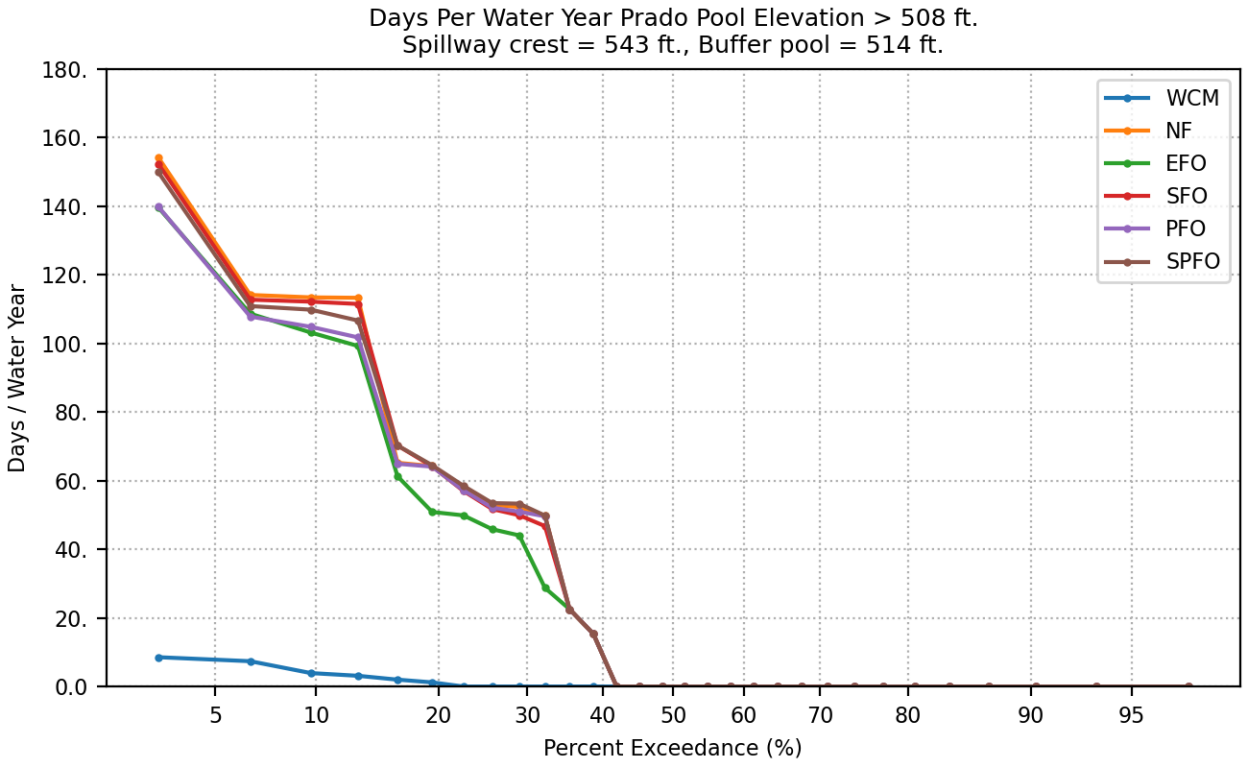

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

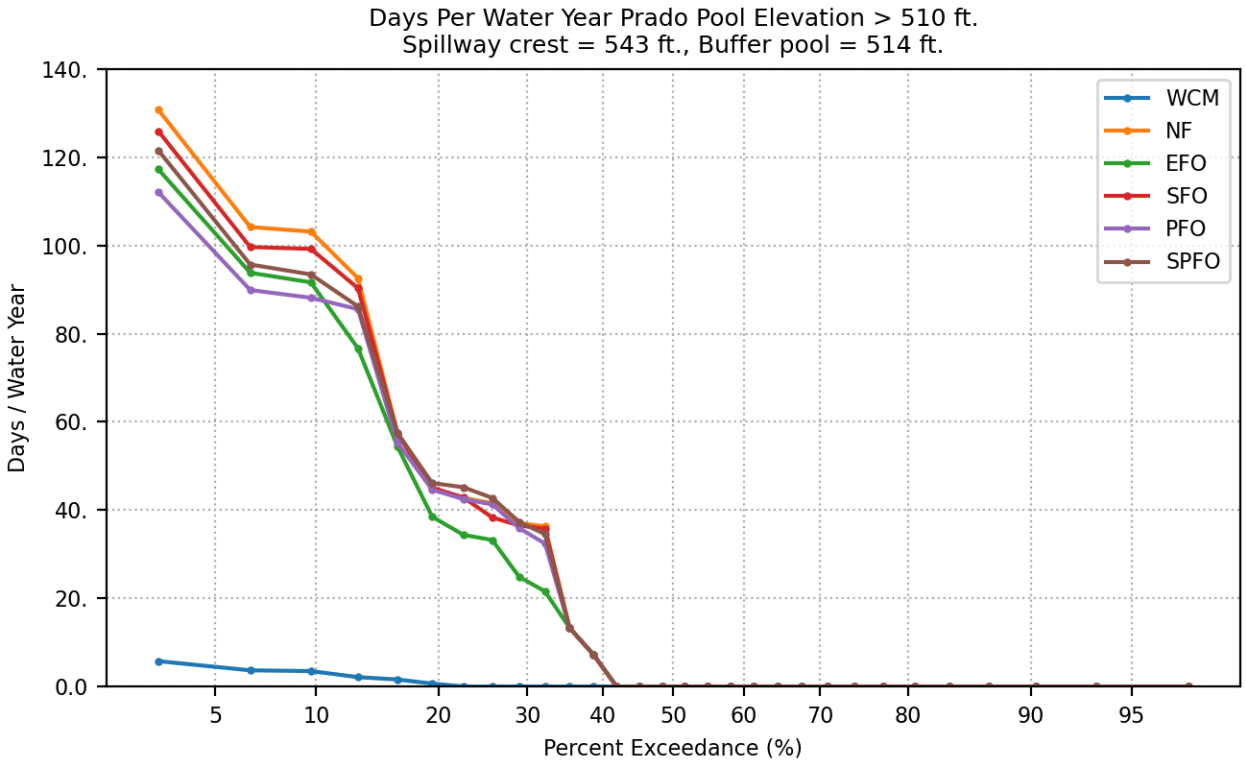

Groundwater Recharge Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 514 ft.
Volume / Water Year (1,000 acre-feet per water year)
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

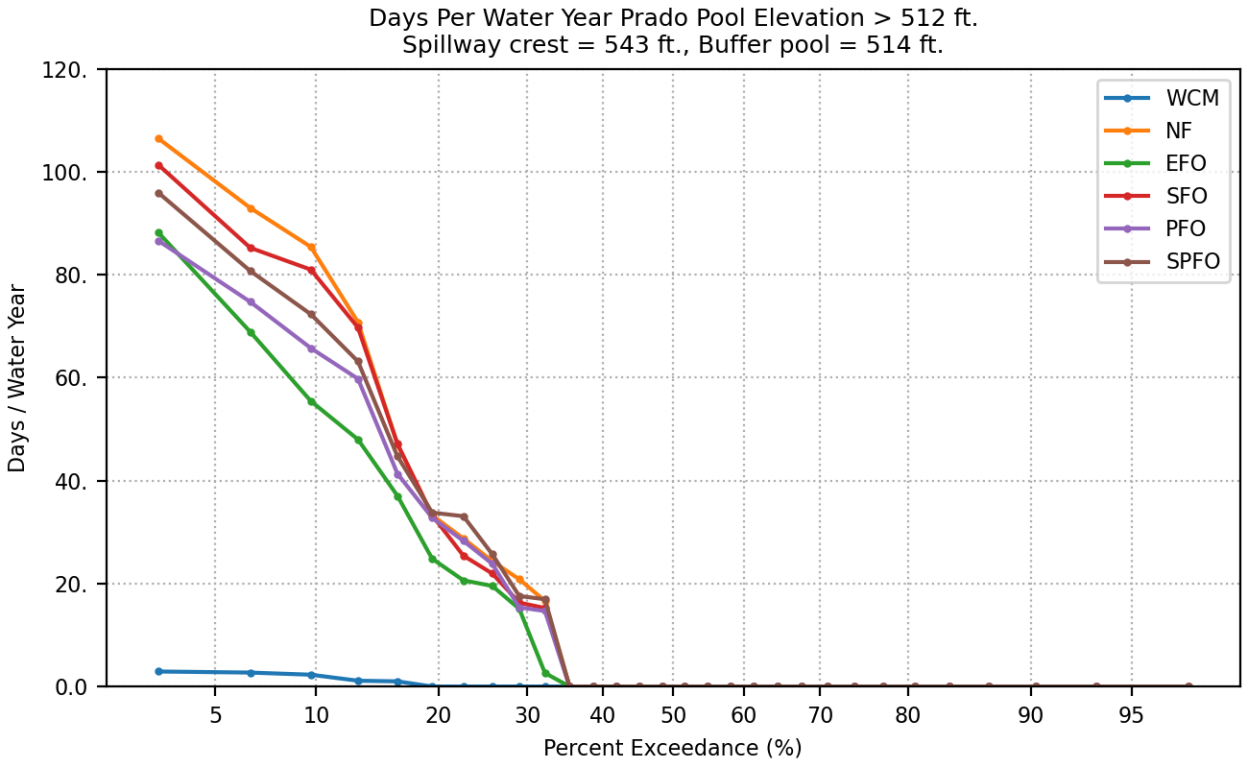

Santa Ana River Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 514 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

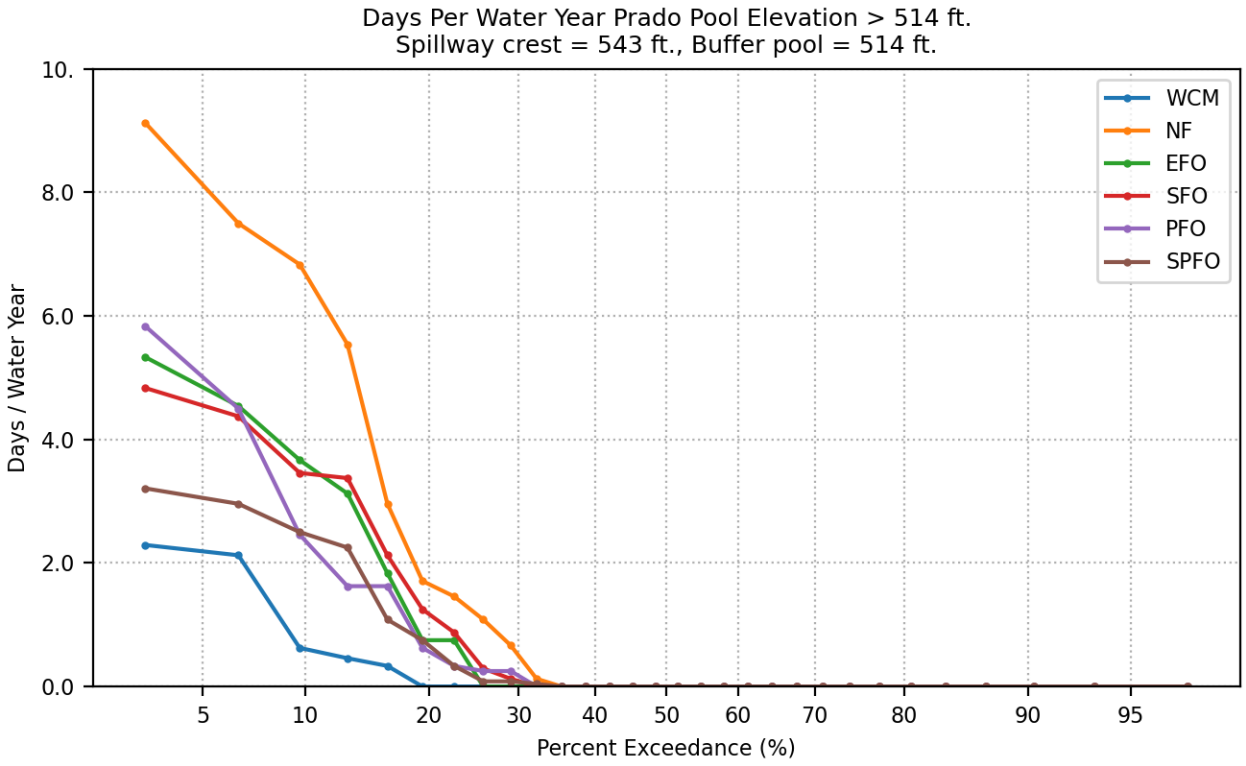

Days Per Water Year Elevation Change > 2-meters
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

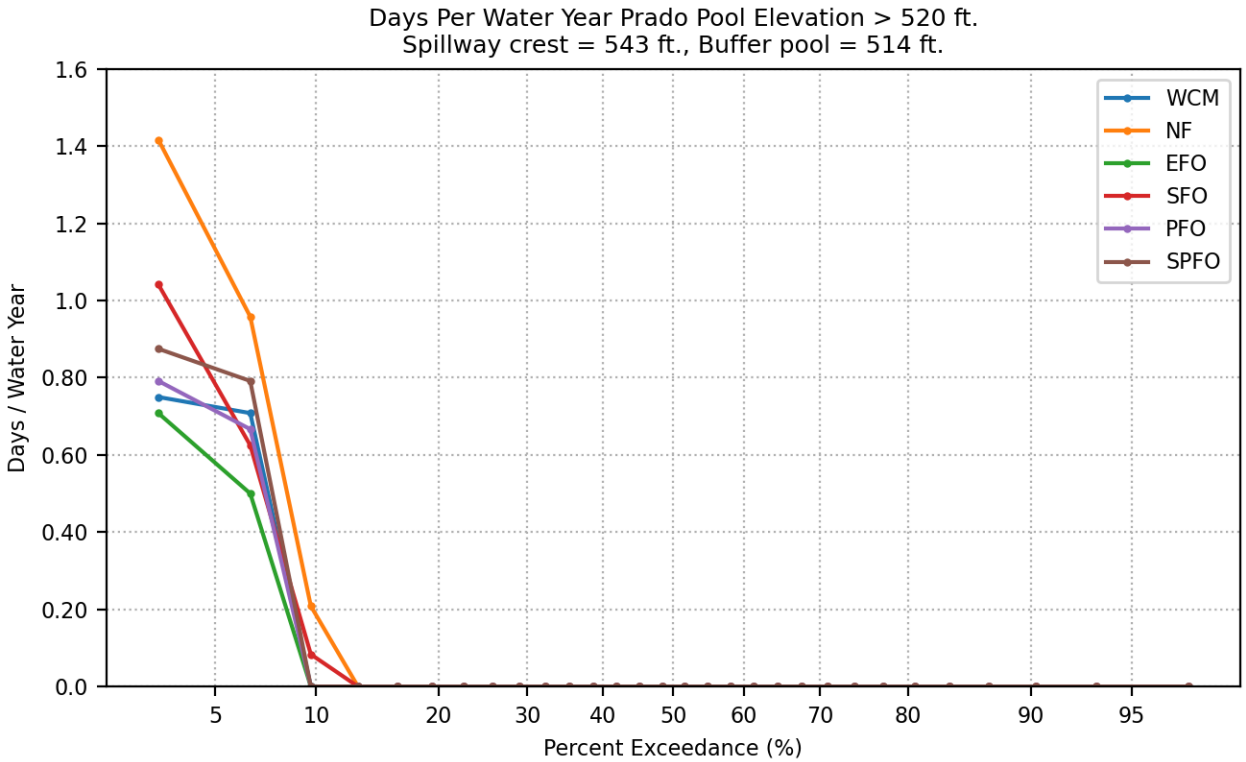

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
200.
180.
150.
120.
100.
75.
50.
25.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

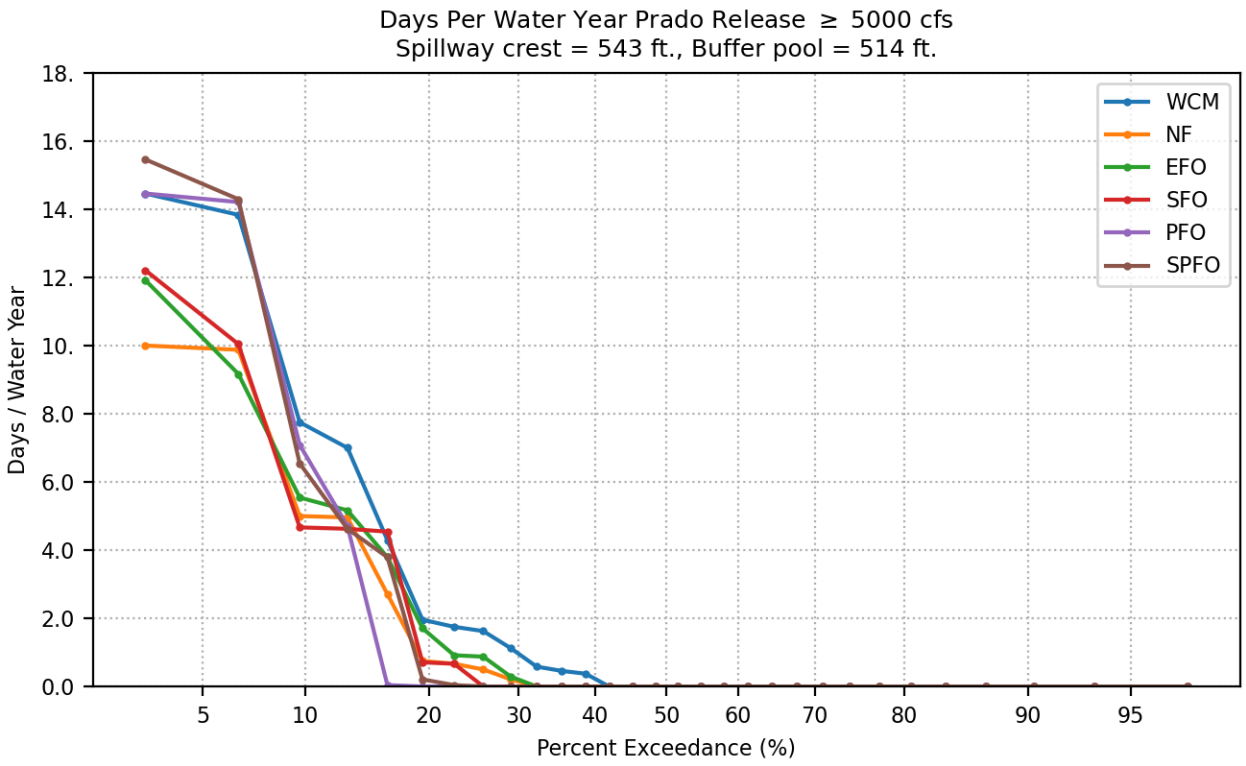

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
180.
160.
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

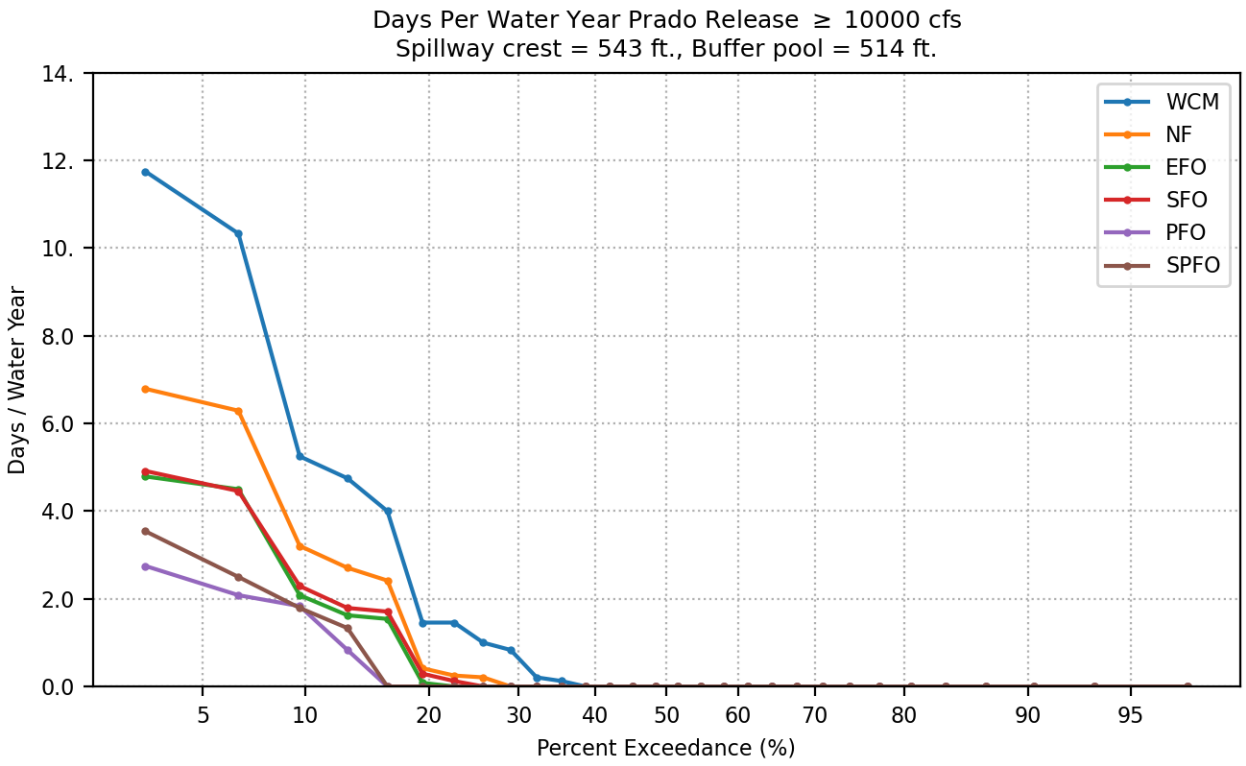

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

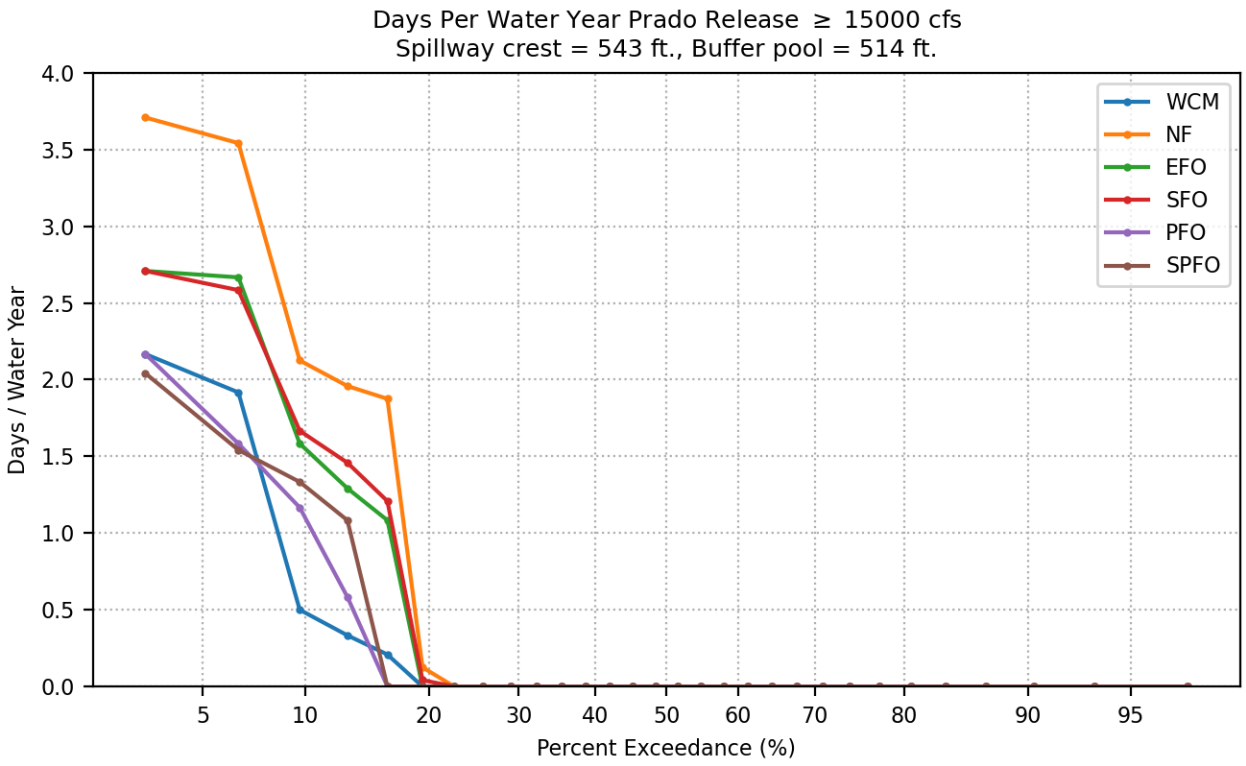

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

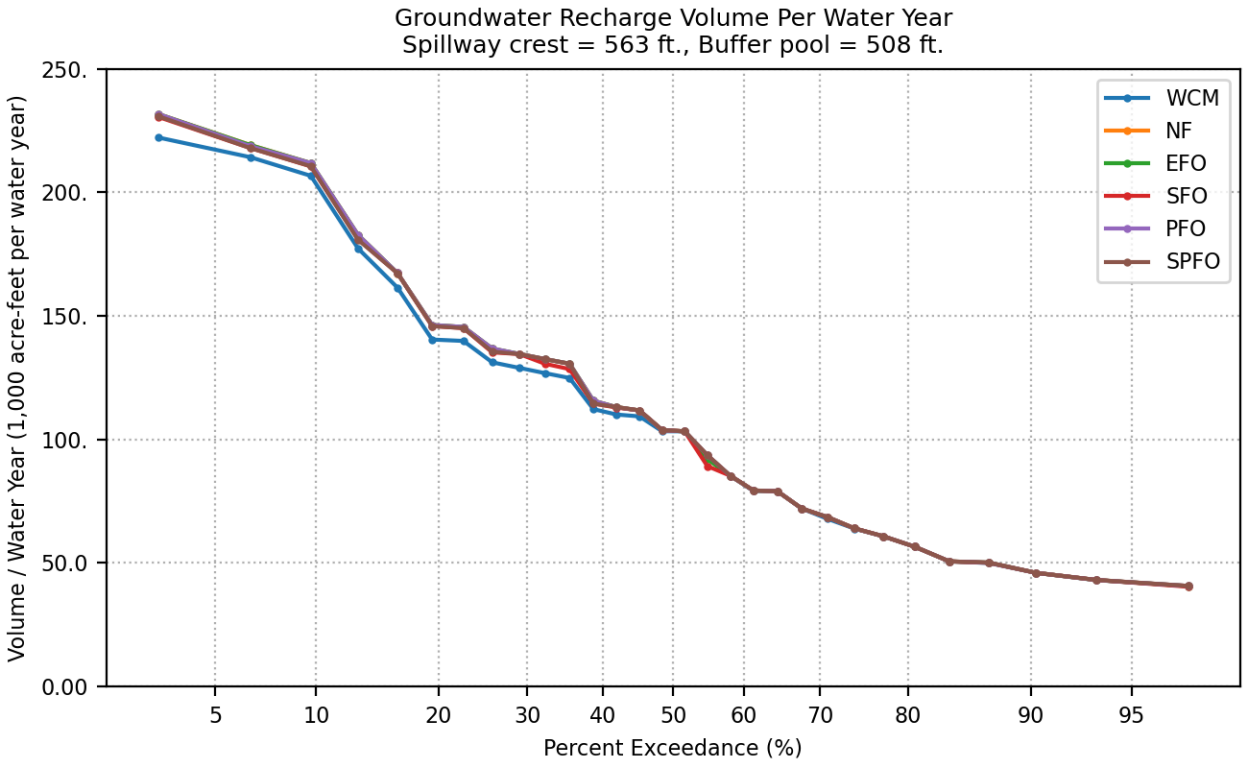

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

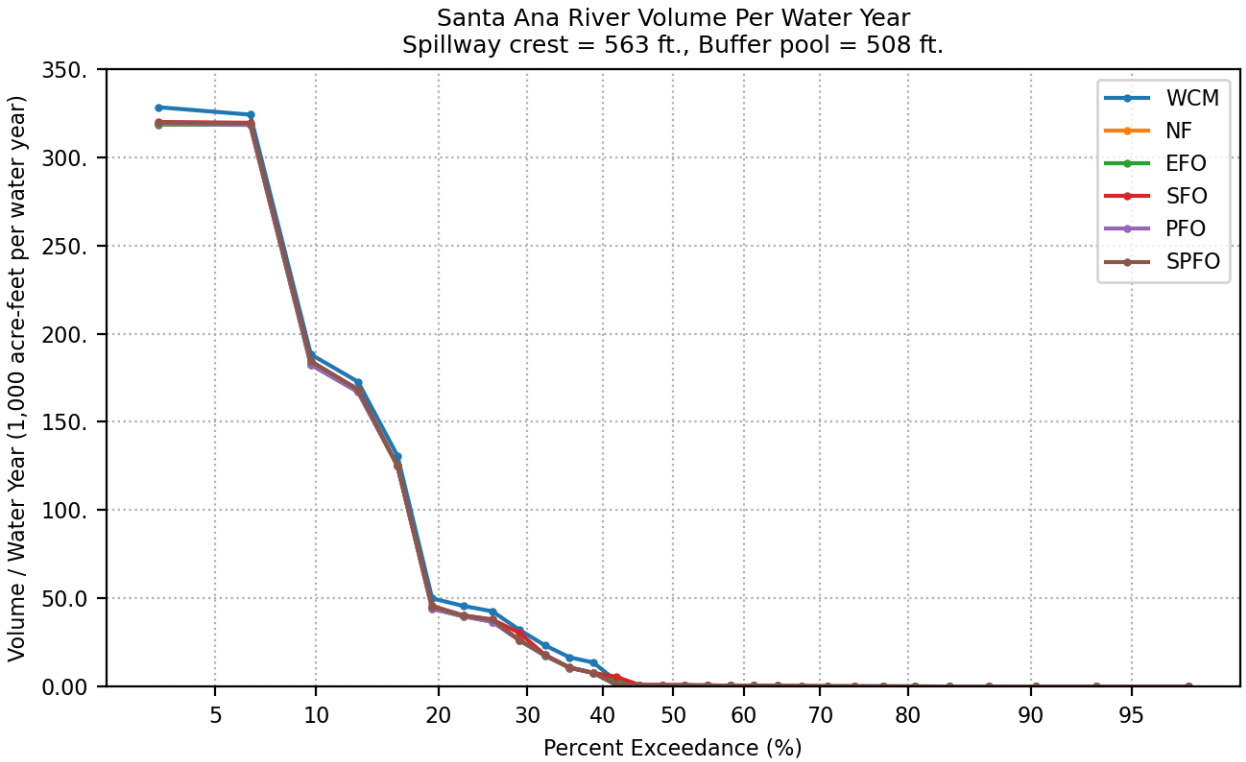

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
1.6
1.4
1.2
1.0
0.80
0.60
0.40
0.20
0.0
5
10
20
30
40
50
60
70
80
90
95

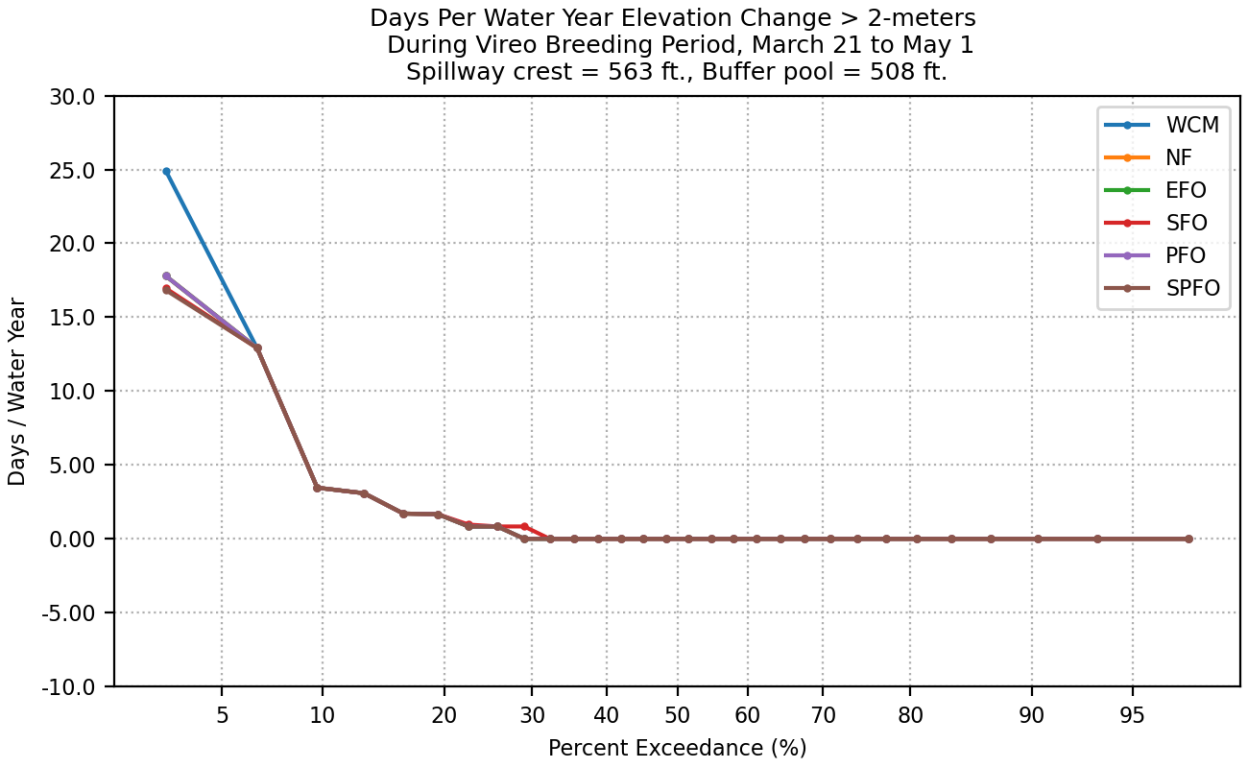

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
18.
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

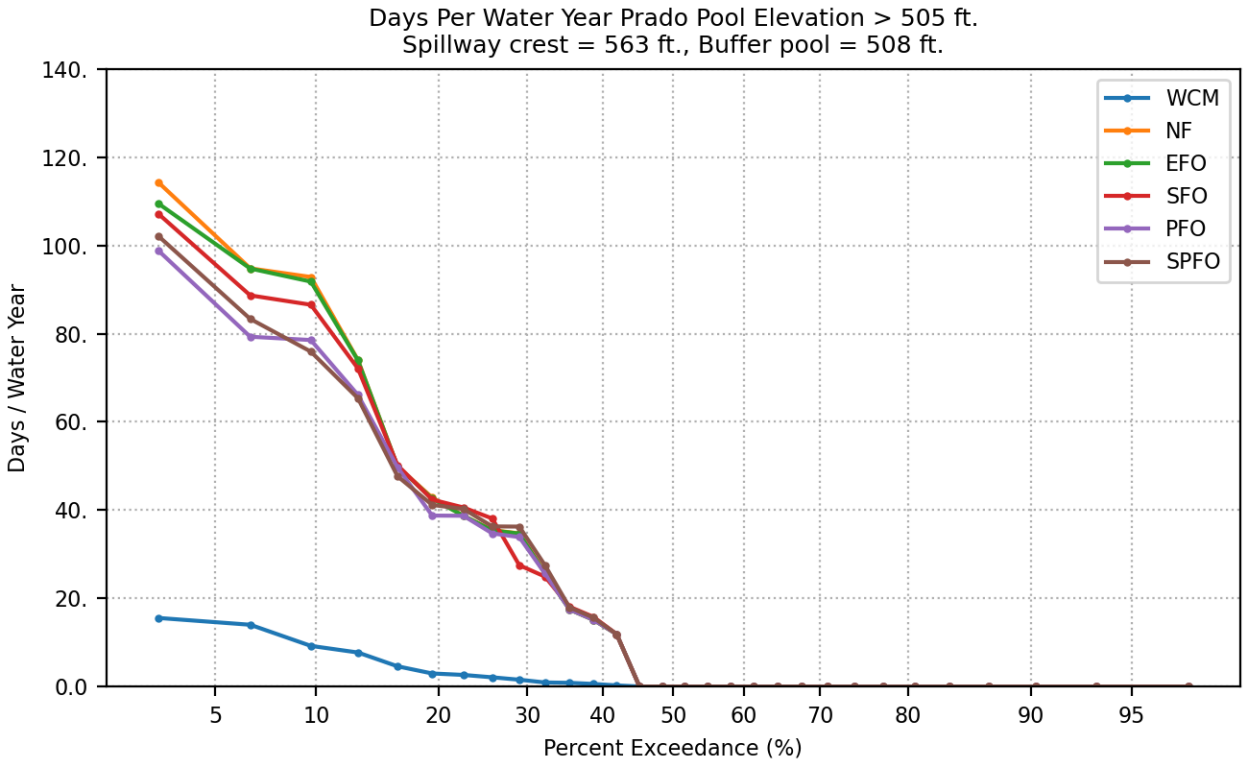

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
0.0
2.0
4.0
6.0
8.0
10.
12.
14.
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

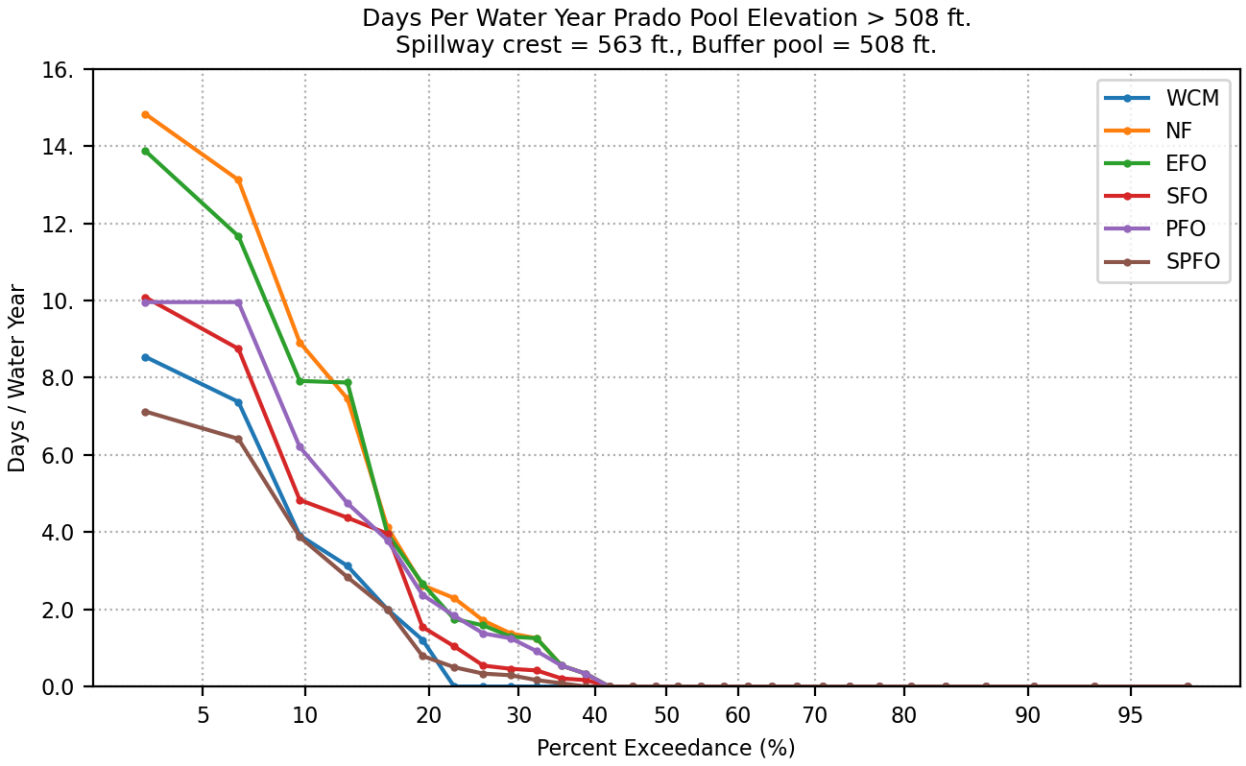

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
5
10
20
30
40
50
60
70
80
90
95

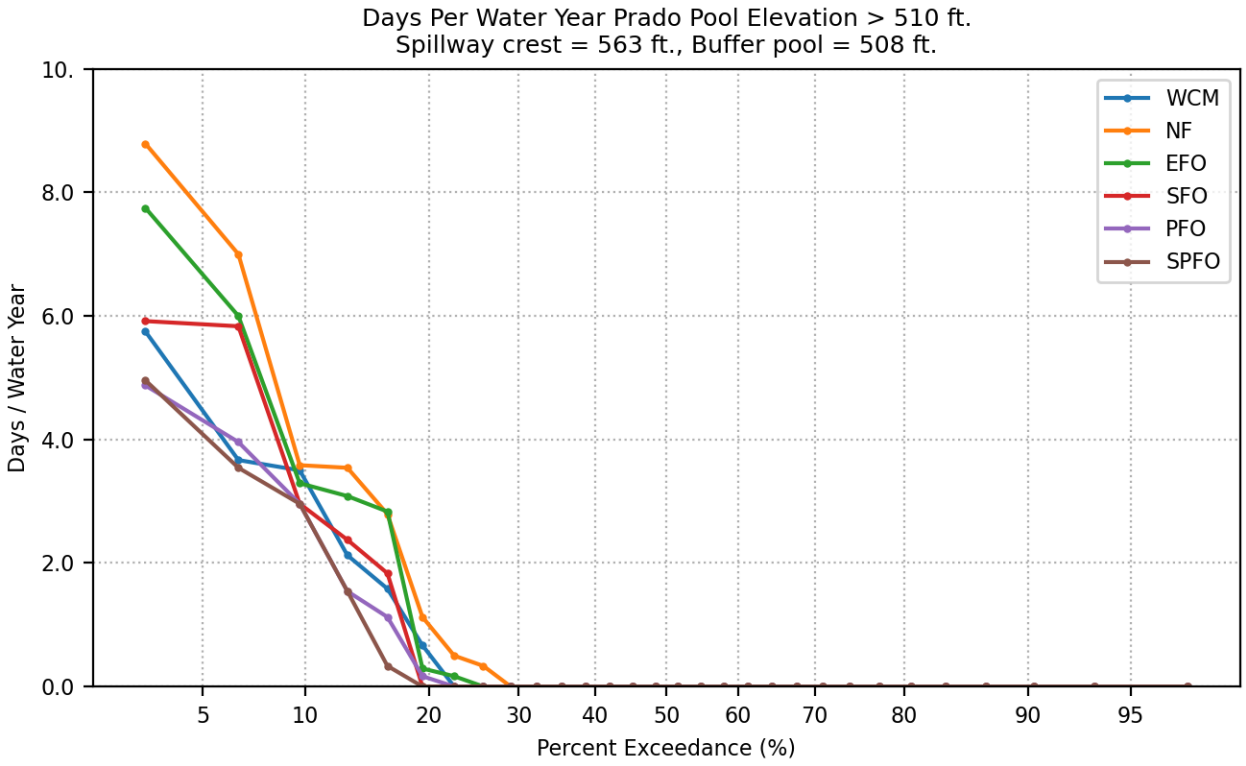

Groundwater Recharge Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 508 ft.
Volume / Water Year (1,000 acre-feet per water year)
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

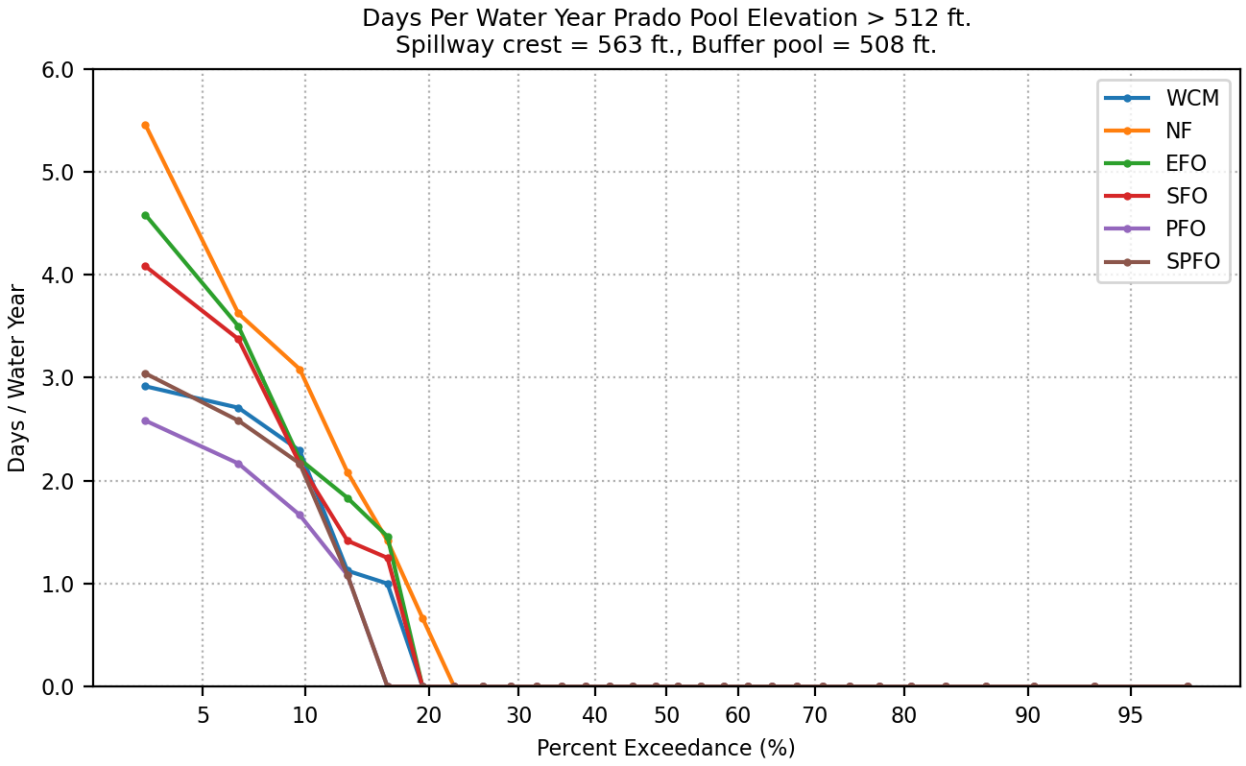

Santa Ana River Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 508 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

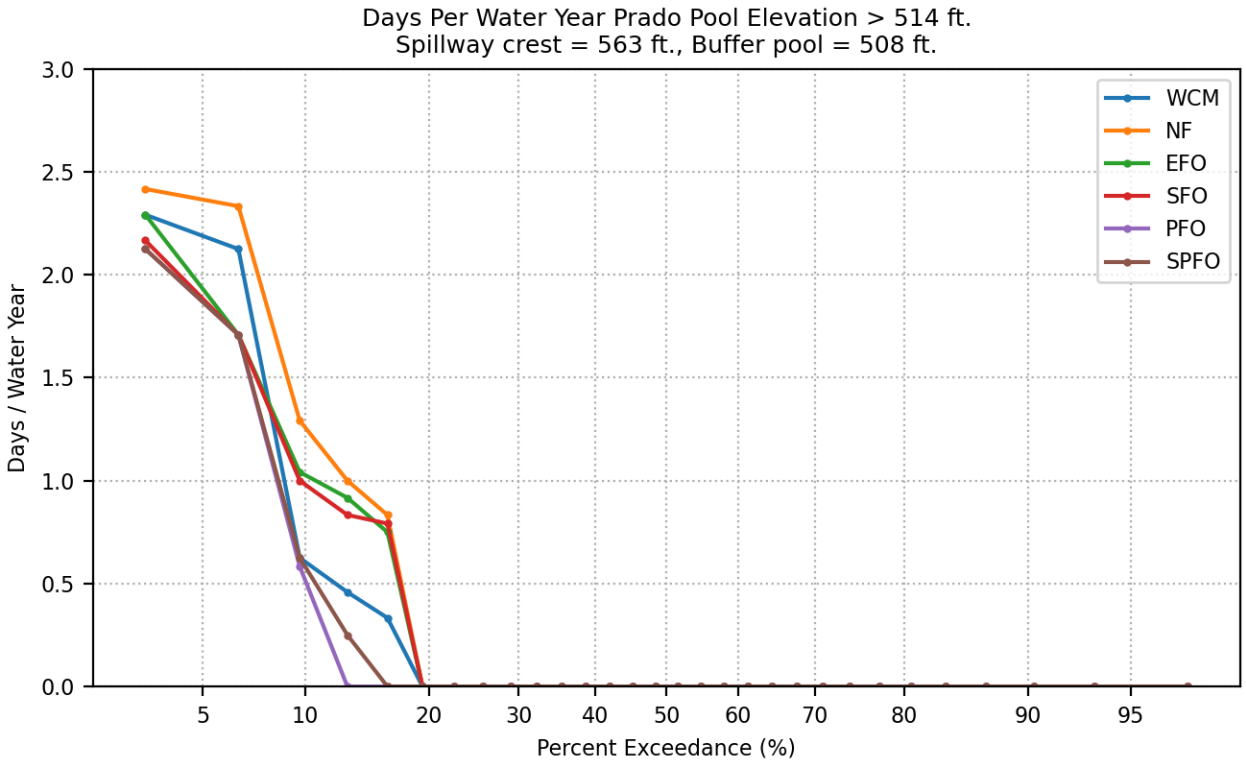

Days Per Water Year Elevation Change > 2-meters
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

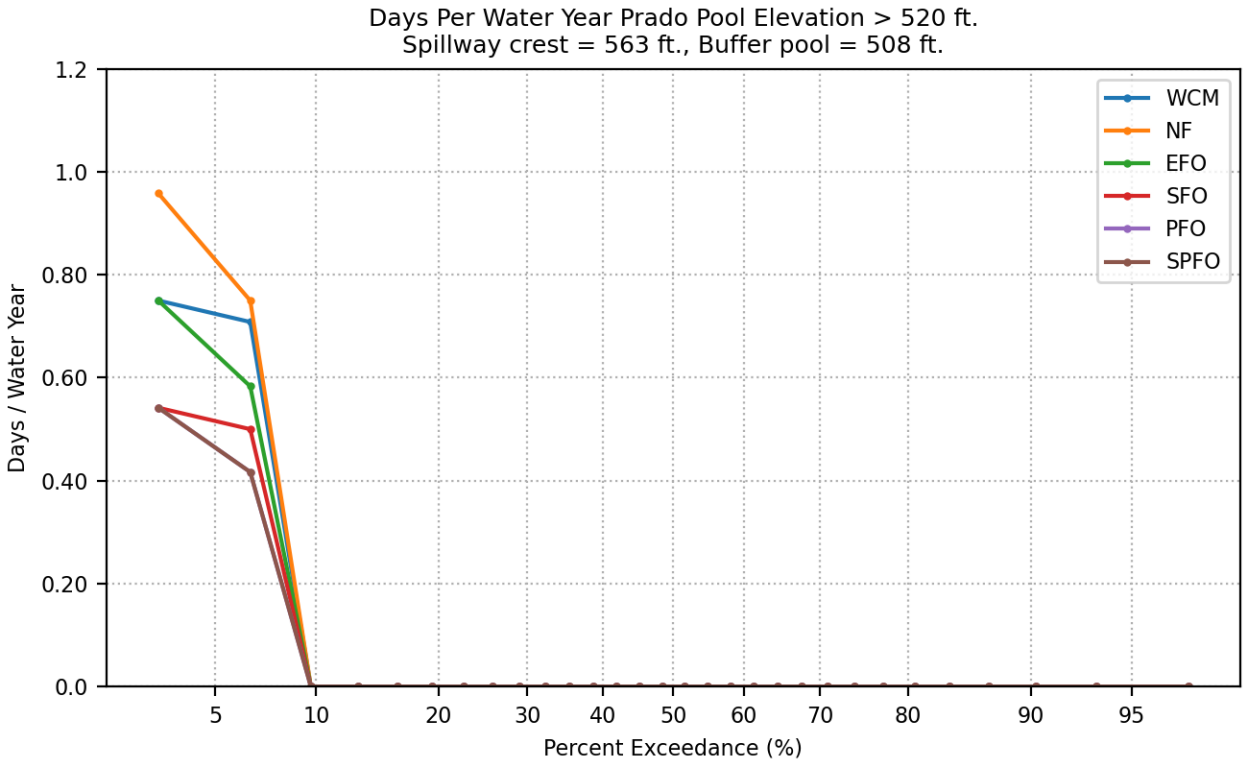

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

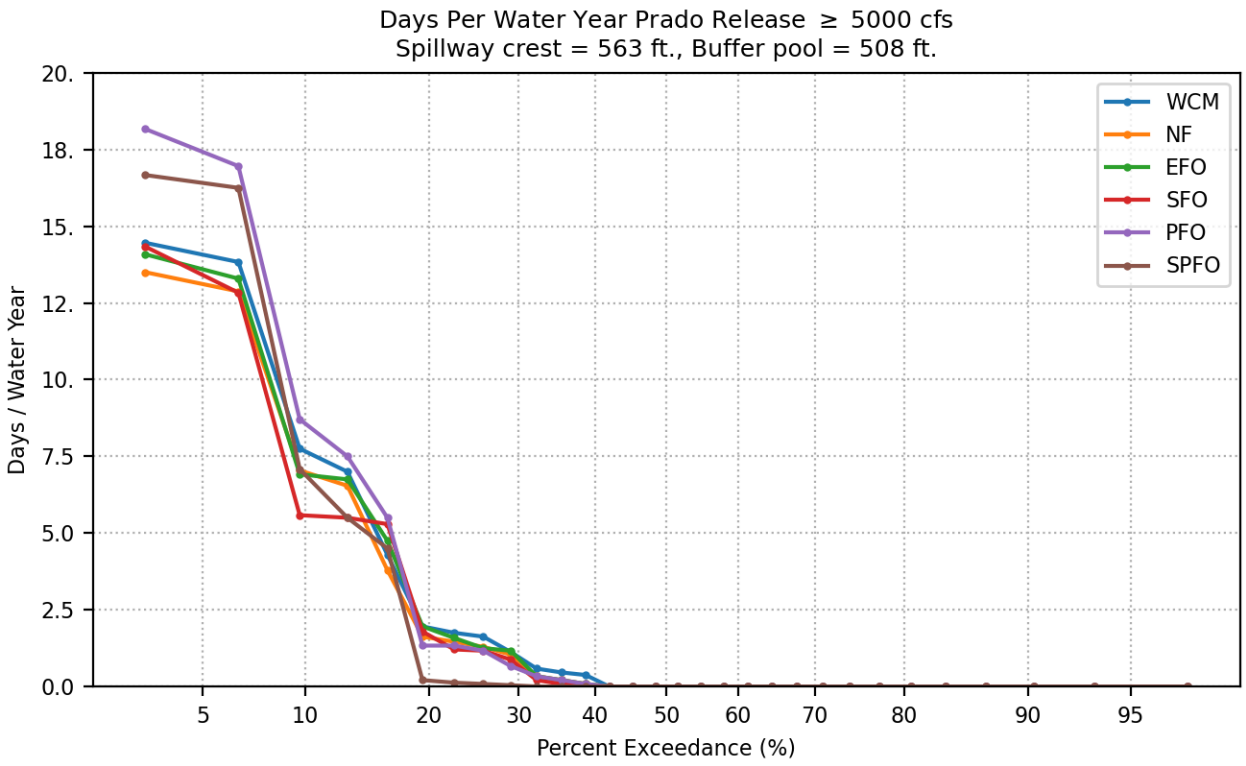

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

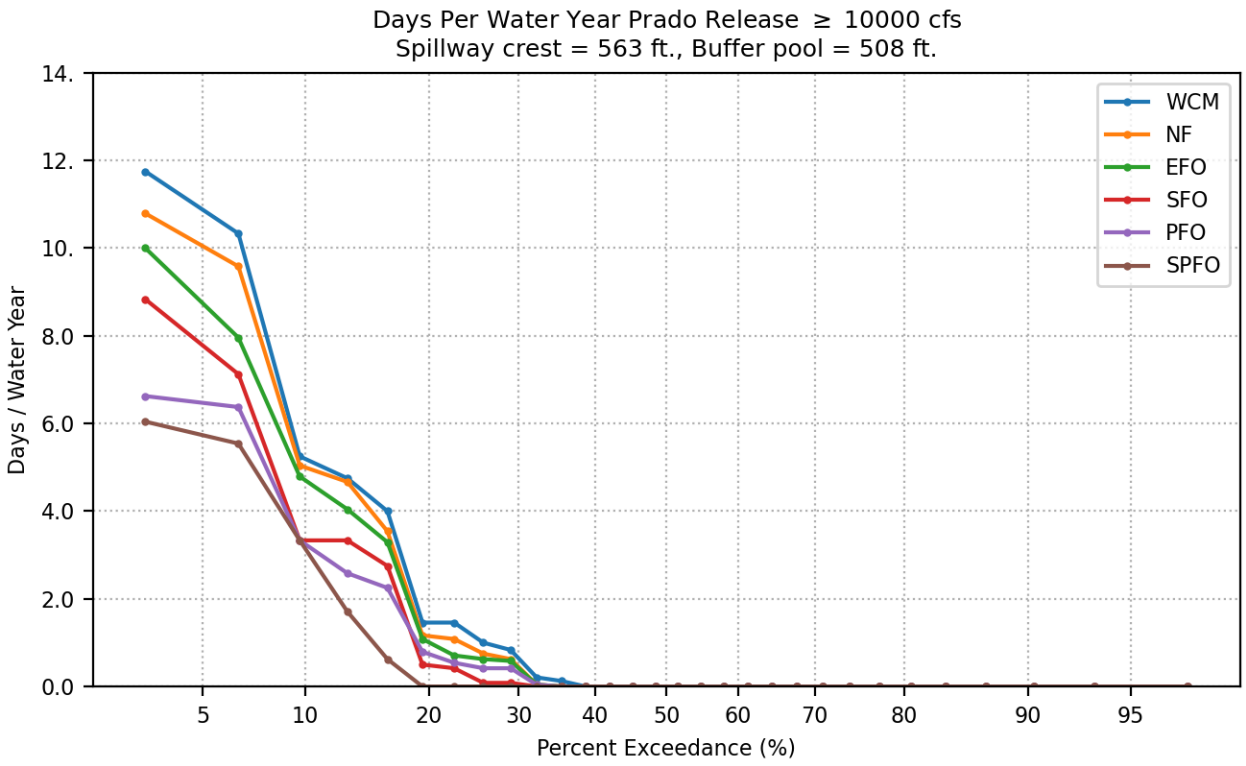

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

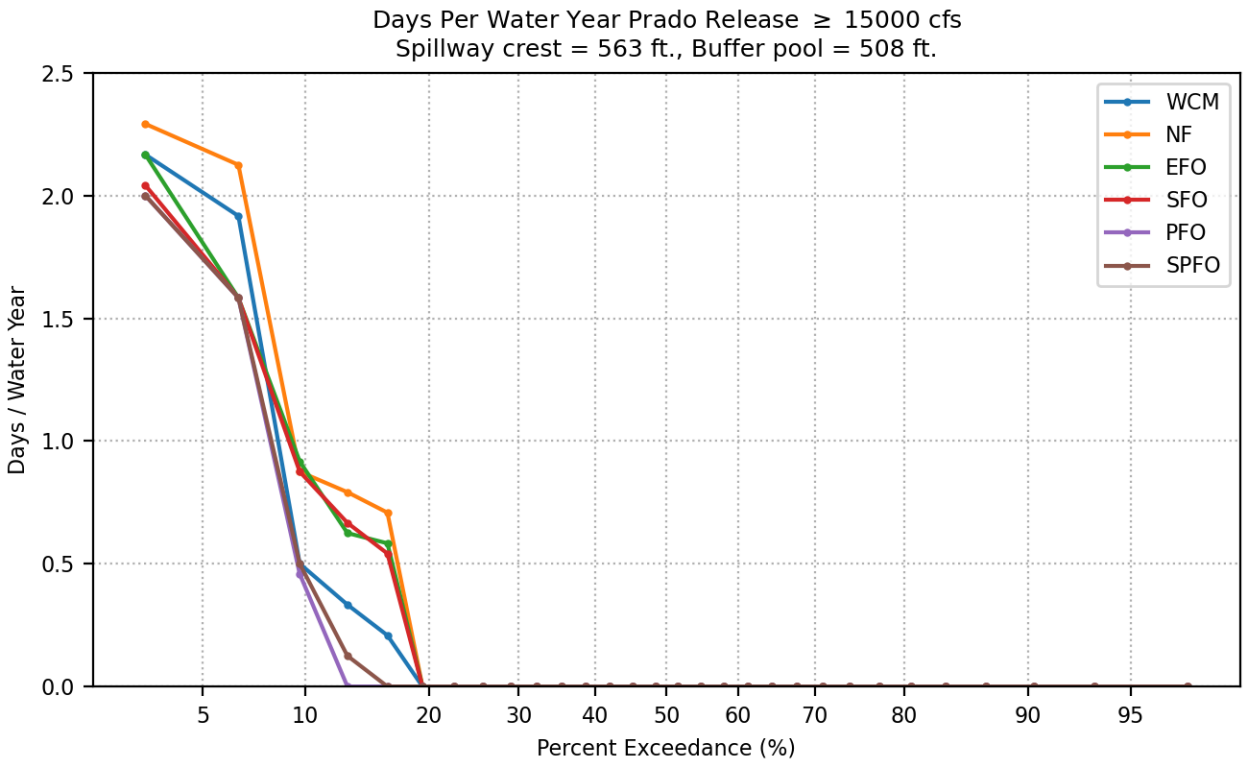

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

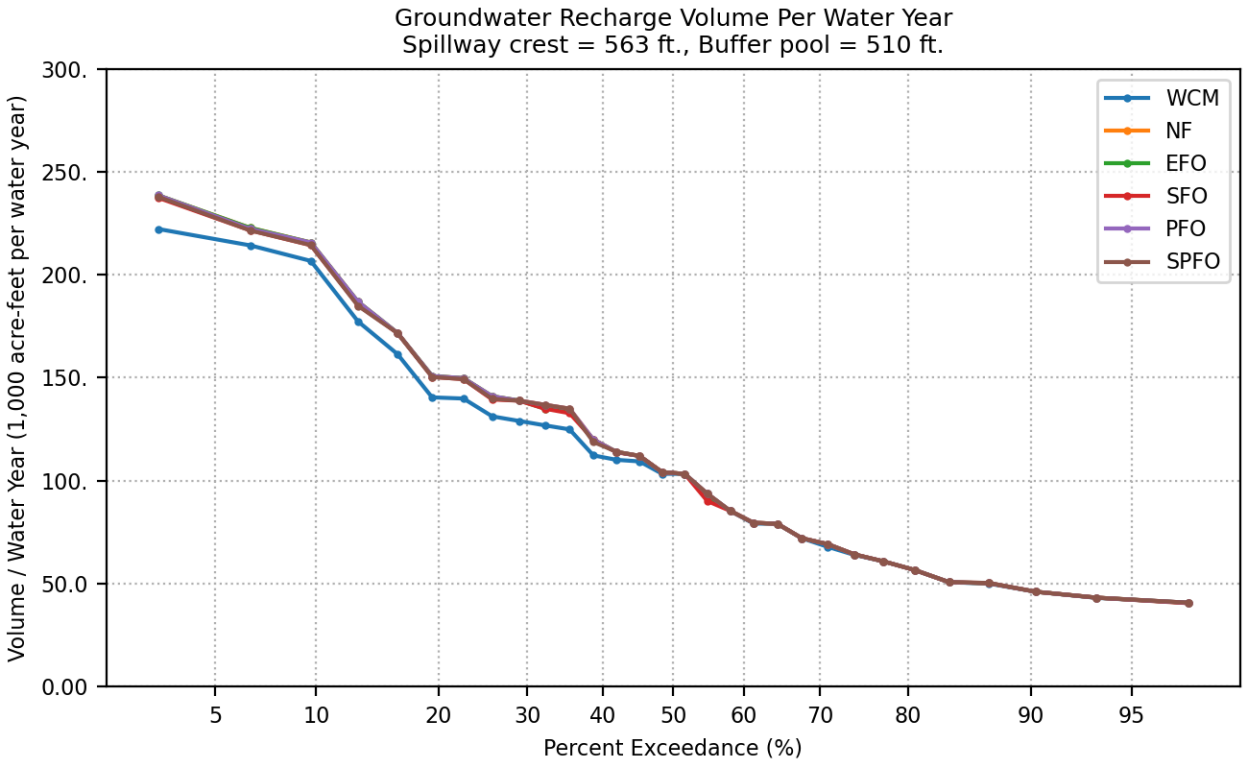

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

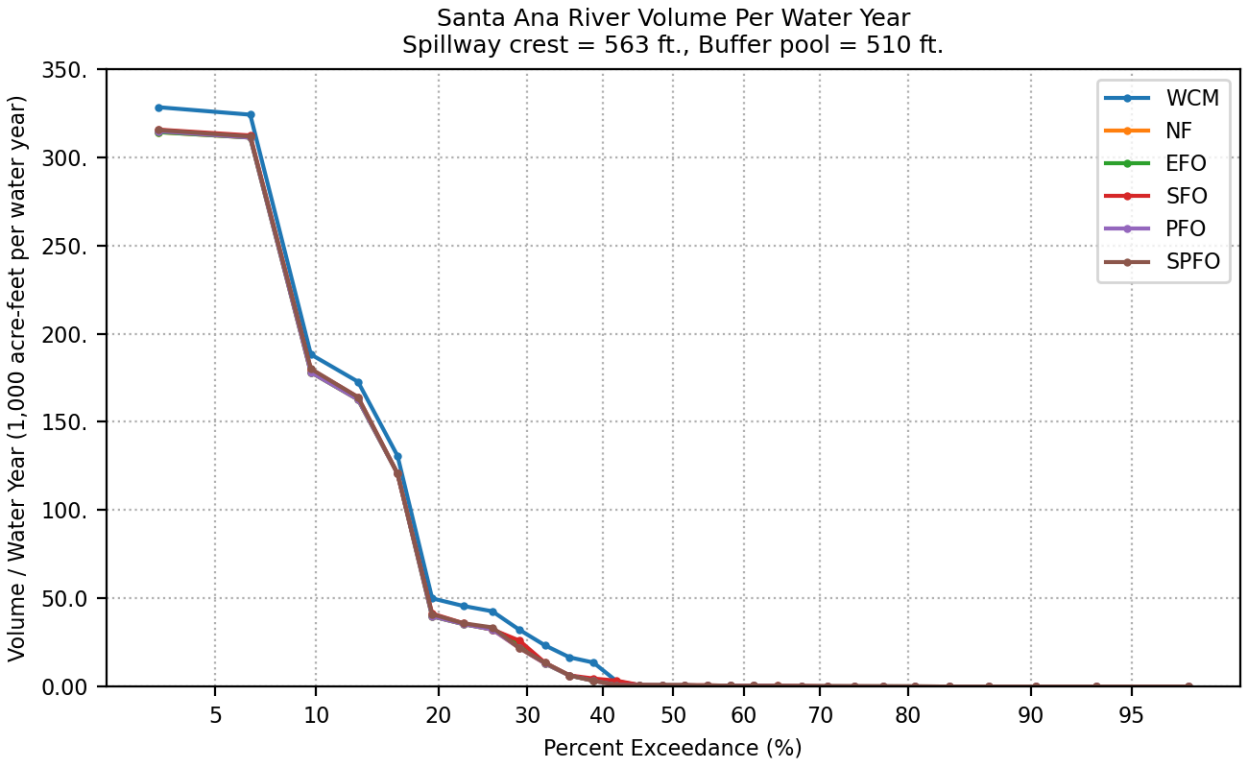

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
1.2
1.0
0.80
0.60
0.40
0.20
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

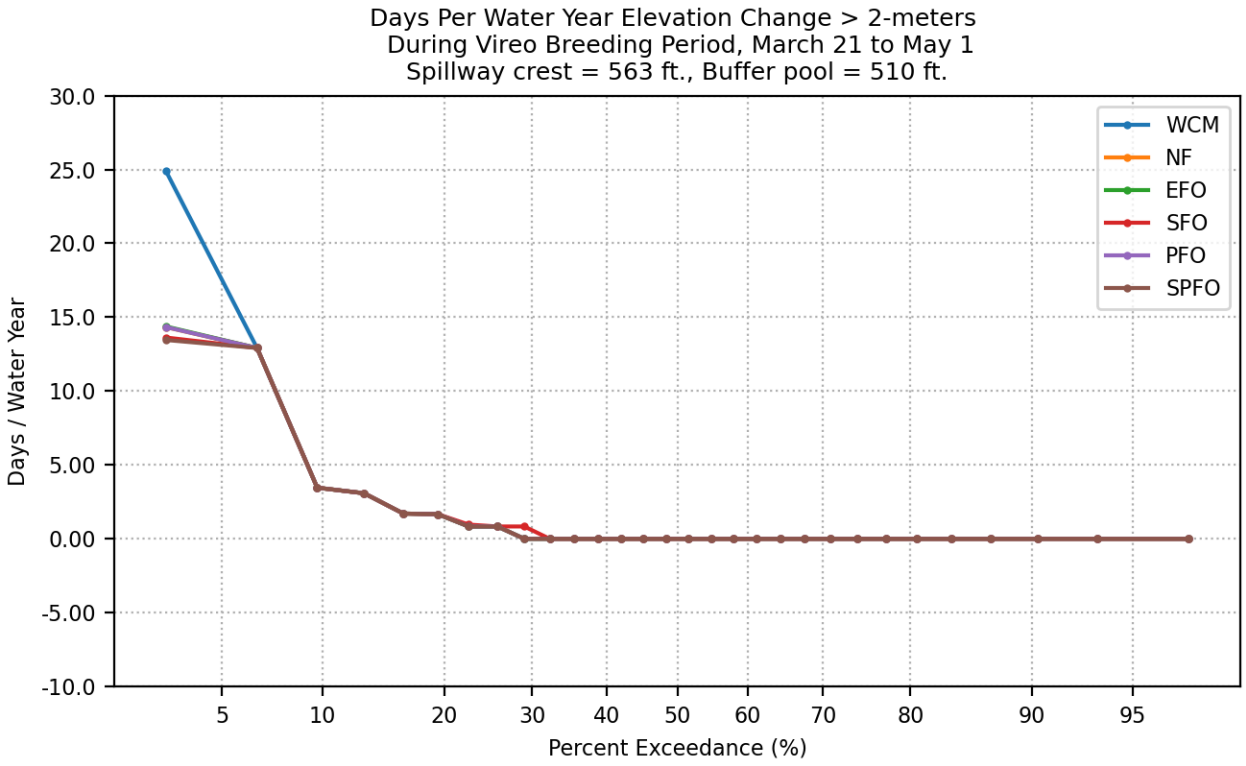

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
20.
18.
15.
12.
10.
7.5
5.0
2.5
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

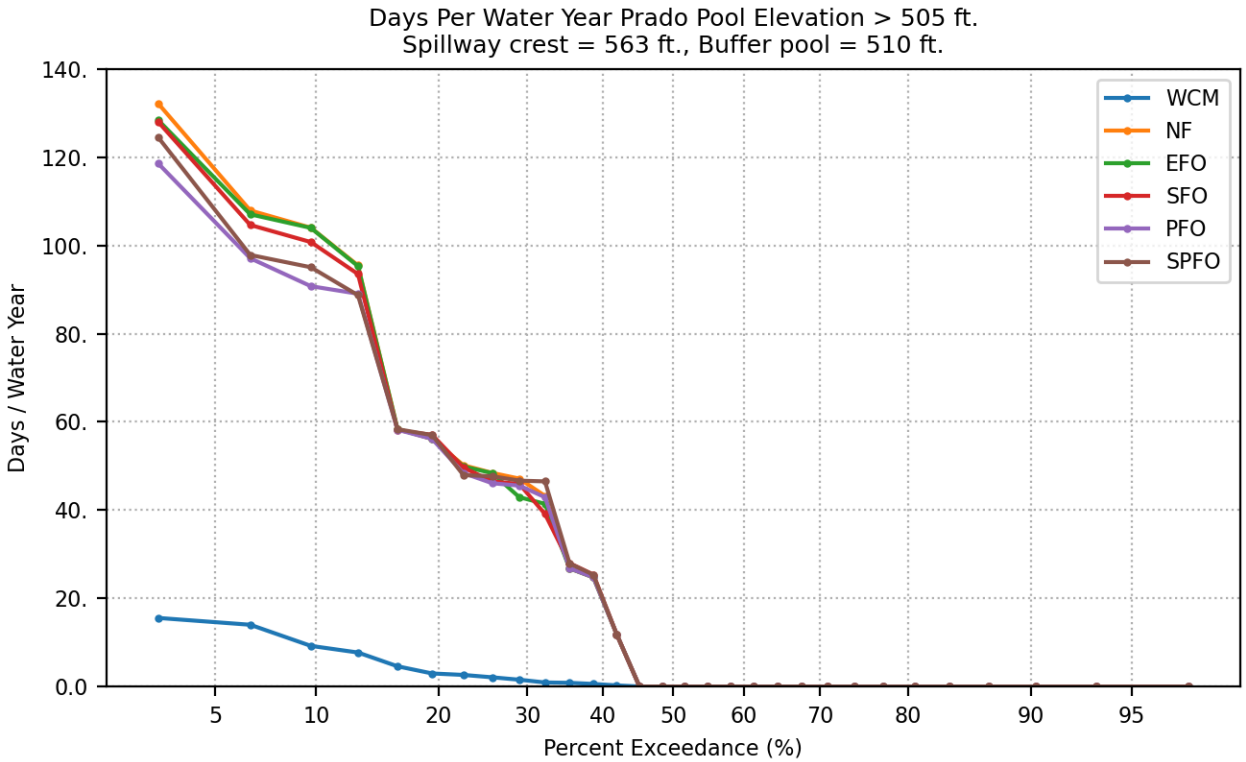

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
0.0
2.0
4.0
6.0
8.0
10.
12.
14.
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

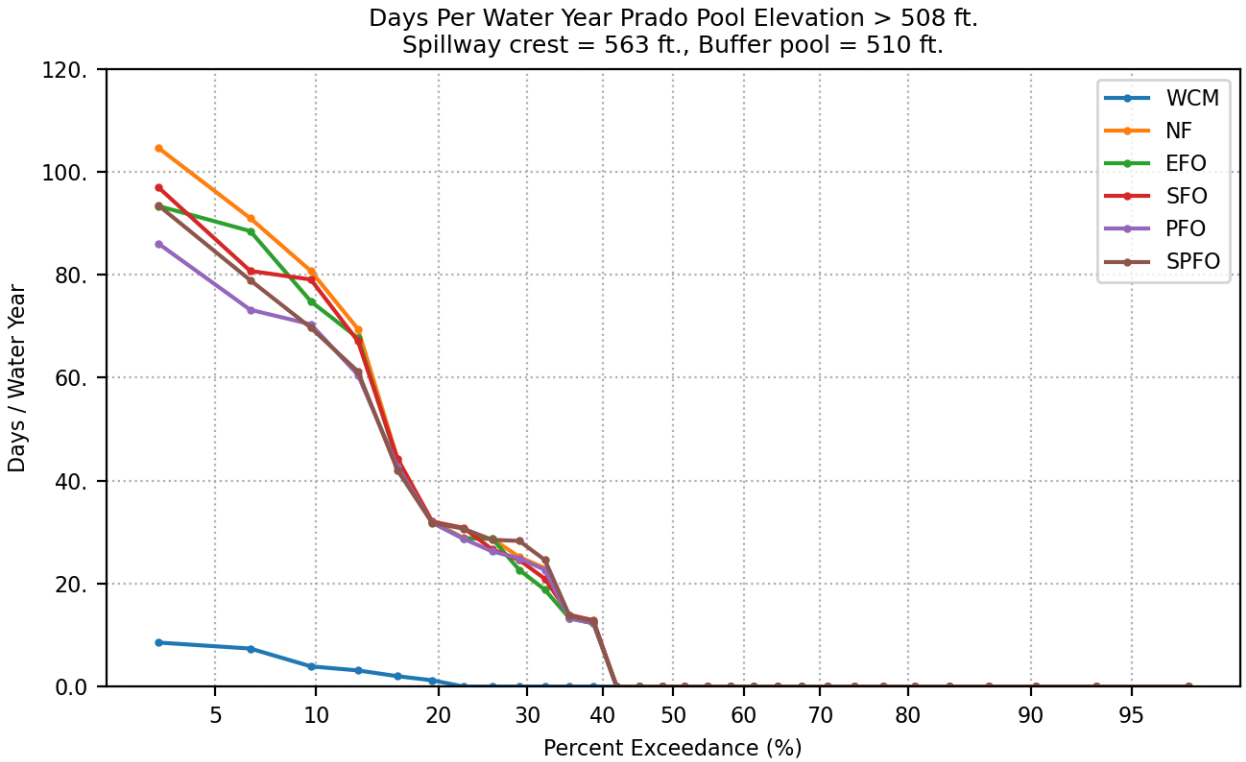

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
0.0
0.5
1.0
1.5
2.0
2.5
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

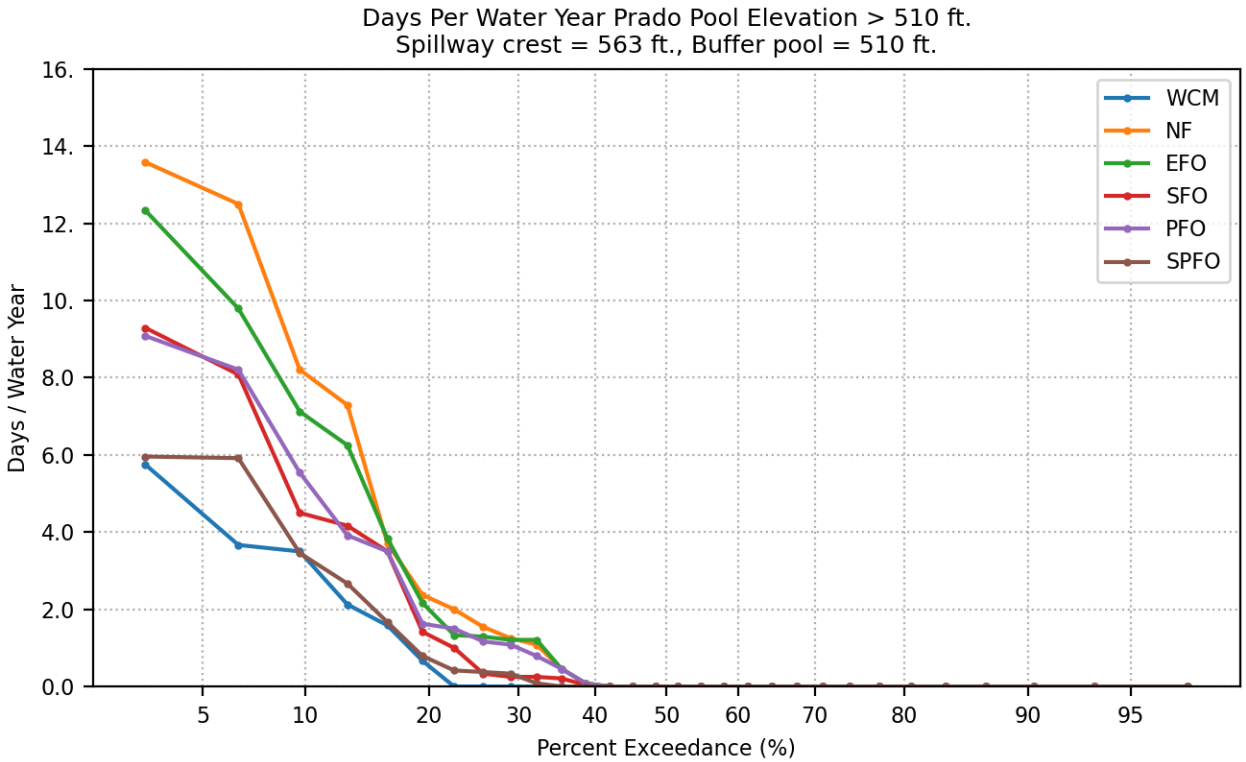

Groundwater Recharge Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 510 ft.
Volume / Water Year (1,000 acre-feet per water year)
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

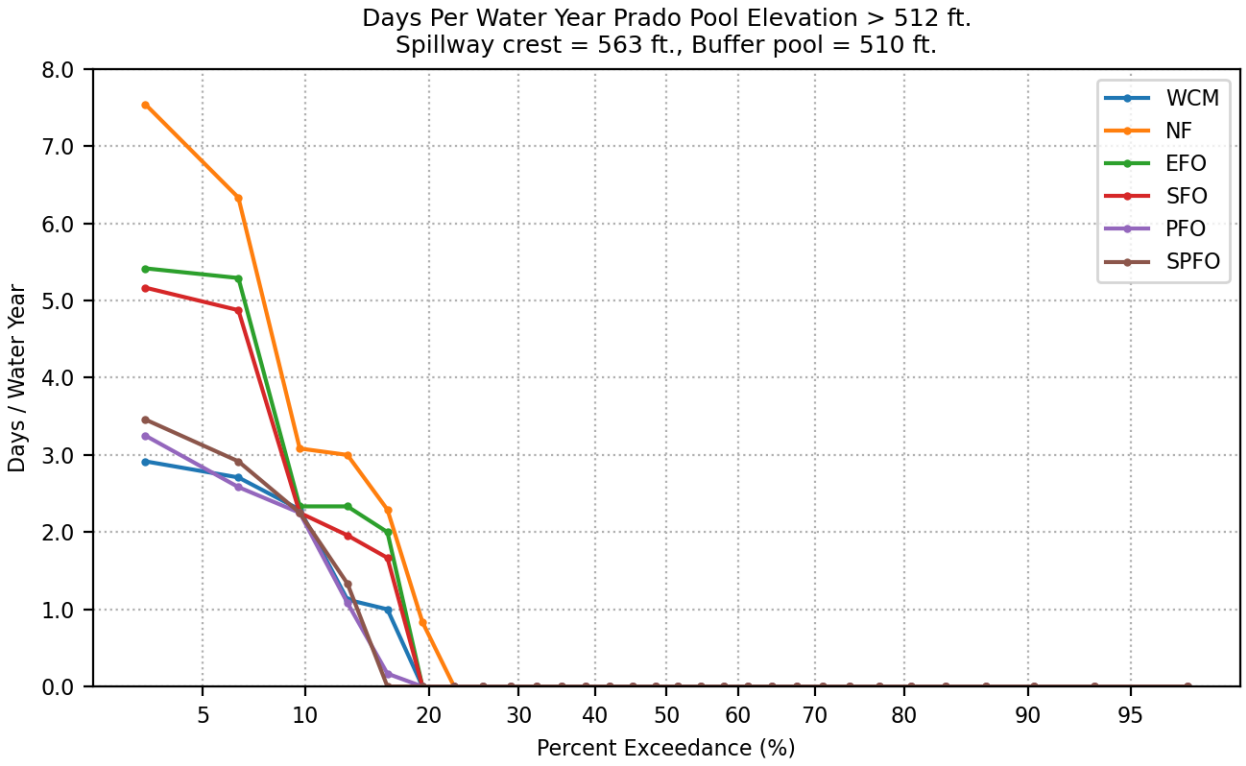

Santa Ana River Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 510 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

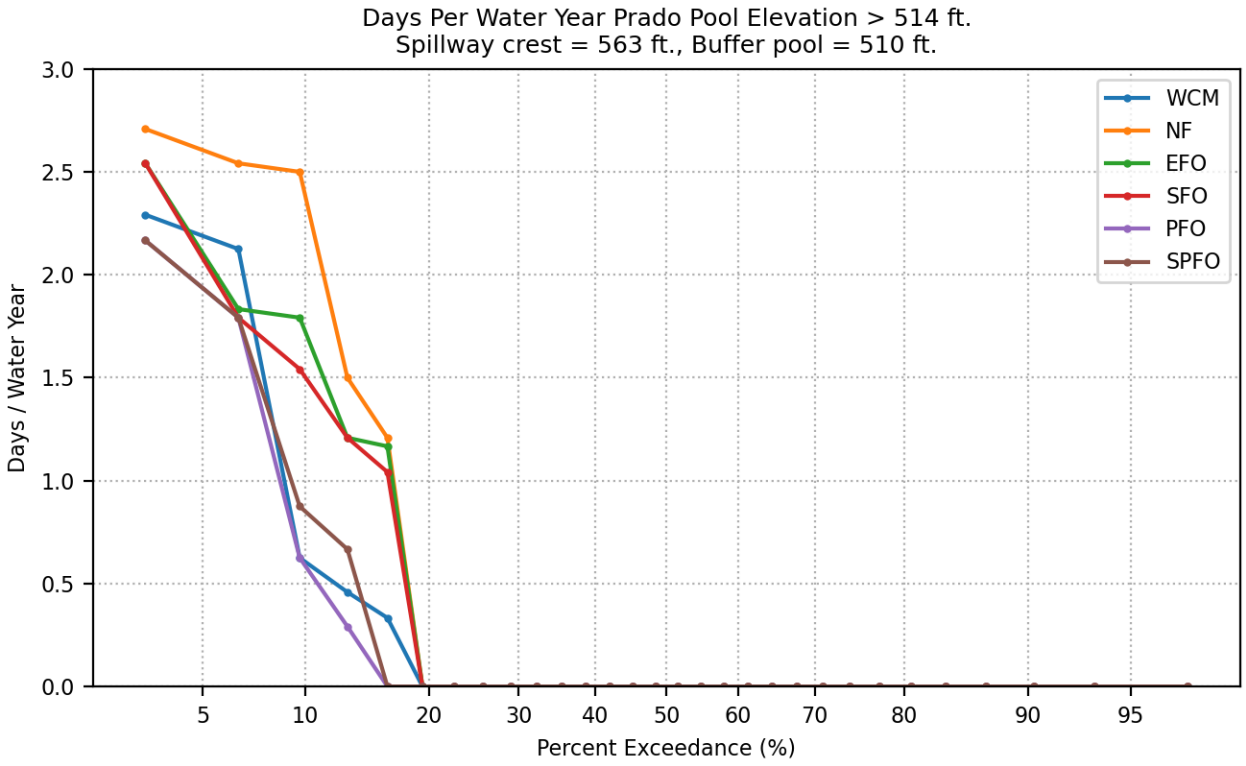

Days Per Water Year Elevation Change > 2-meters
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

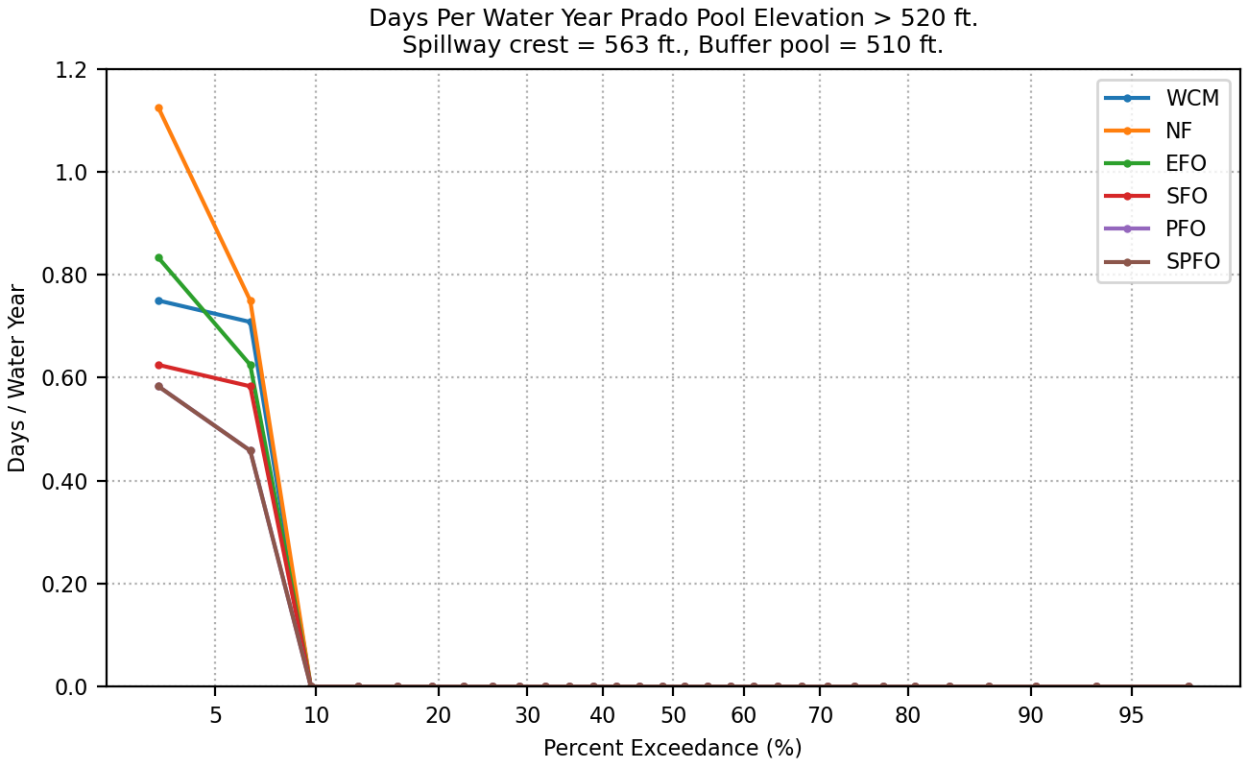

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

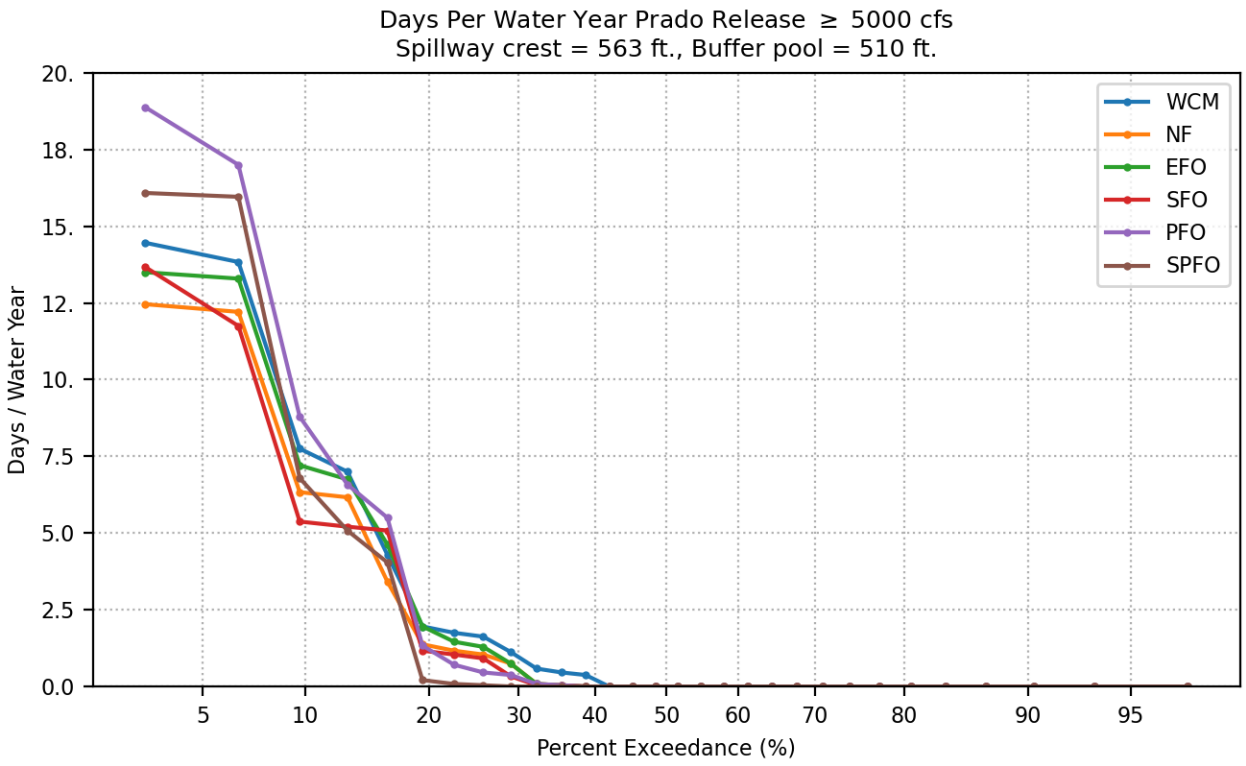

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

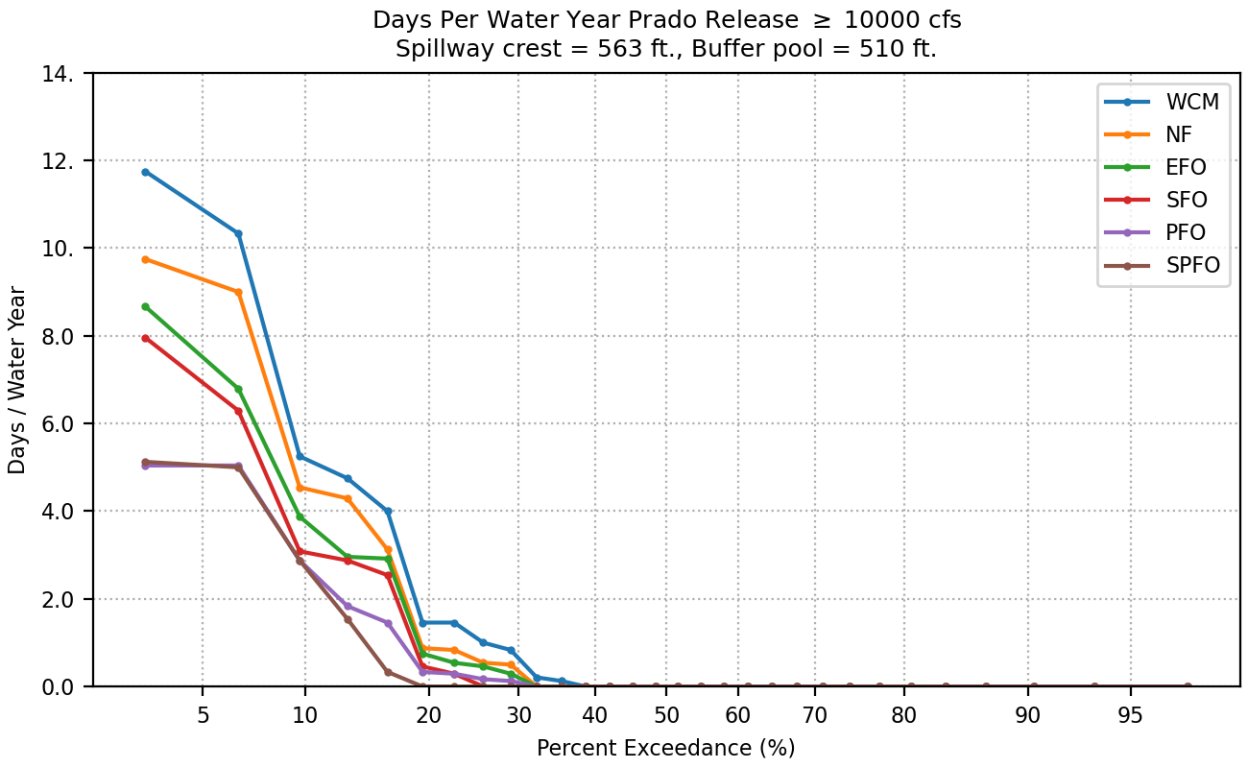

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

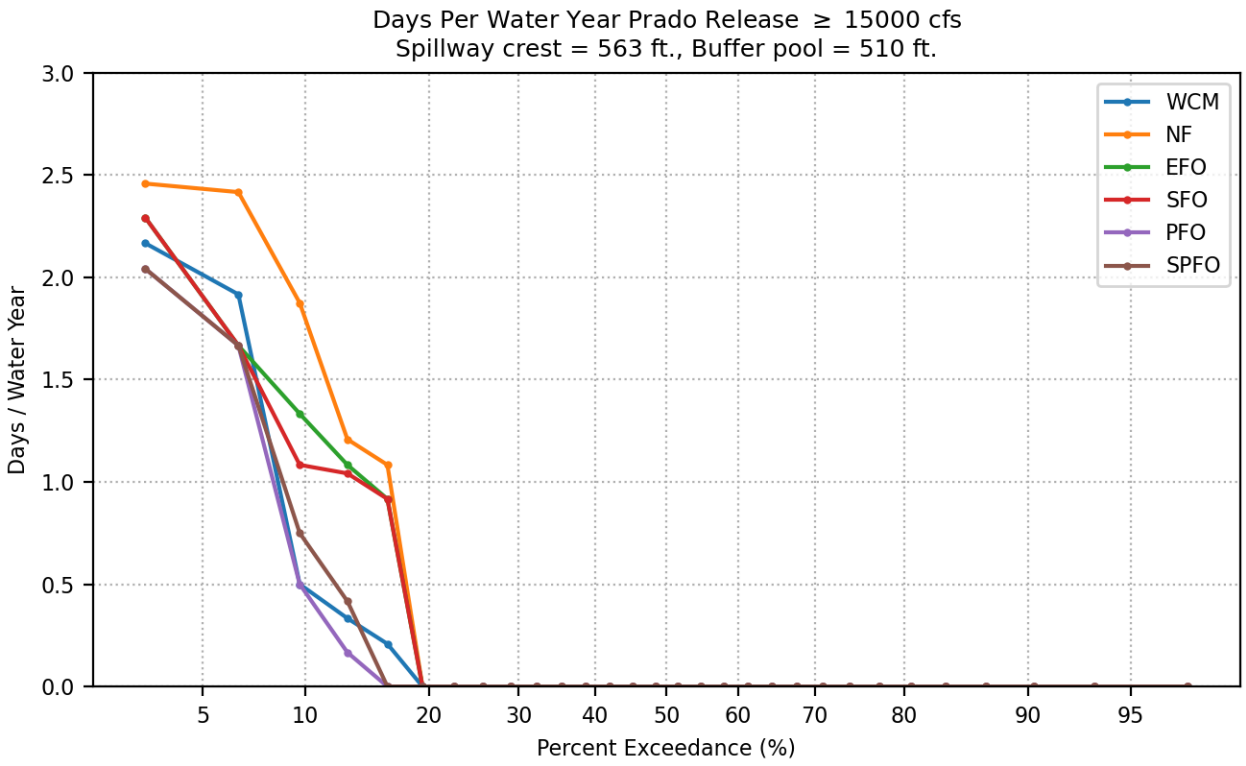

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

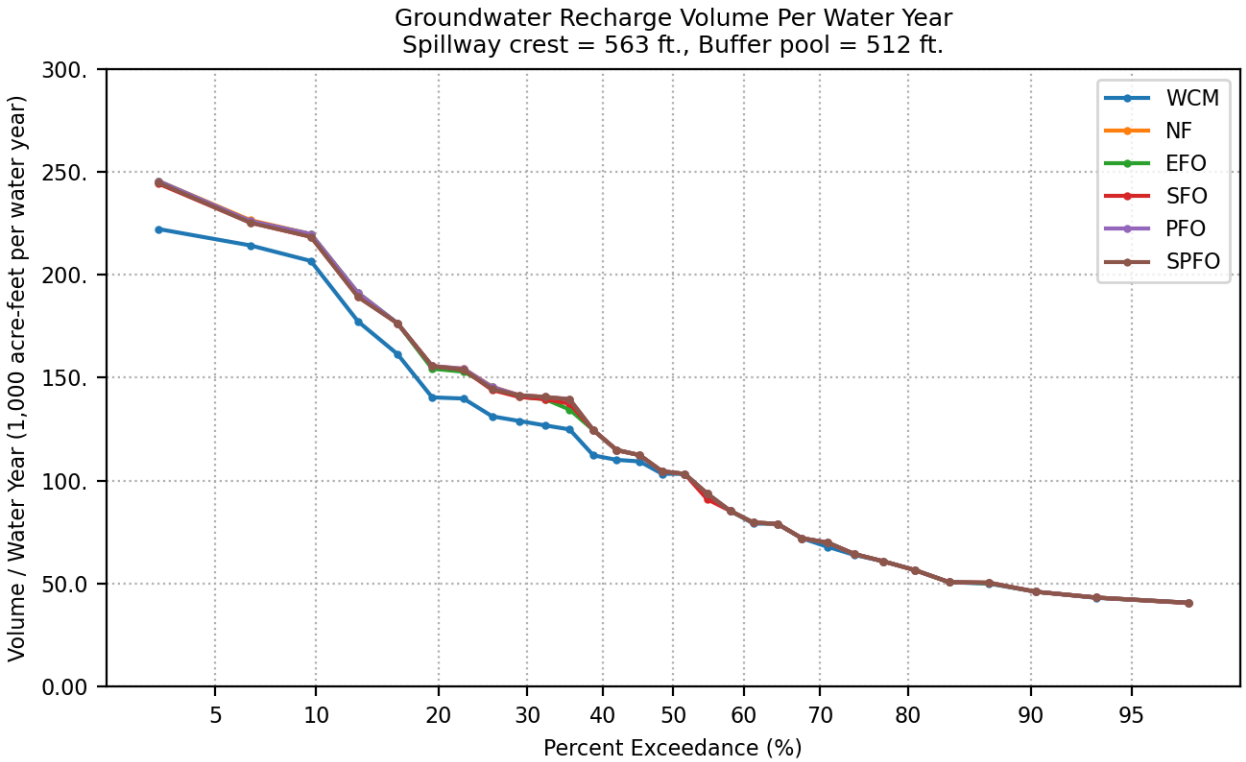

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

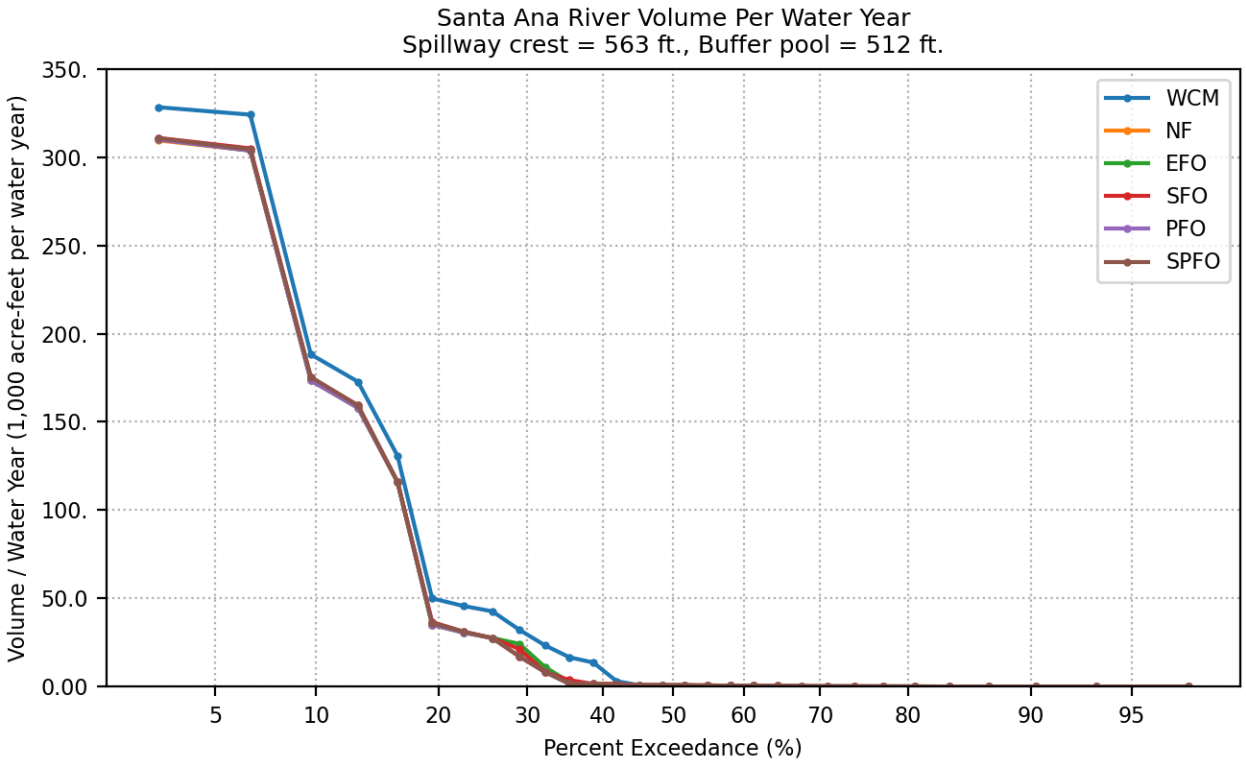

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
1.2
1.0
0.80
0.60
0.40
0.20
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

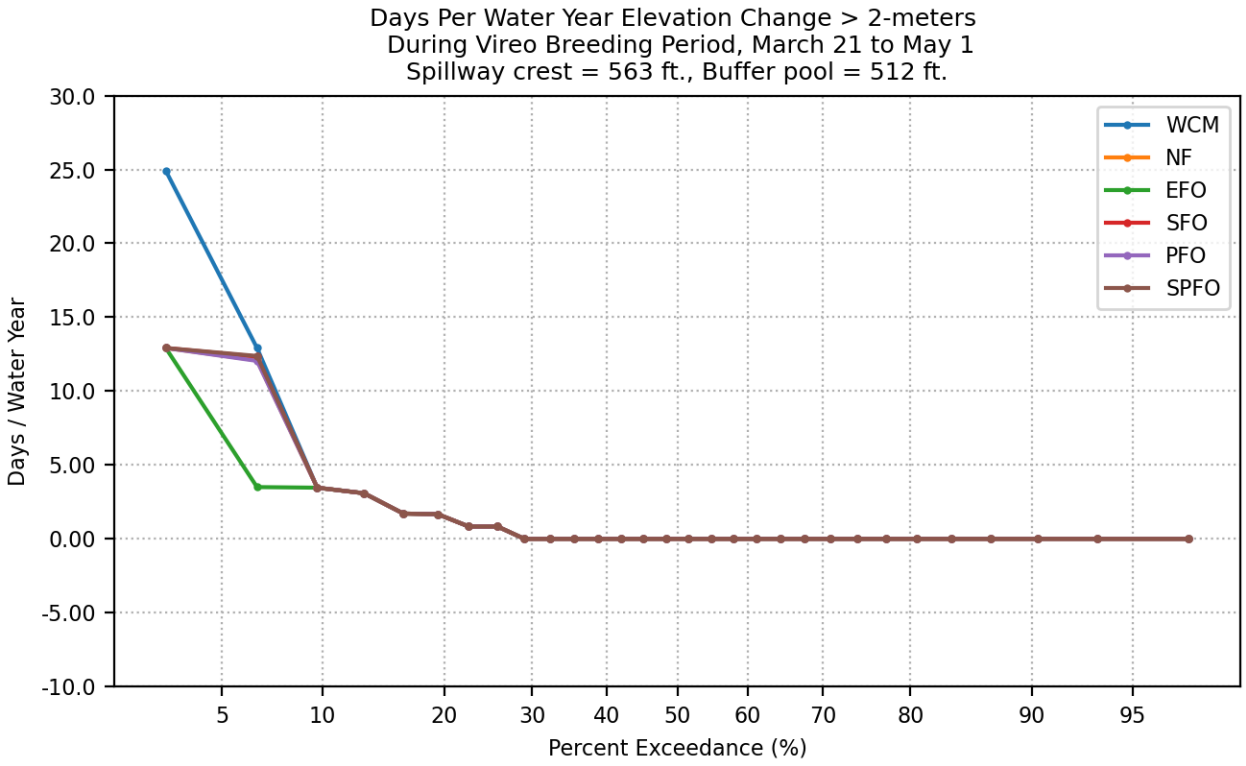

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
20.
18.
15.
12.
10.
7.5
5.0
2.5
0.0
5
10
20
30
40
50
60
70
80
90
95

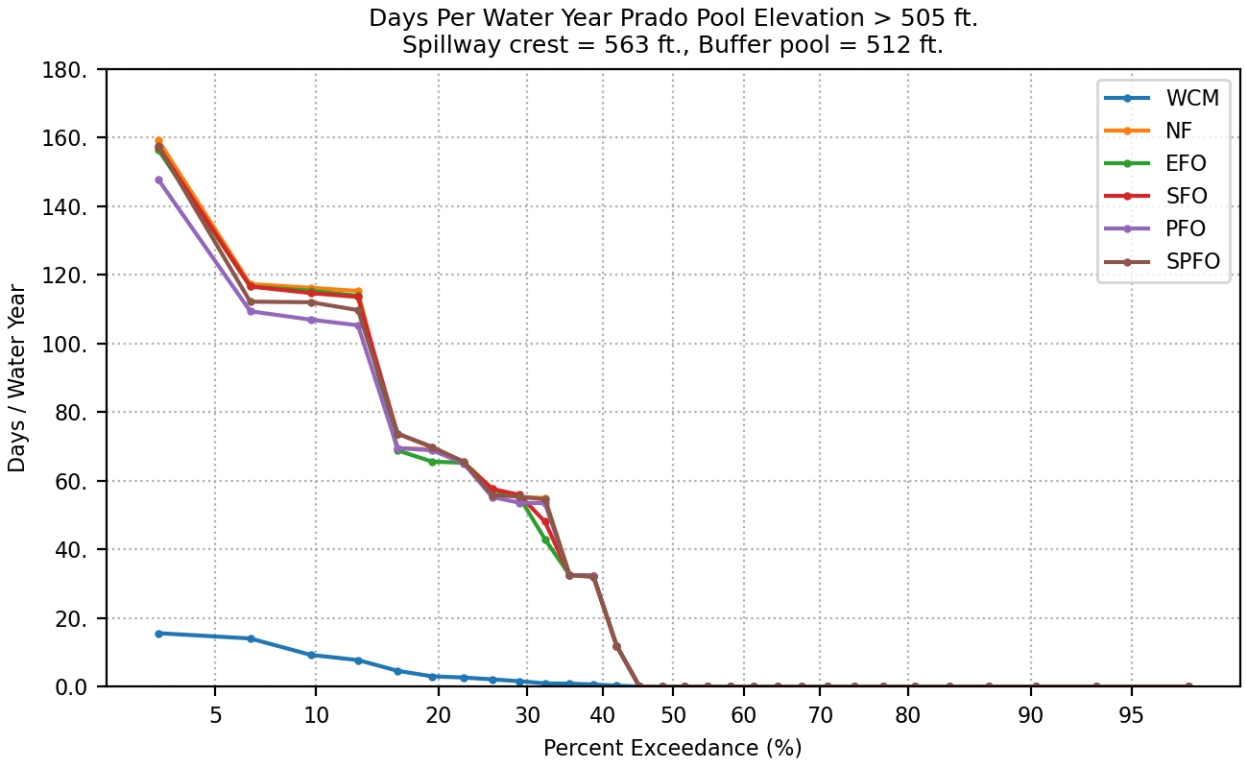

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
0.0
2.0
4.0
6.0
8.0
10.
12.
14.
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

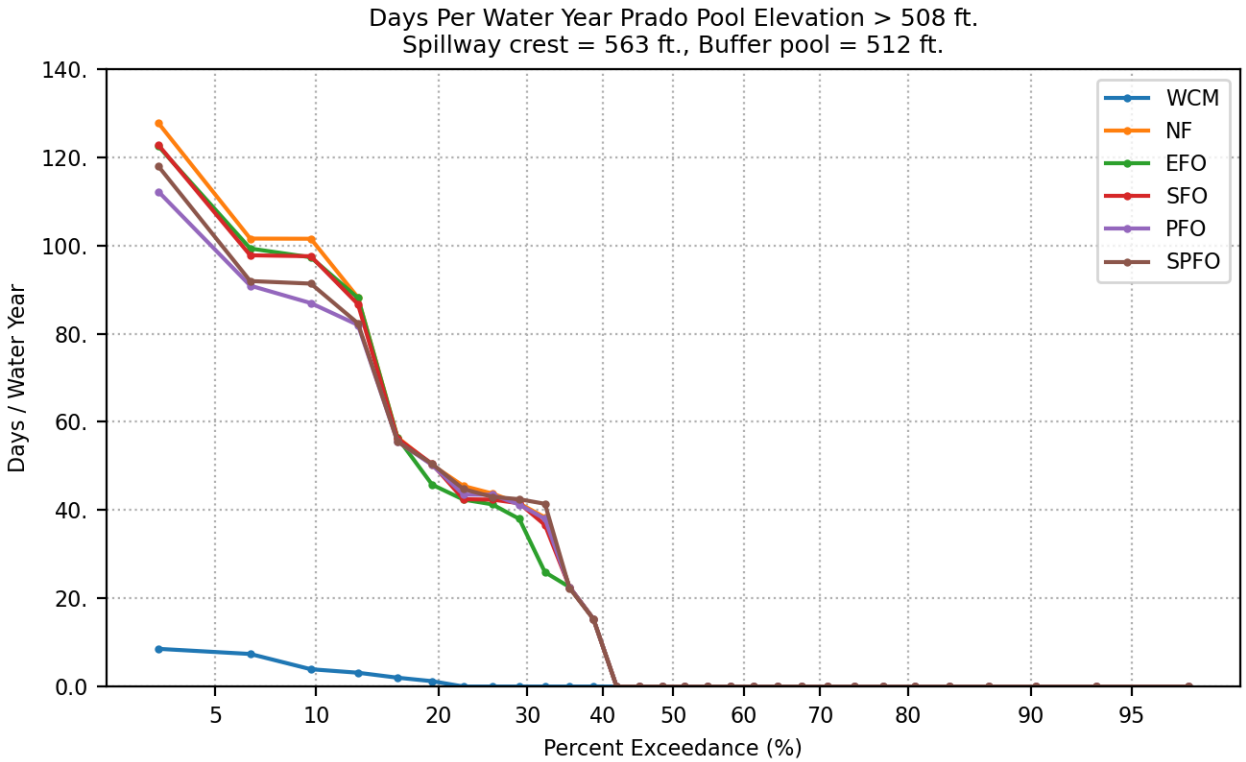

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

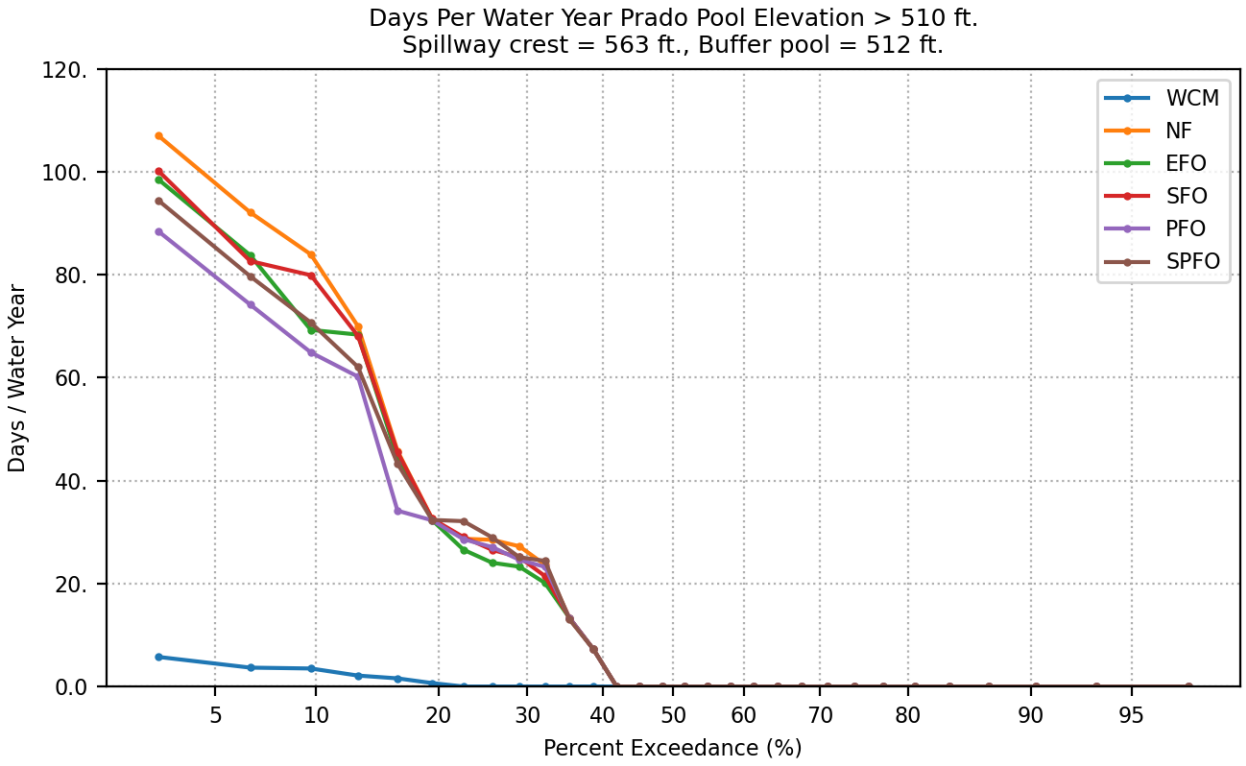

Groundwater Recharge Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 512 ft.
Volume / Water Year (1,000 acre-feet per water year)
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

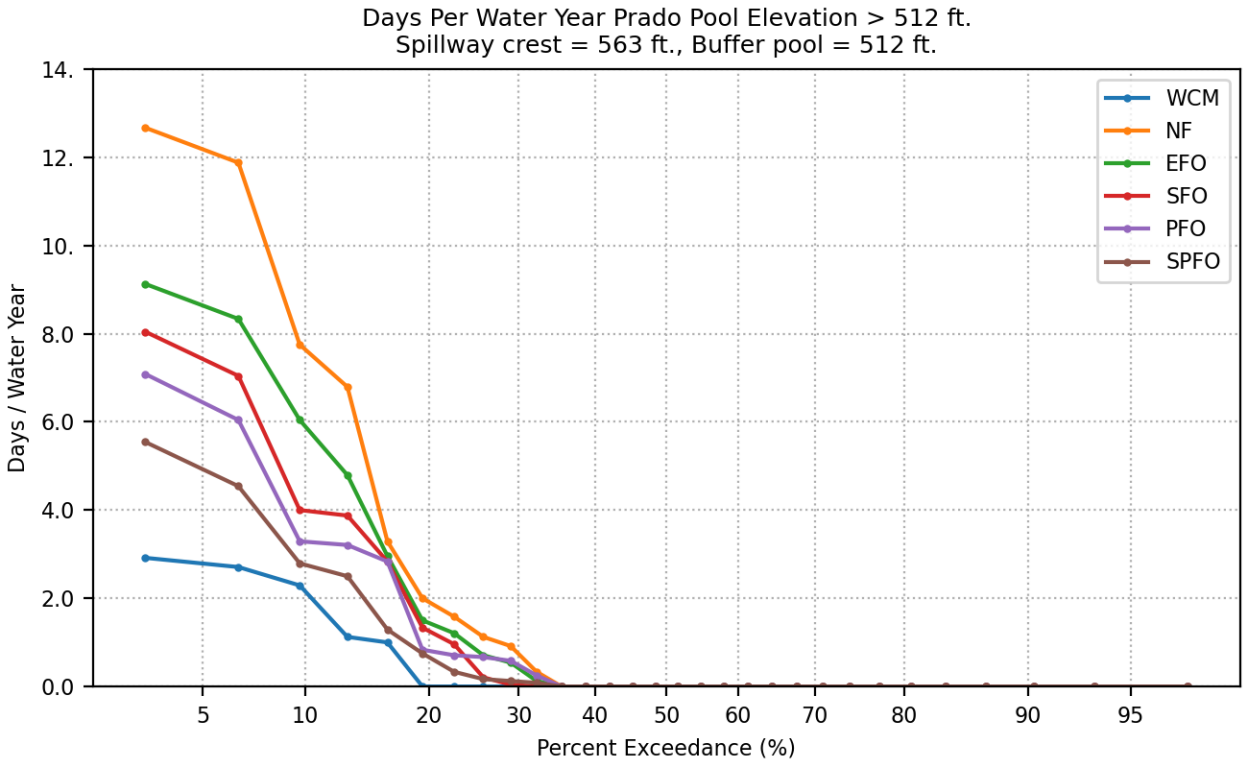

Santa Ana River Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 512 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

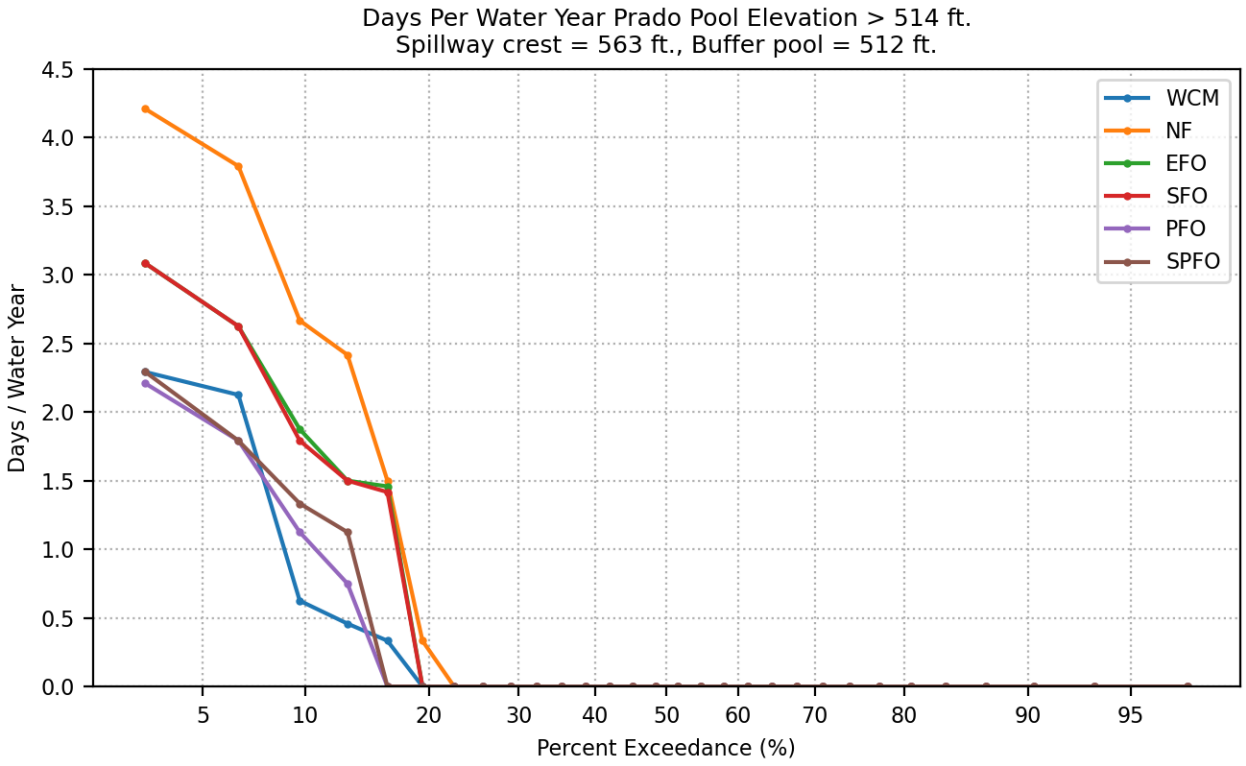

Days Per Water Year Elevation Change > 2-meters
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

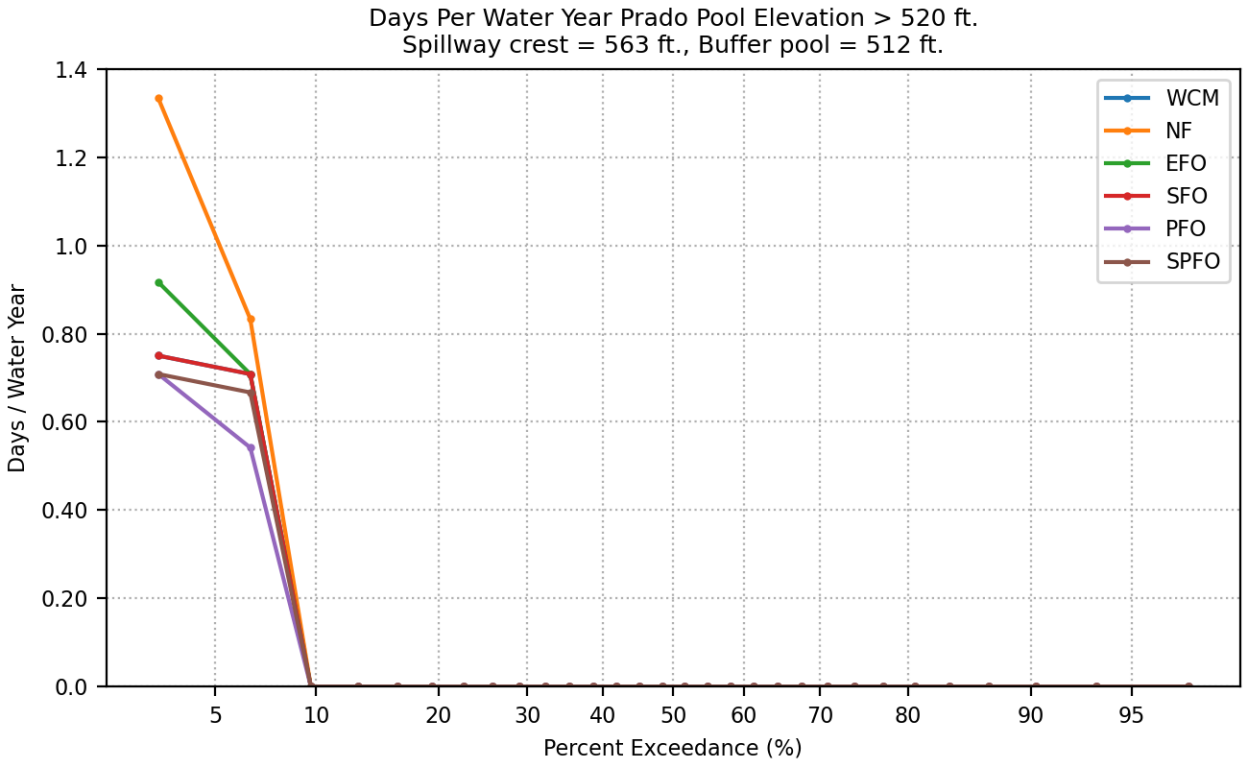

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
180.
160.
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

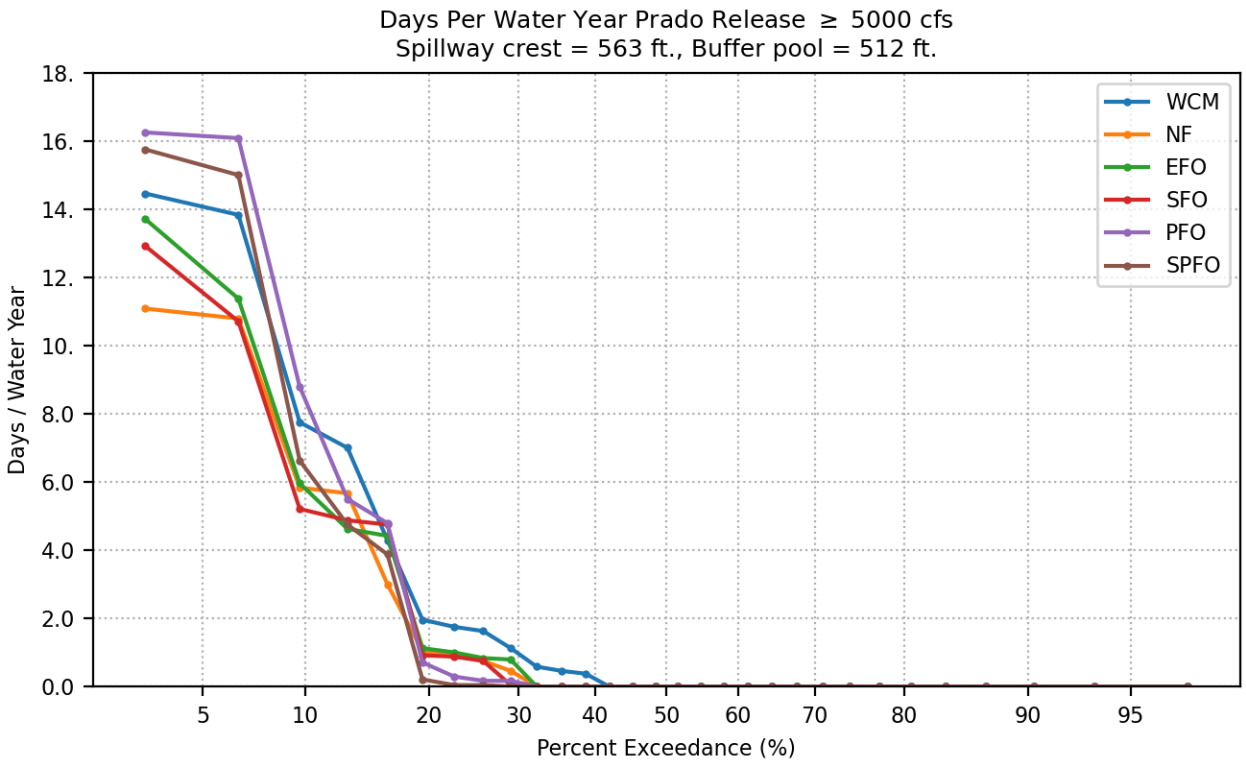

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

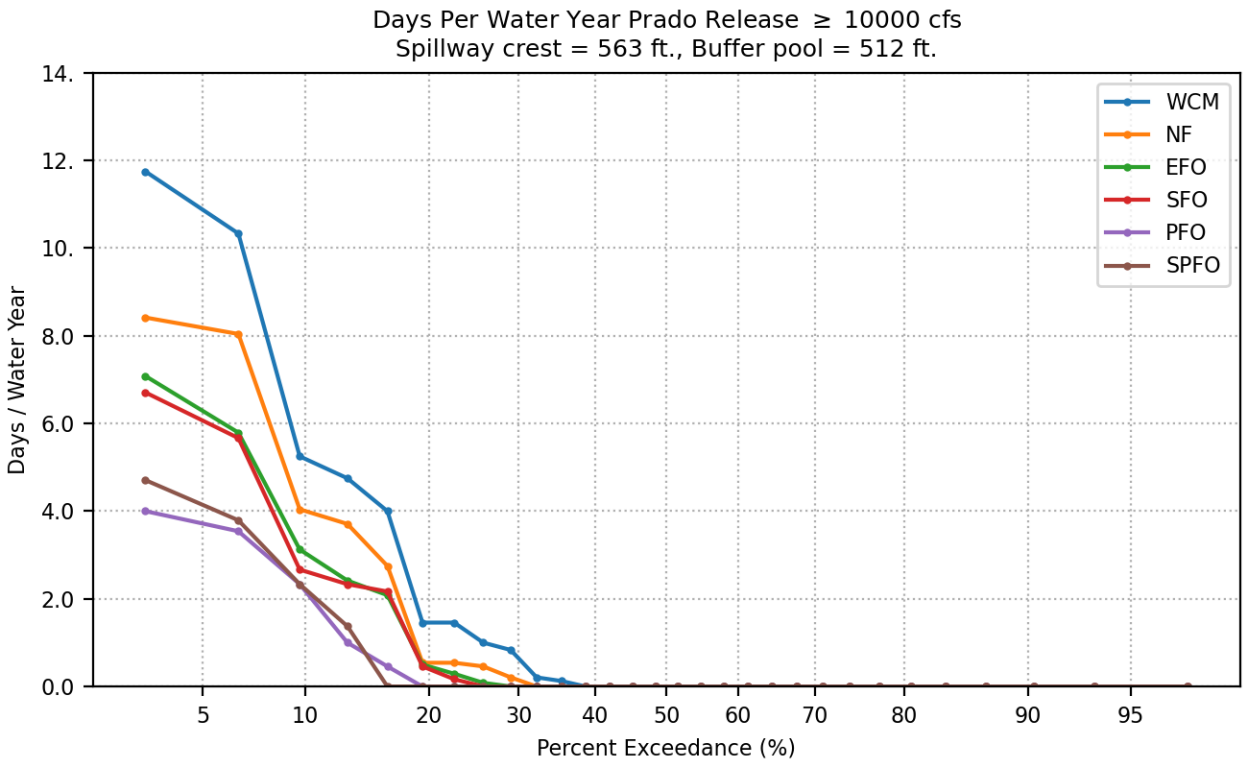

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

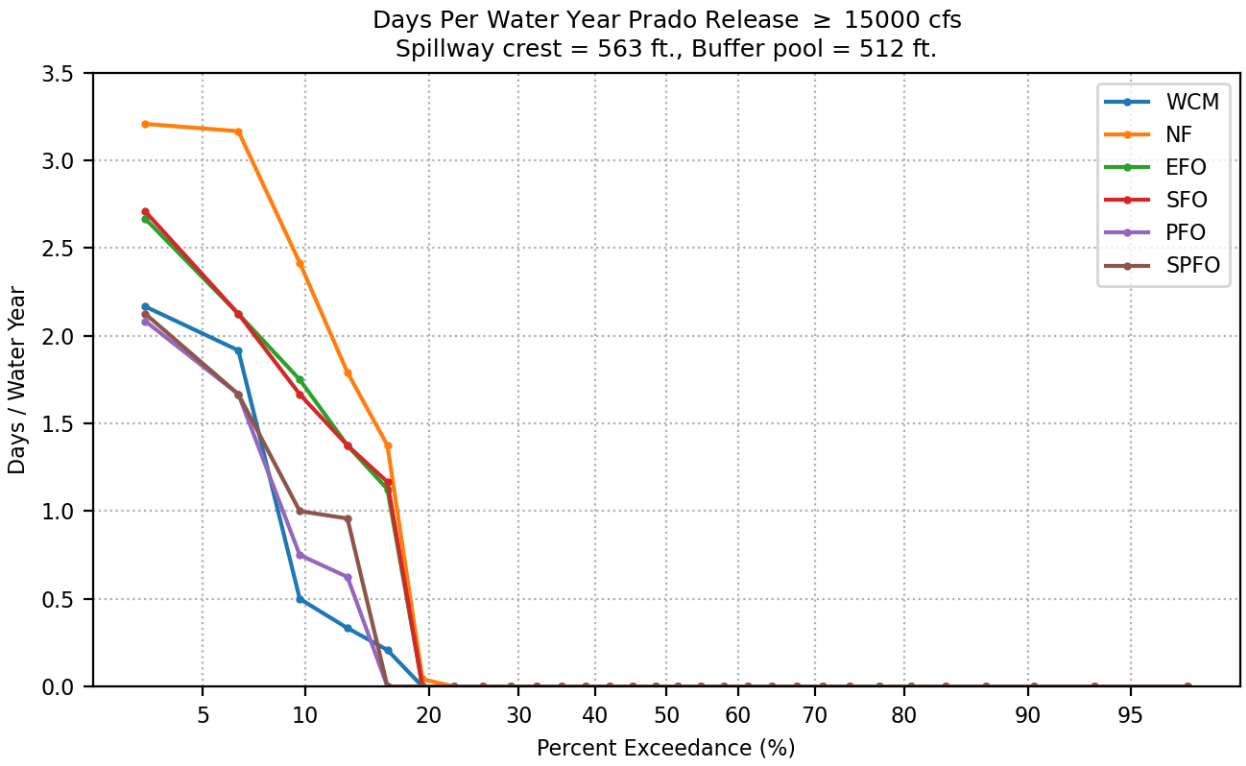

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

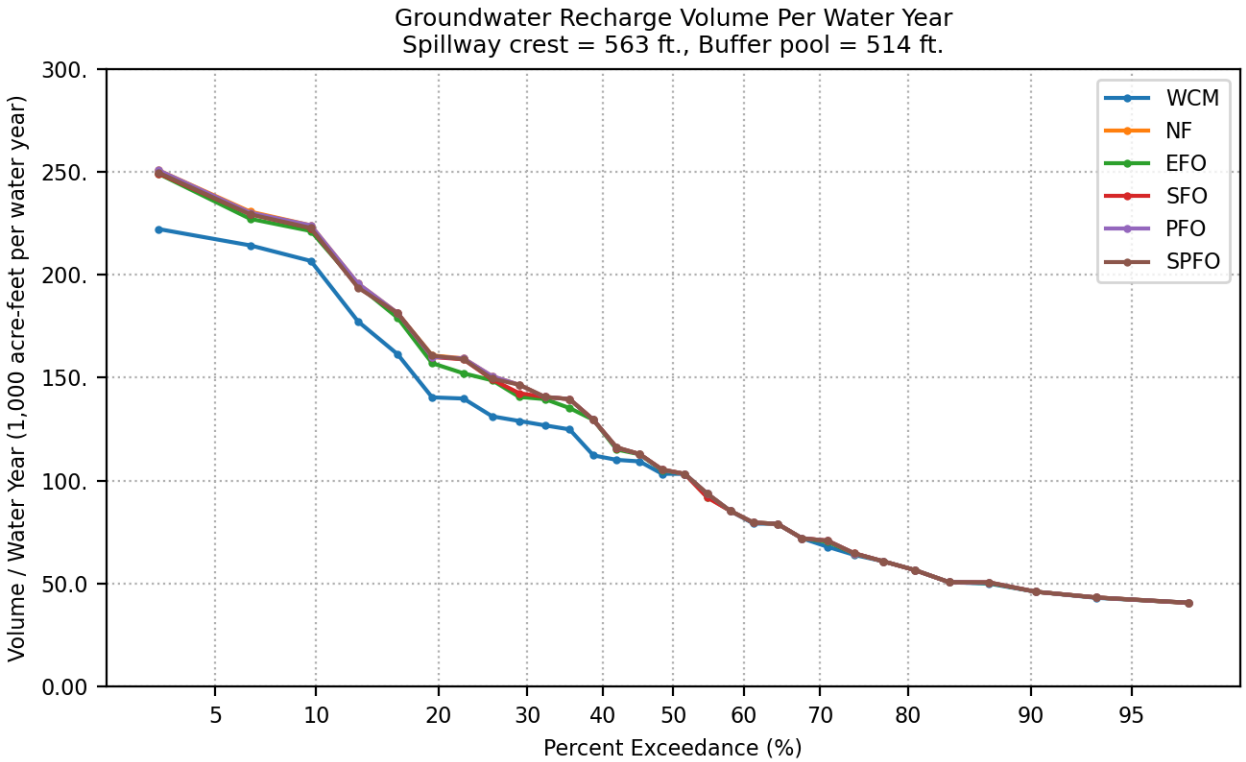

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5
10
20
30
40
50
60
70
80
90
95

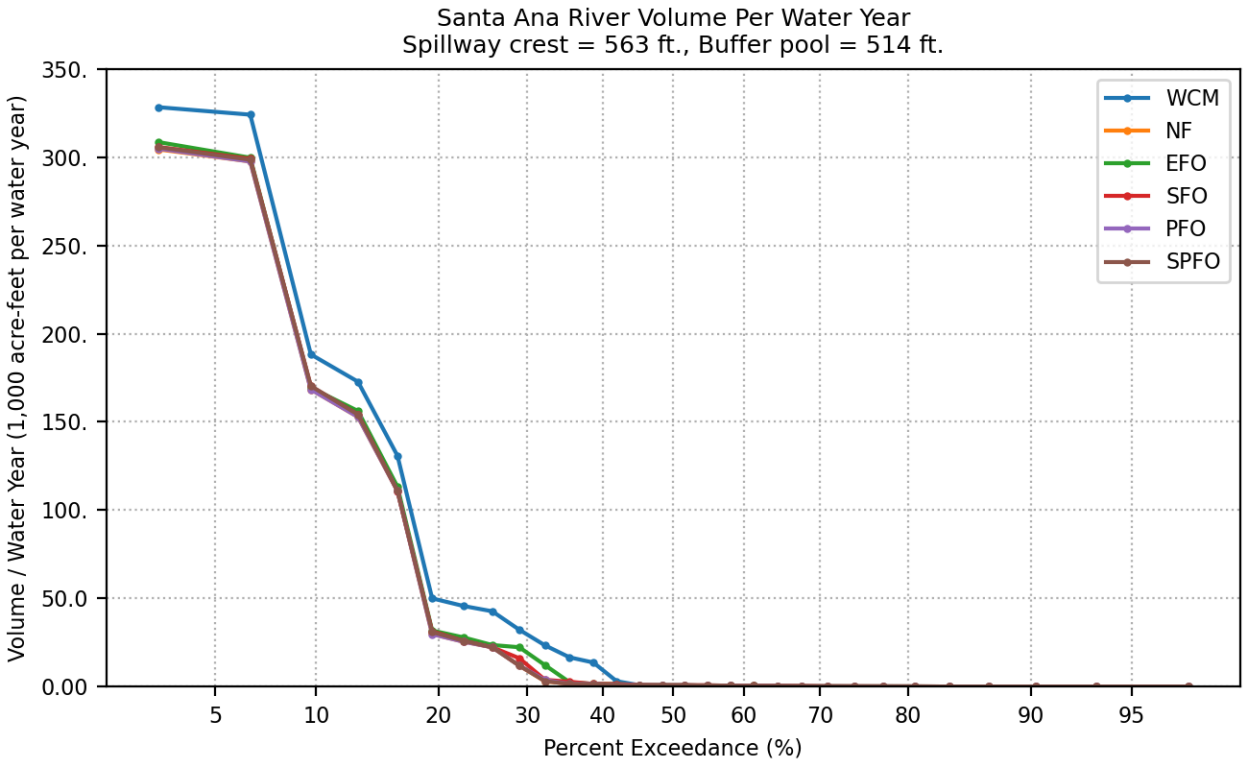

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
1.4
1.2
1.0
0.80
0.60
0.40
0.20
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

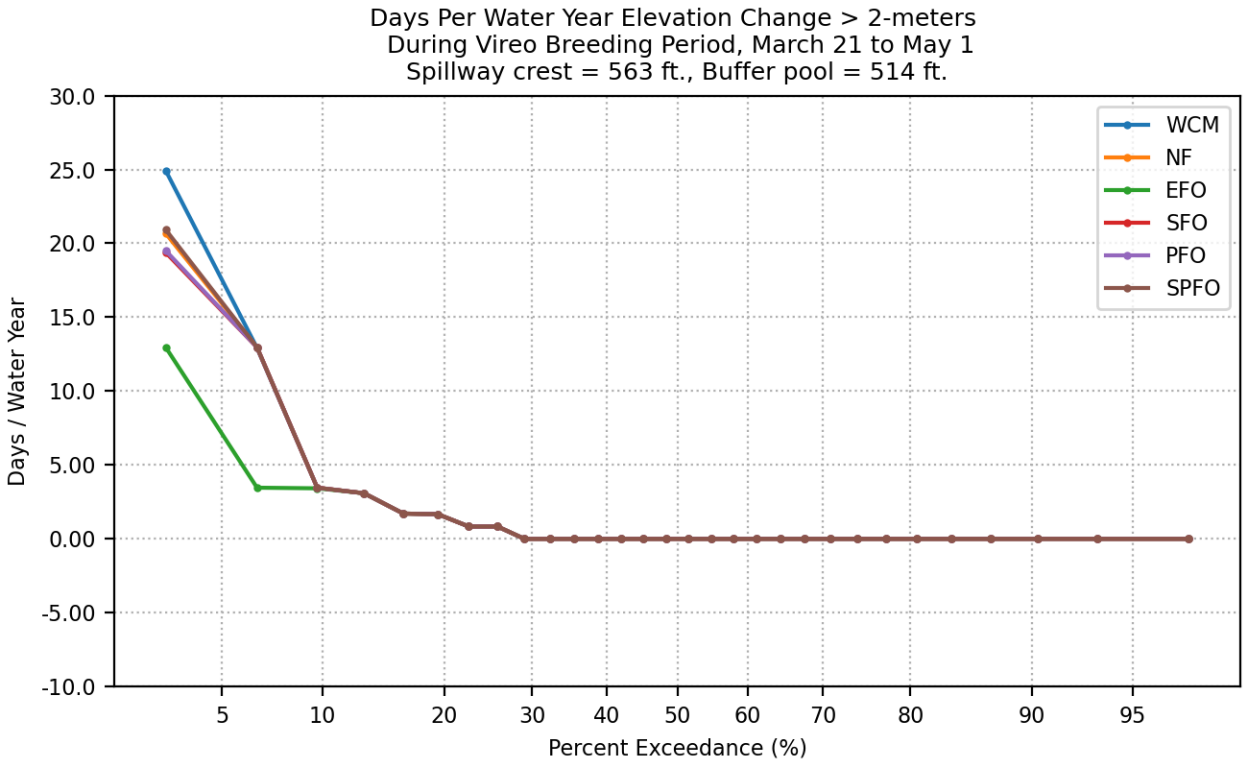

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
0.0
2.0
4.0
6.0
8.0
10.
12.
14.
16.
18.
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

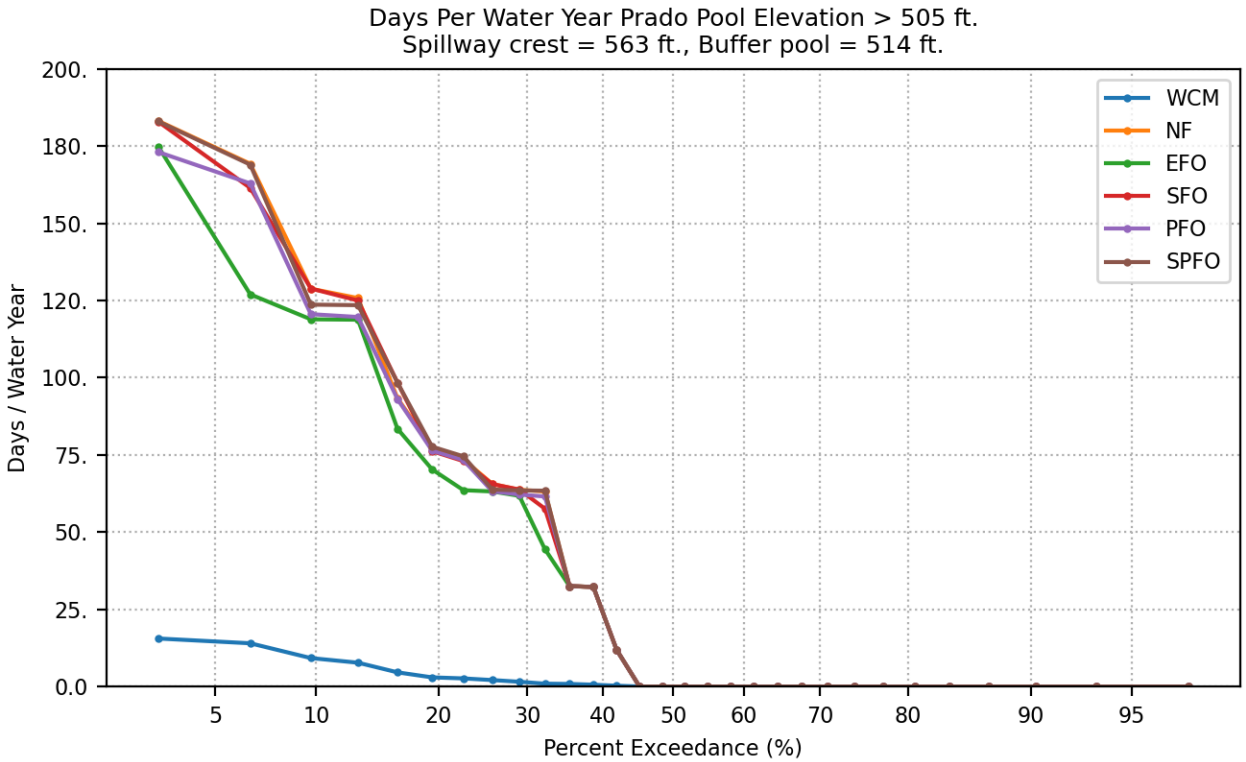

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
0.0
2.0
4.0
6.0
8.0
10.
12.
14.
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

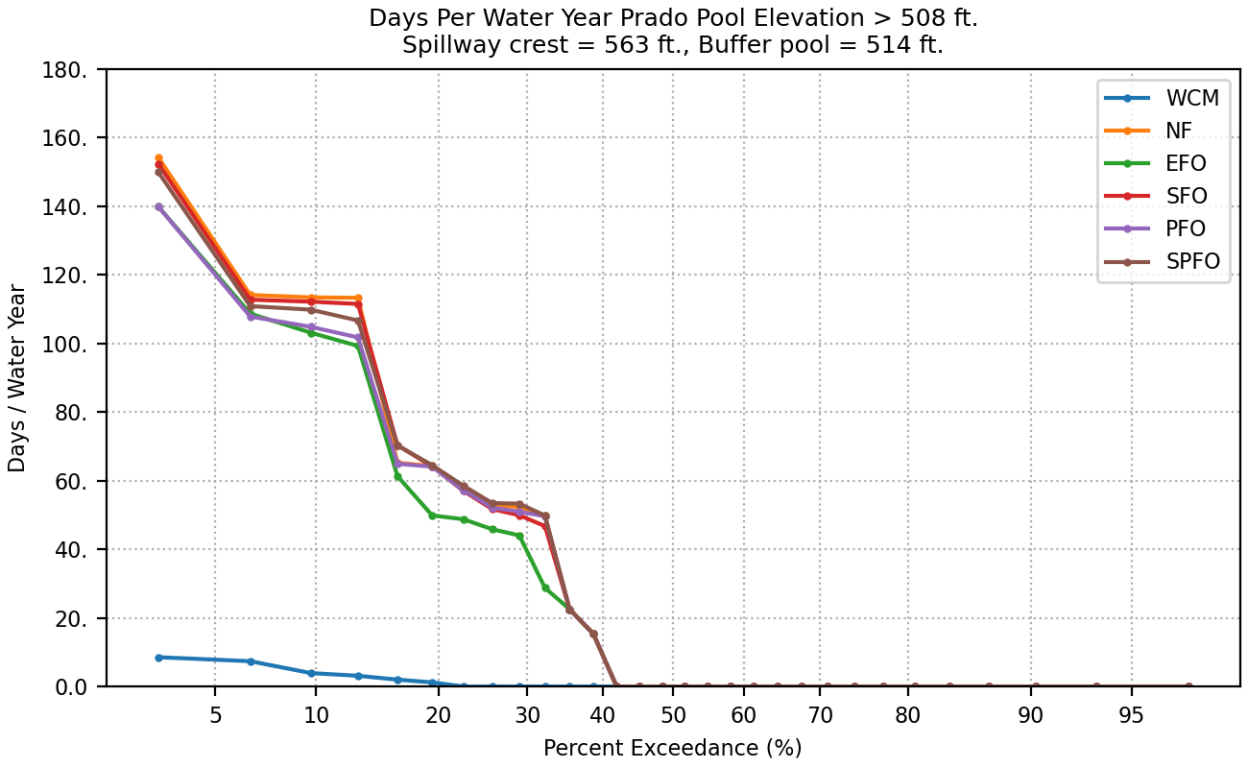

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

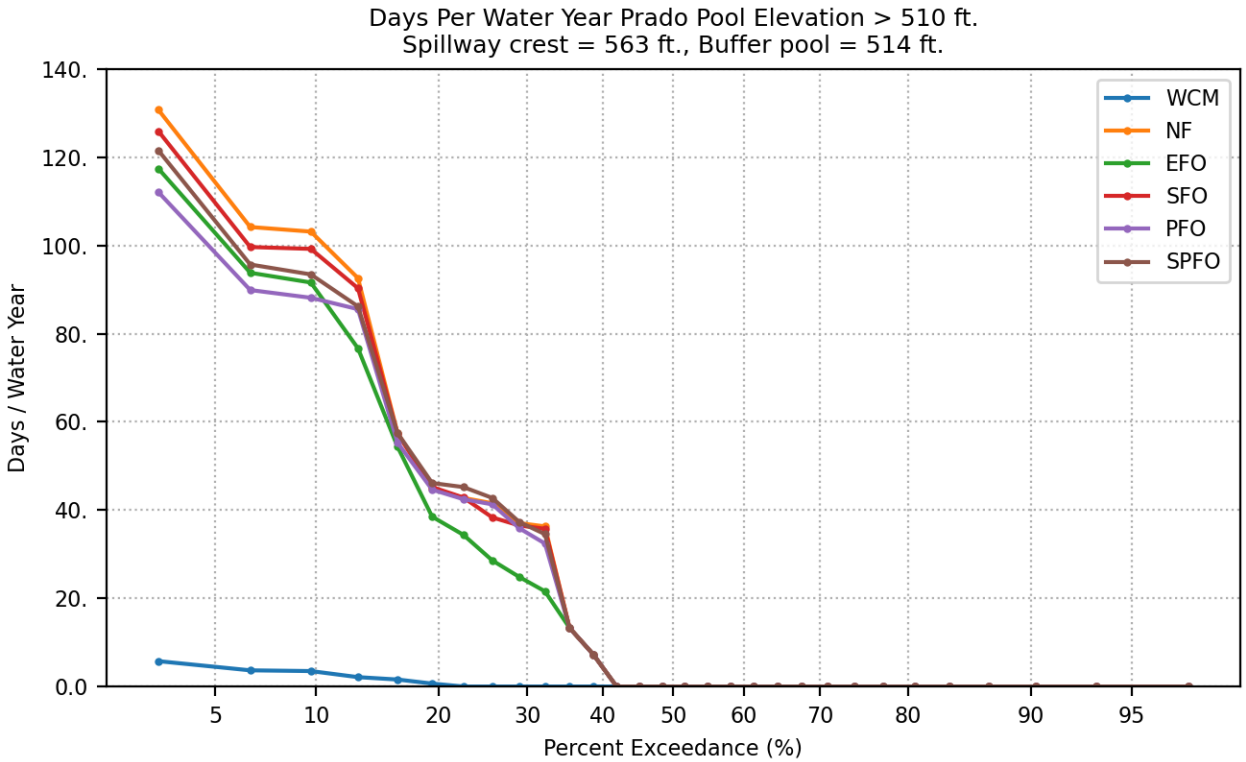

Groundwater Recharge Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 514 ft.
Volume / Water Year (1,000 acre-feet per water year)
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

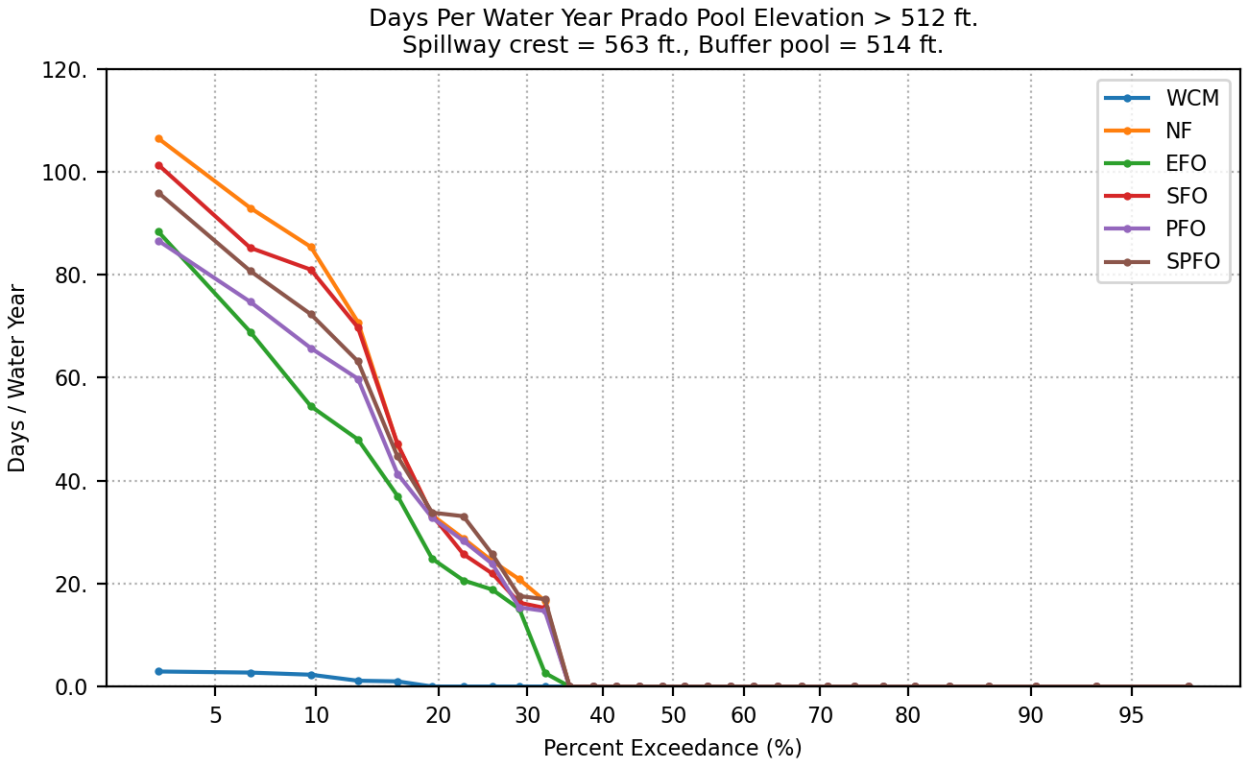

Santa Ana River Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 514 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

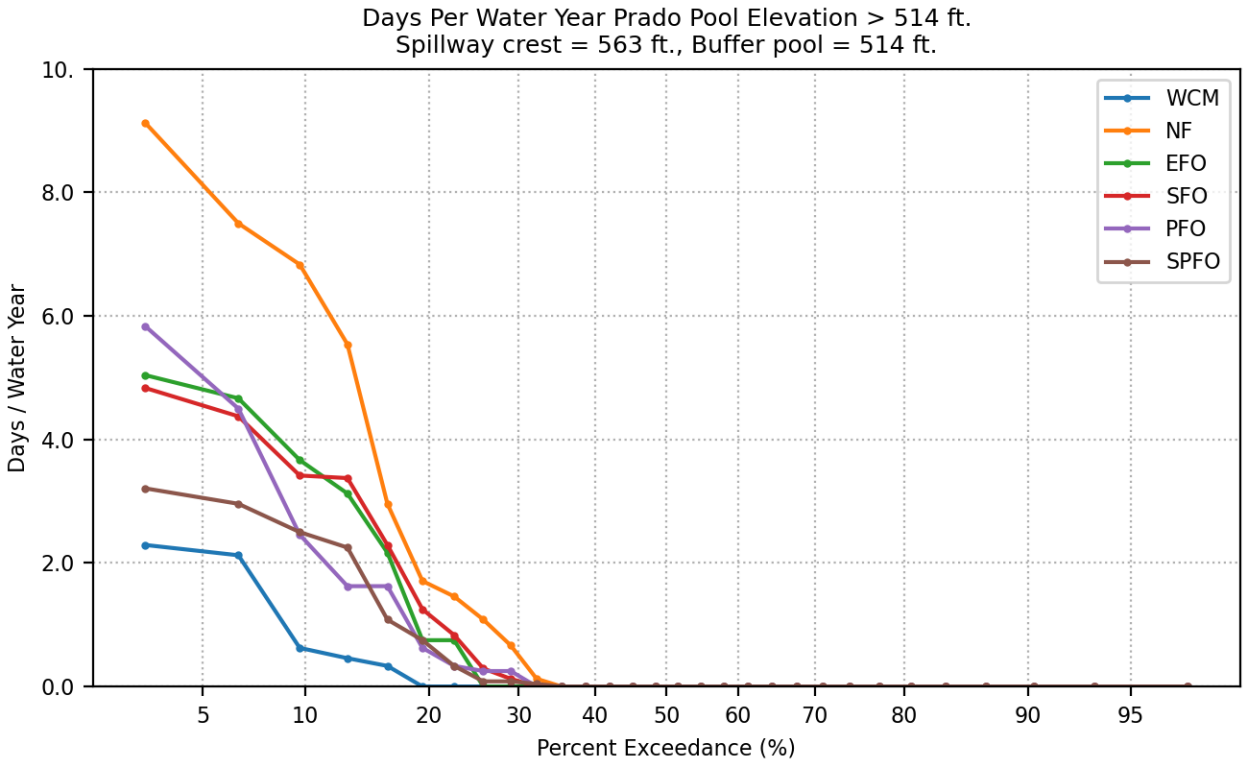

Days Per Water Year Elevation Change > 2-meters
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO

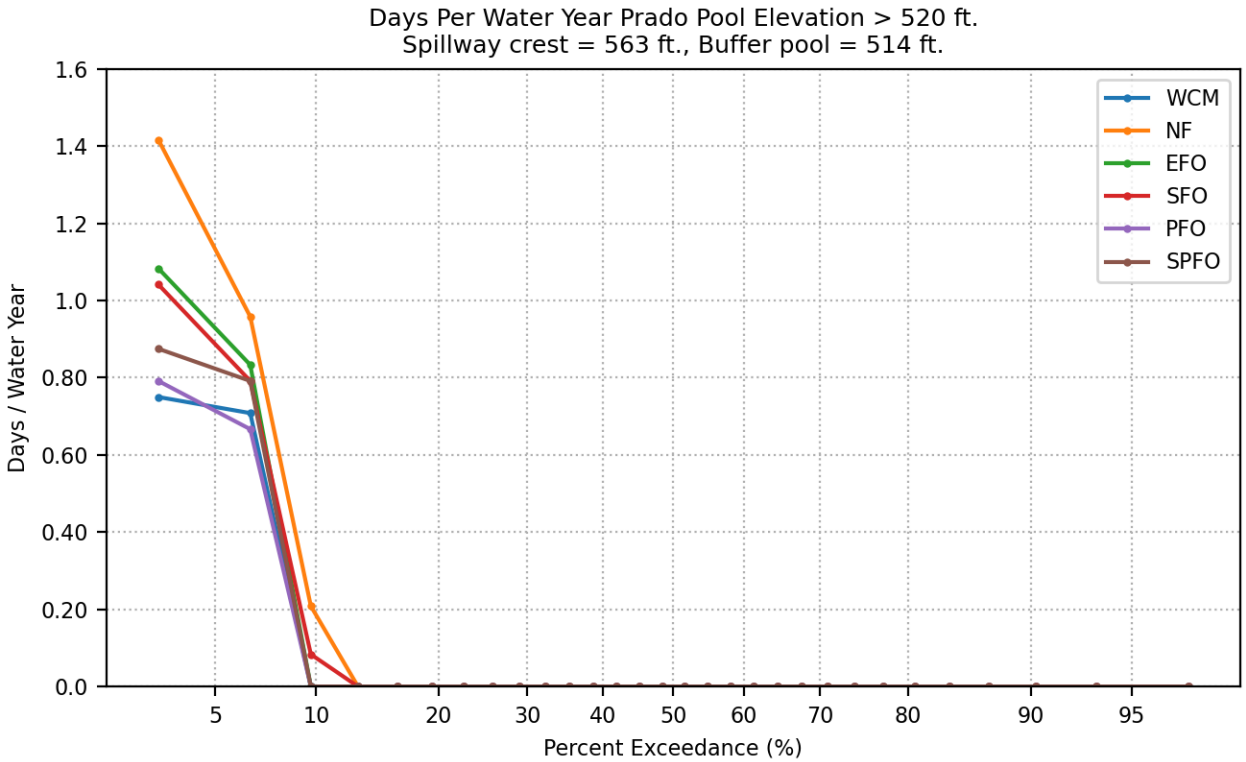

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
200.
180.
150.
120.
100.
75.
50.
25.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

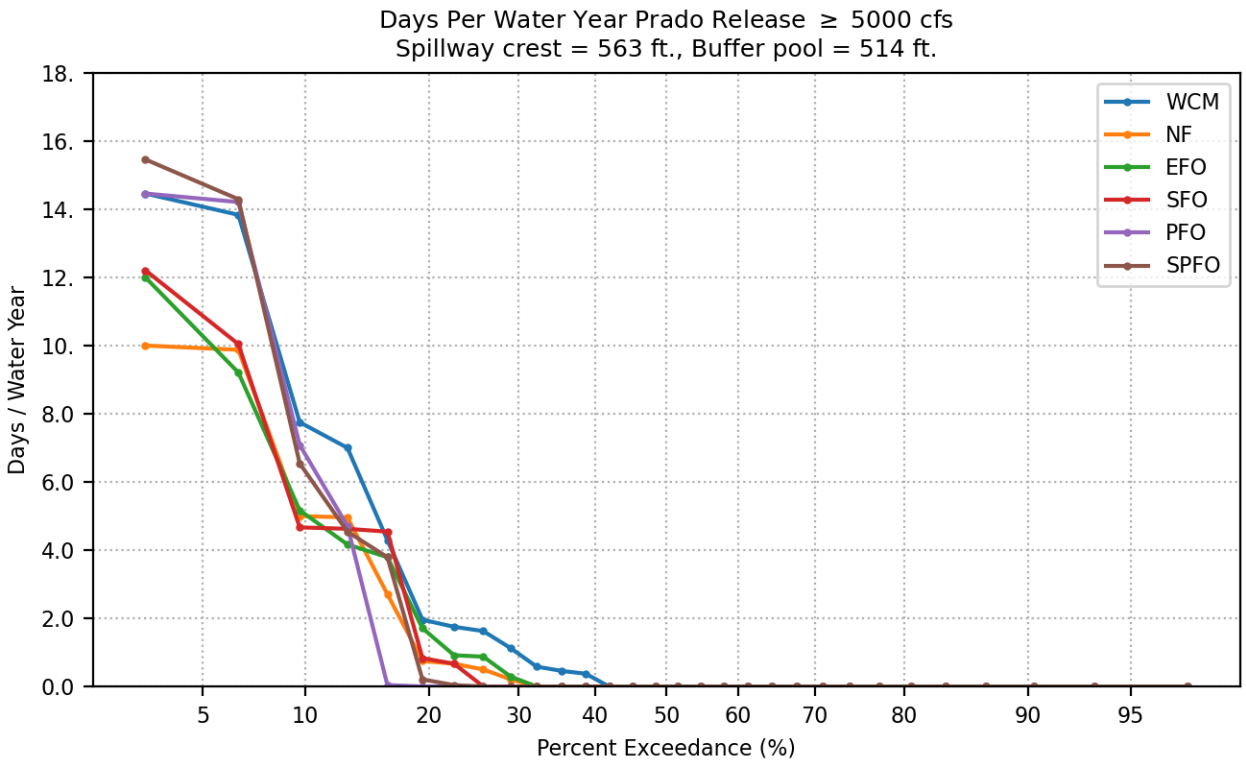

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
180.
160.
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

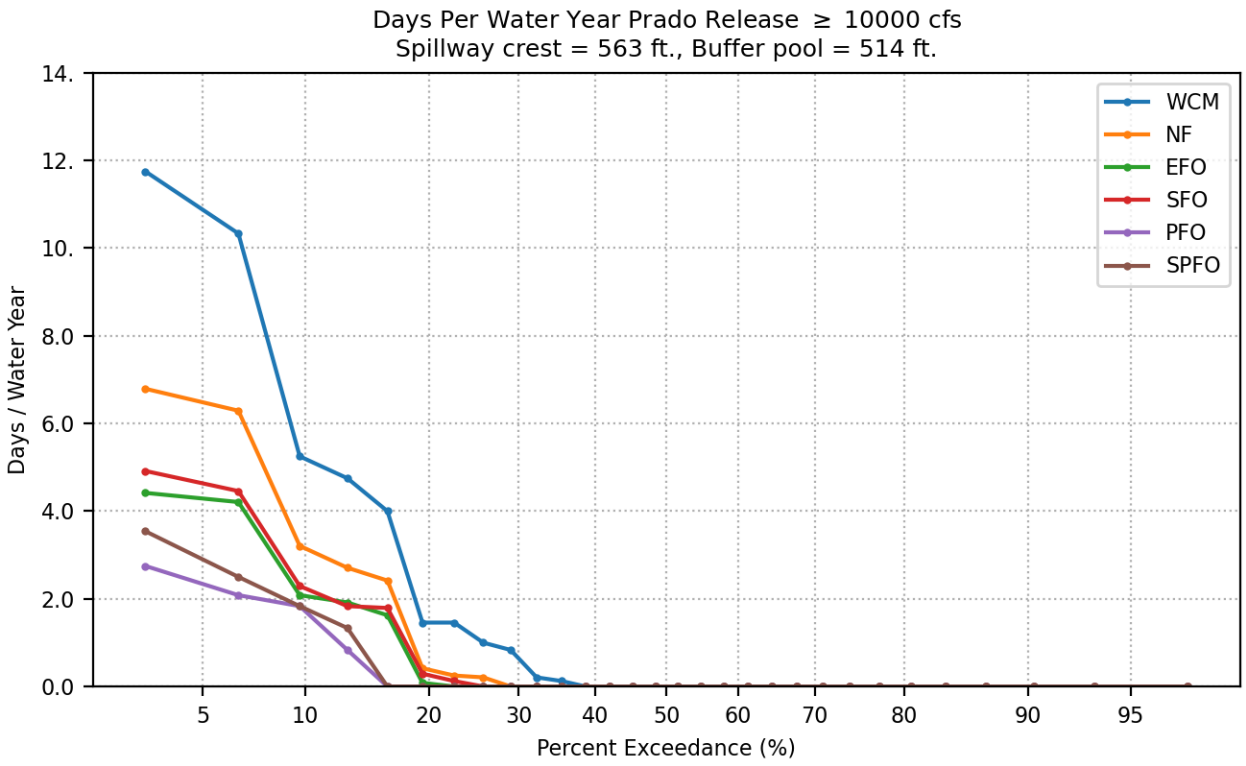

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

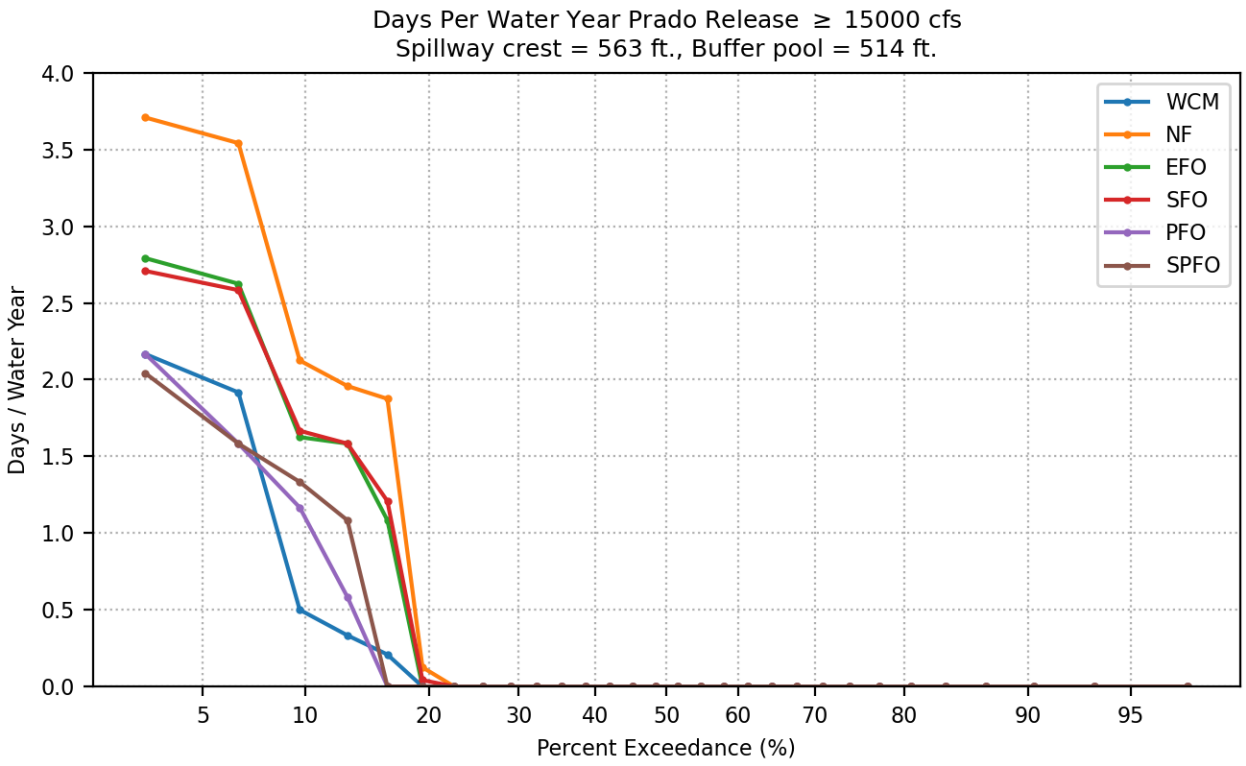

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO


Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO


Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
1.6
1.4
1.2
1.0
0.80
0.60
0.40
0.20
0.0
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO


Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
0.0
2.0
4.0
6.0
8.0
10.
12.
14.
16.
18.
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO


Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
0.0
2.0
4.0
6.0
8.0
10.
12.
14.
5
10
20
30
40
50
60
70
80
90
95
WCM
NF
EFO
SFO
PFO
SPFO

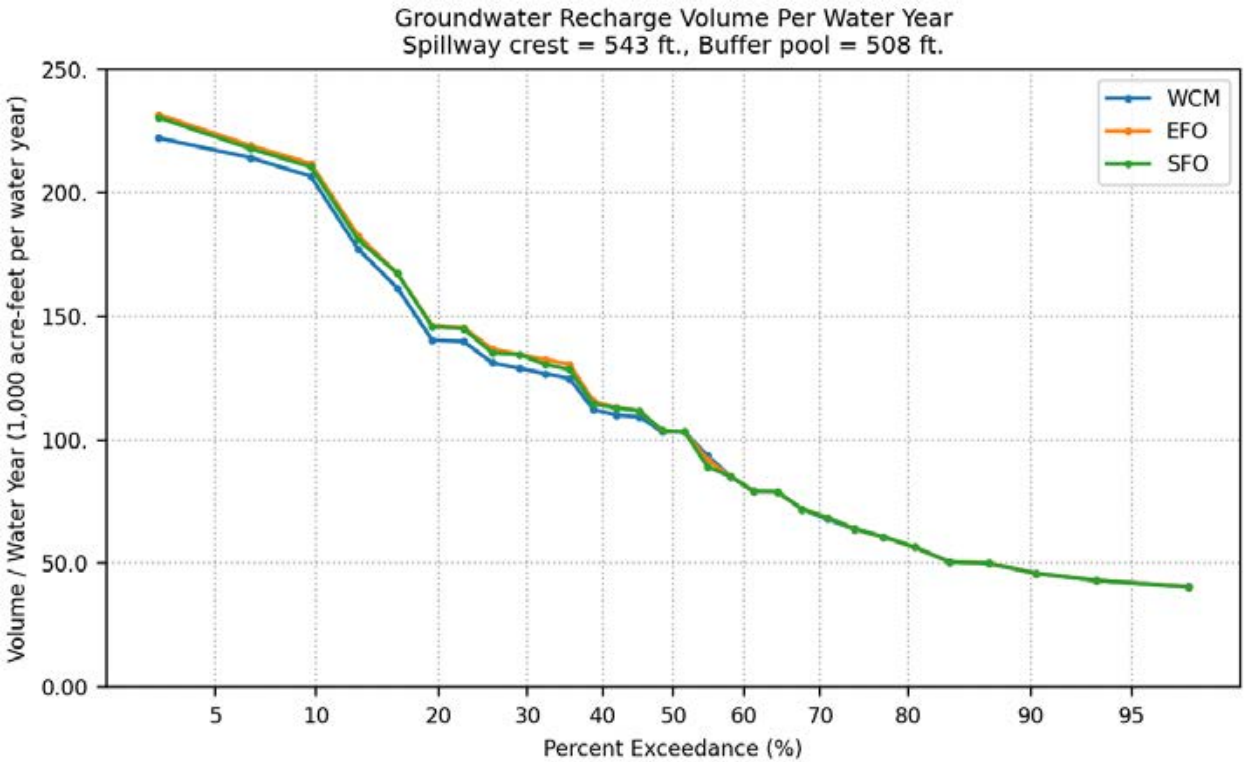

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
NF
EFO
SFO
PFO
SPFO
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
5
10
20
30
40
50
60
70
80
90
95

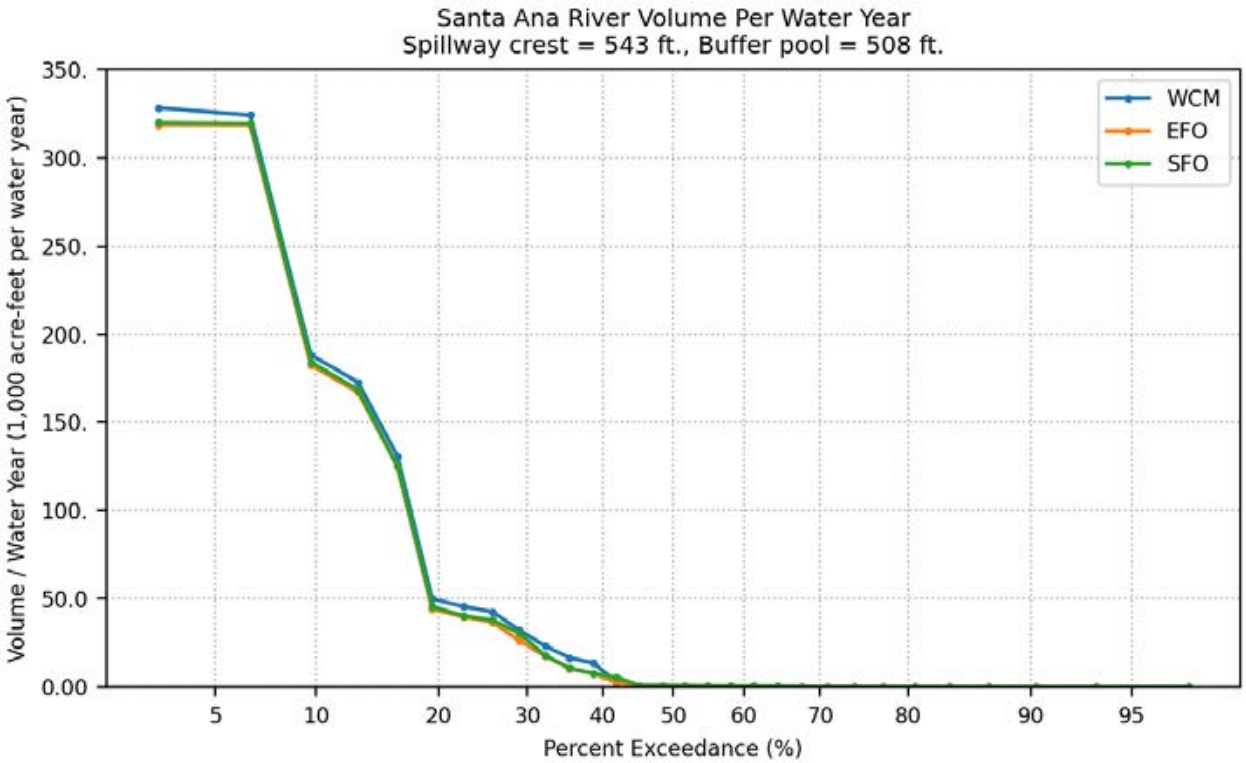
HEMP Metrics (No PF / No NF)

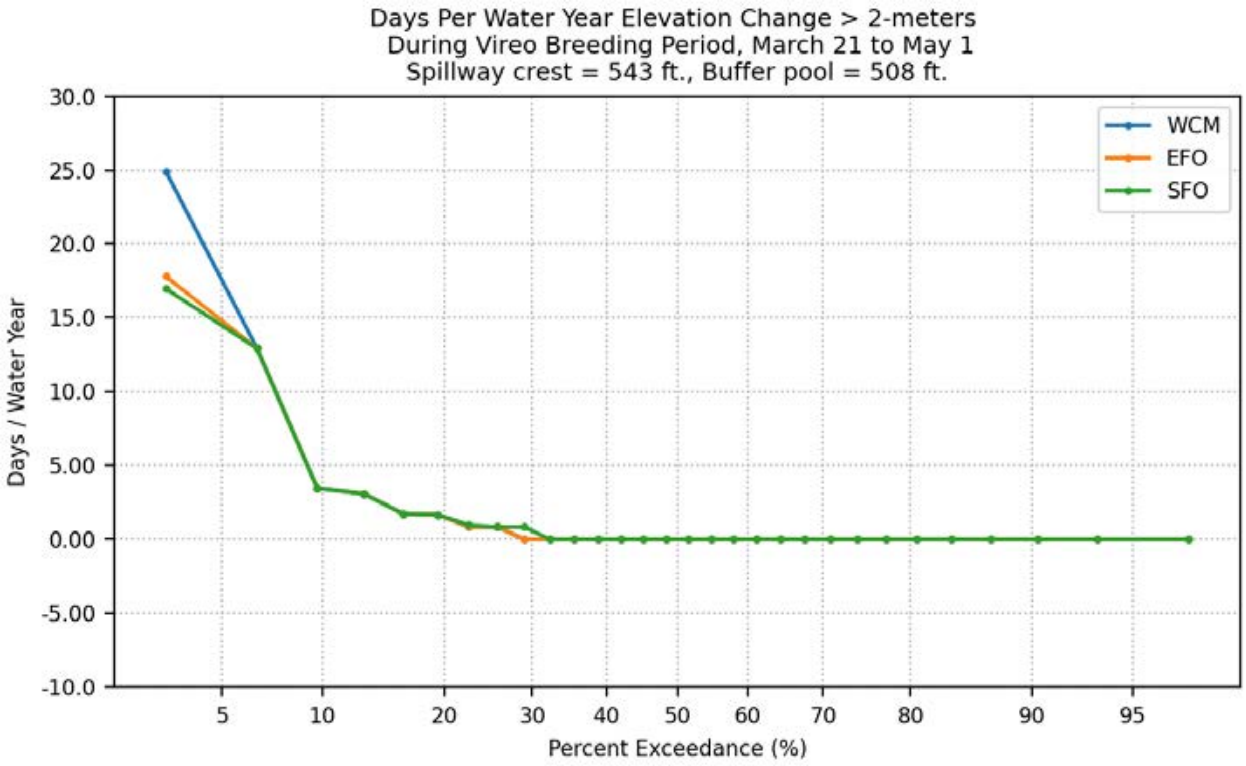
- Groundwater Recharge (KAF/yr)
- Discharge to Pacific Ocean (KAF/yr)
- >1 meter rise between 3/21 and 5/1 (days/yr)
- Pool elevation > 505’, 508’, 510’, 512’, 514’, 520’ (days/yr)
- Reservoir release > 5,000 cfs, 10,000 cfs, 15,000 cfs (days/yr)

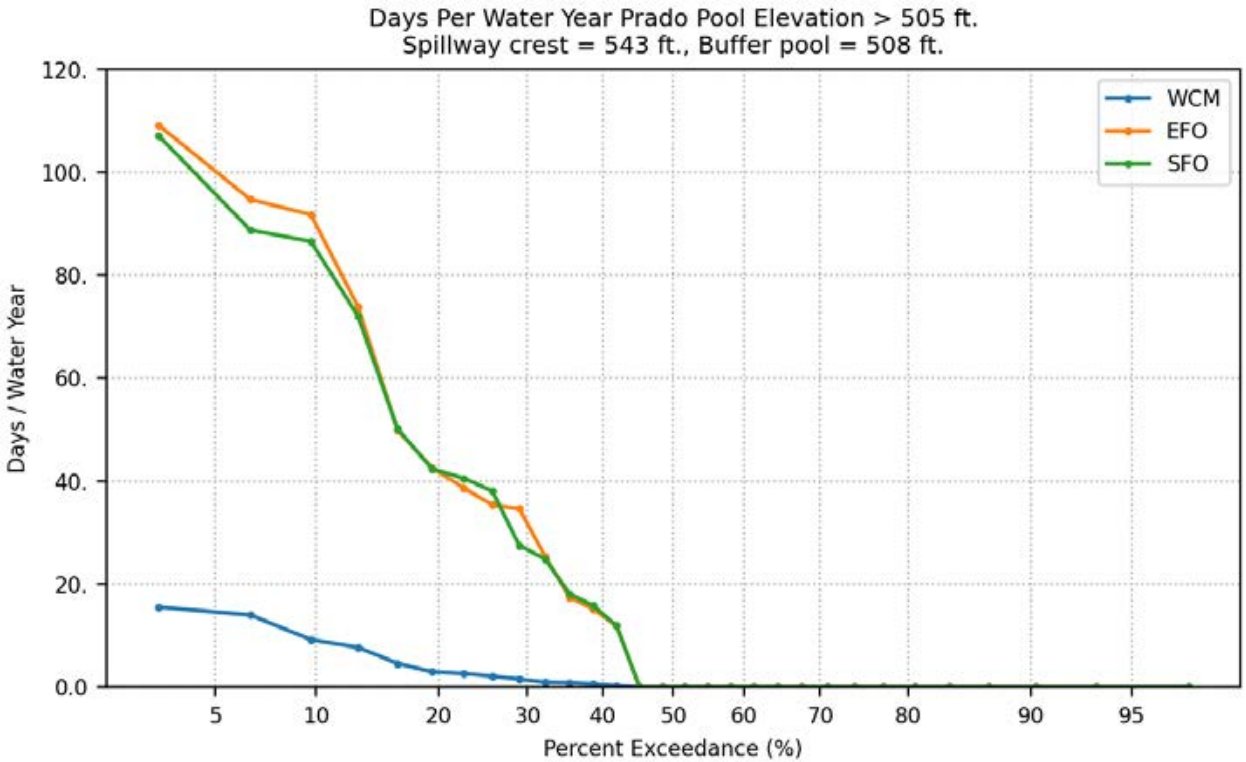
HEMP Metrics (No PF / No NF)

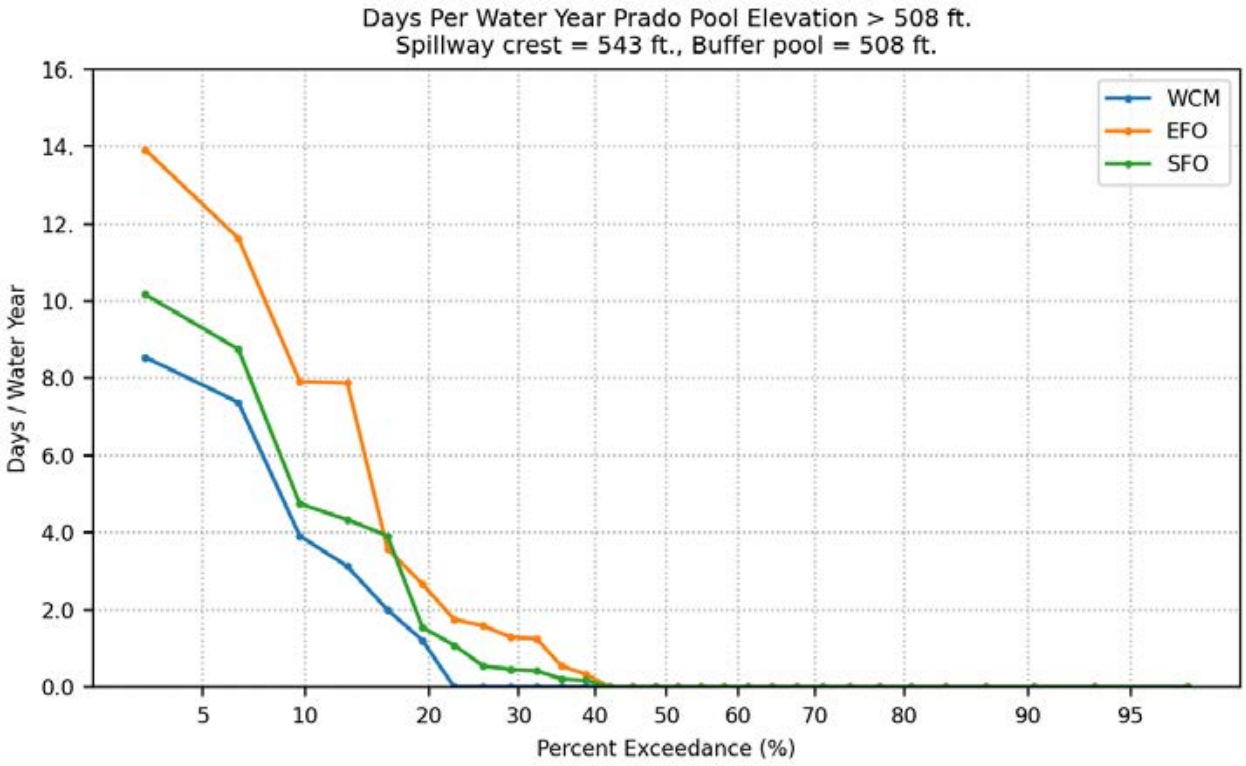
- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’, 510’, 512’, 514’, 520’
  - WCP alternatives in legend
    - Perfect Forecast and No Forecast alternatives omitted

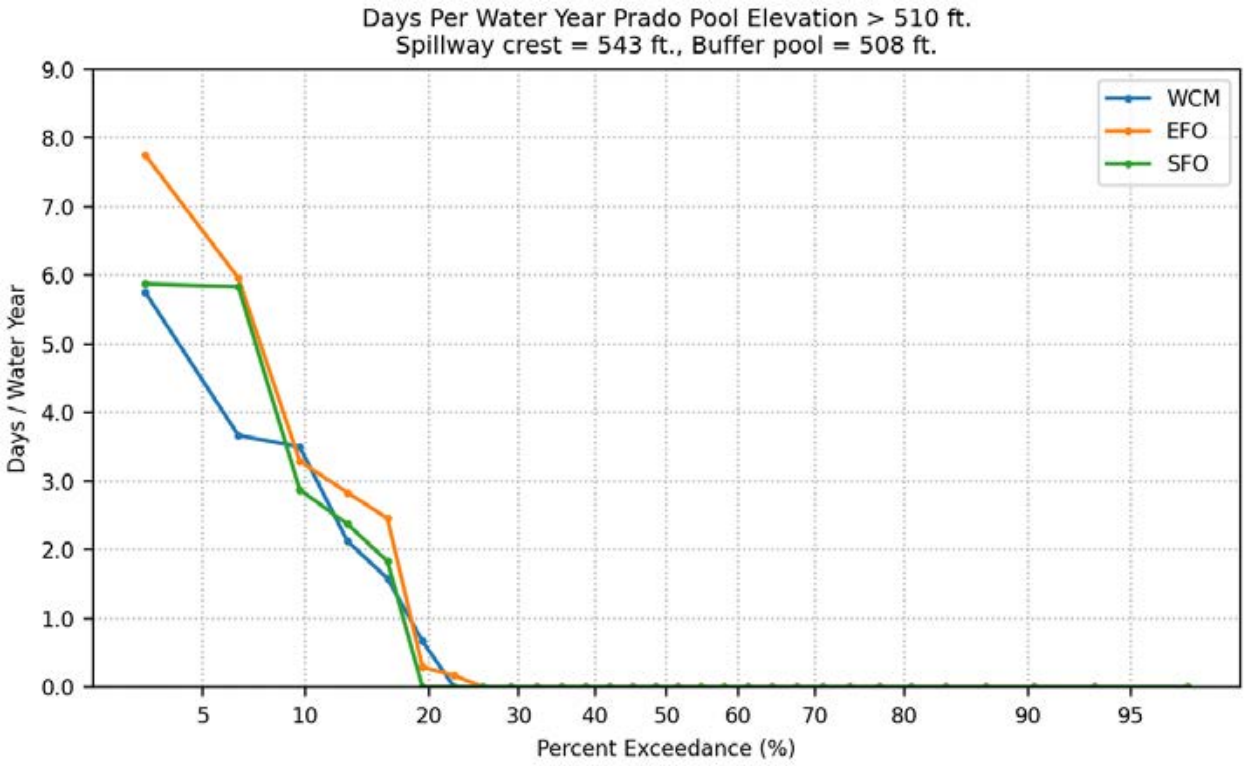

Groundwater Recharge Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 508 ft.
Volume / Water Year (1,000 acre-feet per water year)
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

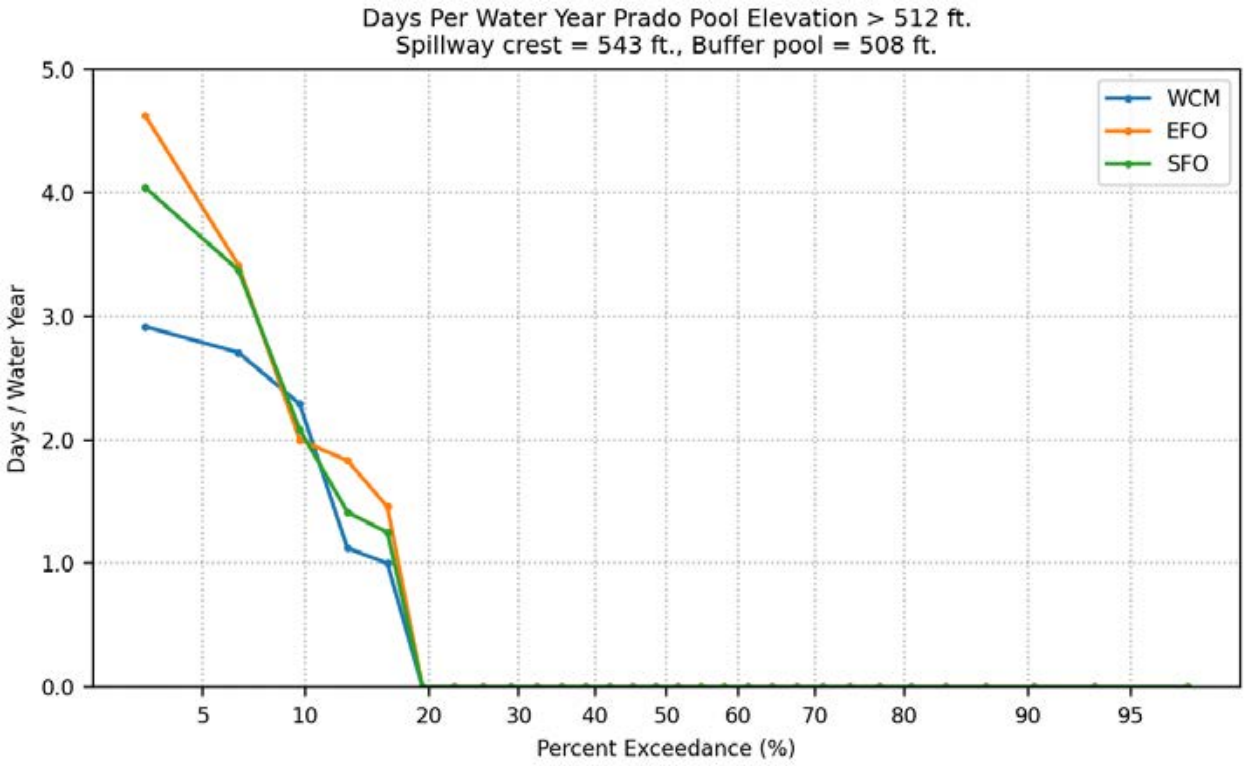

Santa Ana River Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 508 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

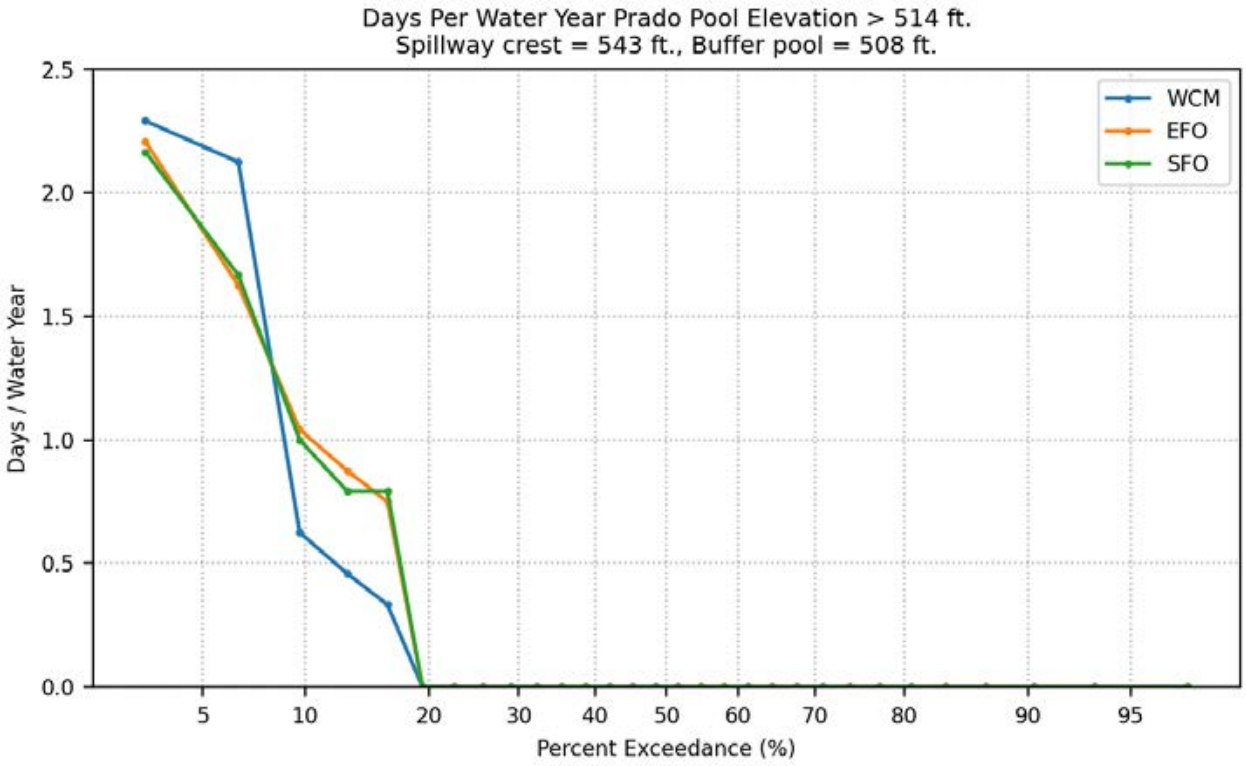

Days Per Water Year Elevation Change > 2-meters
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 543 ft., Buffer pool = 508 ft.
WCM
EFO
SFO
Days / Water Year
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)

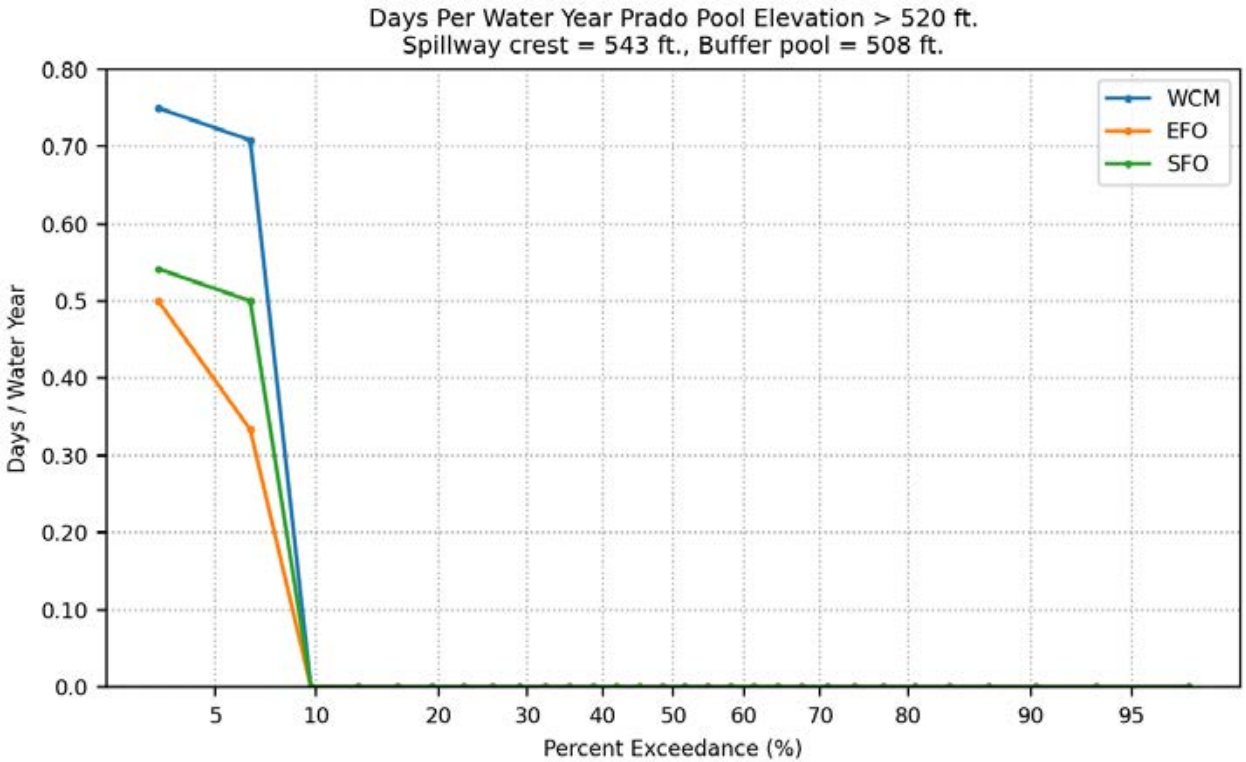

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

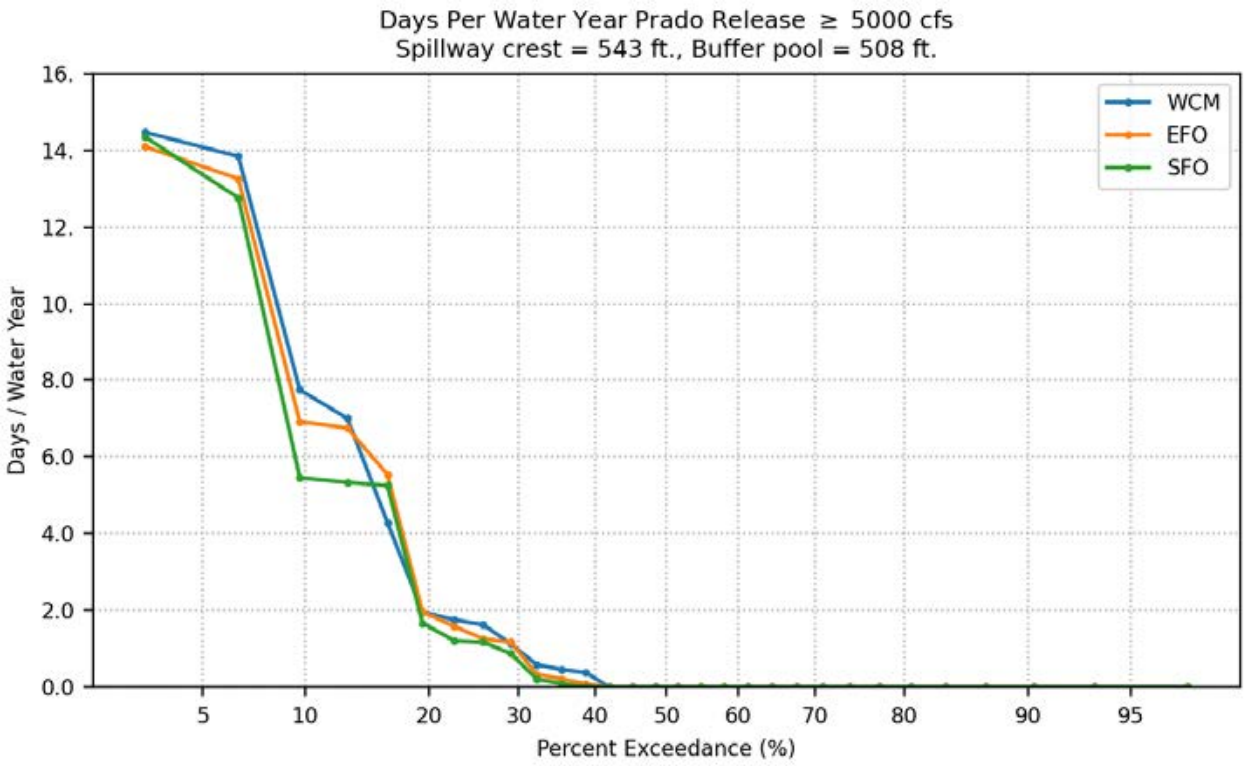

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

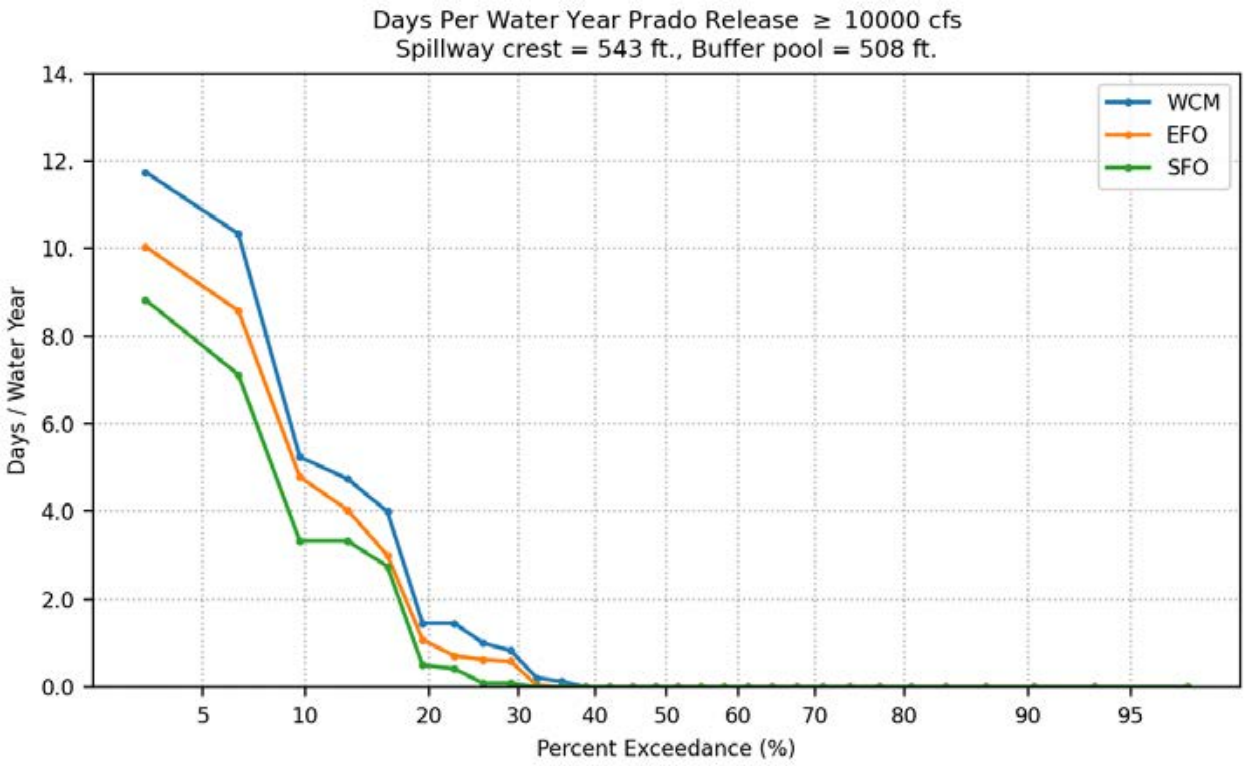

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
5
10
20
30
40
50
60
70
80
90
95

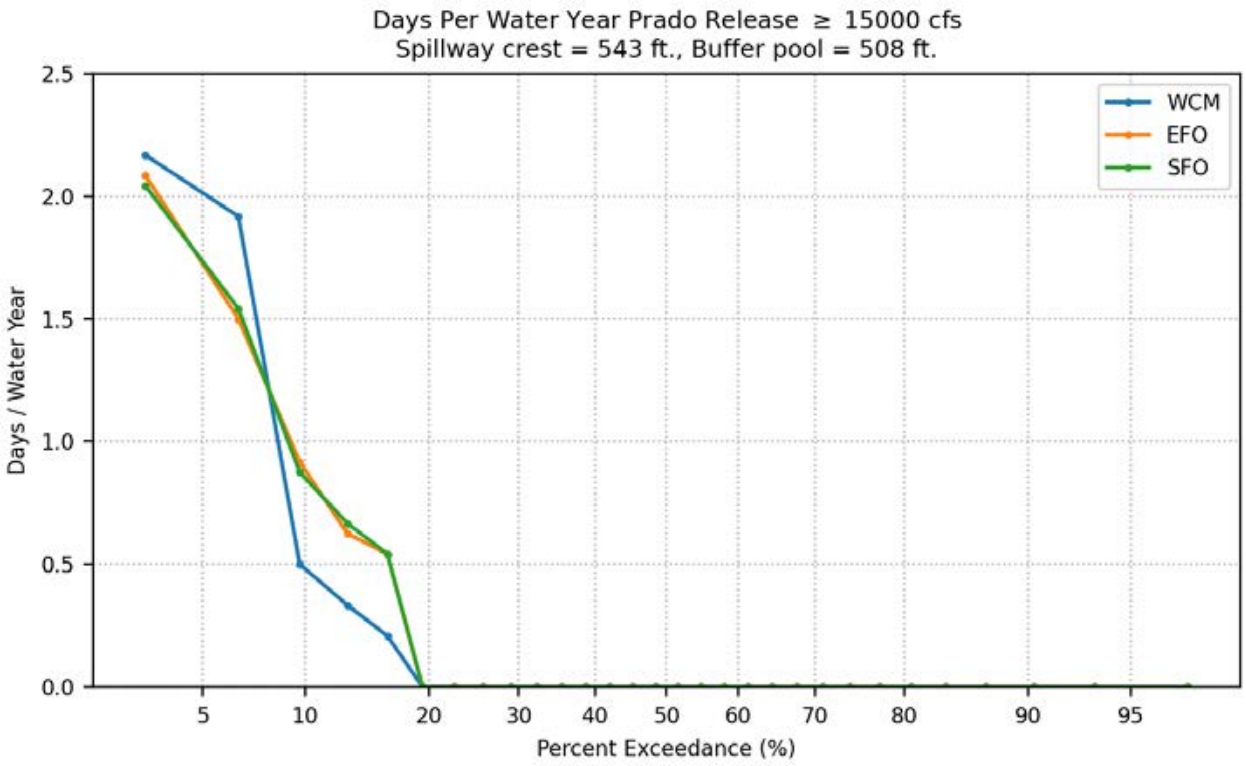

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
5.0
4.0
3.0
2.0
1.0
0.0
5
10
20
30
40
50
60
70
80
90
95

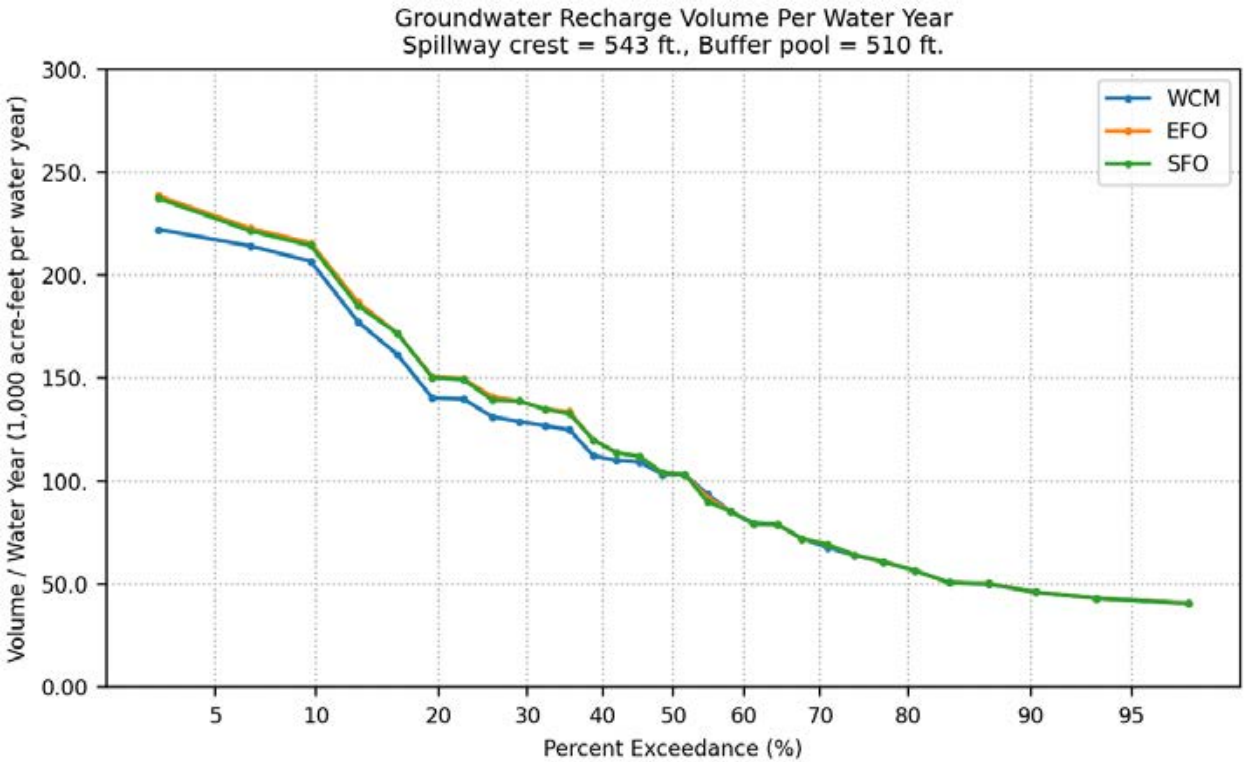

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
0.0
0.5
1.0
1.5
2.0
2.5
5
10
20
30
40
50
60
70
80
90
95

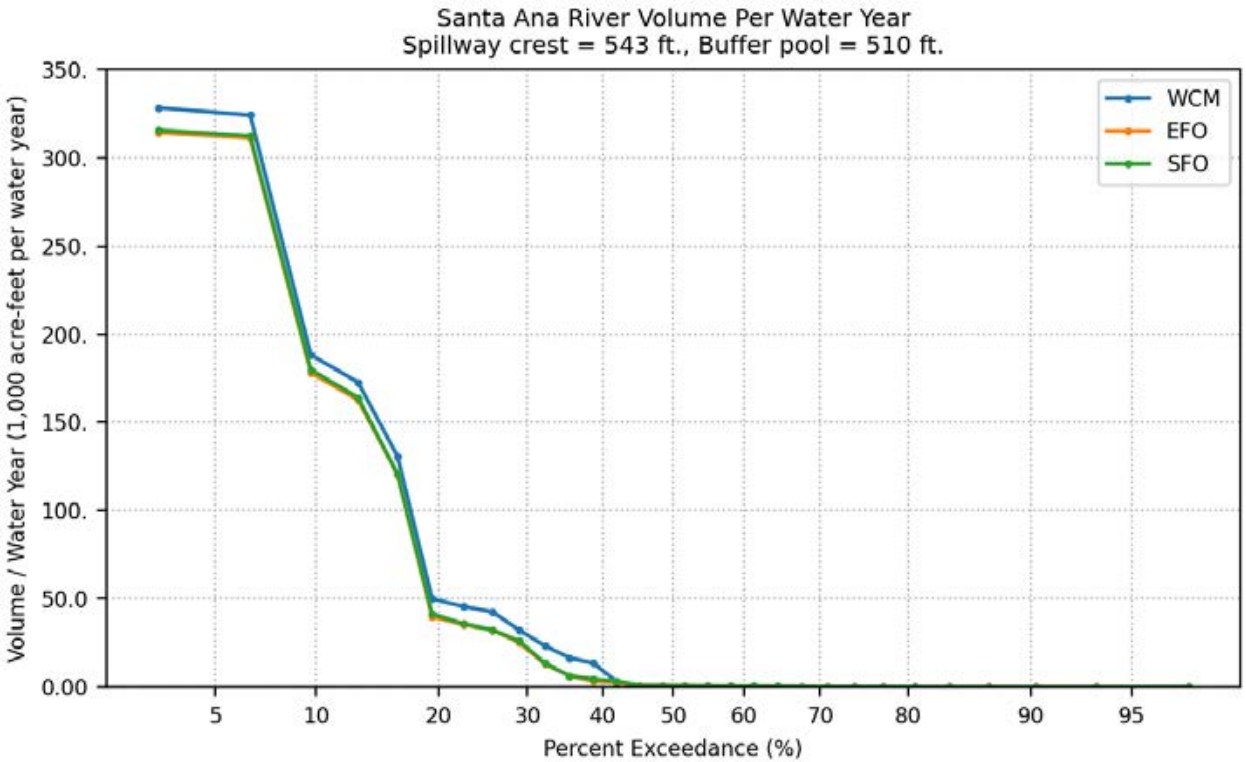

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
0.80
0.70
0.60
0.5
0.40
0.30
0.20
0.10
0.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

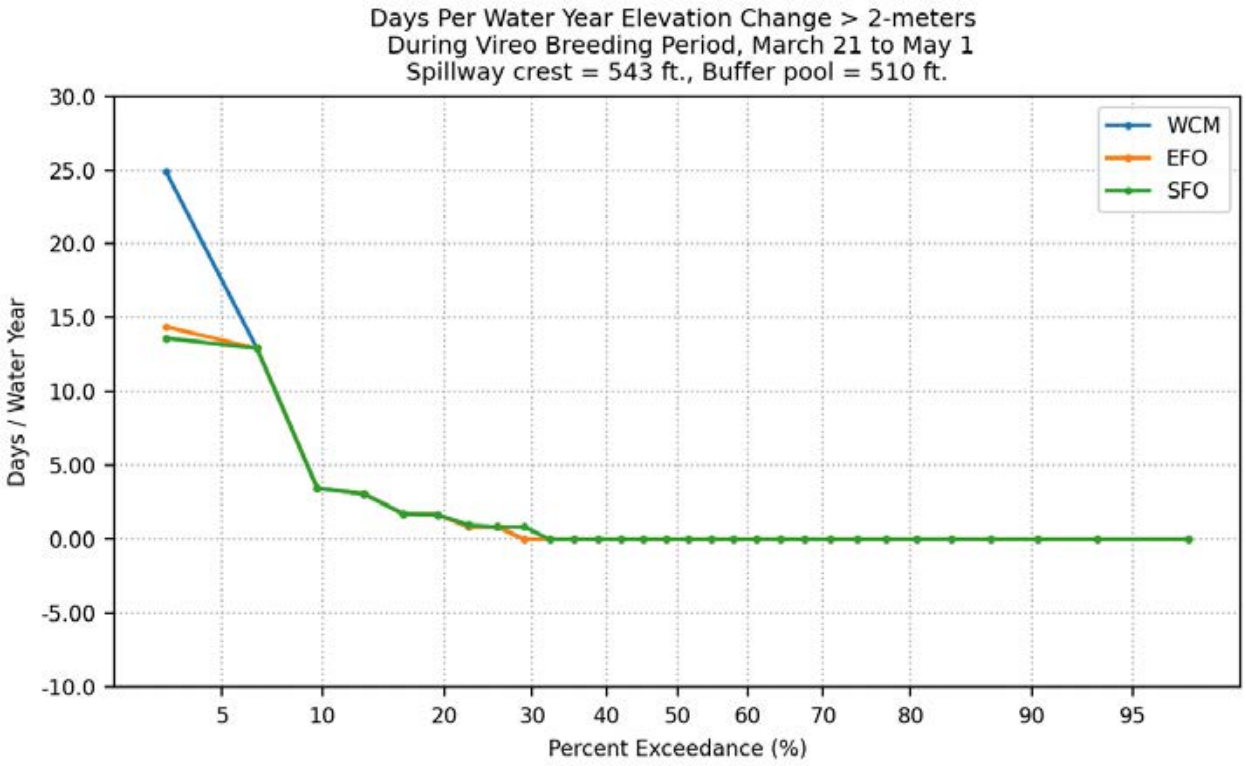

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

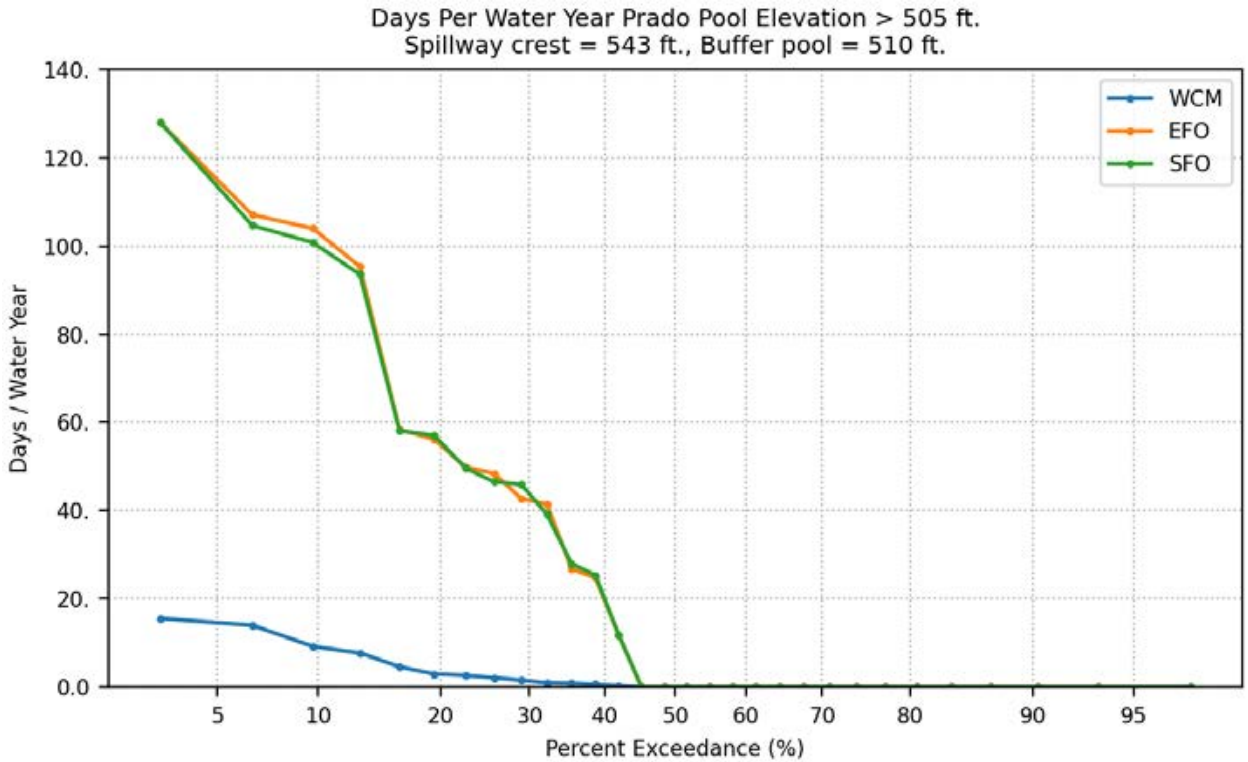

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

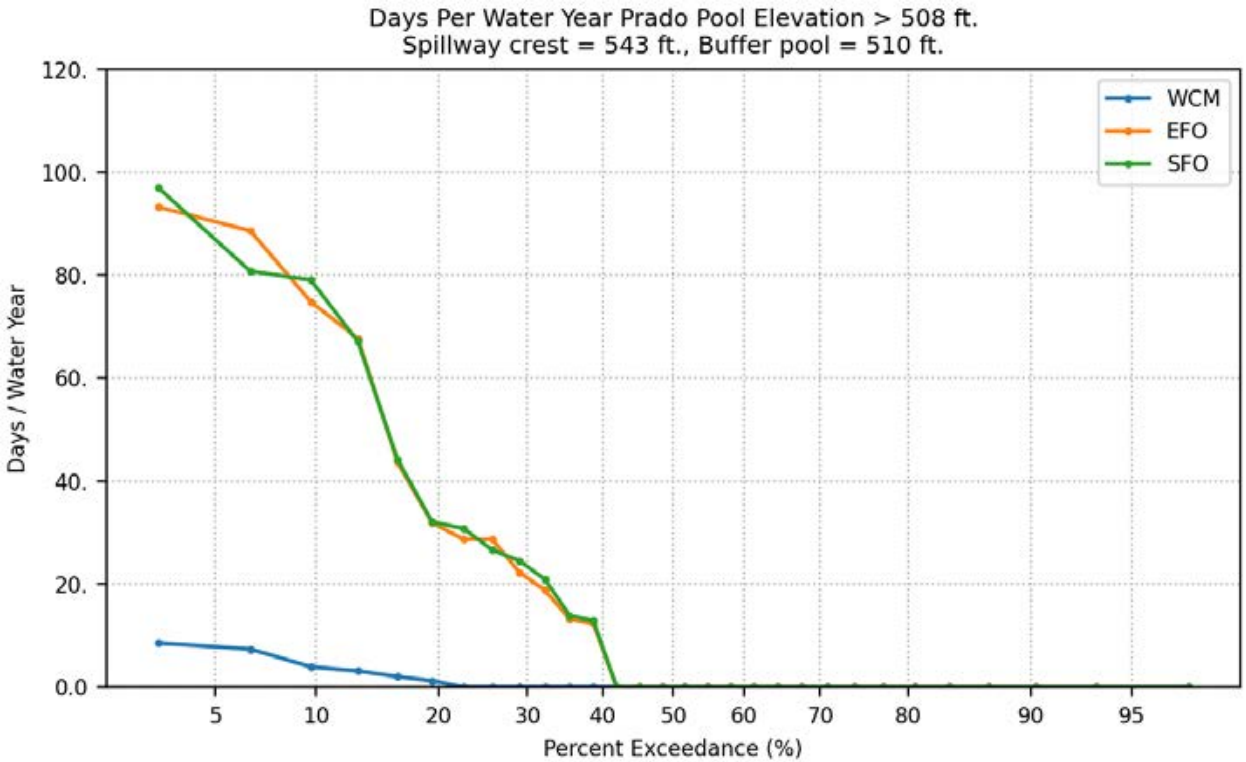

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 543 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
0.0
0.5
1.0
1.5
2.0
2.5
5
10
20
30
40
50
60
70
80
90
95

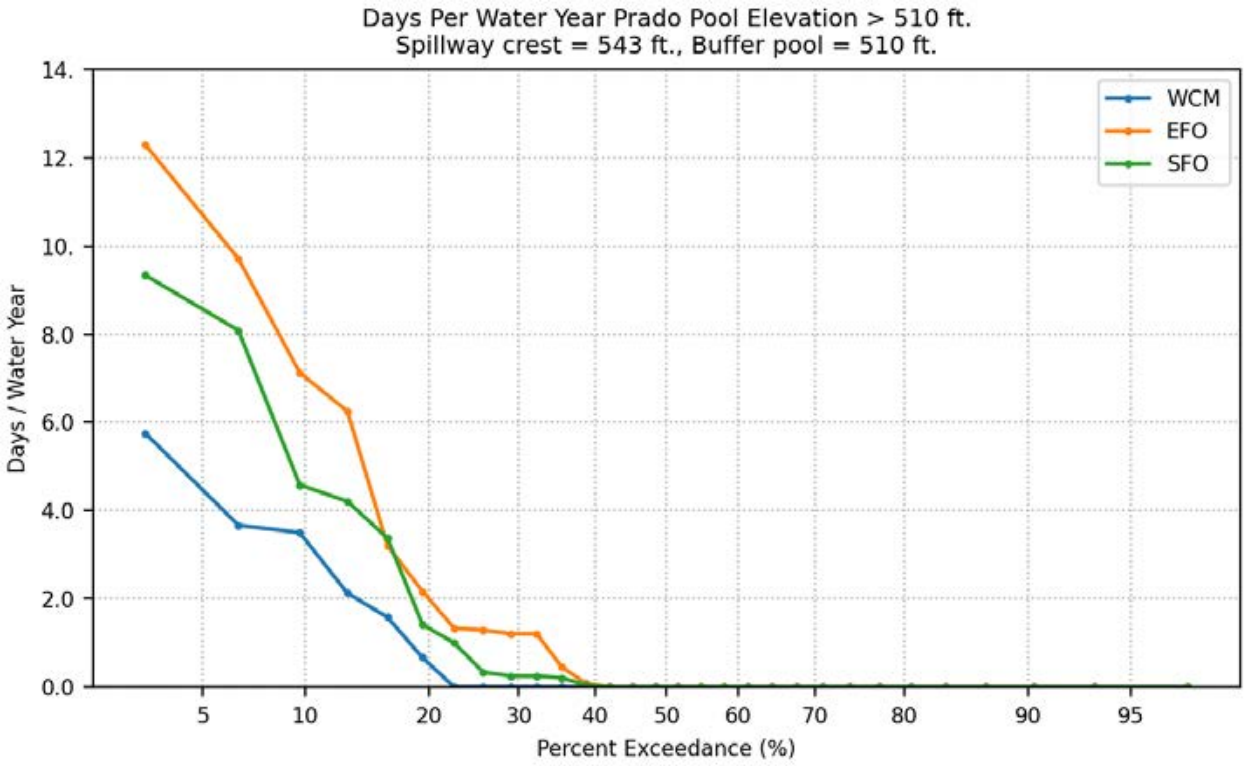

Groundwater Recharge Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 510 ft.
Volume / Water Year (1,000 acre-feet per water year)
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

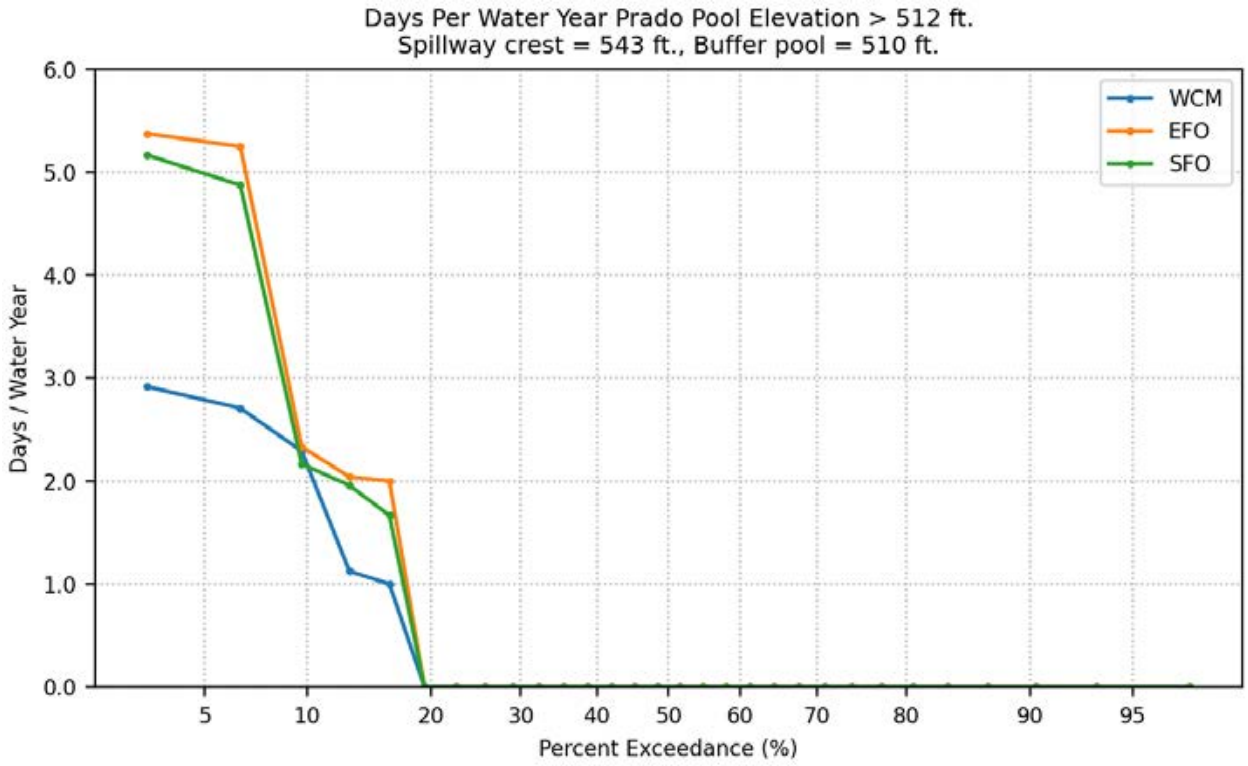

Santa Ana River Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 510 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

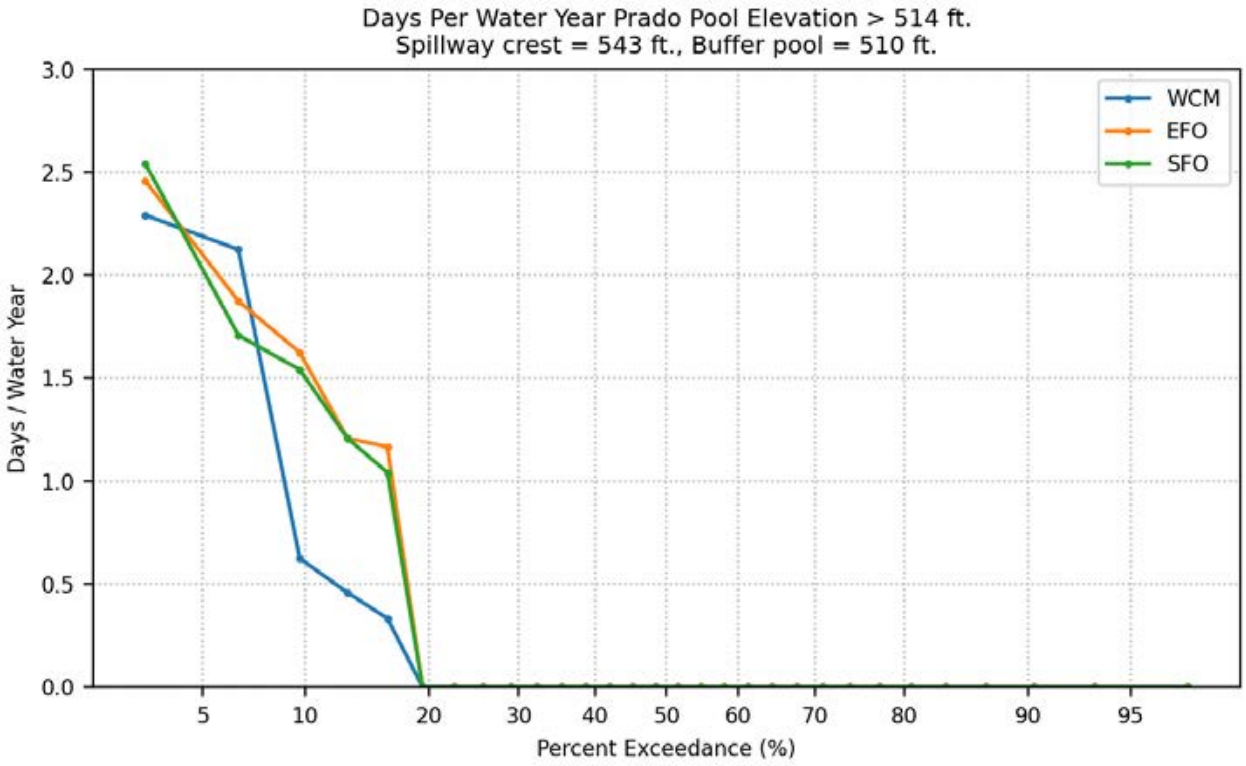

Days Per Water Year Elevation Change > 2-meters
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 543 ft., Buffer pool = 510 ft.
WCM
EFO
SFO
Days / Water Year
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)

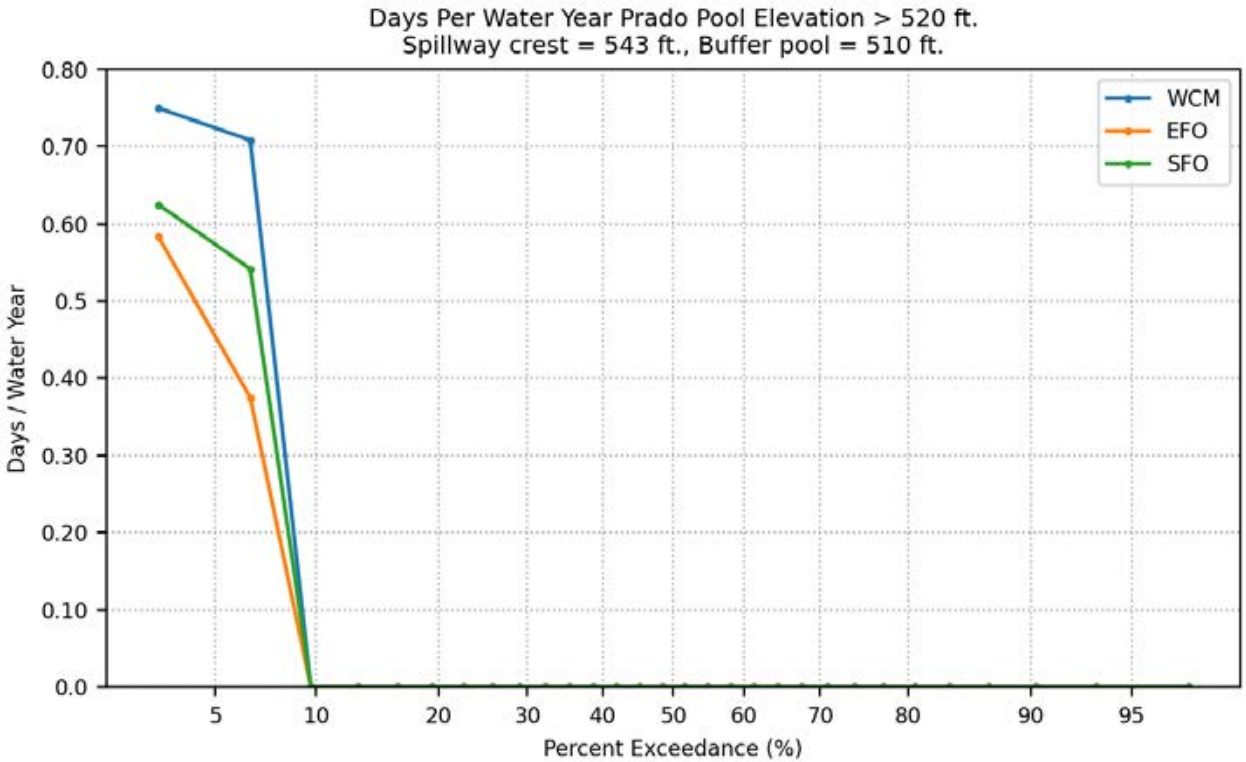

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

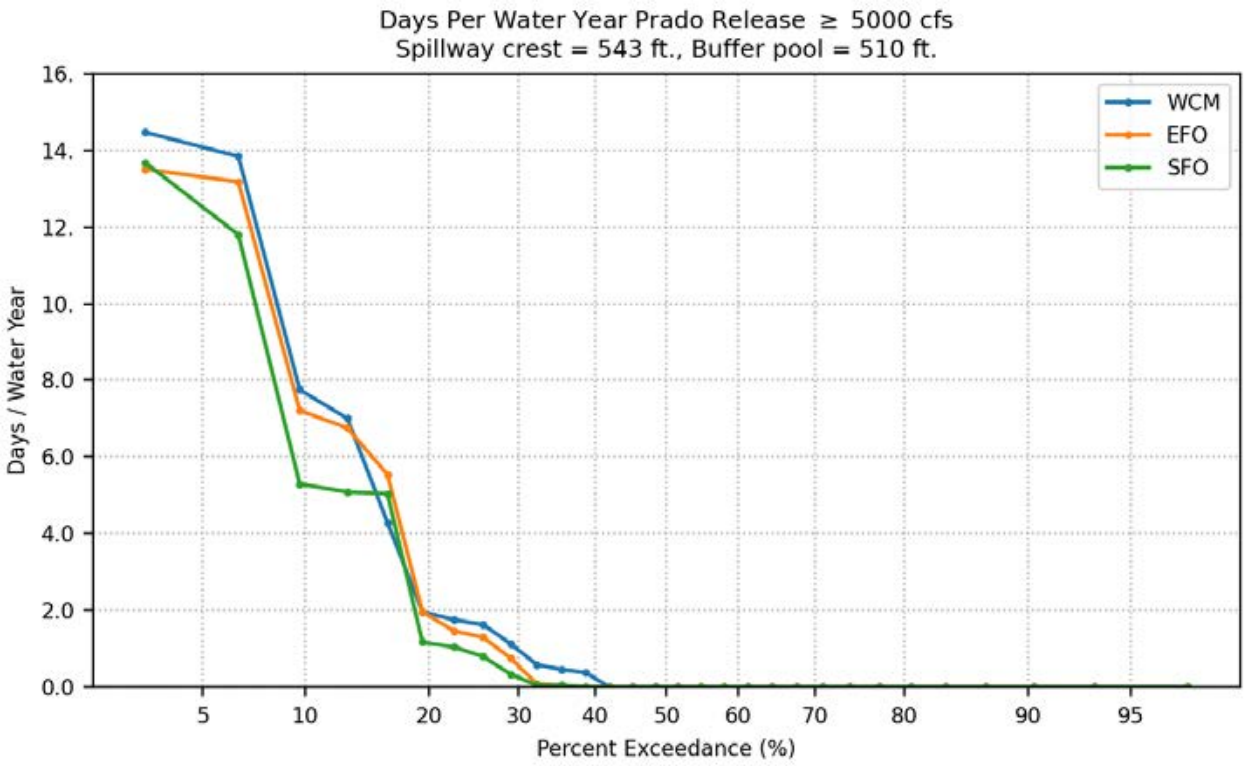

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

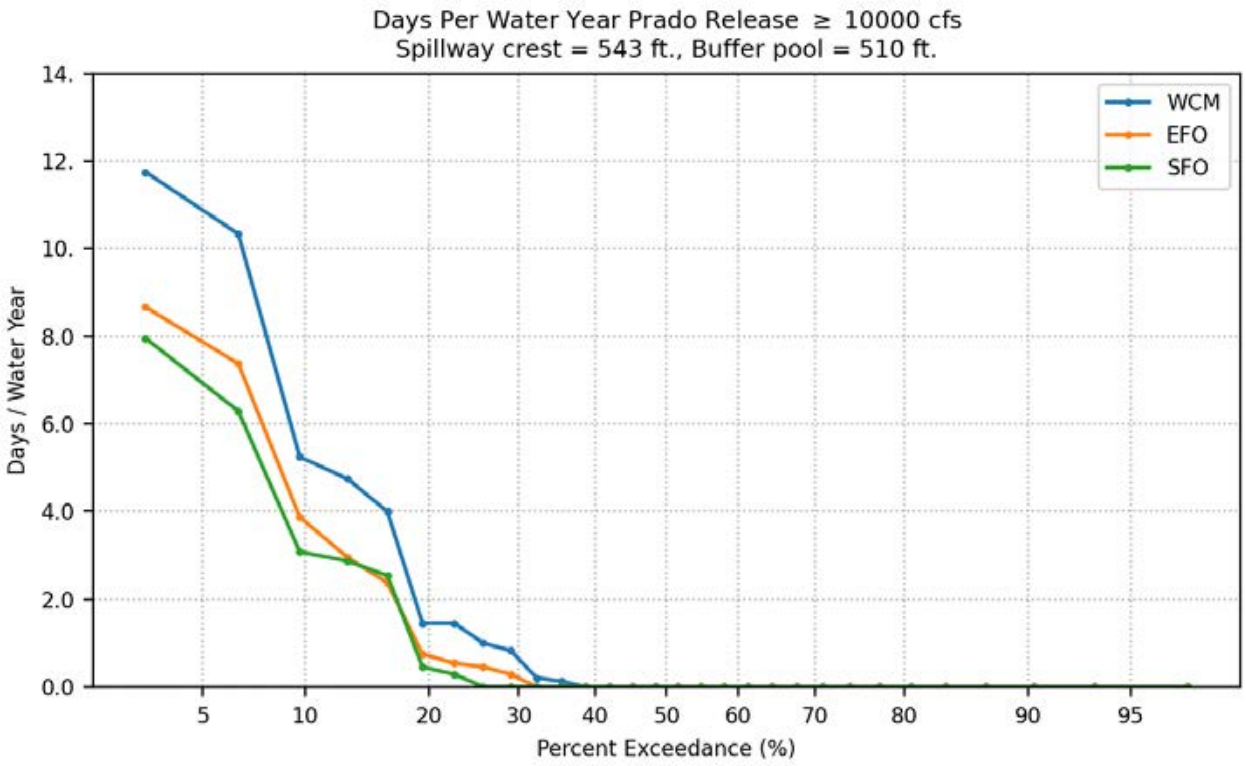

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

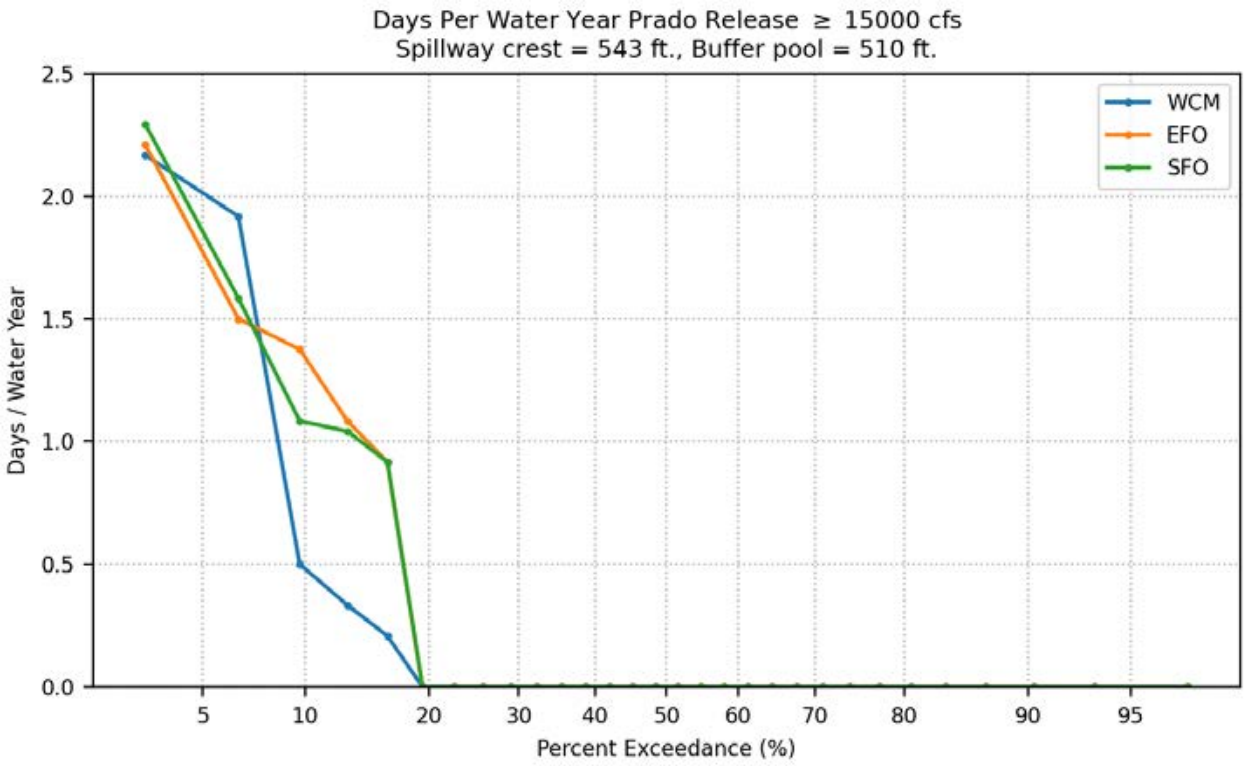

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
6.0
5.0
4.0
3.0
2.0
1.0
0.0
5
10
20
30
40
50
60
70
80
90
95

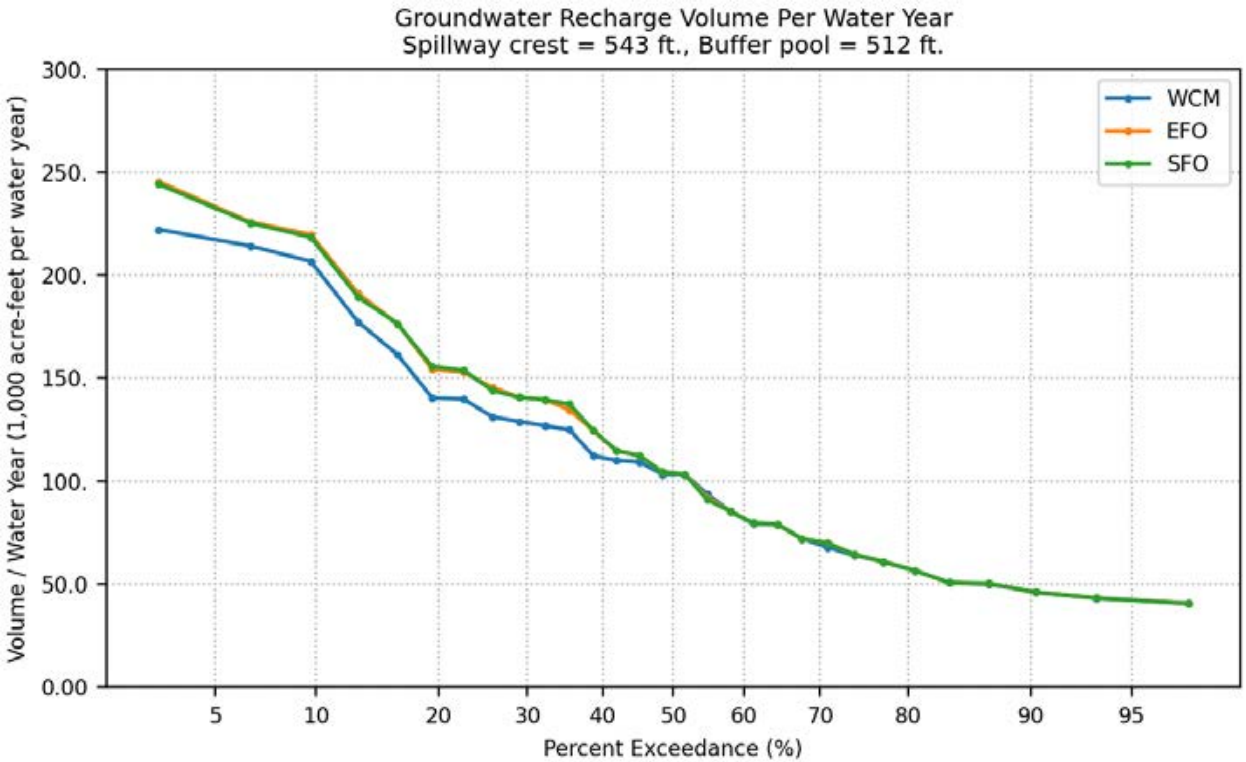

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
20
30
40
50
60
70
80
90
95

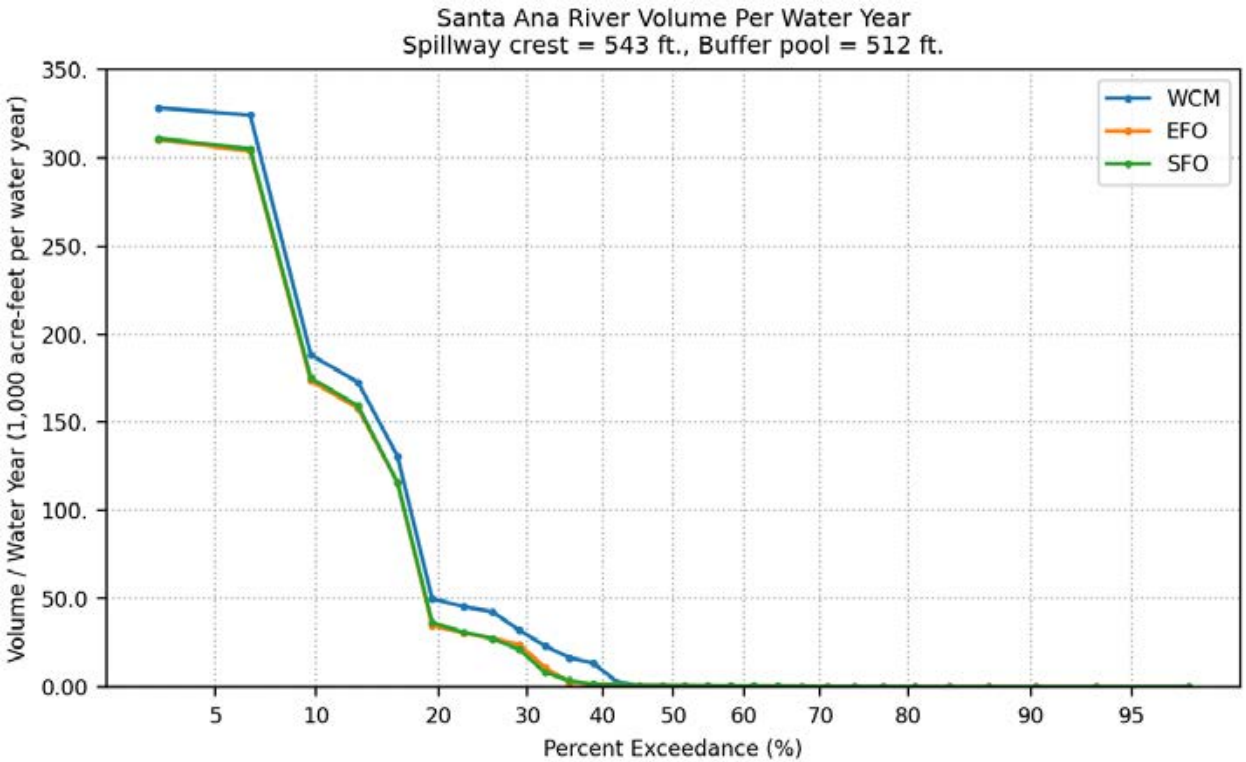

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
0.80
0.70
0.60
0.5
0.40
0.30
0.20
0.10
0.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

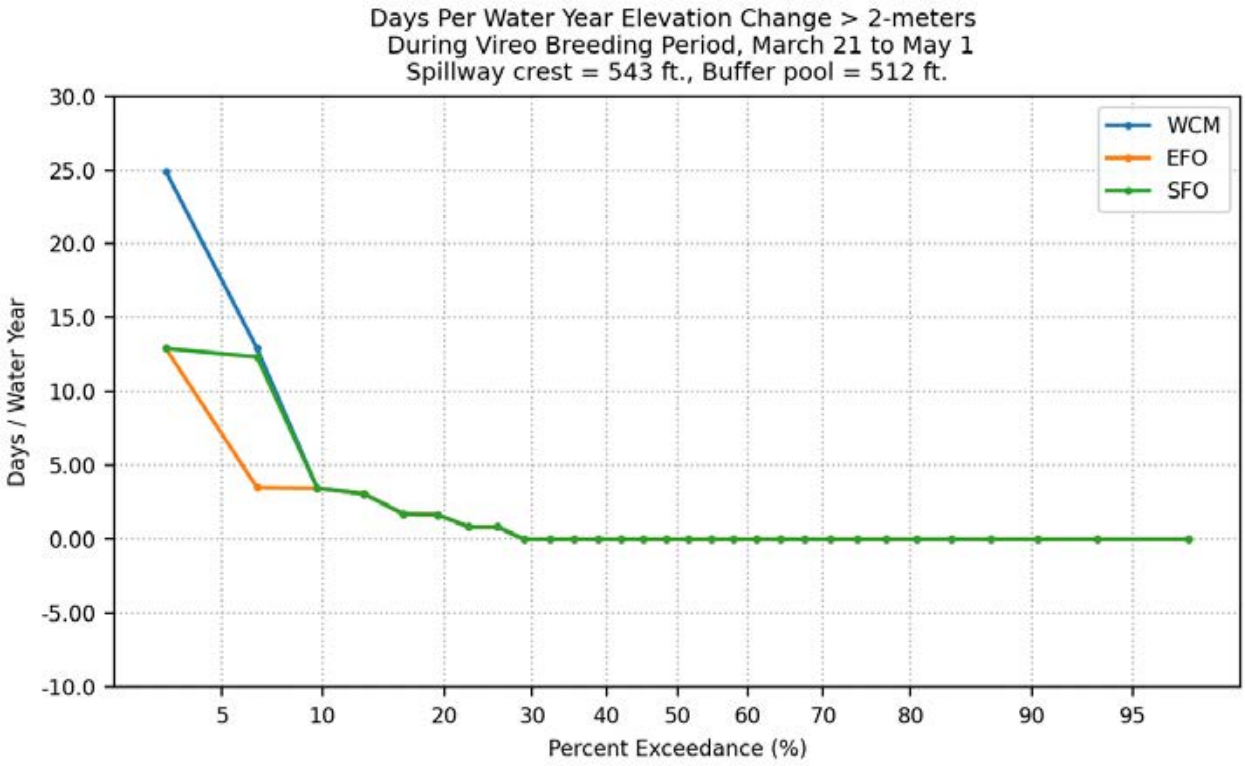

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

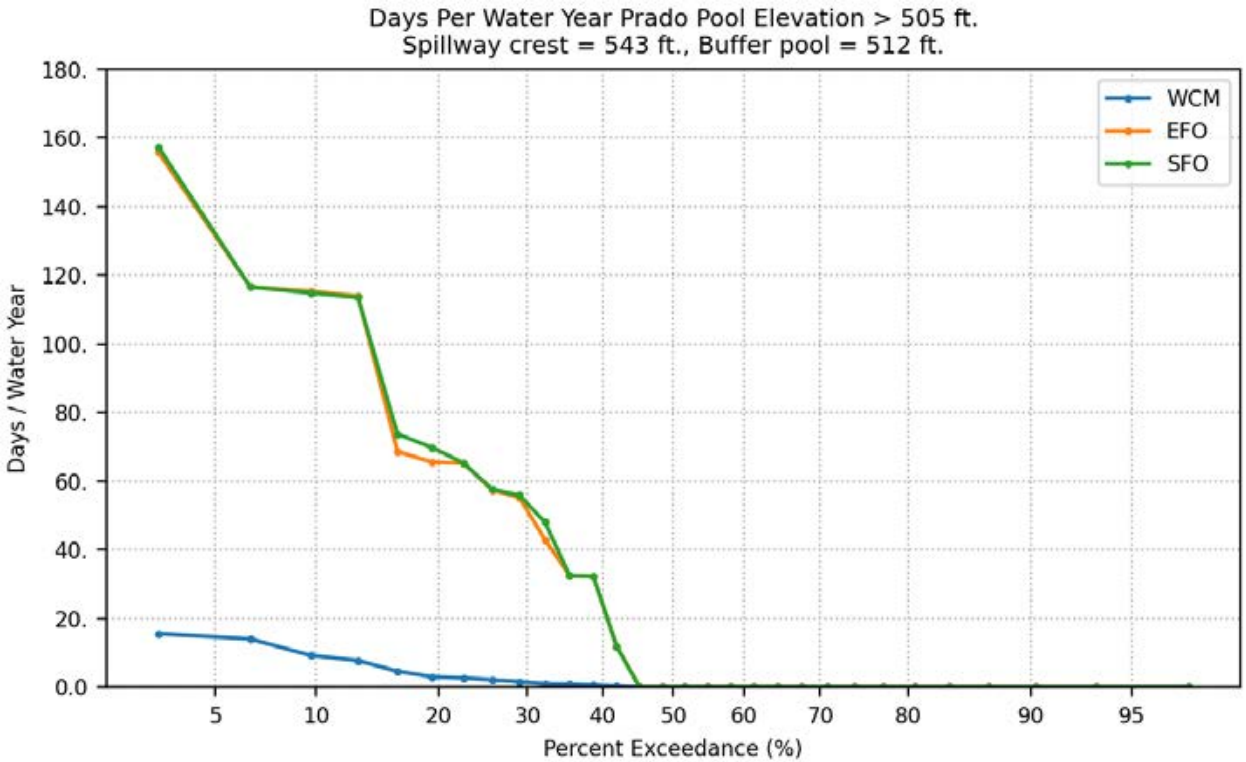

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

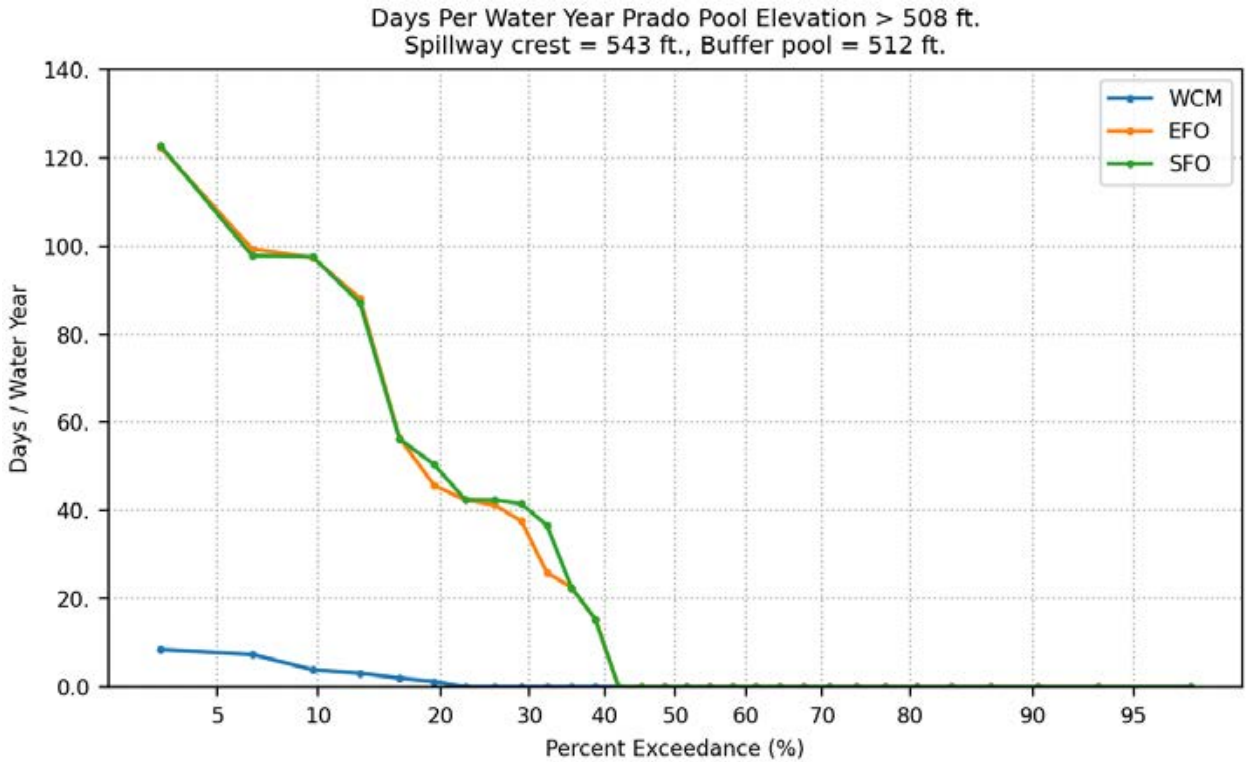

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 543 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
0.0
0.5
1.0
1.5
2.0
2.5
5
10
20
30
40
50
60
70
80
90
95

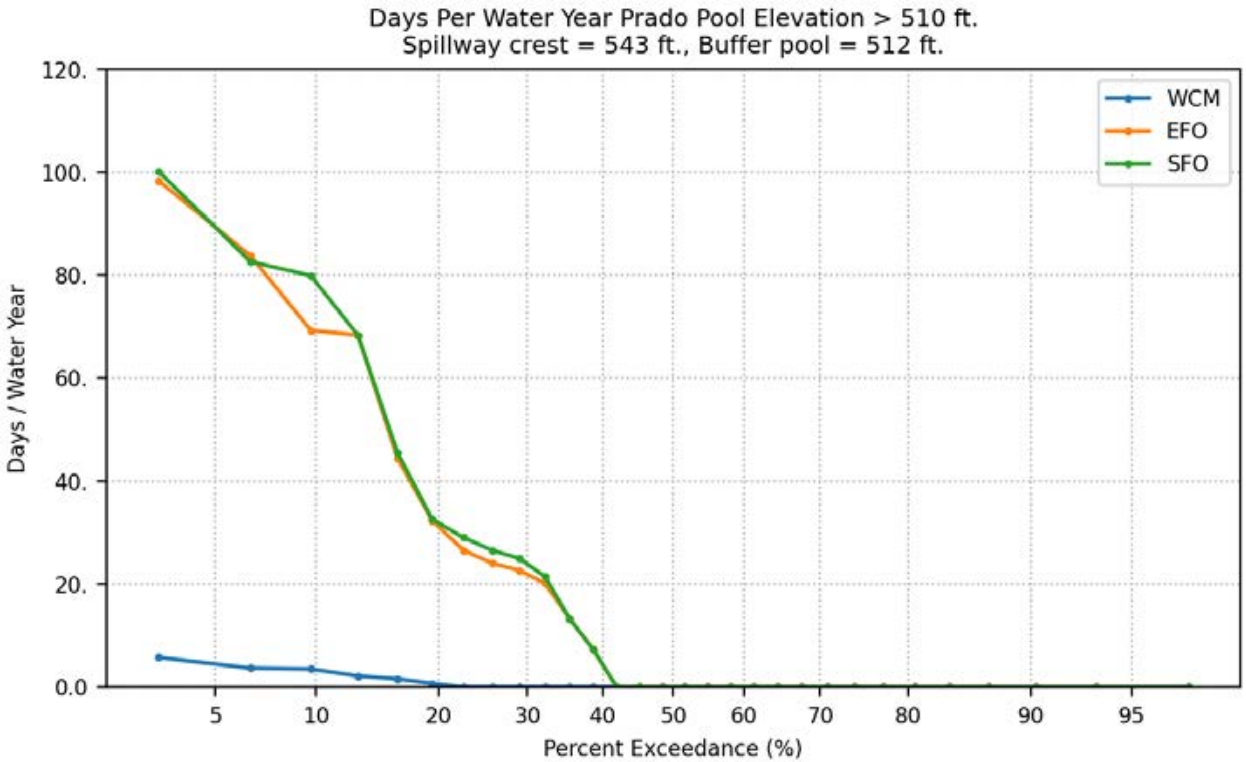

Groundwater Recharge Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 512 ft.
Volume / Water Year (1,000 acre-feet per water year)
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

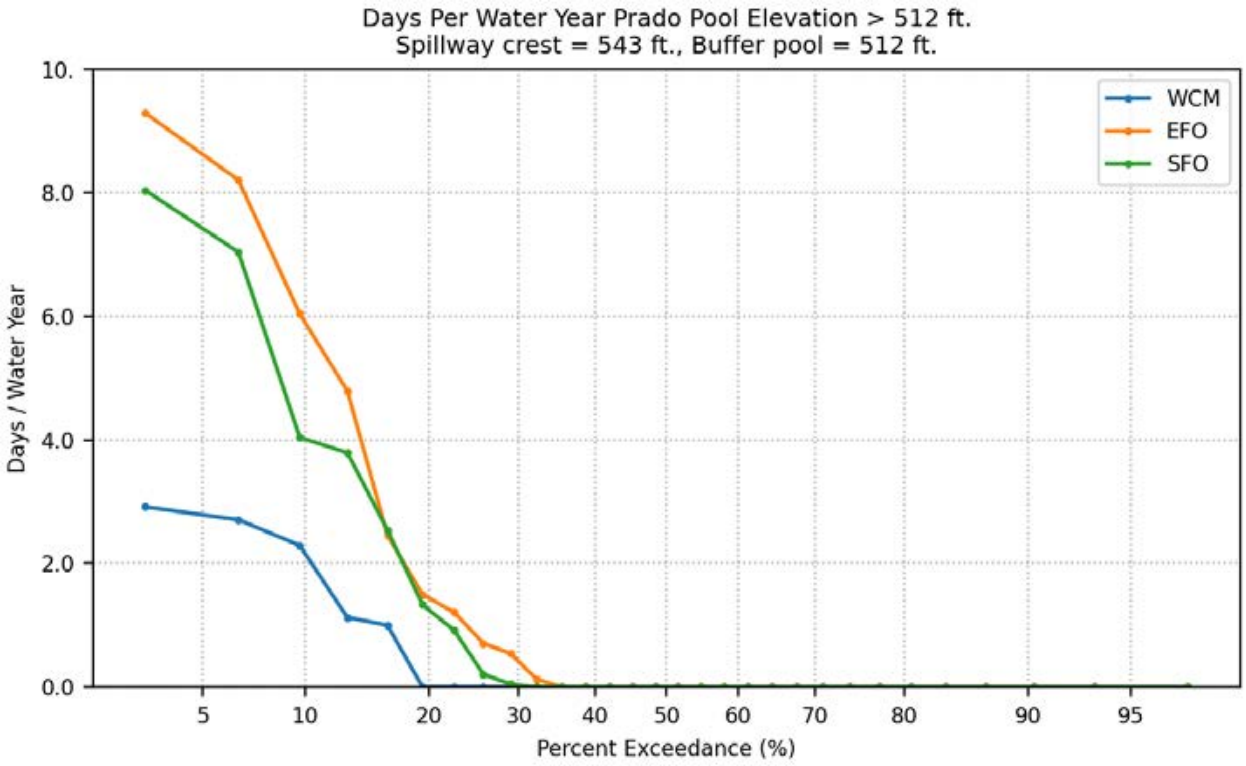

Santa Ana River Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 512 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

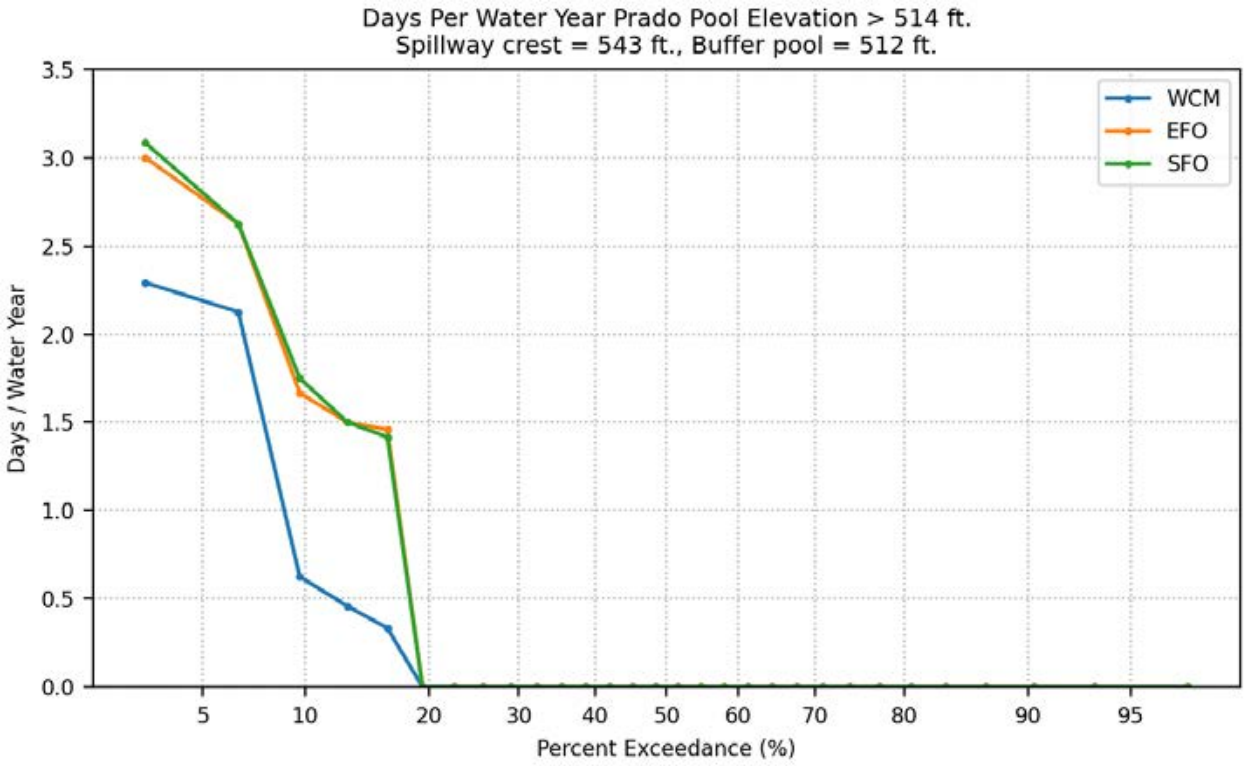

Days Per Water Year Elevation Change > 2-meters
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 543 ft., Buffer pool = 512 ft.
WCM
EFO
SFO
Days / Water Year
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)

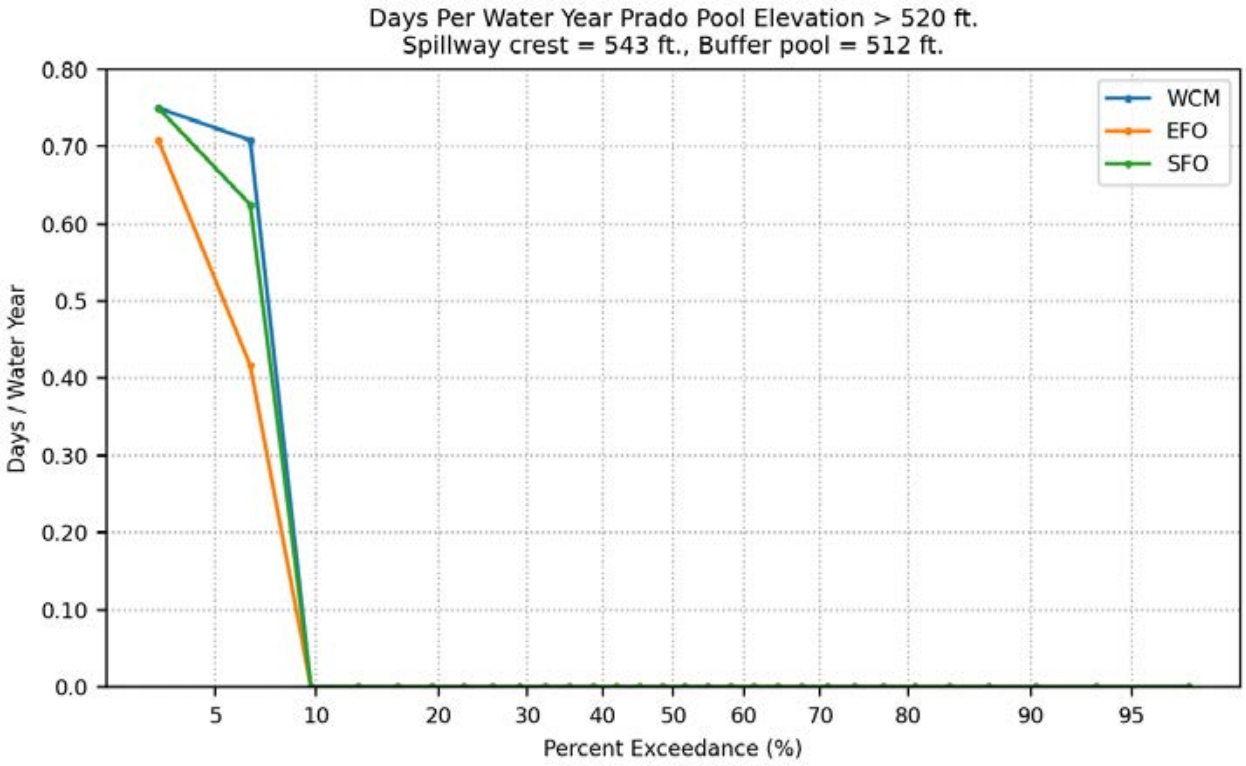

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
180.
160.
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

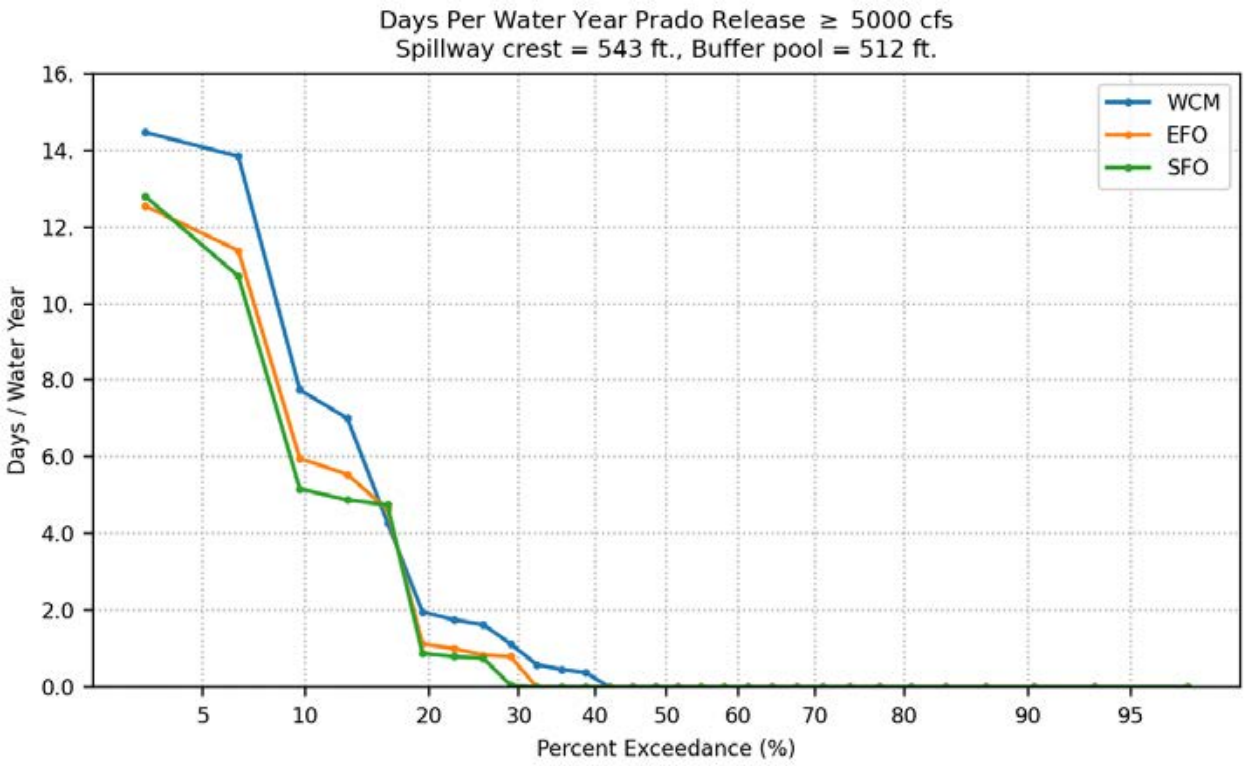

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

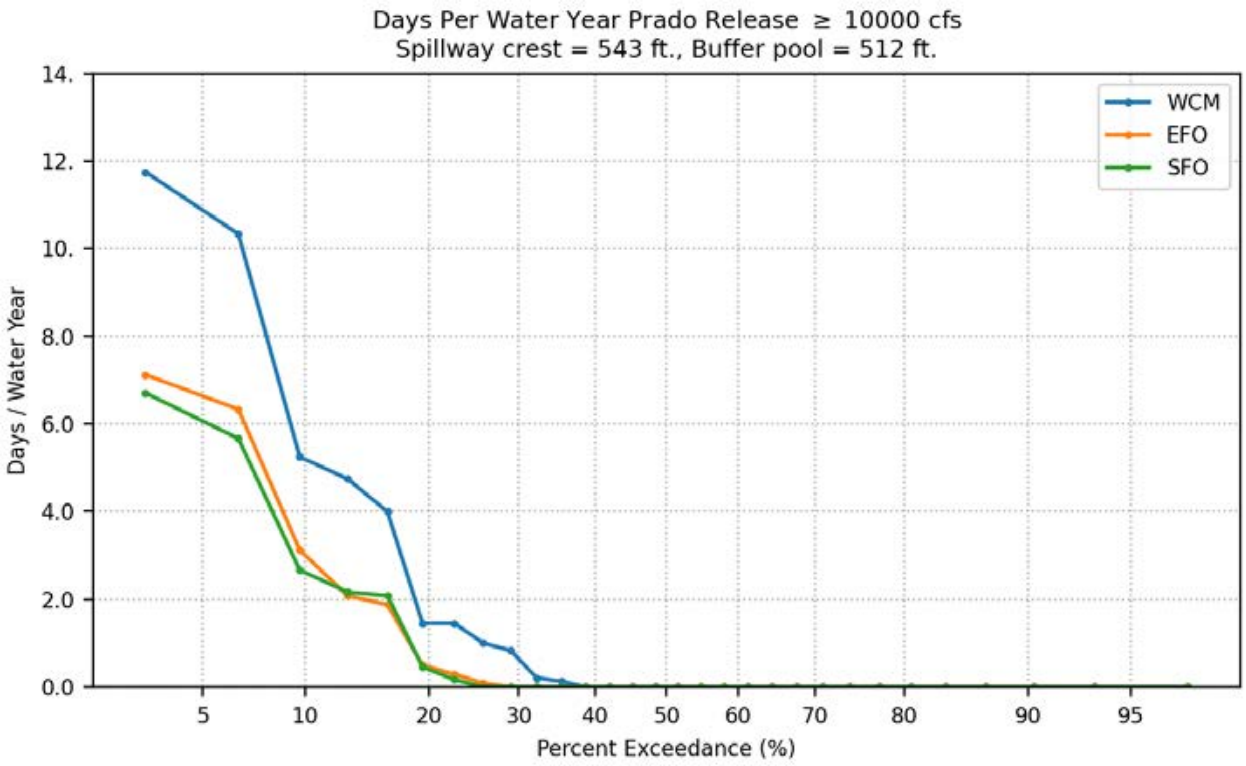

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

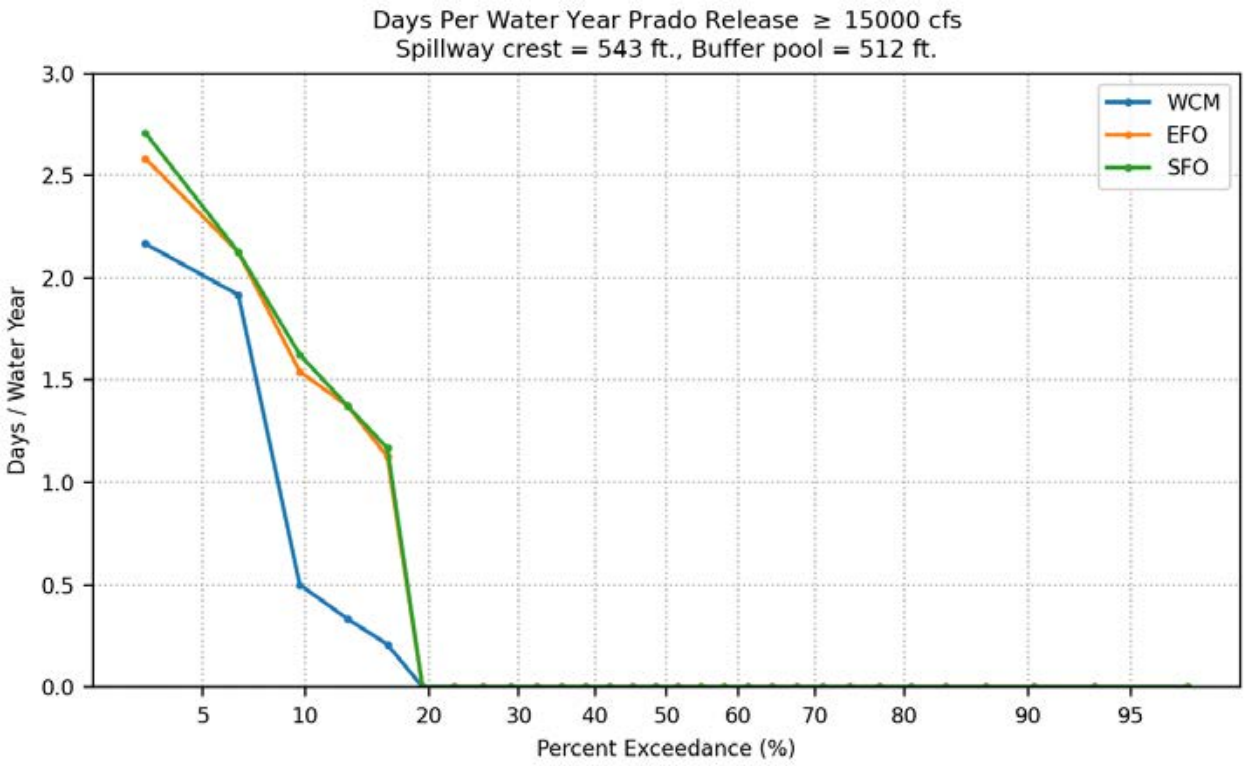

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

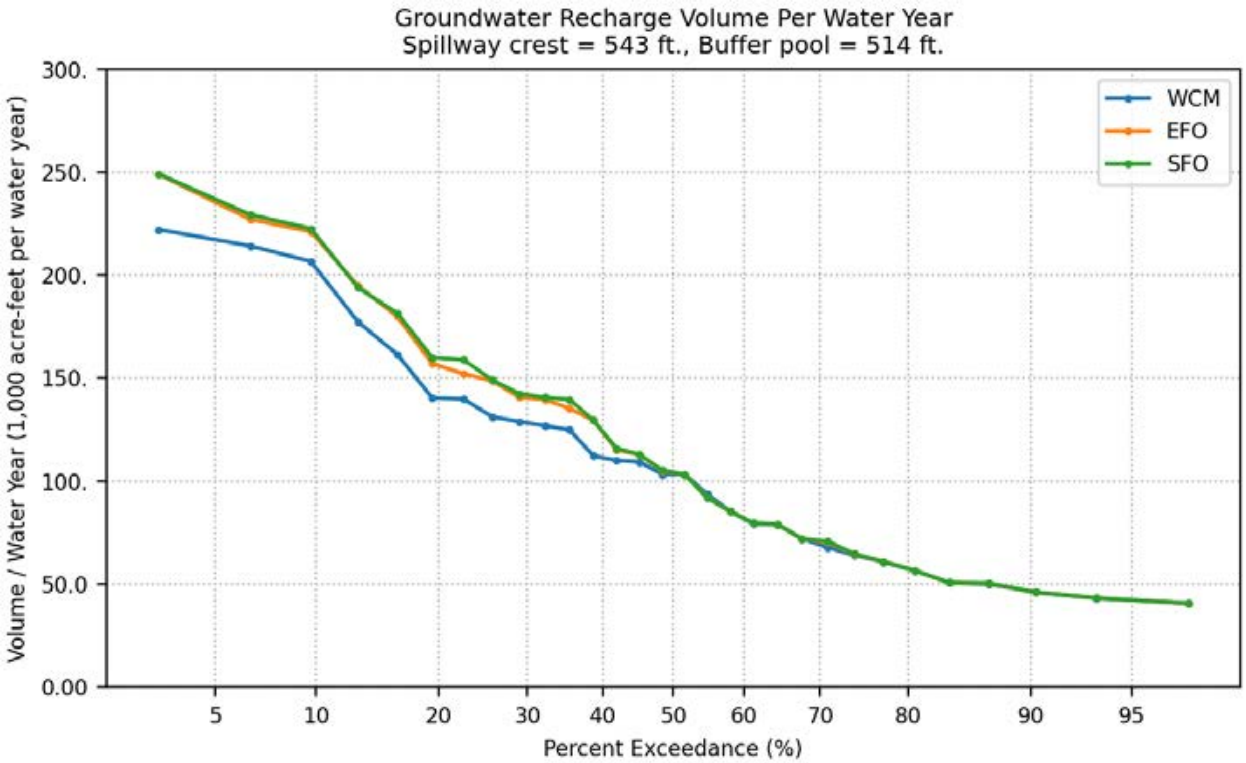

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
5
10
20
30
40
50
60
70
80
90
95

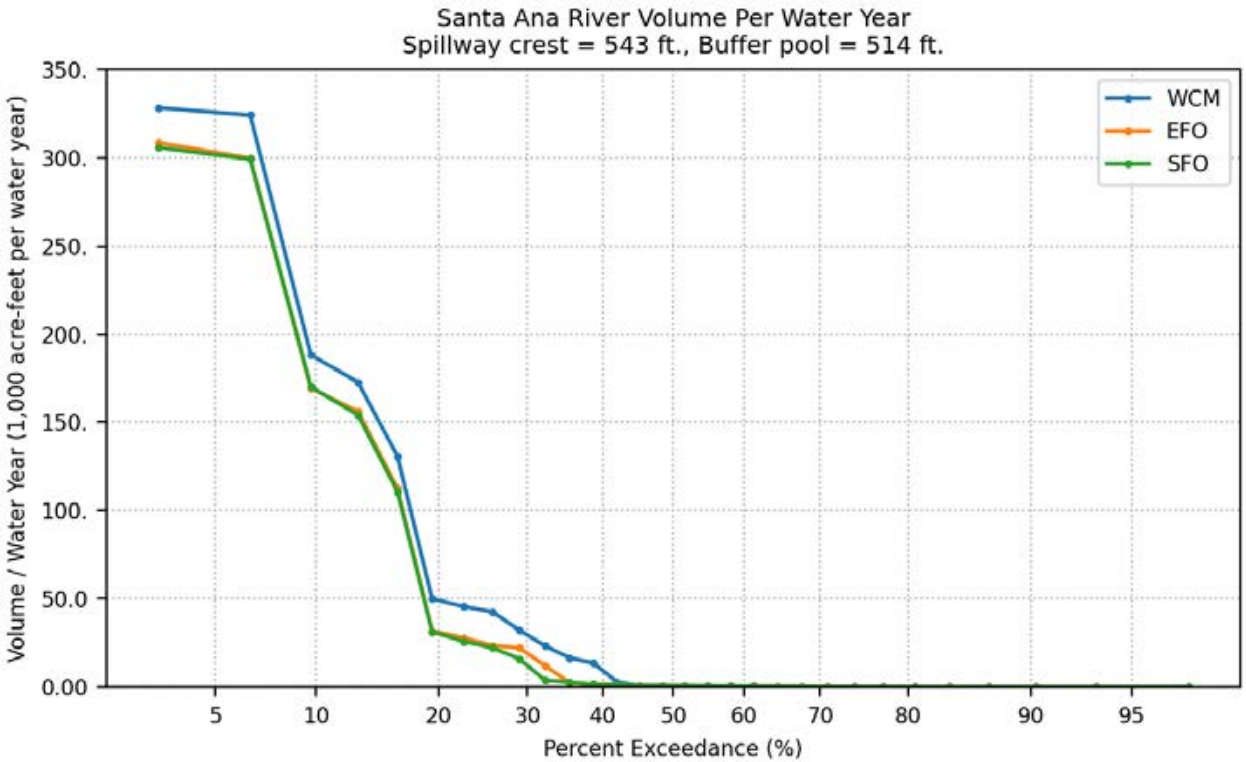

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
0.80
0.70
0.60
0.5
0.40
0.30
0.20
0.10
0.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

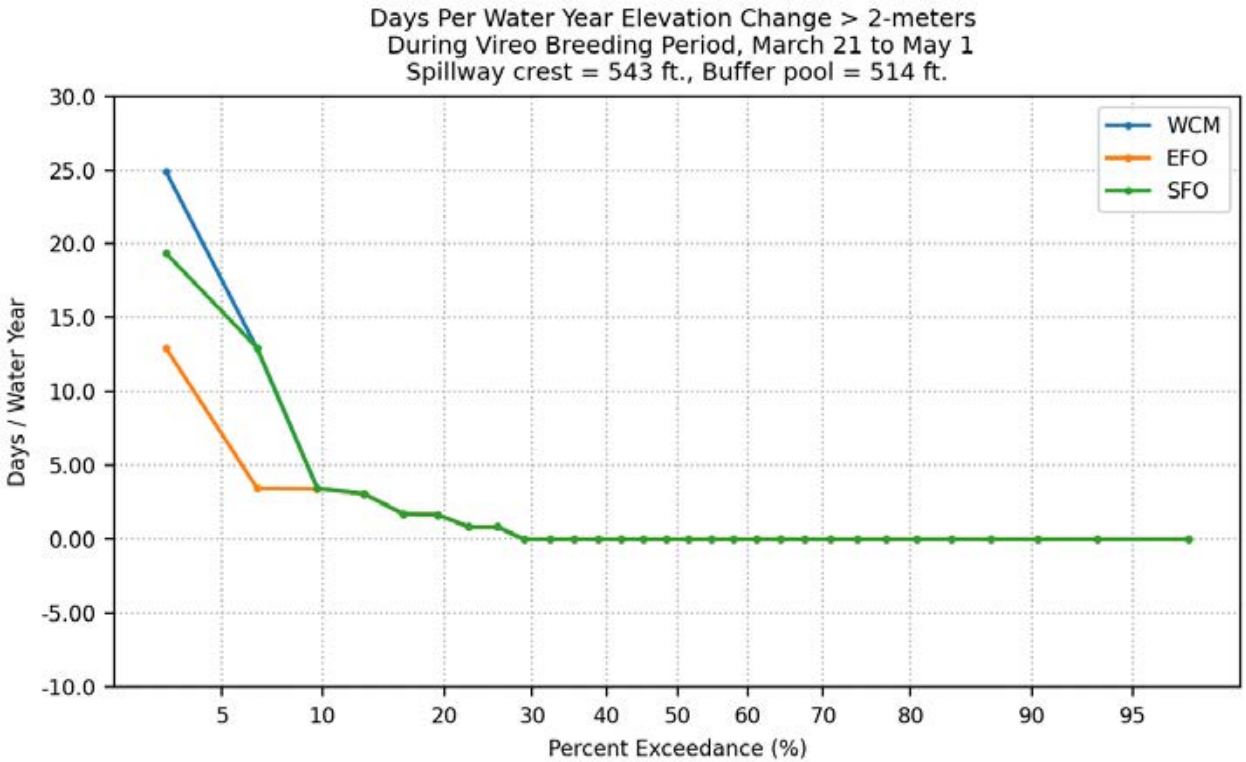

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

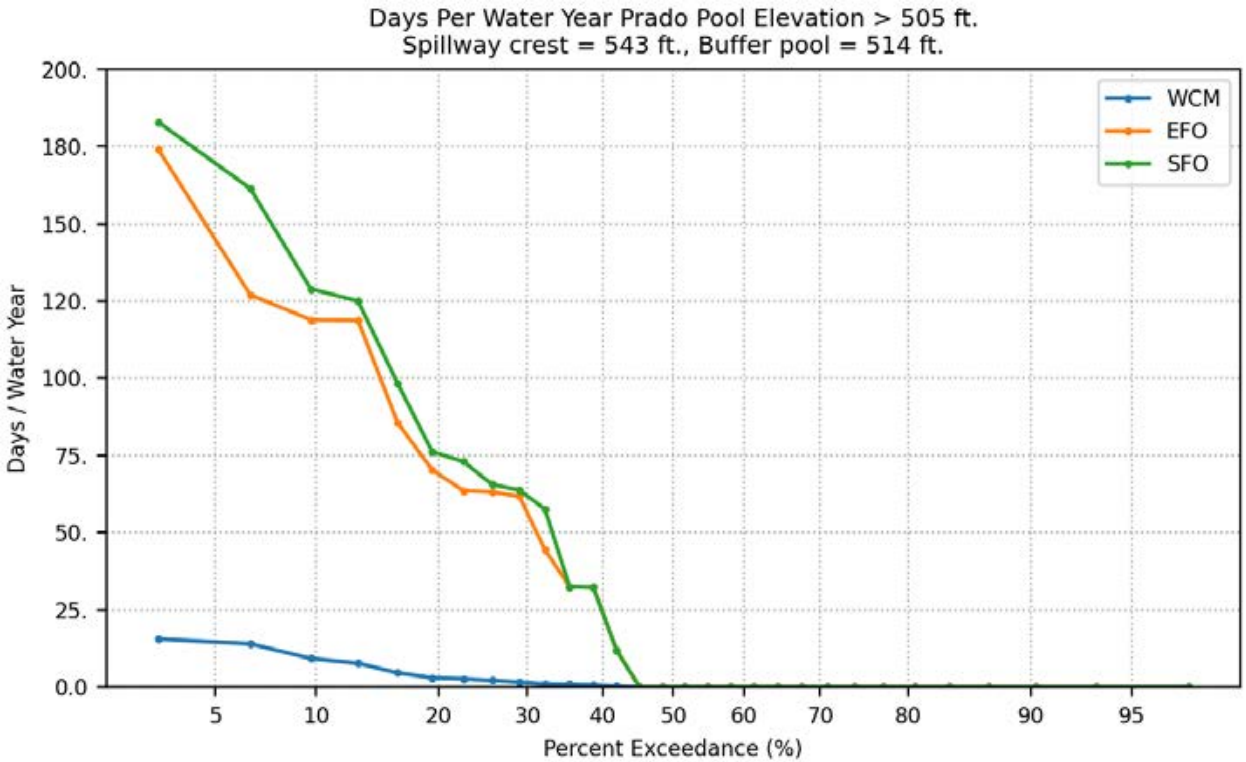

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

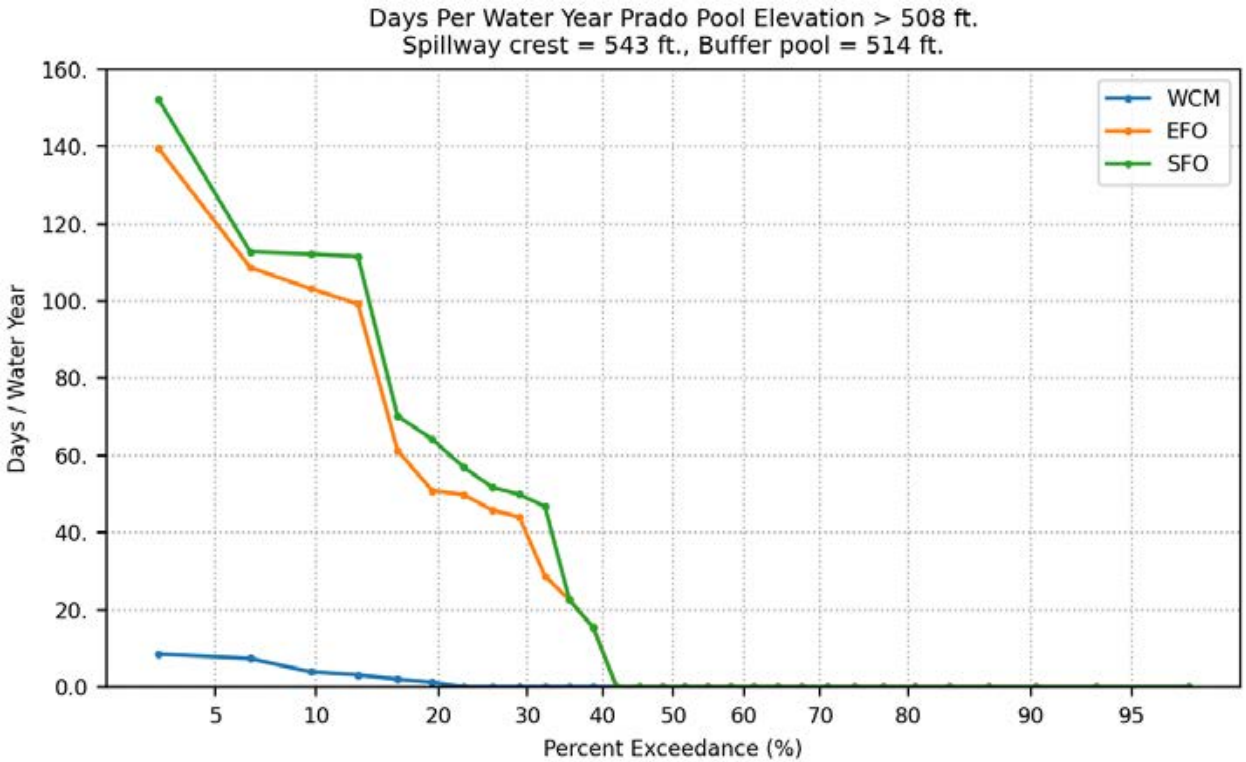

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 543 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
20
30
40
50
60
70
80
90
95

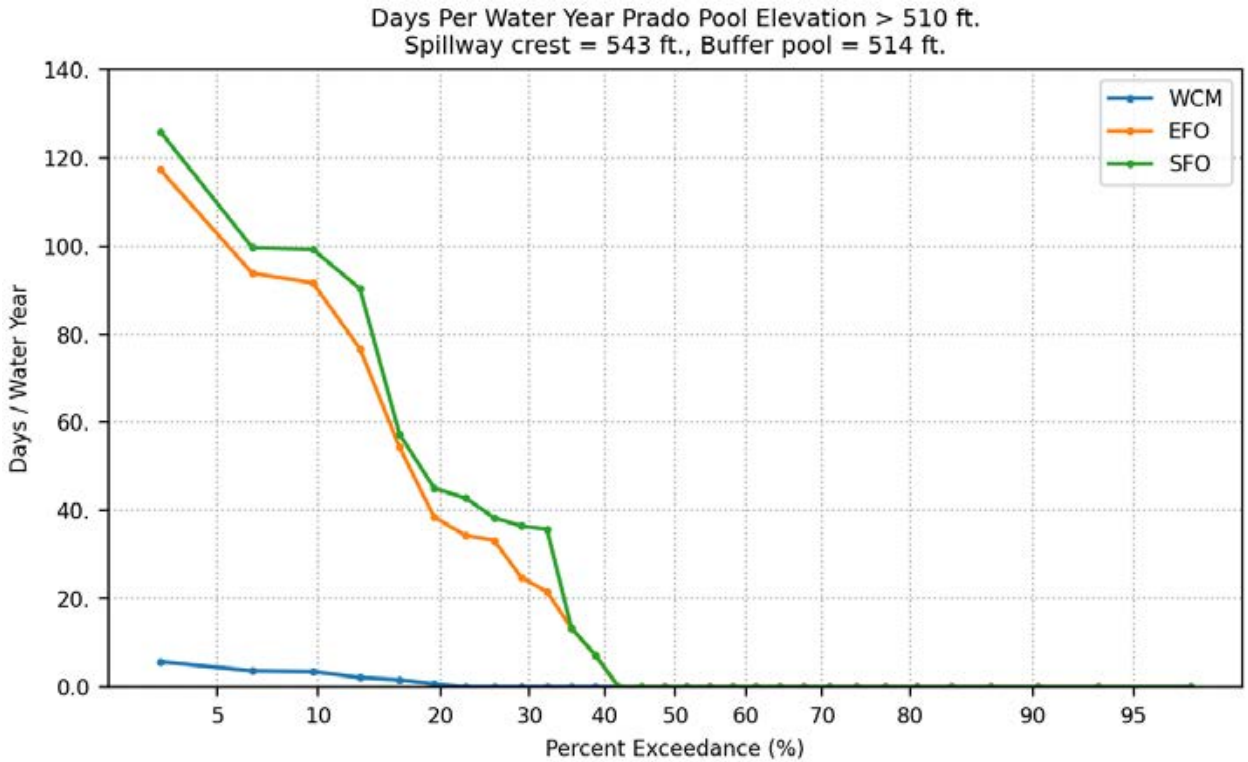

Groundwater Recharge Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 514 ft.
Volume / Water Year (1,000 acre-feet per water year)
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

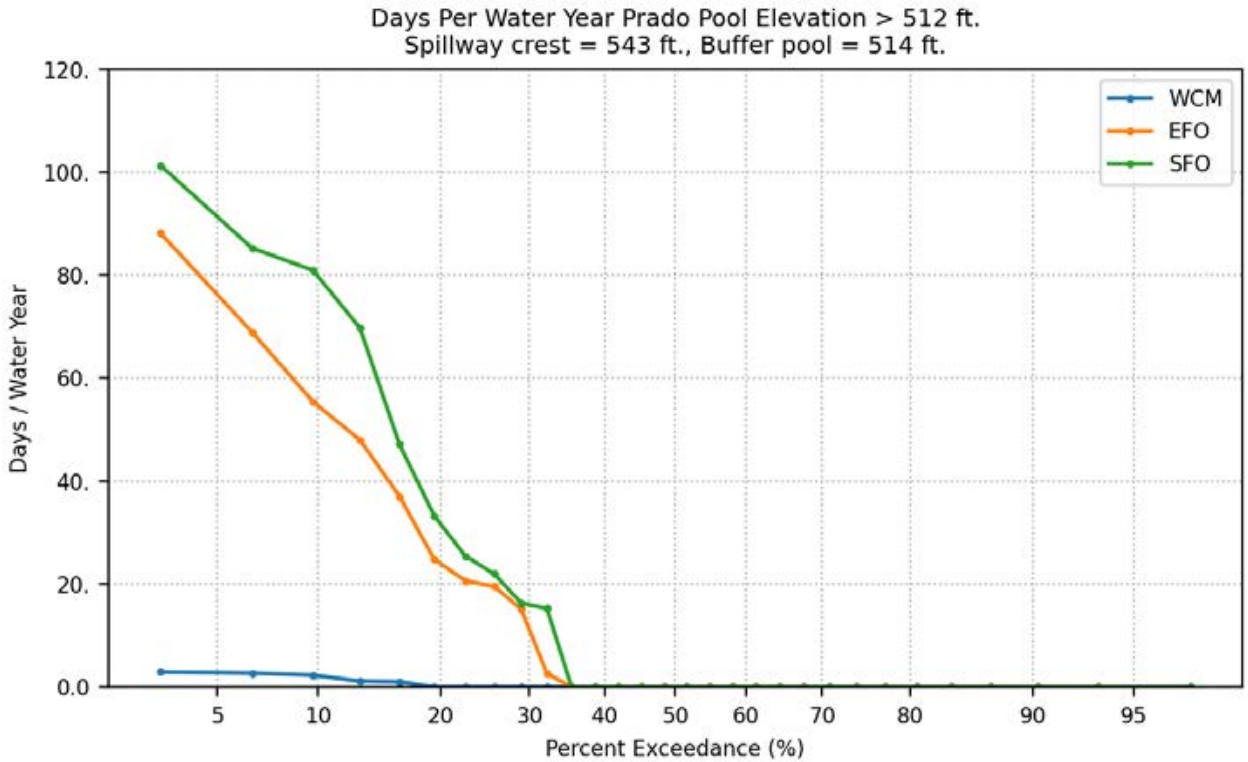

Santa Ana River Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 514 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

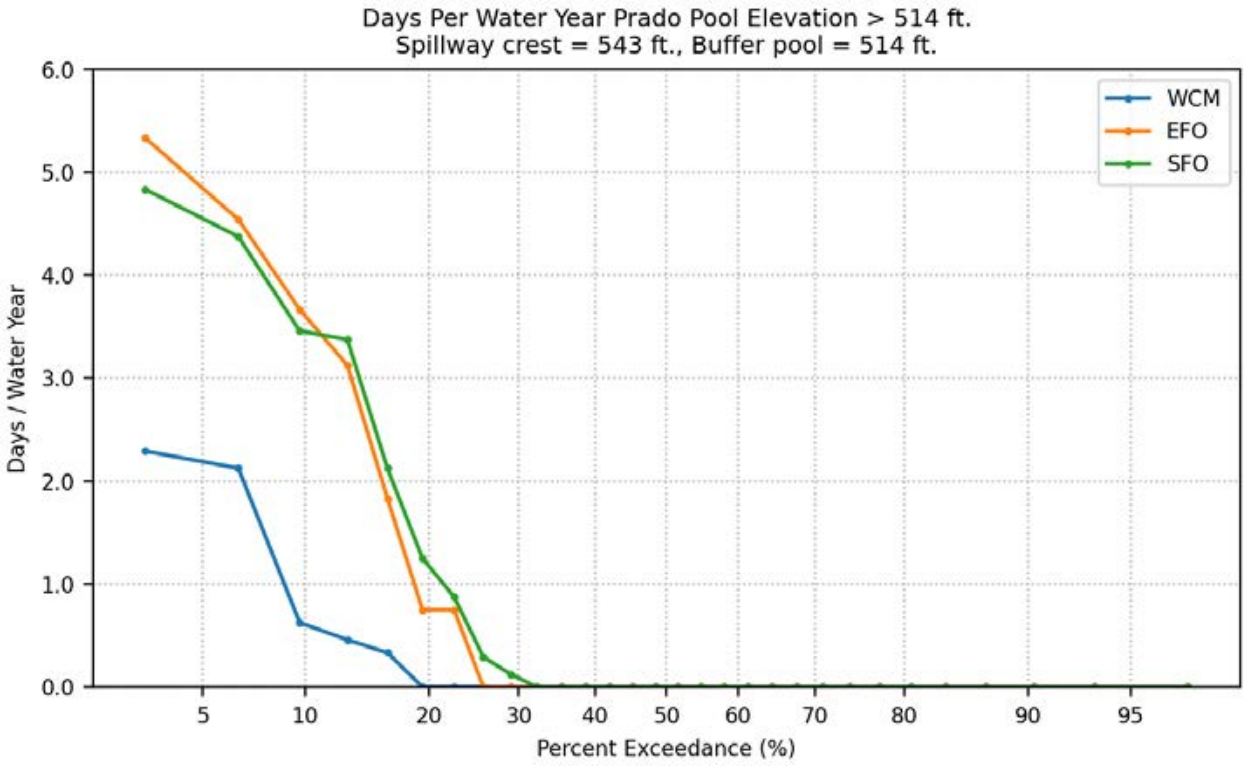

Days Per Water Year Elevation Change > 2-meters
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 543 ft., Buffer pool = 514 ft.
WCM
EFO
SFO
Days / Water Year
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)

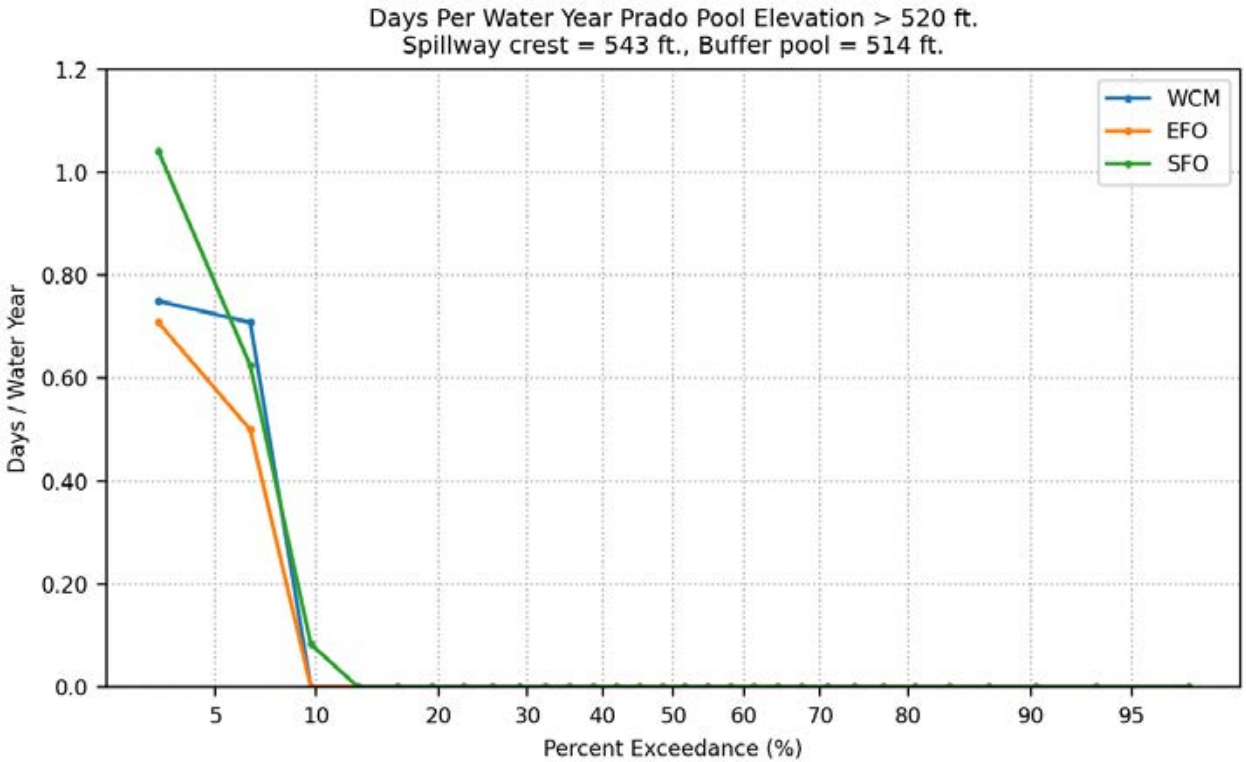

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
200.
180.
150.
120.
100.
75.
50.
25.
0.0
5
10
20
30
40
50
60
70
80
90
95

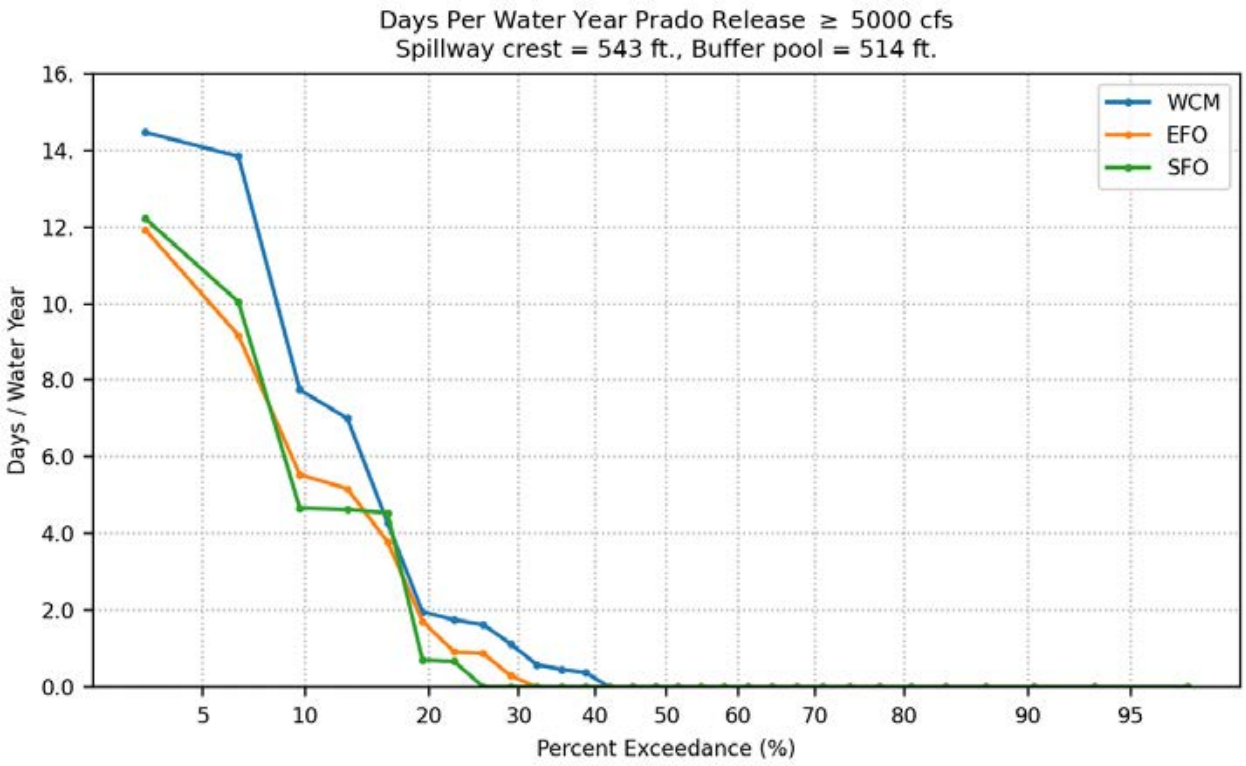

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
160.
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

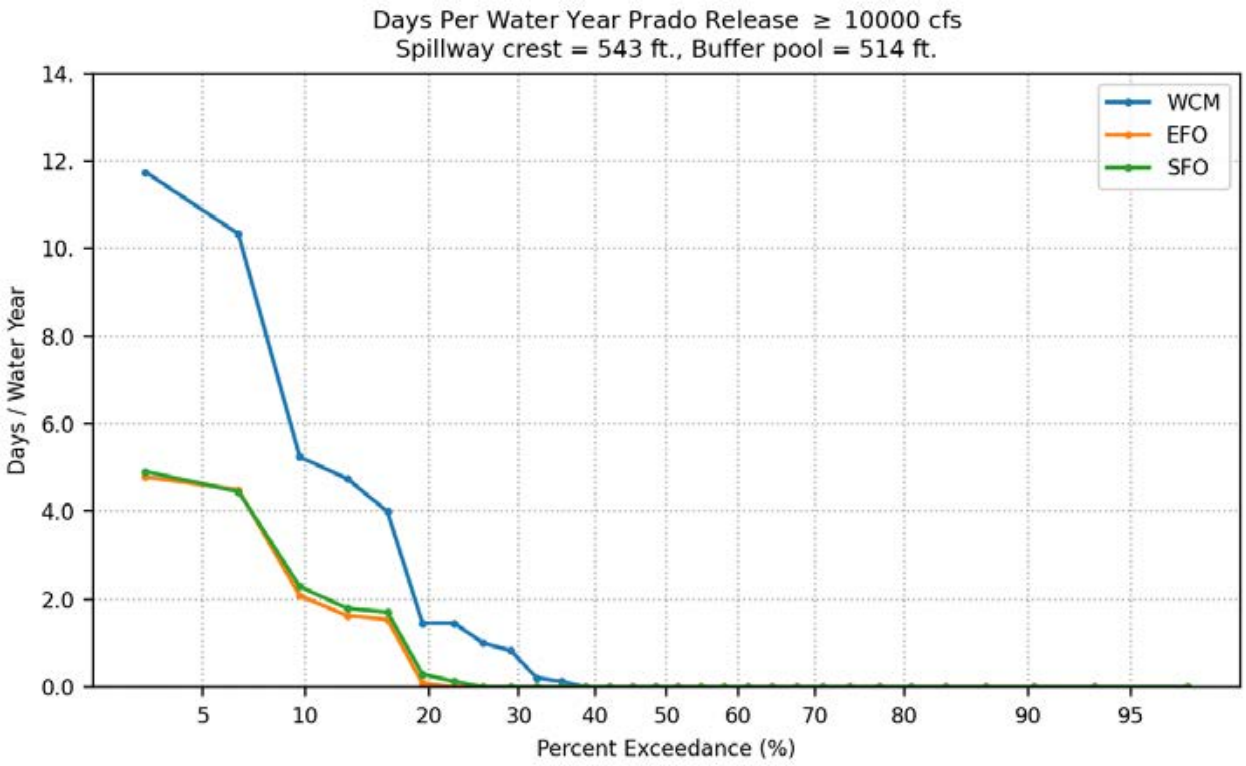

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

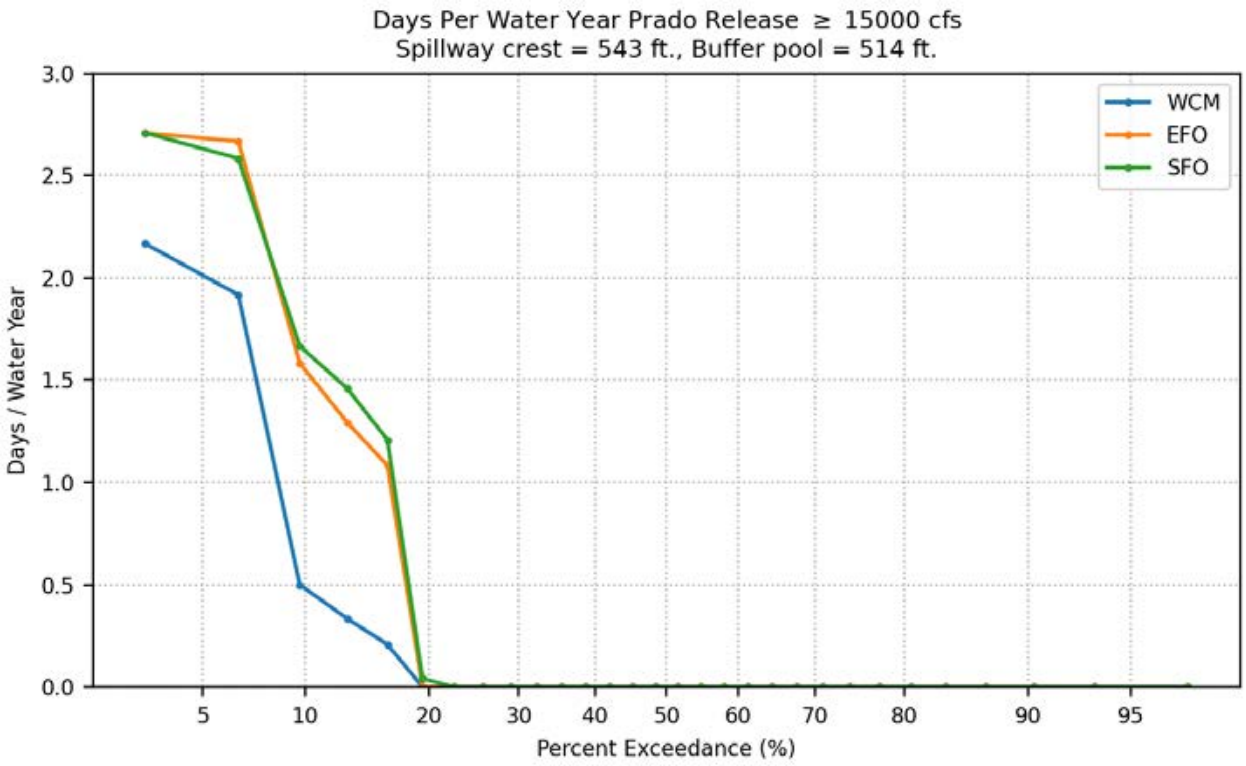

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

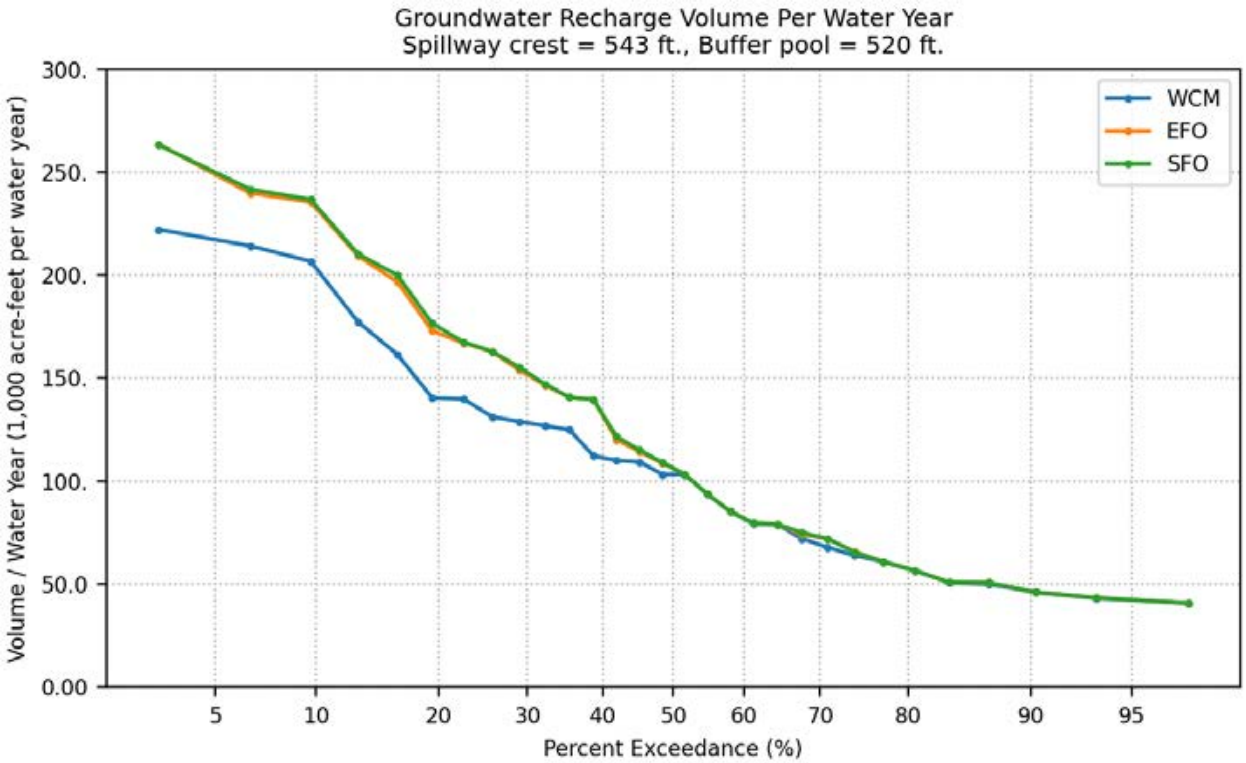

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
6.0
5.0
4.0
3.0
2.0
1.0
0.0
5
10
20
30
40
50
60
70
80
90
95

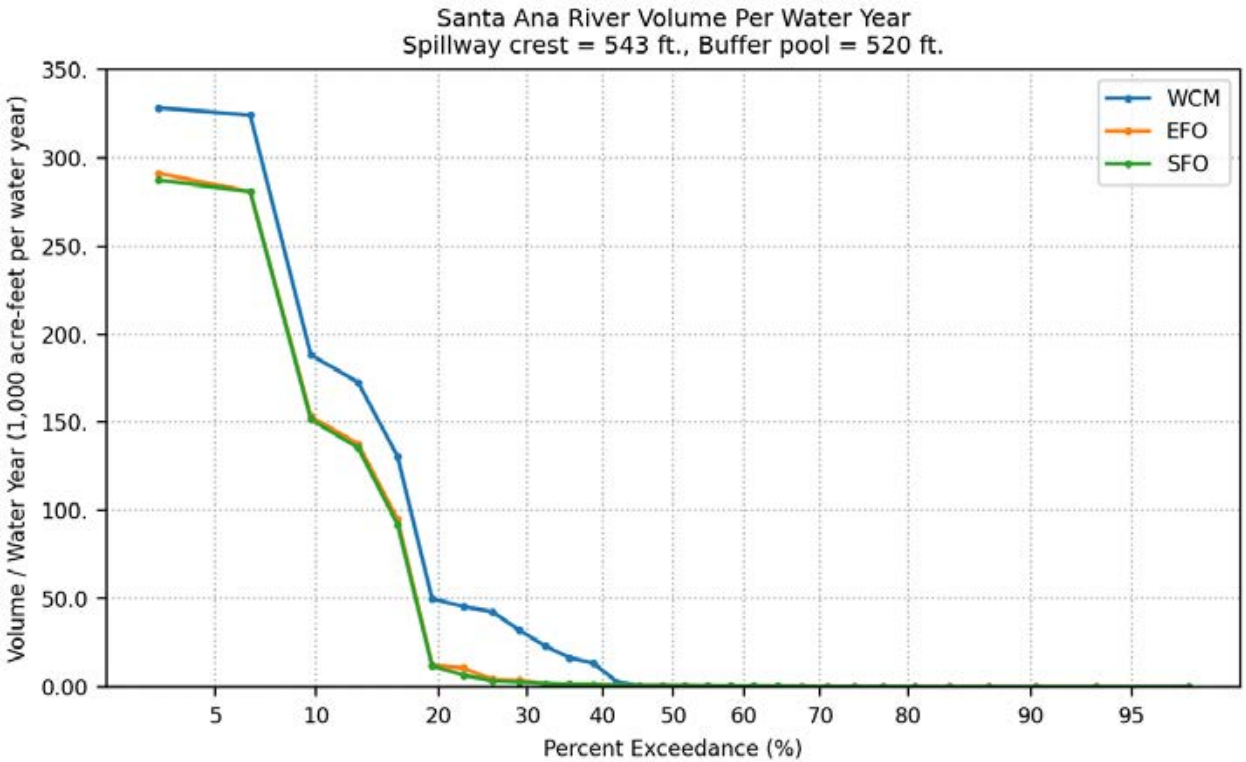

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
1.2
1.0
0.80
0.60
0.40
0.20
0.0
5
10
20
30
40
50
60
70
80
90
95

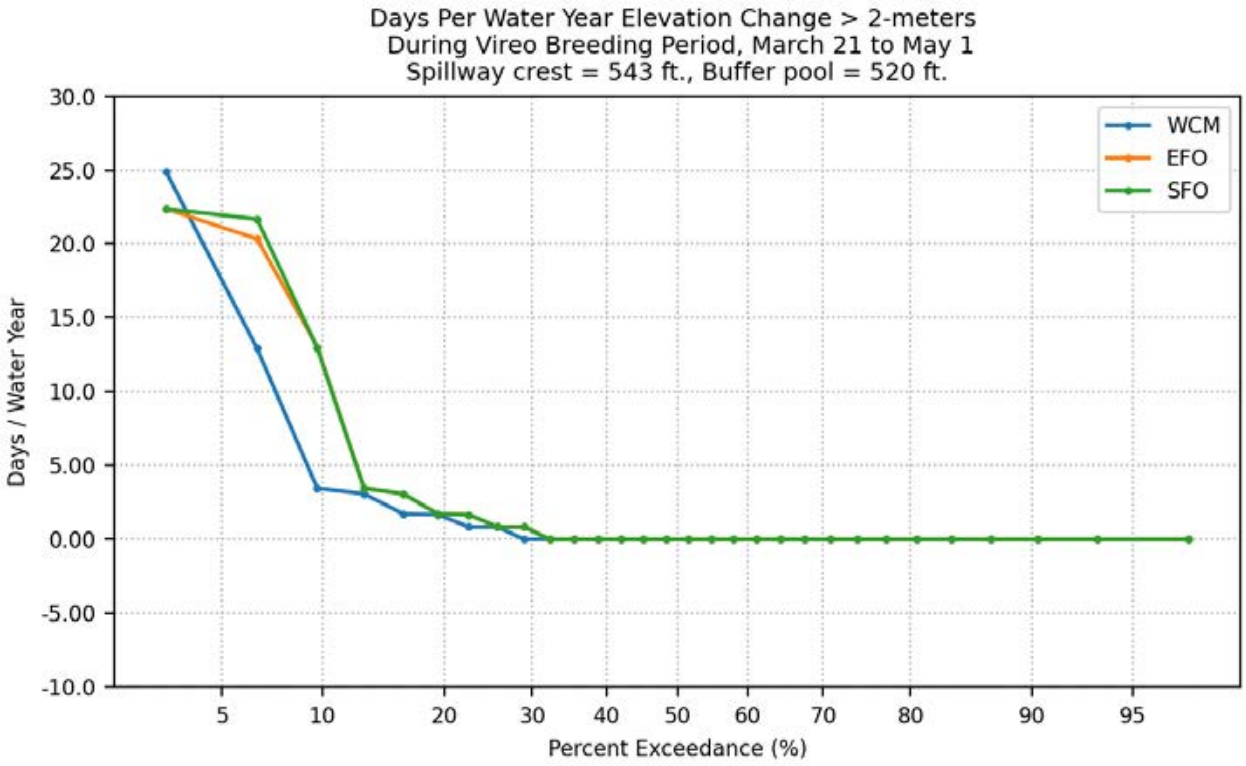

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

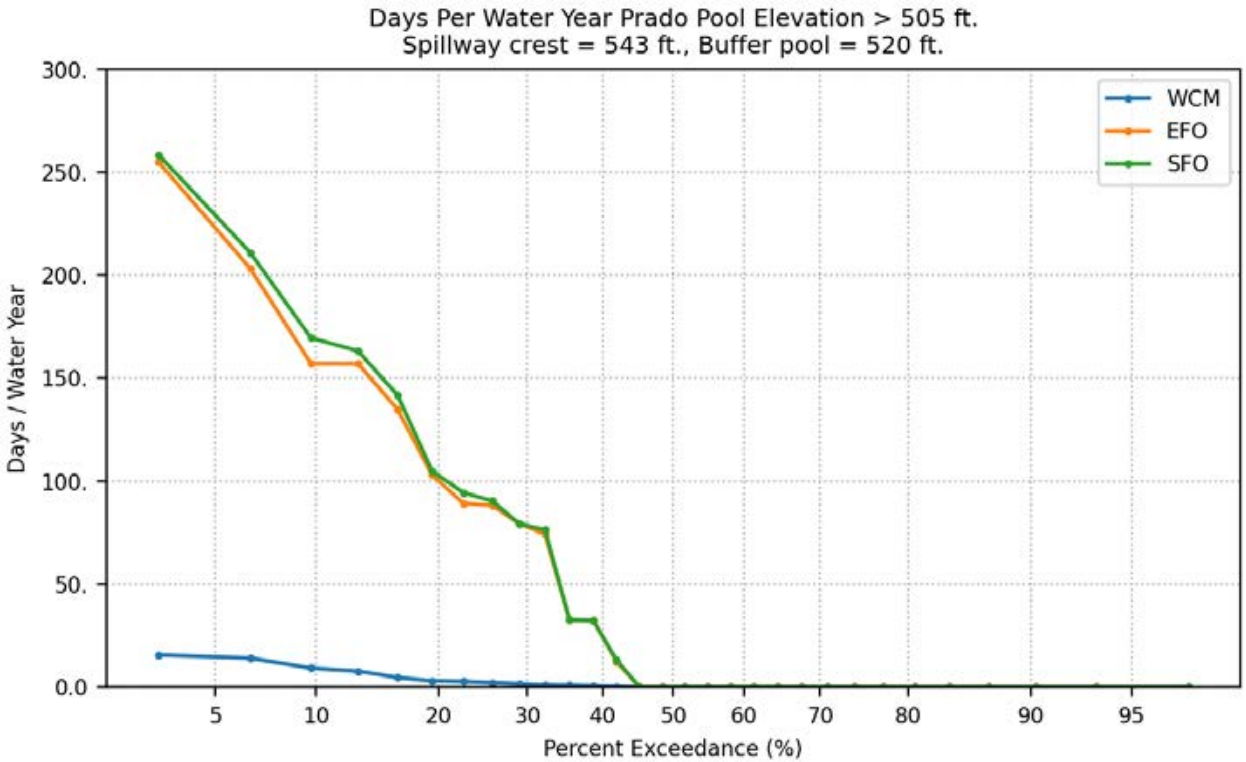

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

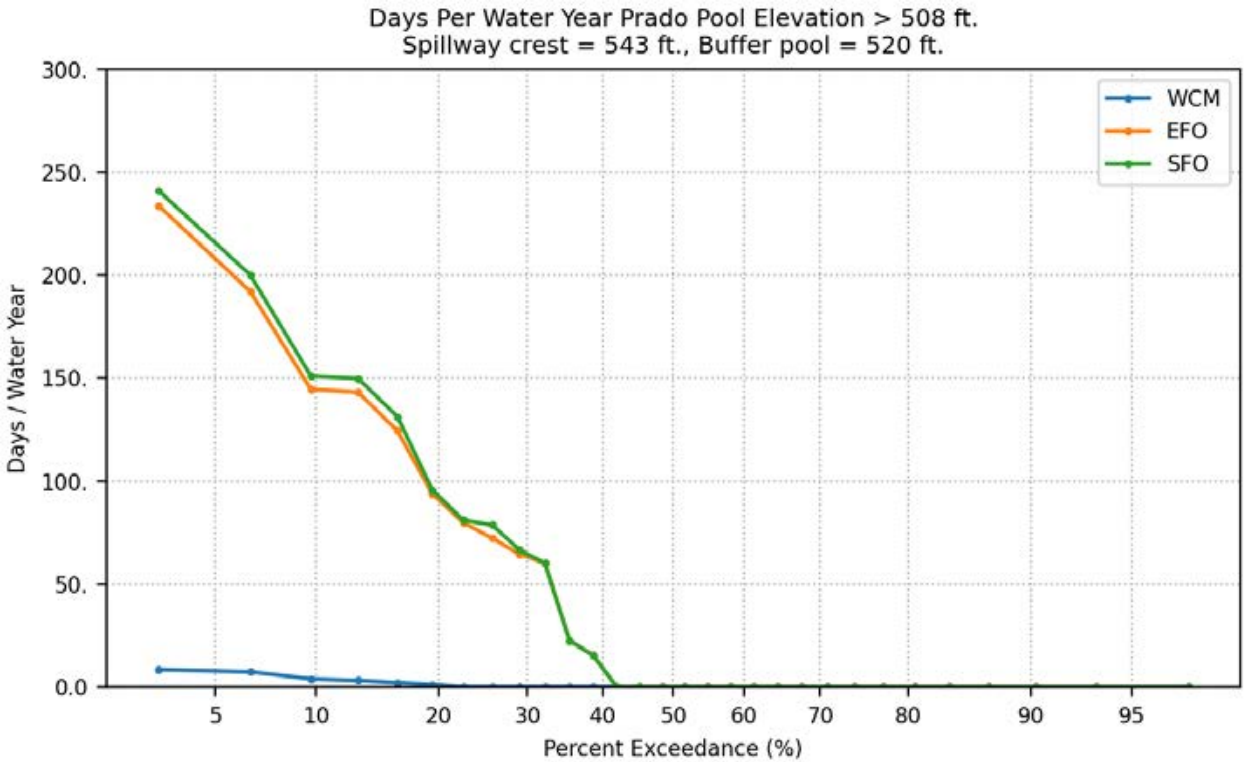

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 543 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
20
30
40
50
60
70
80
90
95

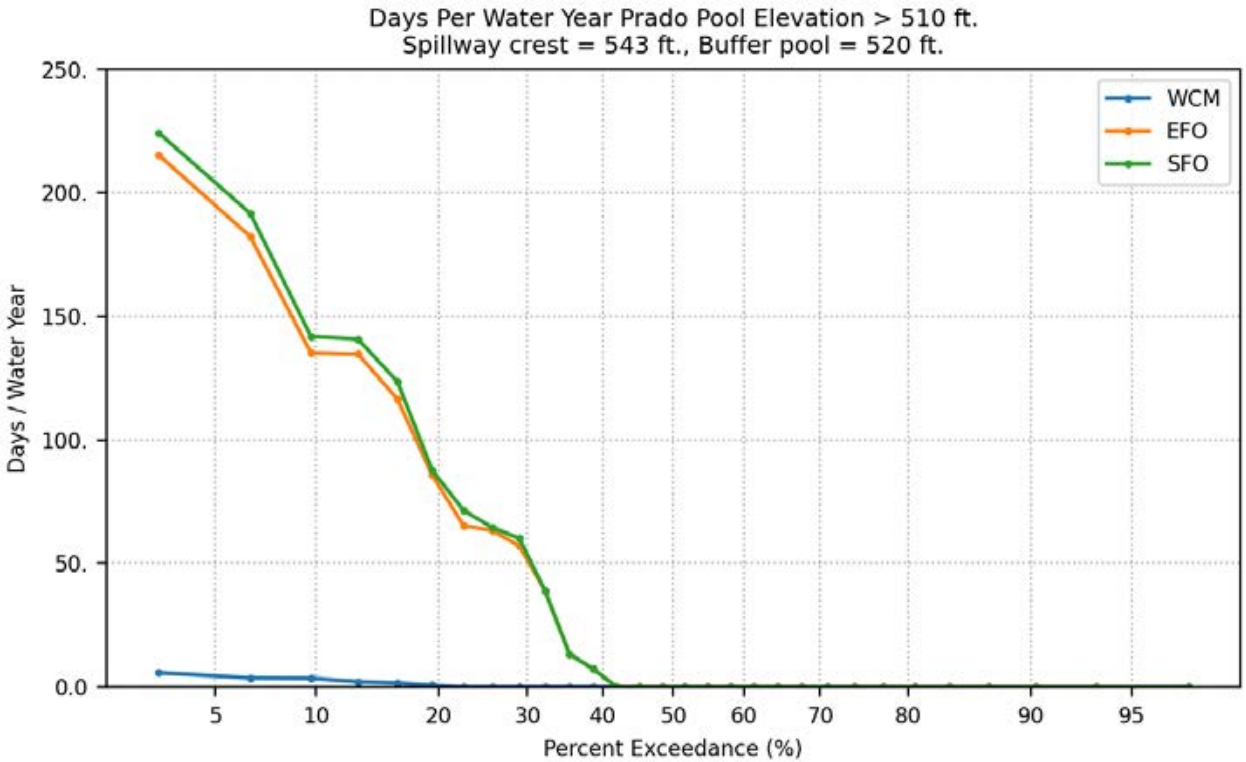

Groundwater Recharge Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 520 ft.
Volume / Water Year (1,000 acre-feet per water year)
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

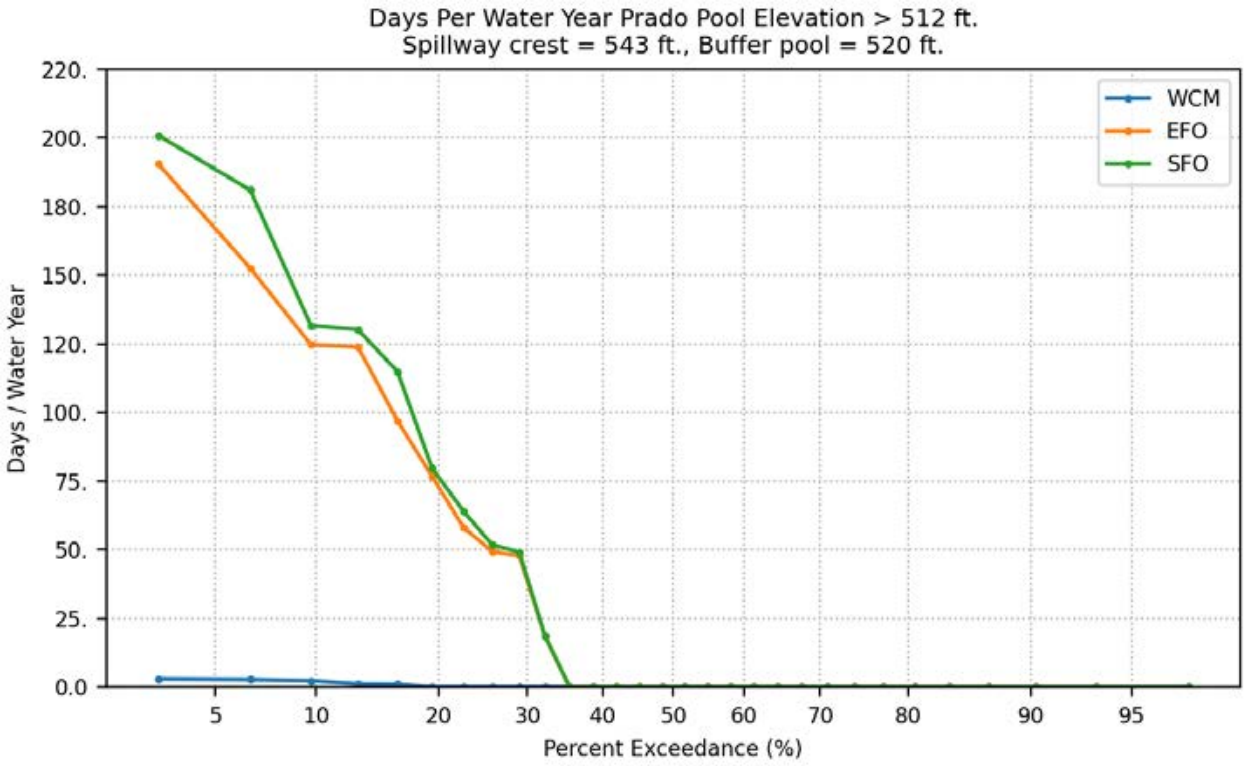

Santa Ana River Volume Per Water Year
Spillway crest = 543 ft., Buffer pool = 520 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

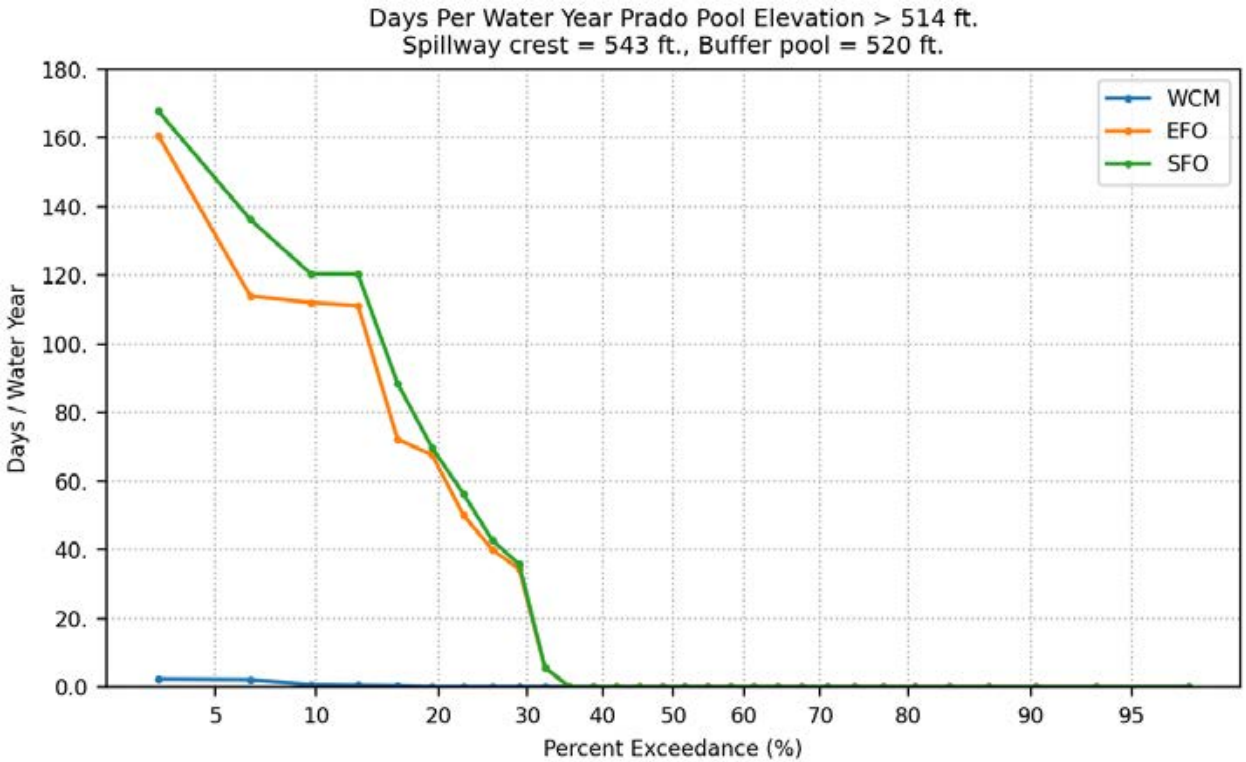

Days Per Water Year Elevation Change > 2-meters
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 543 ft., Buffer pool = 520 ft.
WCM
EFO
SFO
Days / Water Year
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)

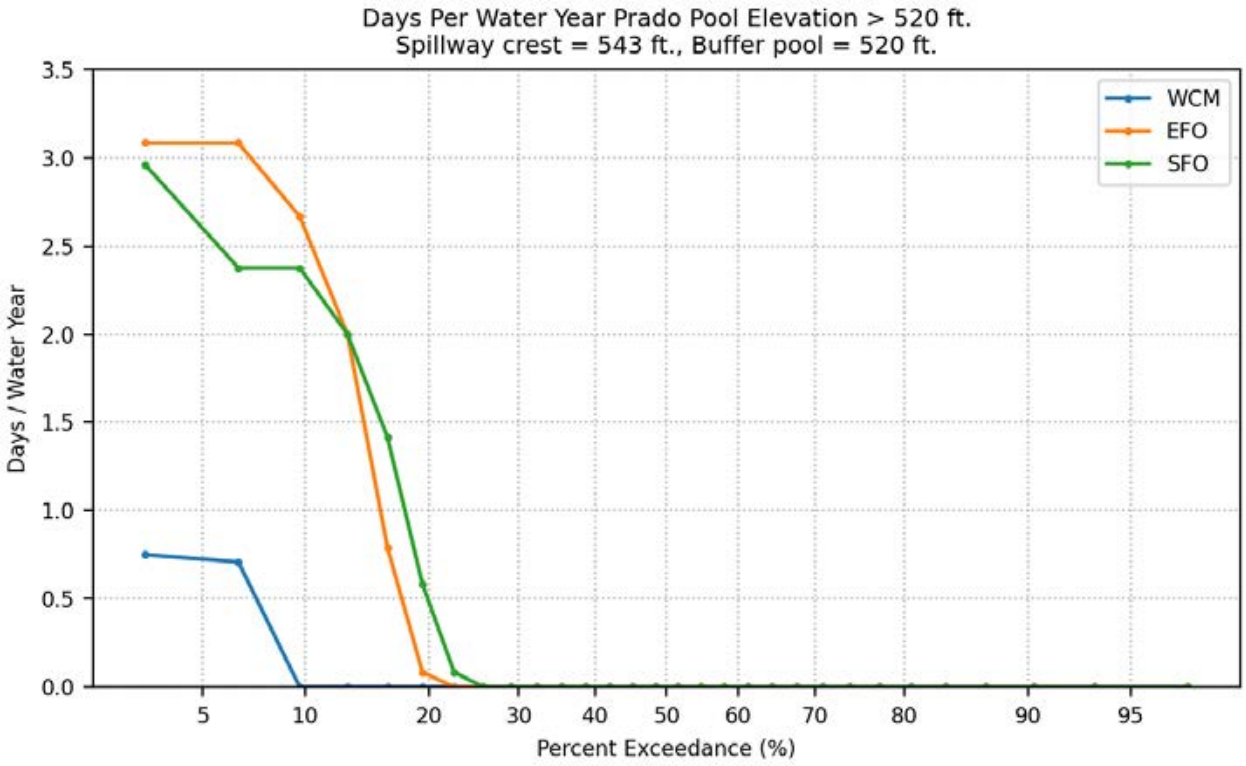

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 543 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
300.
250.
200.
150.
100.
50.
0.0
5
10
20
30
40
50
60
70
80
90
95

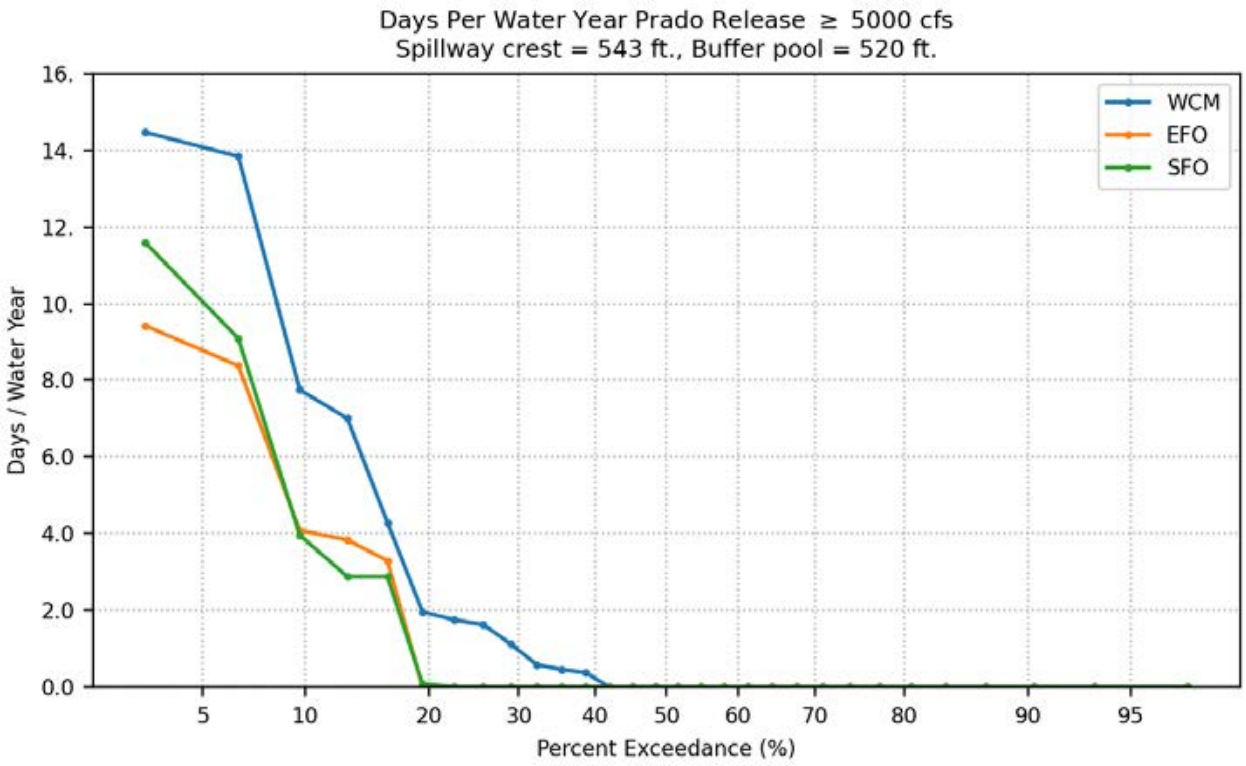

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 543 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
300.
250.
200.
150.
100.
50.
0.0
5
10
20
30
40
50
60
70
80
90
95

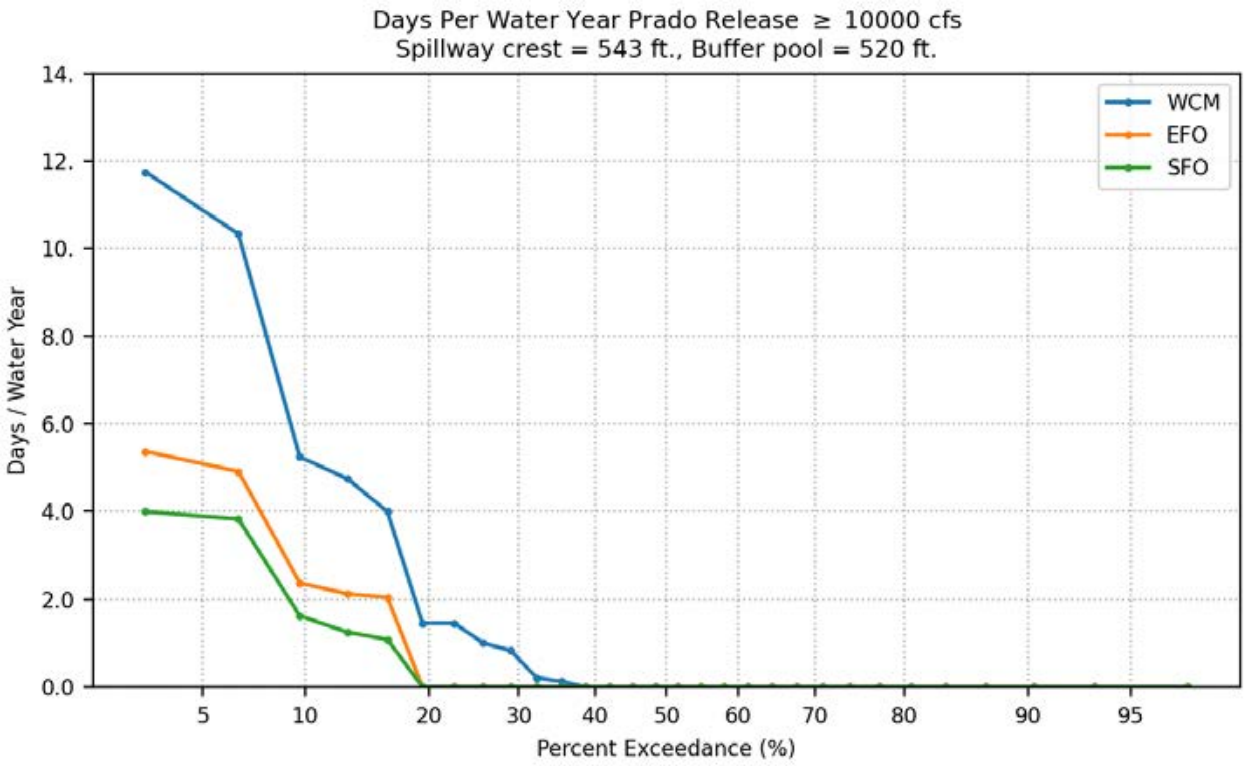

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 543 ft., Buffer pool = 520 ft.
Days / Water Year
250.
200.
150.
100.
50.
0.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

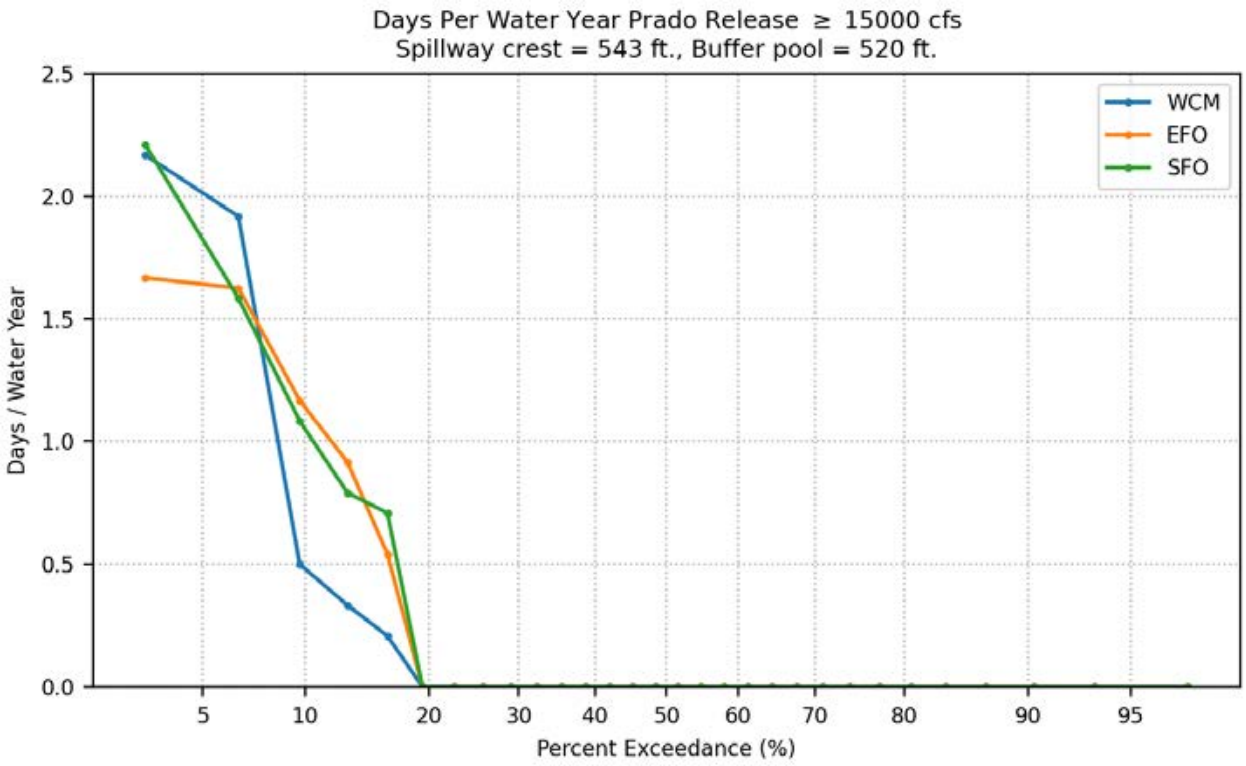

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 543 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
220.
200.
180.
150.
120.
100.
75.
50.
25.
0.0
5
10
20
30
40
50
60
70
80
90
95

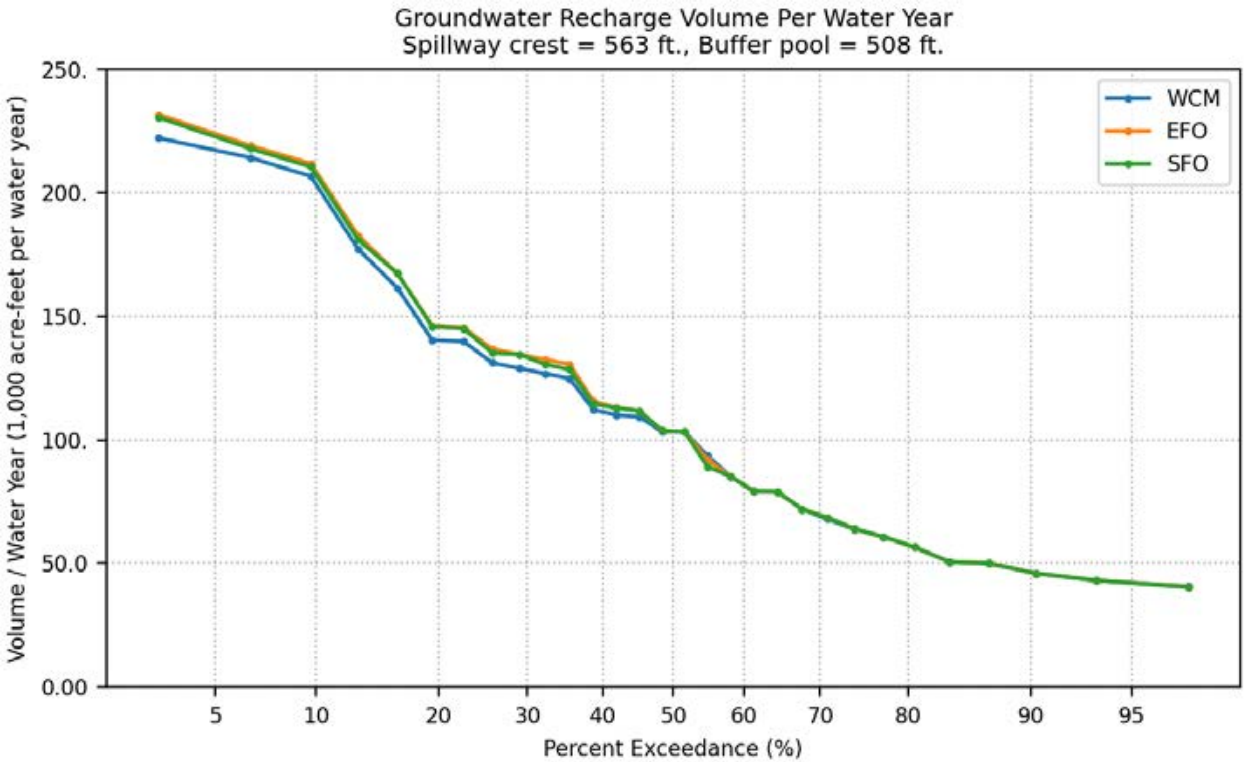

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 543 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
180.
160.
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

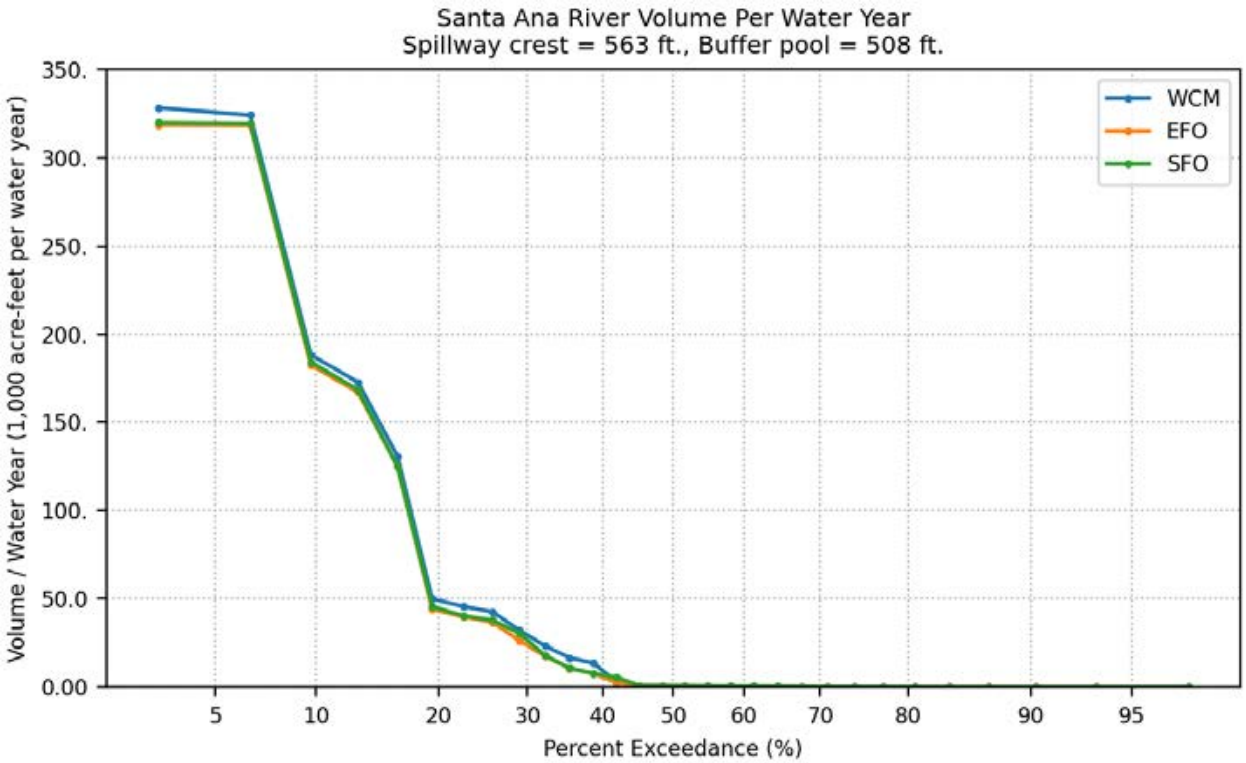

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 543 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
5
10
20
30
40
50
60
70
80
90
95

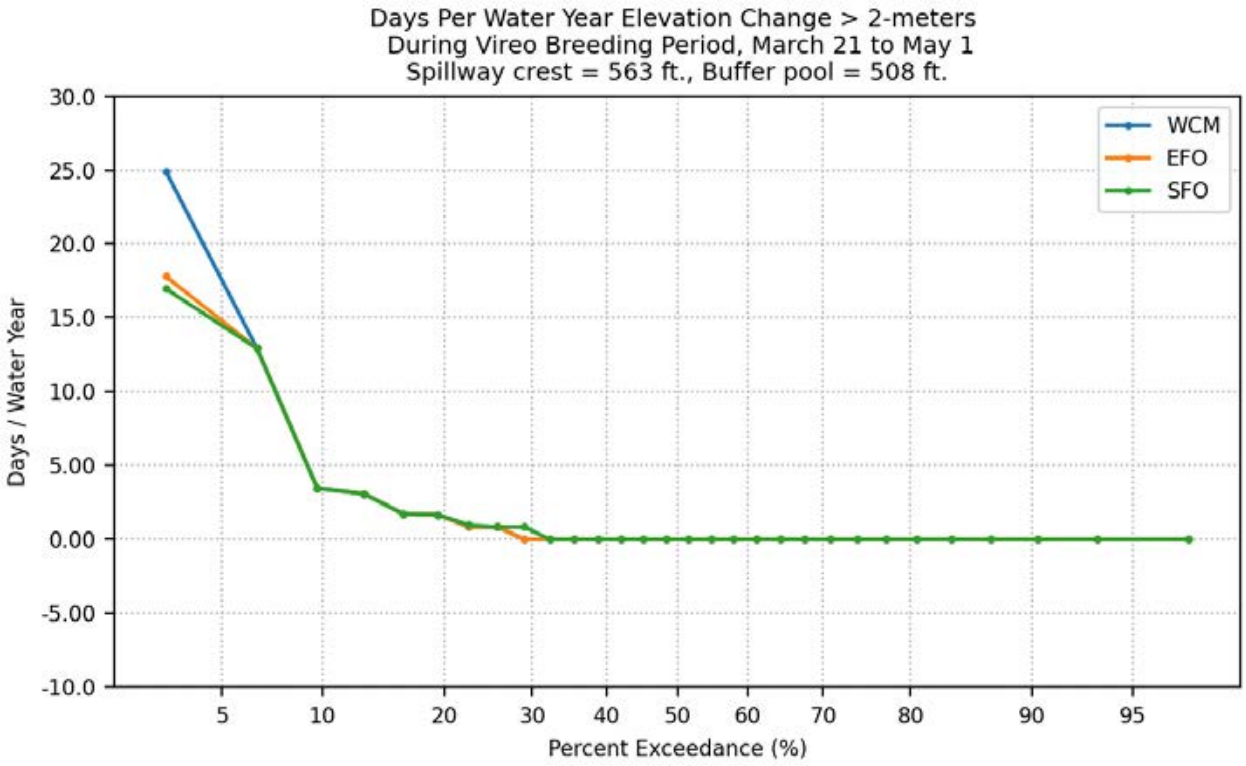

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 543 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

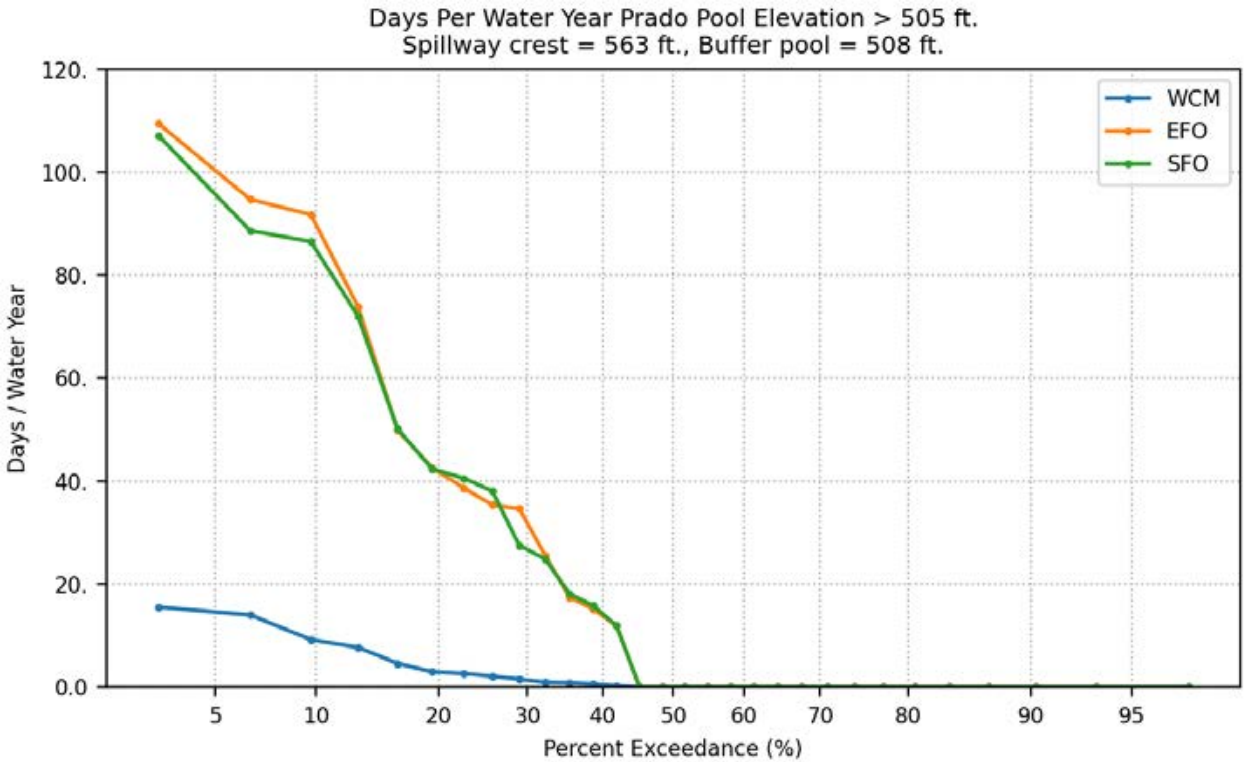

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 543 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
0.0
2.0
4.0
6.0
8.0
10.
12.
14.
5
10
20
30
40
50
60
70
80
90
95

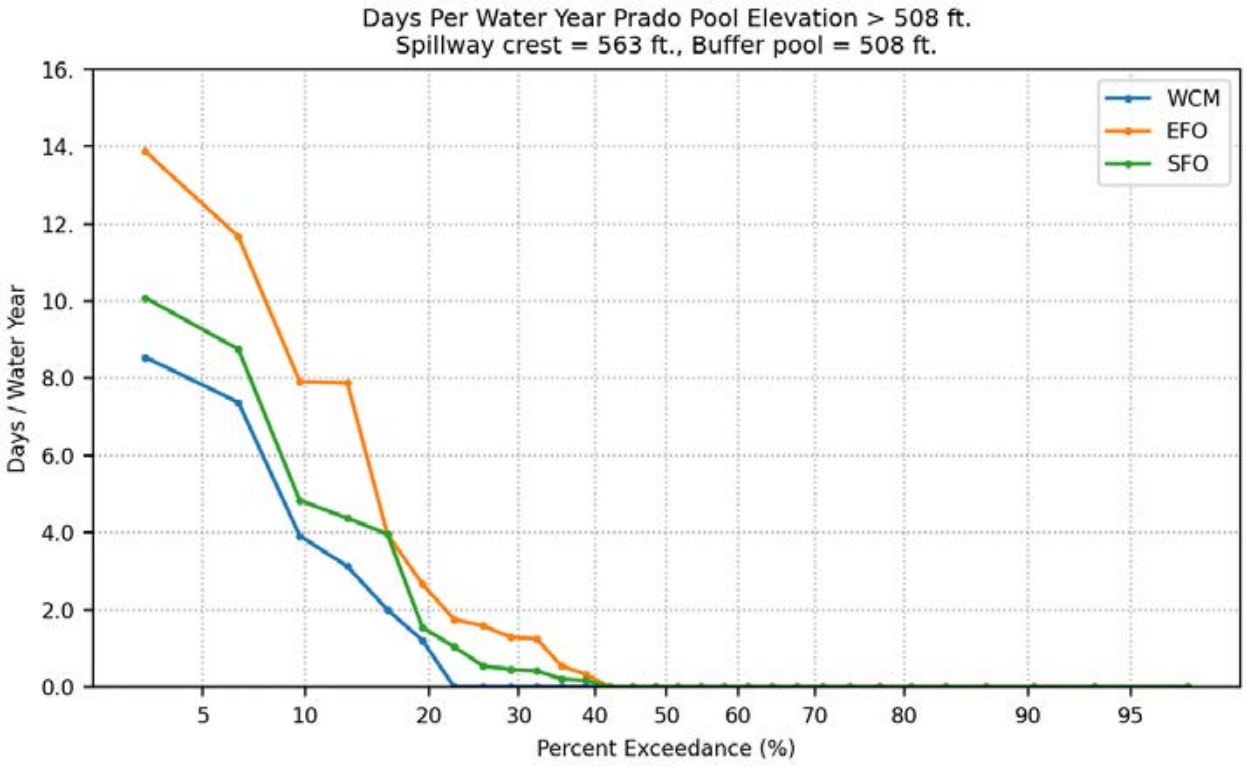

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 543 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
0.0
0.5
1.0
1.5
2.0
2.5
5
10
20
30
40
50
60
70
80
90
95

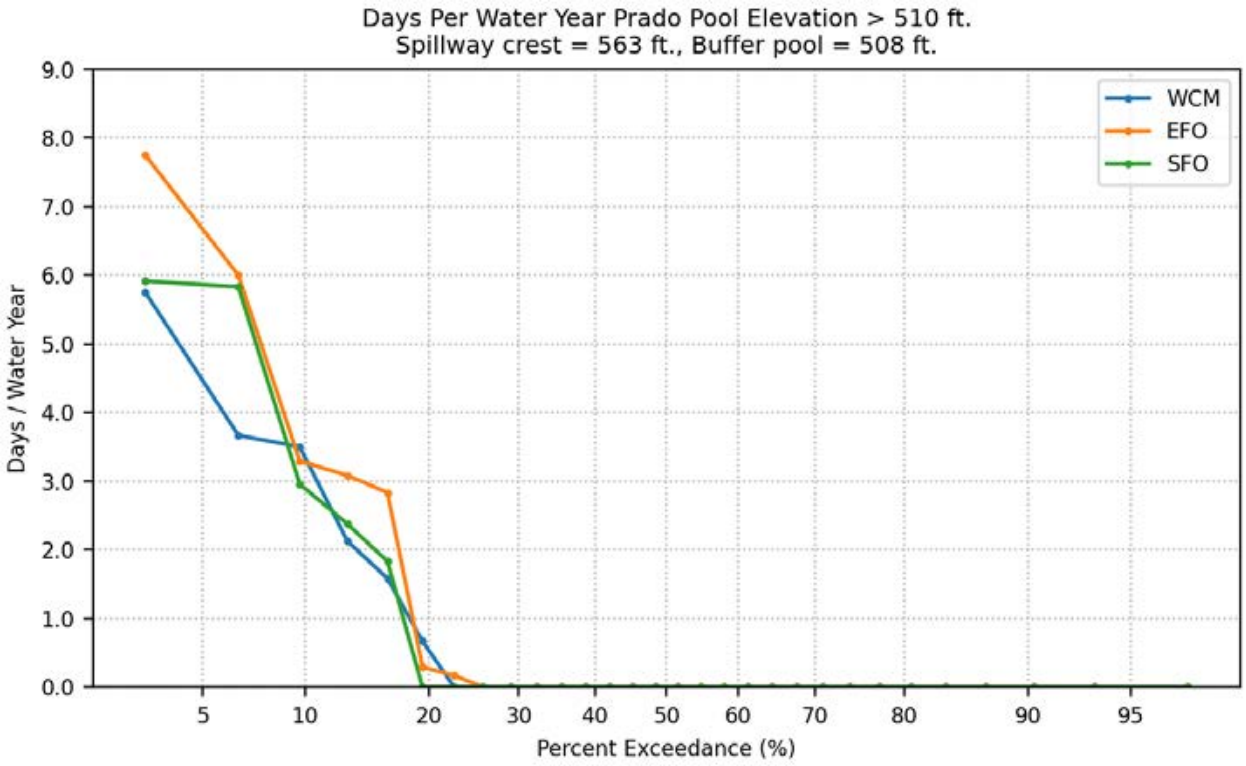

Groundwater Recharge Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 508 ft.
Volume / Water Year (1,000 acre-feet per water year)
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

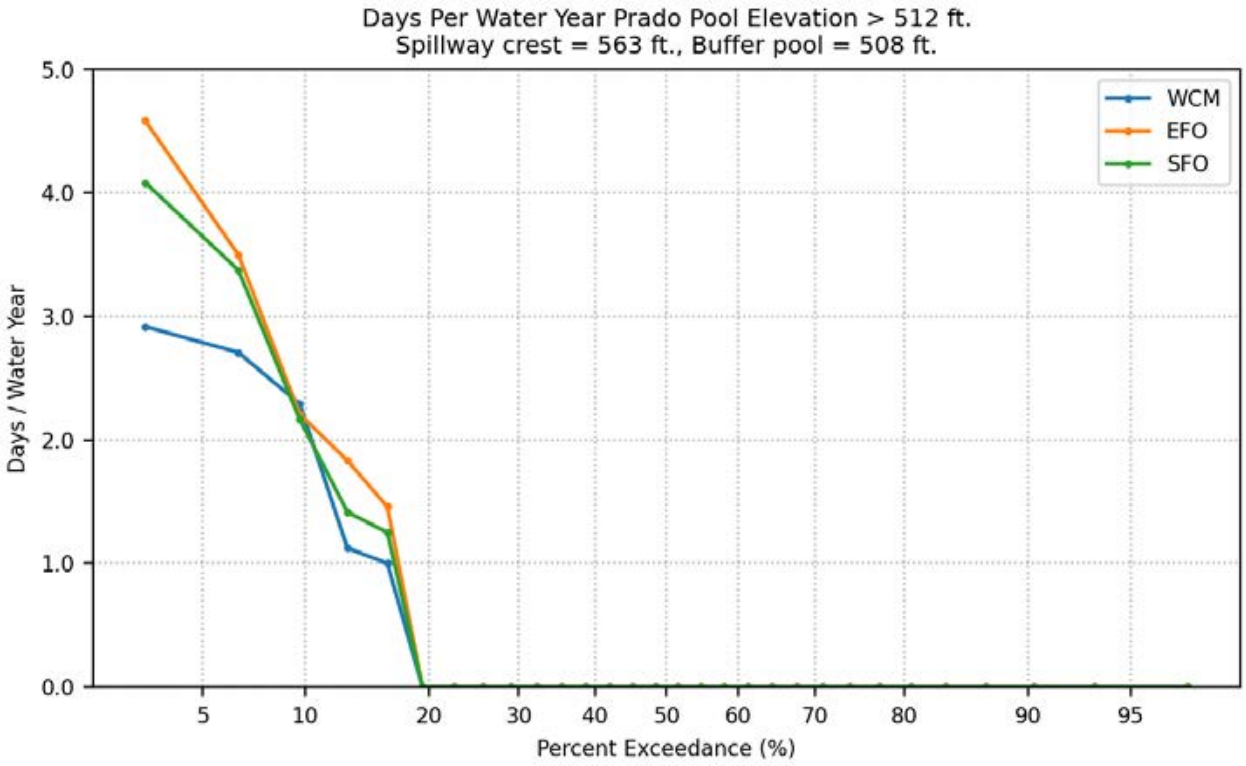

Santa Ana River Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 508 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

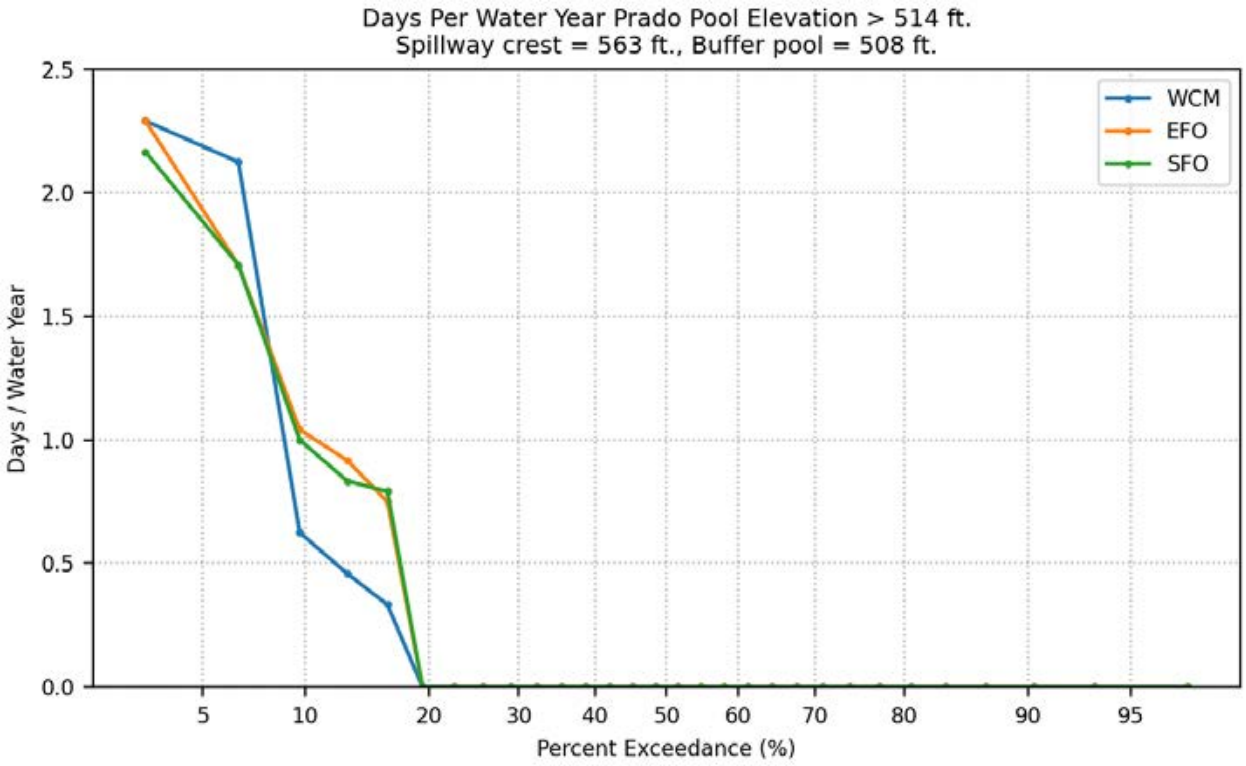

Days Per Water Year Elevation Change > 2-meters
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 563 ft., Buffer pool = 508 ft.
WCM
EFO
SFO
Days / Water Year
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)

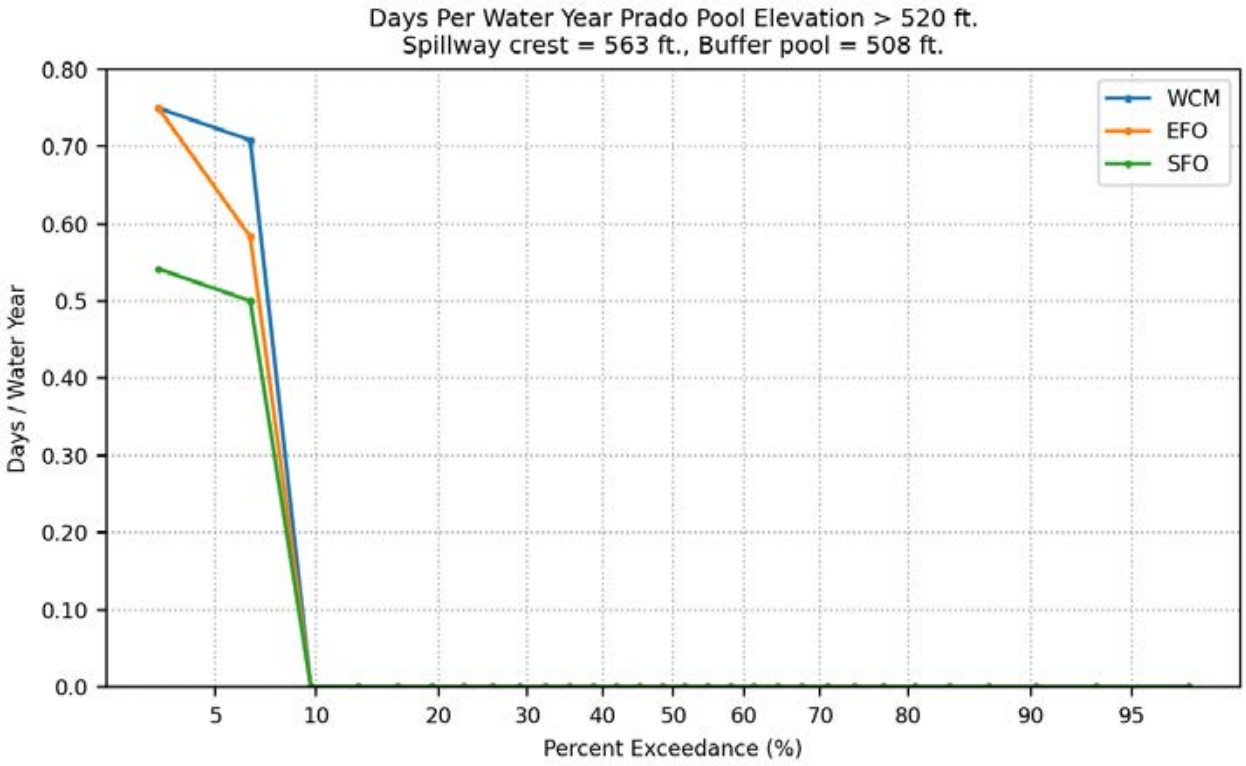

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

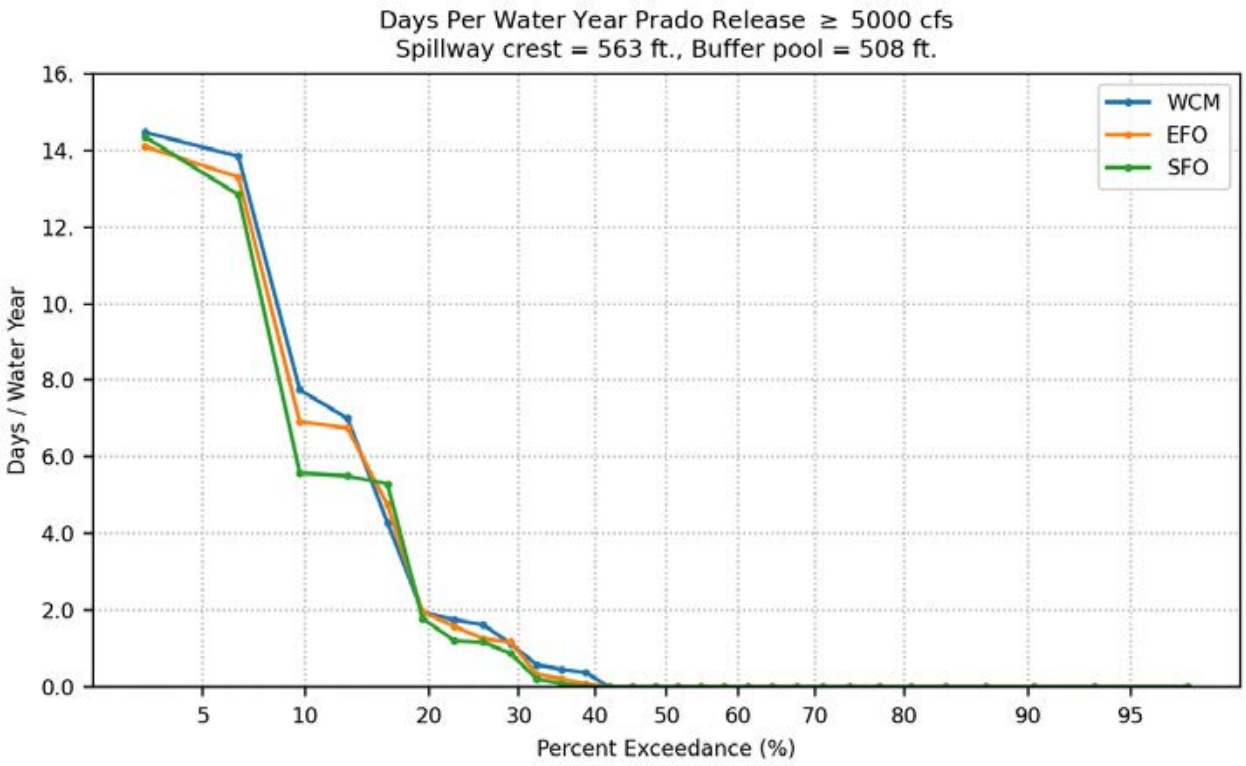

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

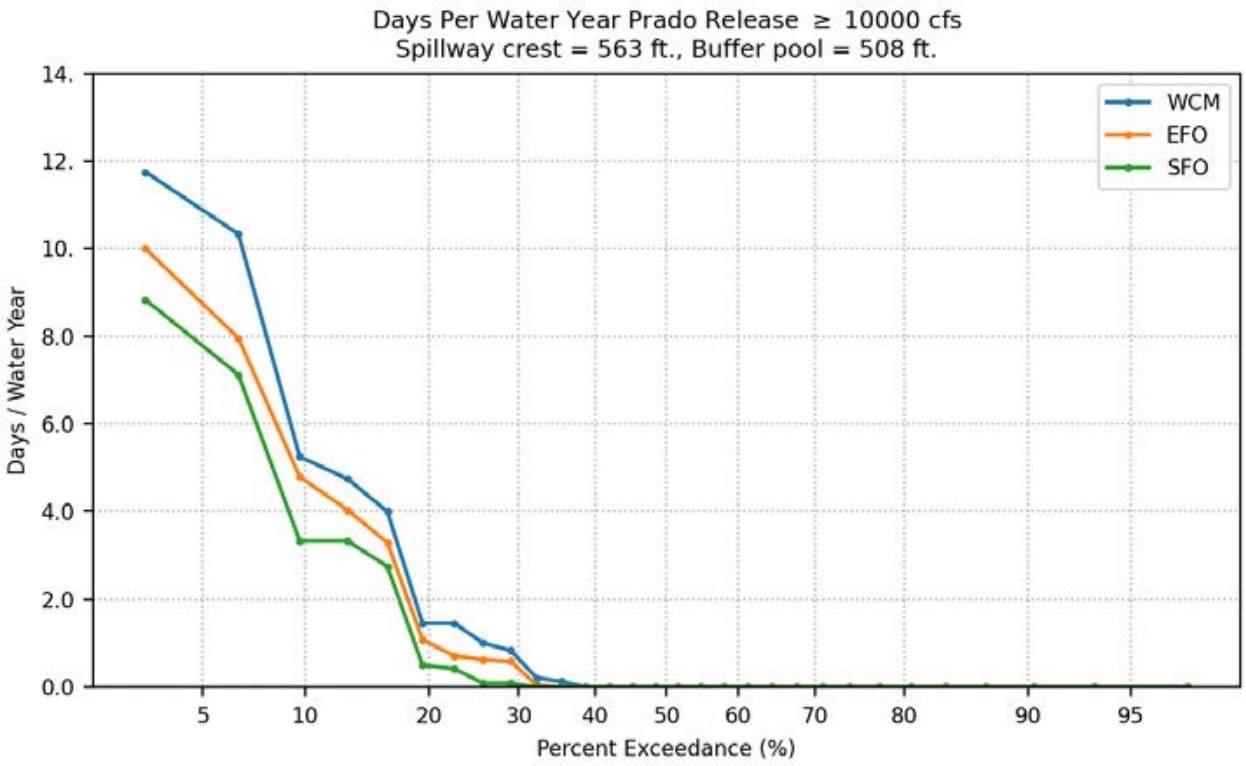

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
5
10
20
30
40
50
60
70
80
90
95

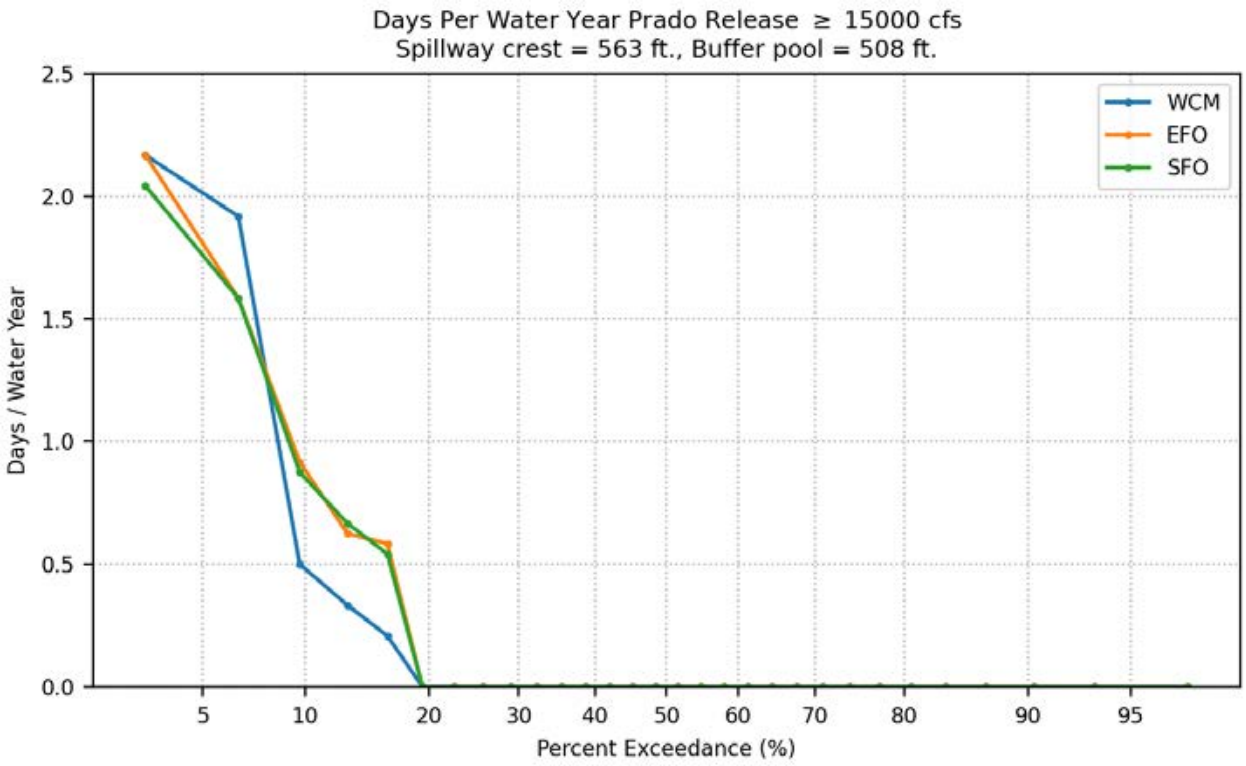

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
5.0
4.0
3.0
2.0
1.0
0.0
5
10
20
30
40
50
60
70
80
90
95

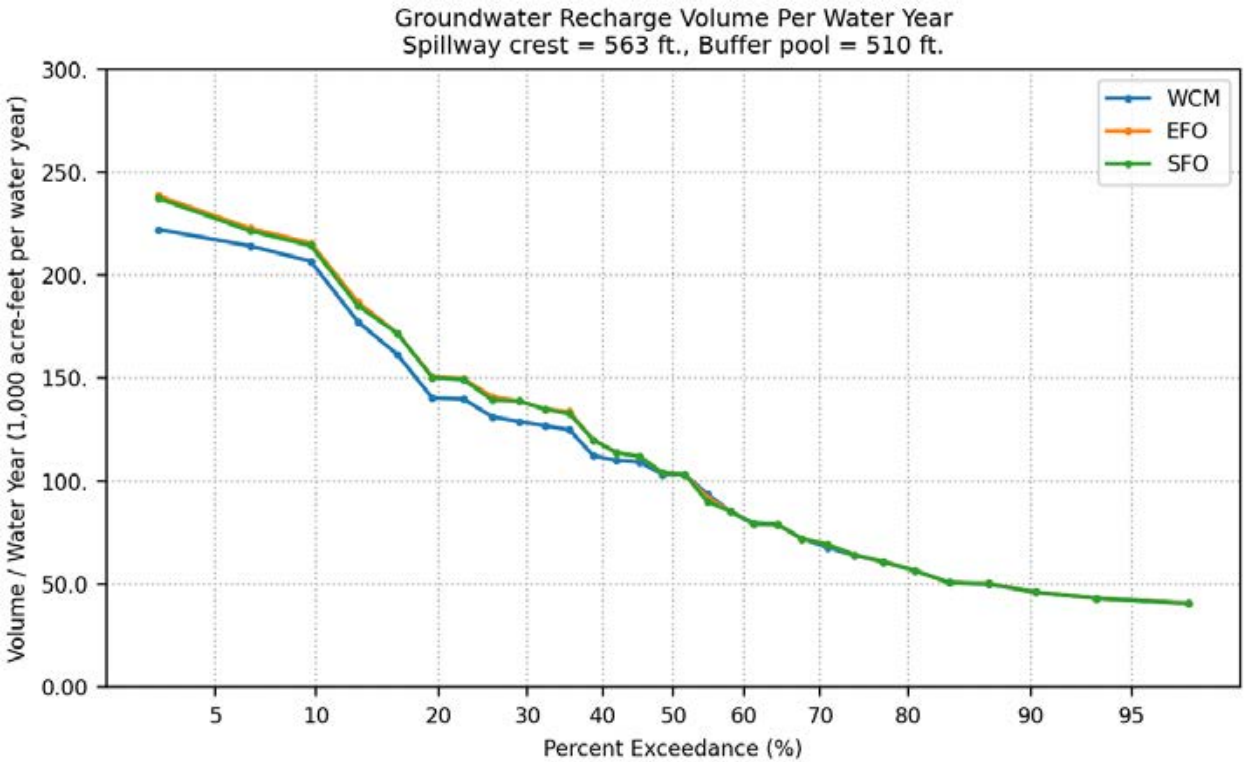

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
0.0
0.5
1.0
1.5
2.0
2.5
5
10
20
30
40
50
60
70
80
90
95

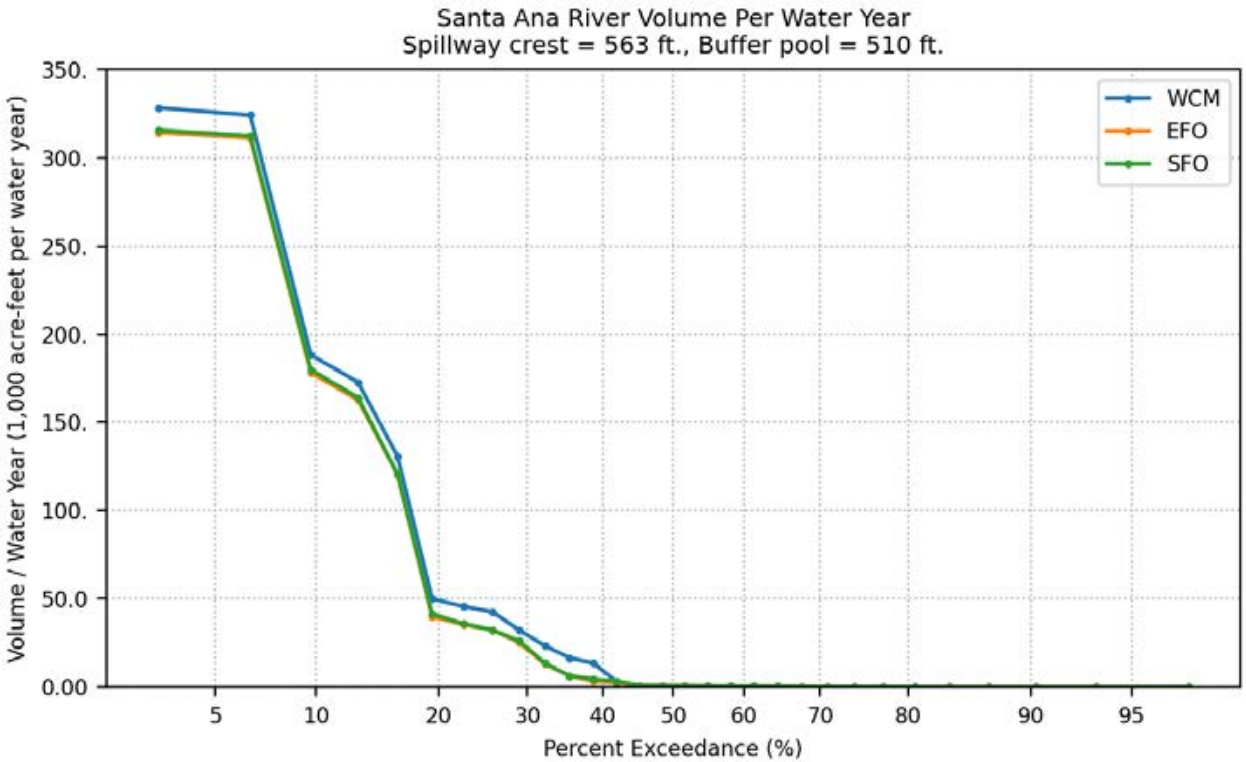

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
0.80
0.70
0.60
0.5
0.40
0.30
0.20
0.10
0.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

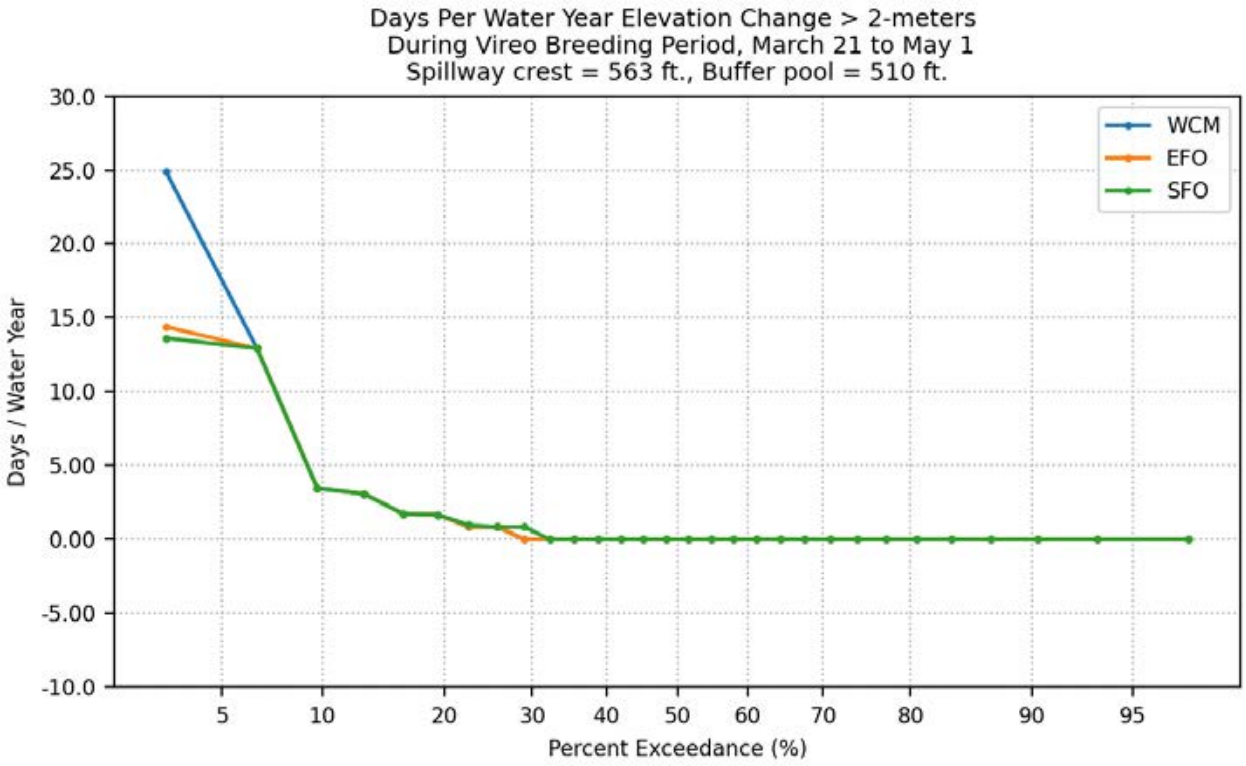

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

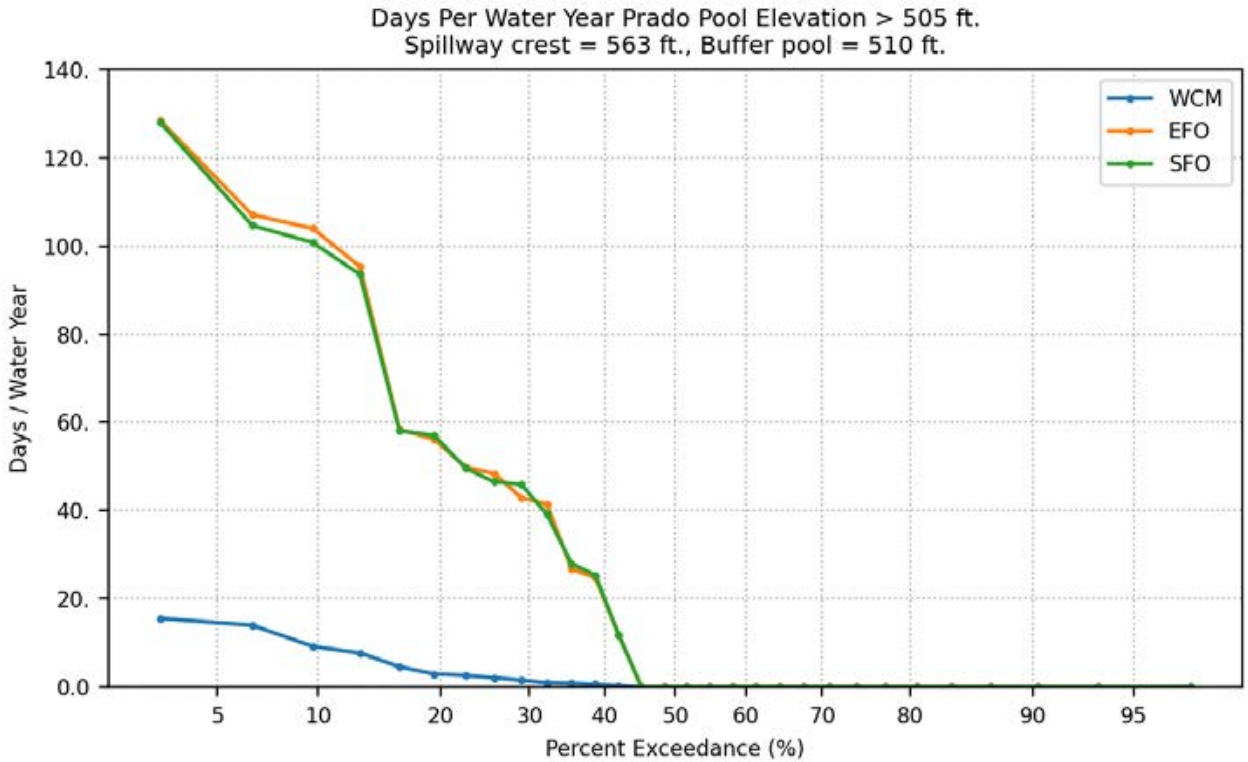

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

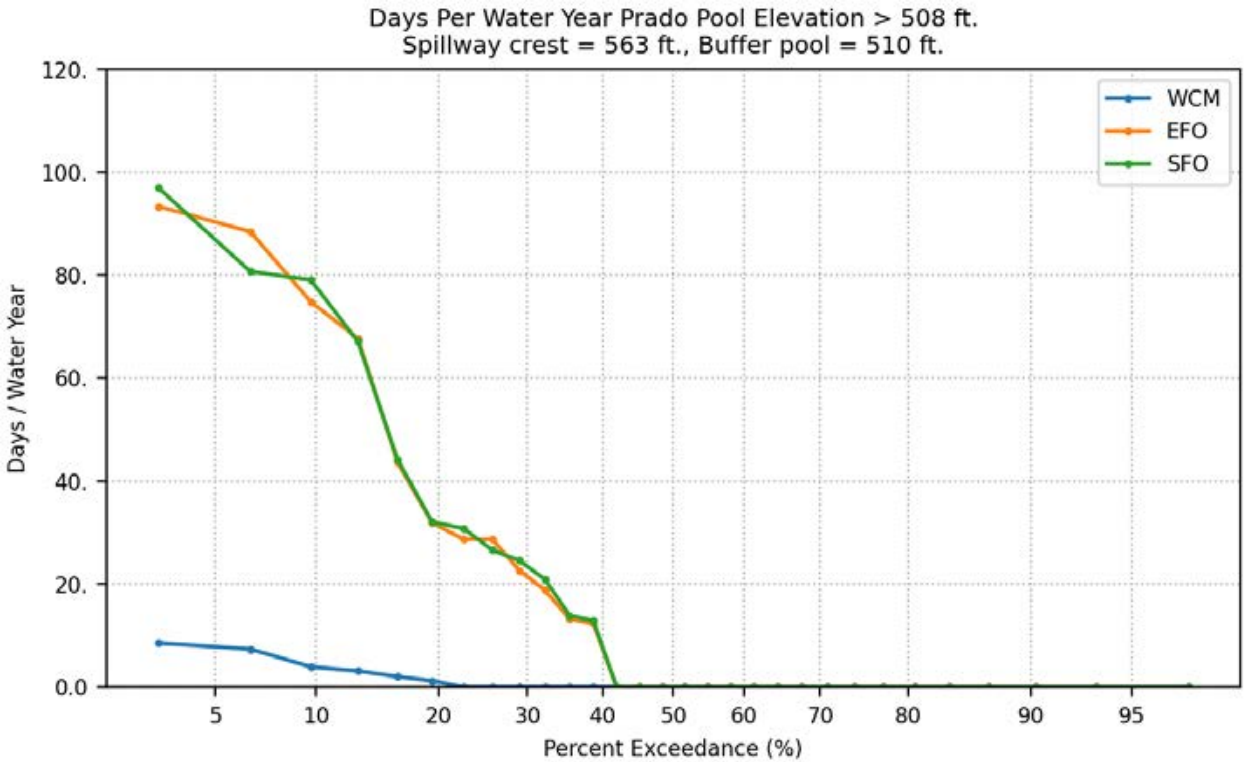

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 563 ft., Buffer pool = 508 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
0.0
0.5
1.0
1.5
2.0
2.5
5
10
20
30
40
50
60
70
80
90
95

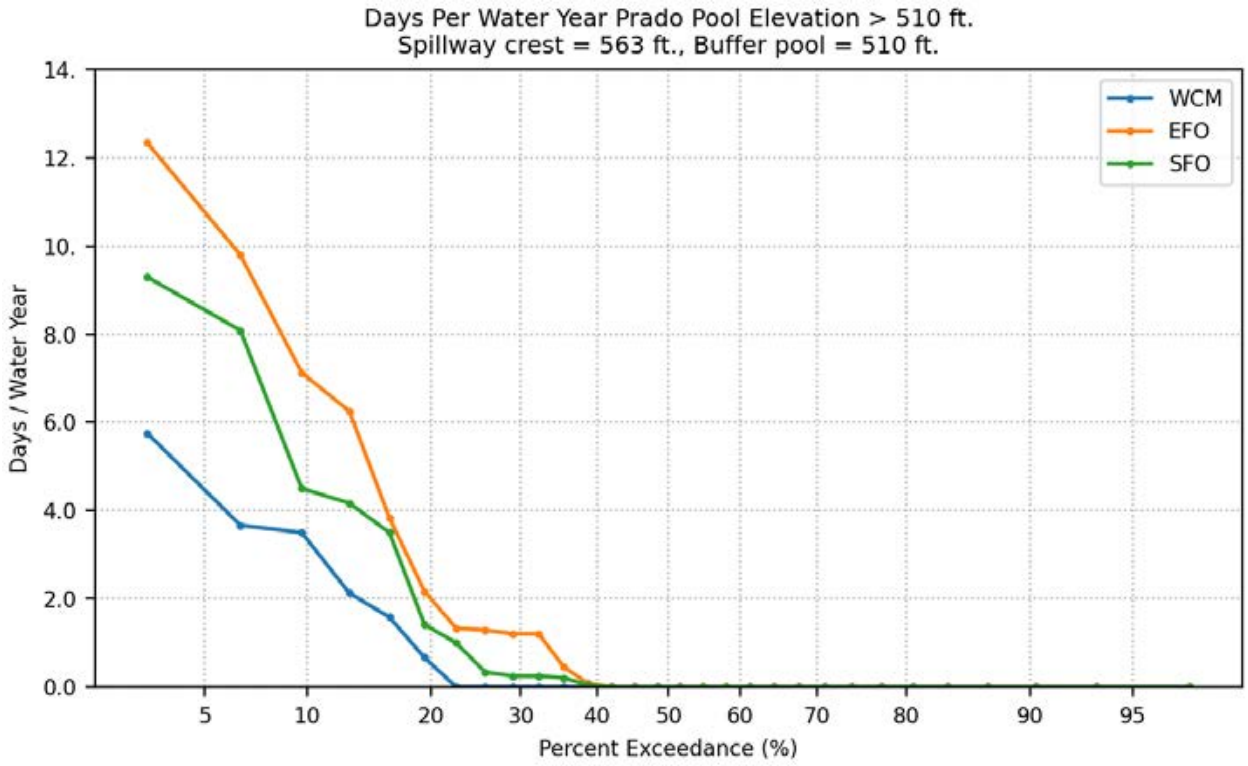

Groundwater Recharge Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 510 ft.
Volume / Water Year (1,000 acre-feet per water year)
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

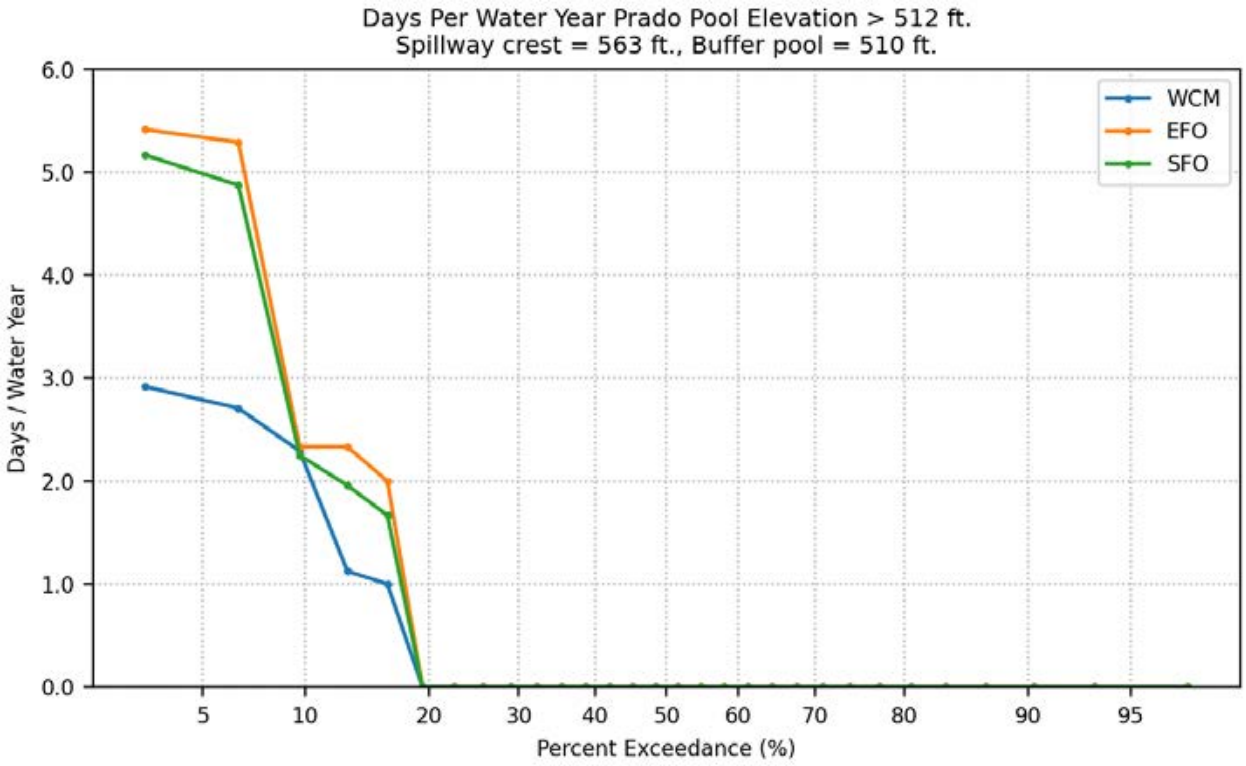

Santa Ana River Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 510 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

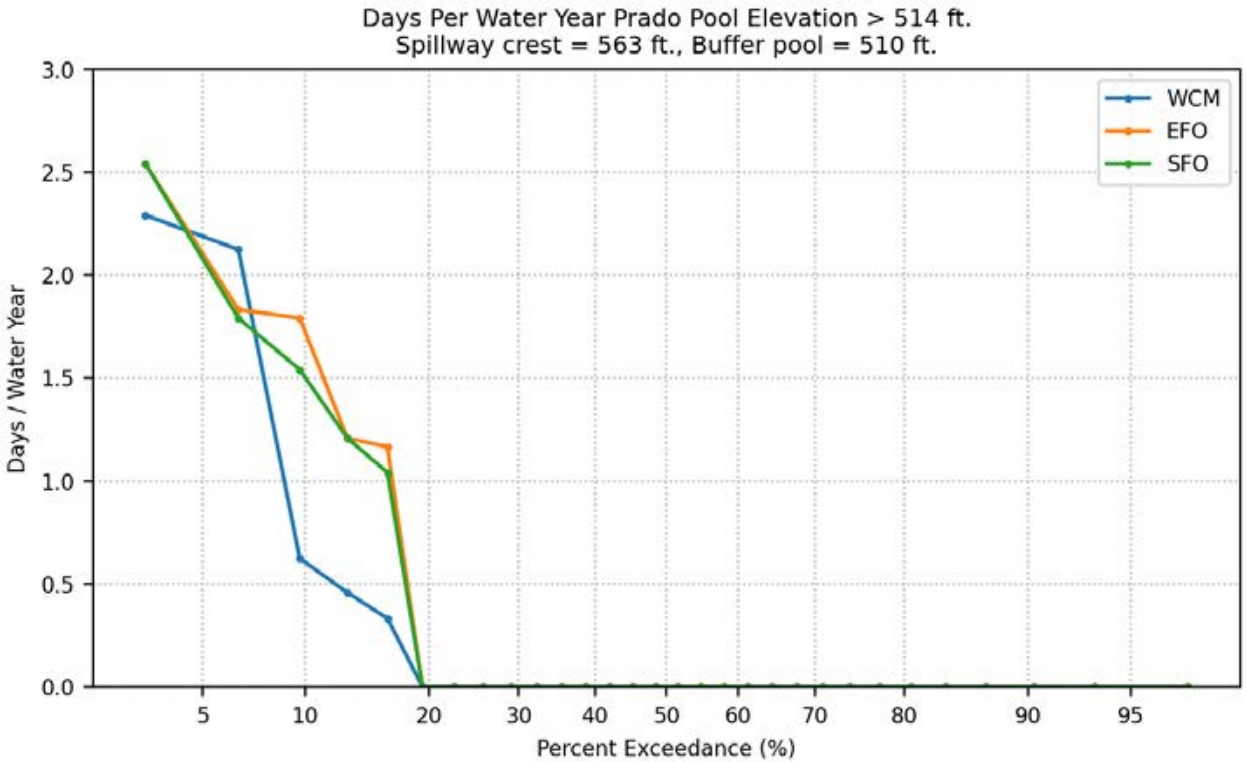

Days Per Water Year Elevation Change > 2-meters
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 563 ft., Buffer pool = 510 ft.
WCM
EFO
SFO
Days / Water Year
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)

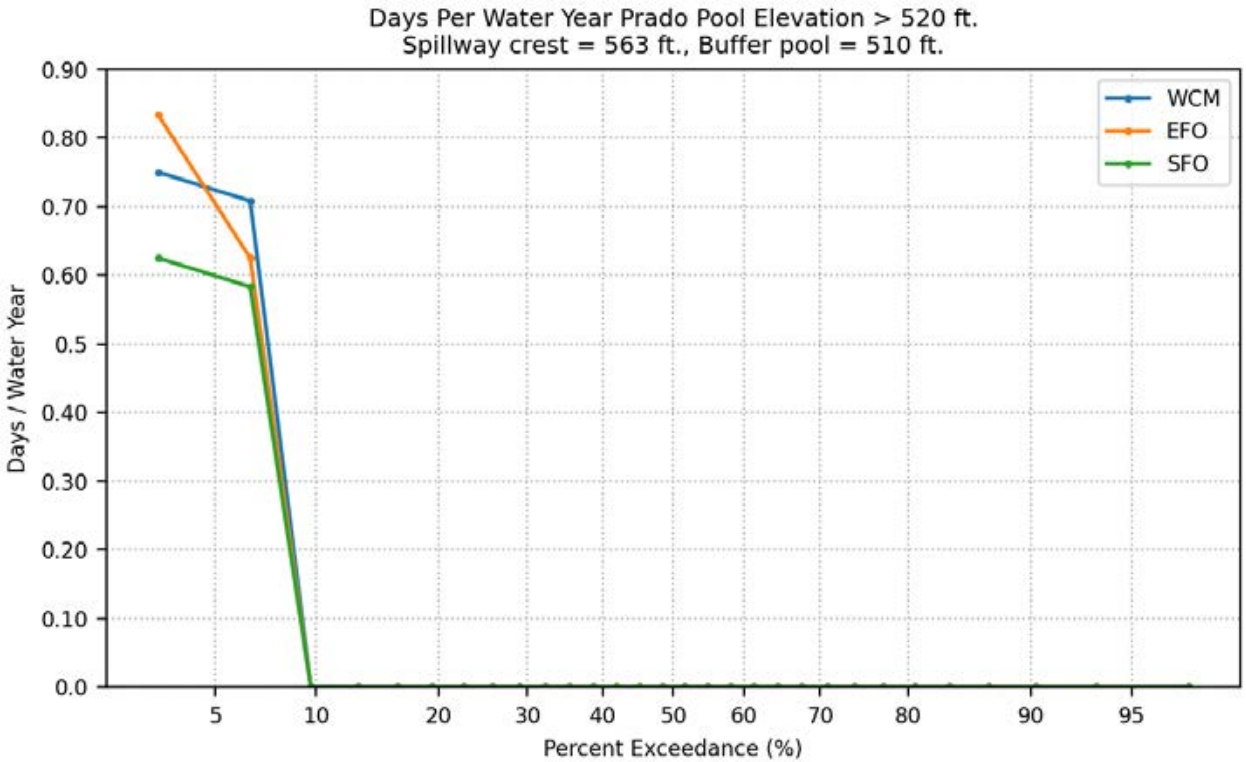

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

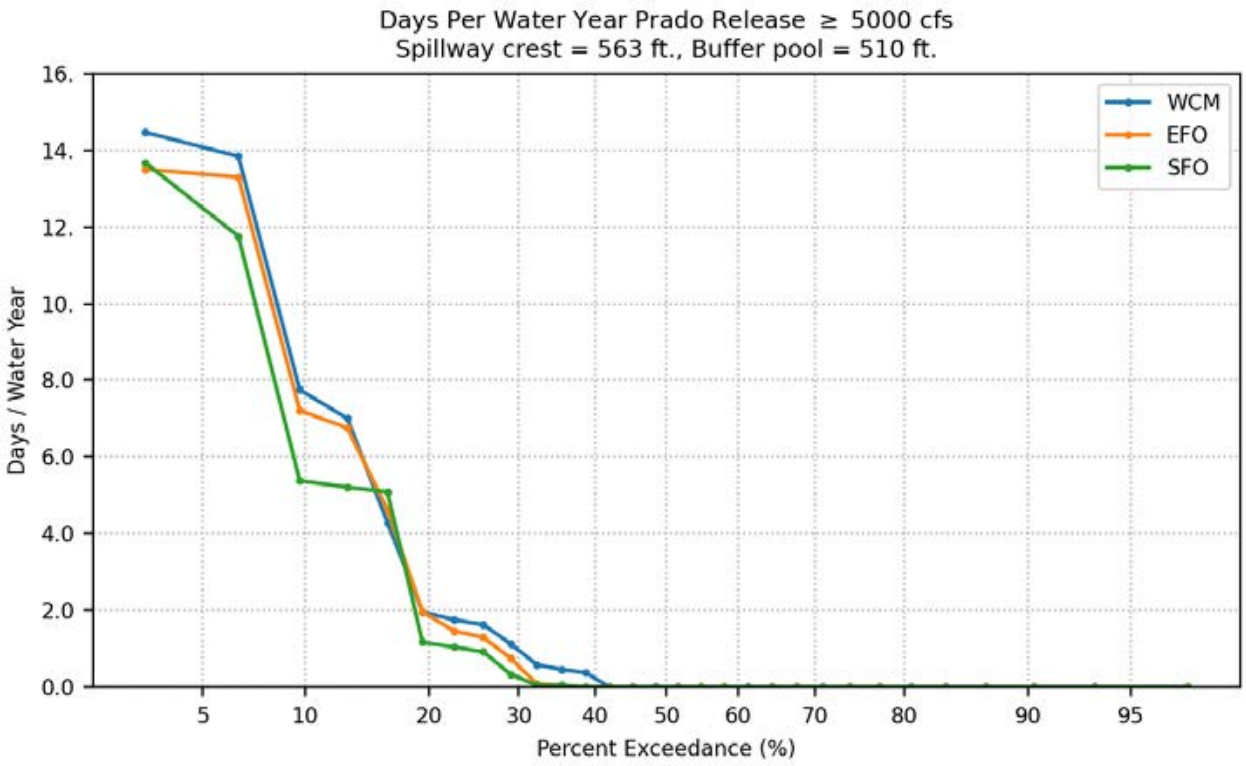

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

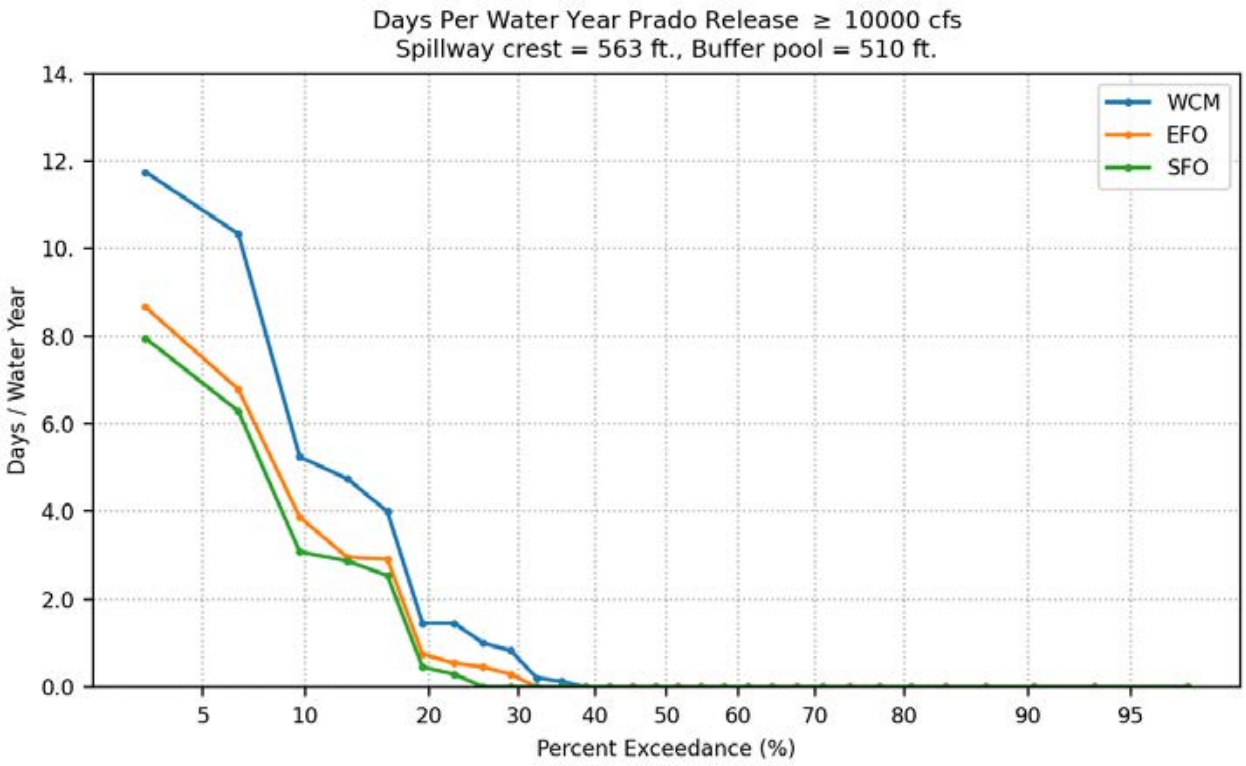

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

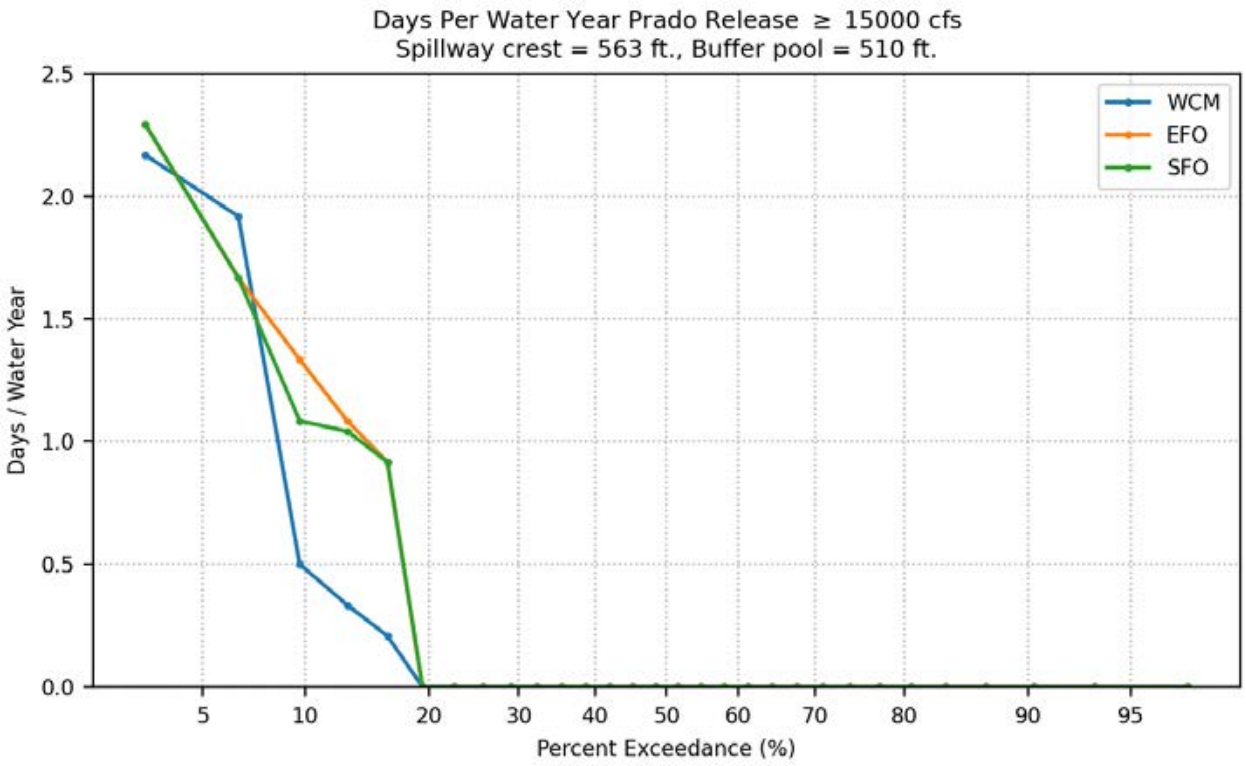

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
6.0
5.0
4.0
3.0
2.0
1.0
0.0
5
10
20
30
40
50
60
70
80
90
95

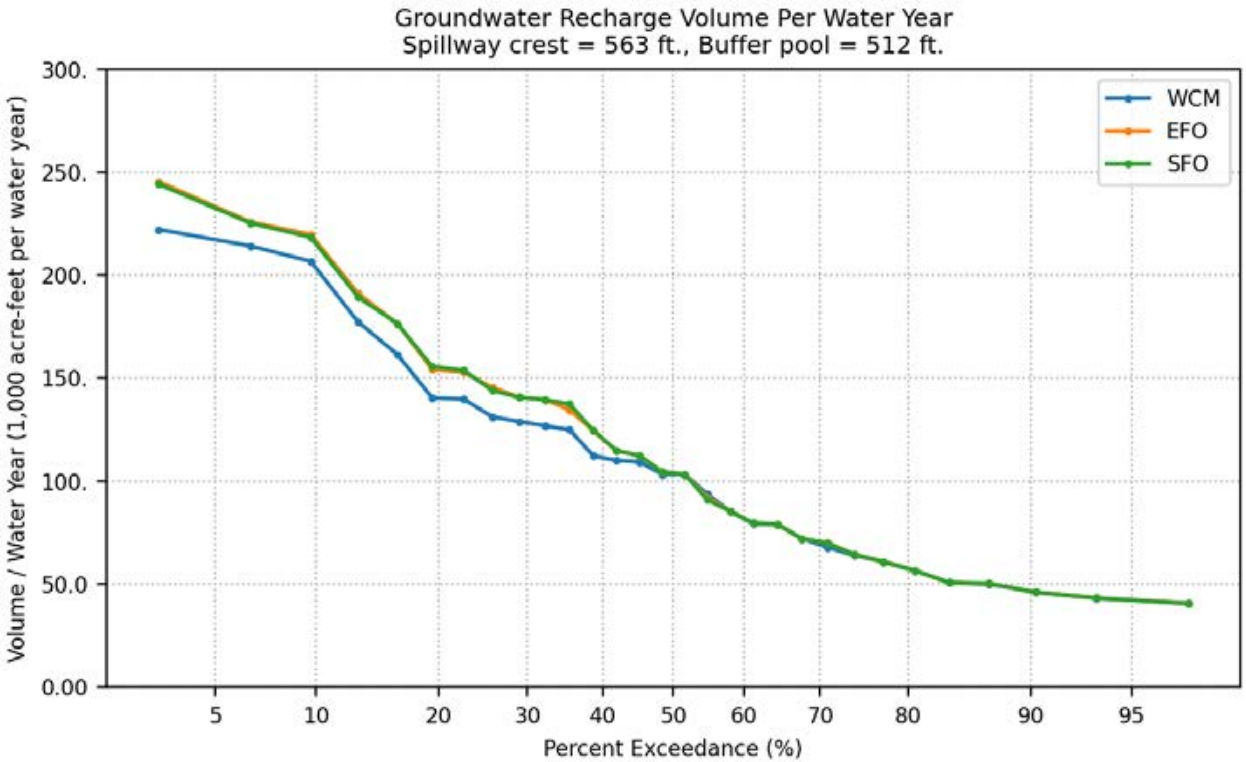

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
20
30
40
50
60
70
80
90
95

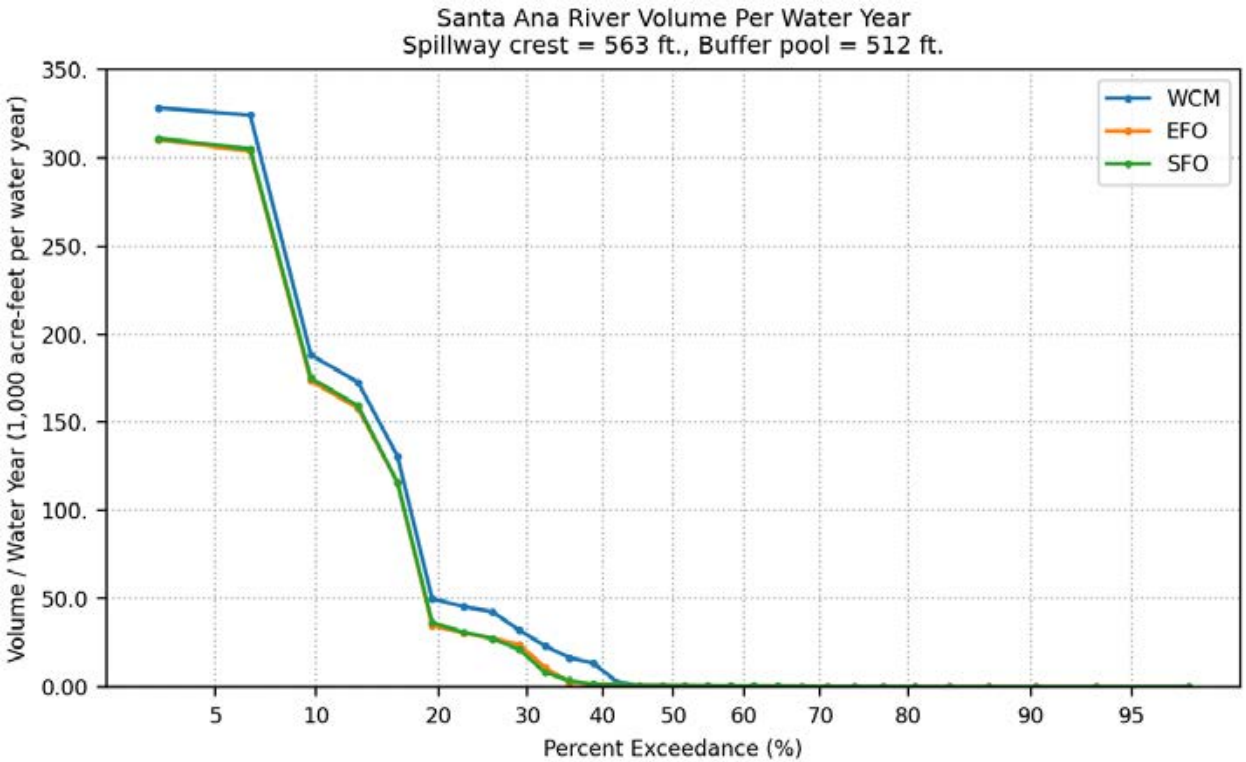

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
0.90
0.80
0.70
0.60
0.5
0.40
0.30
0.20
0.10
0.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

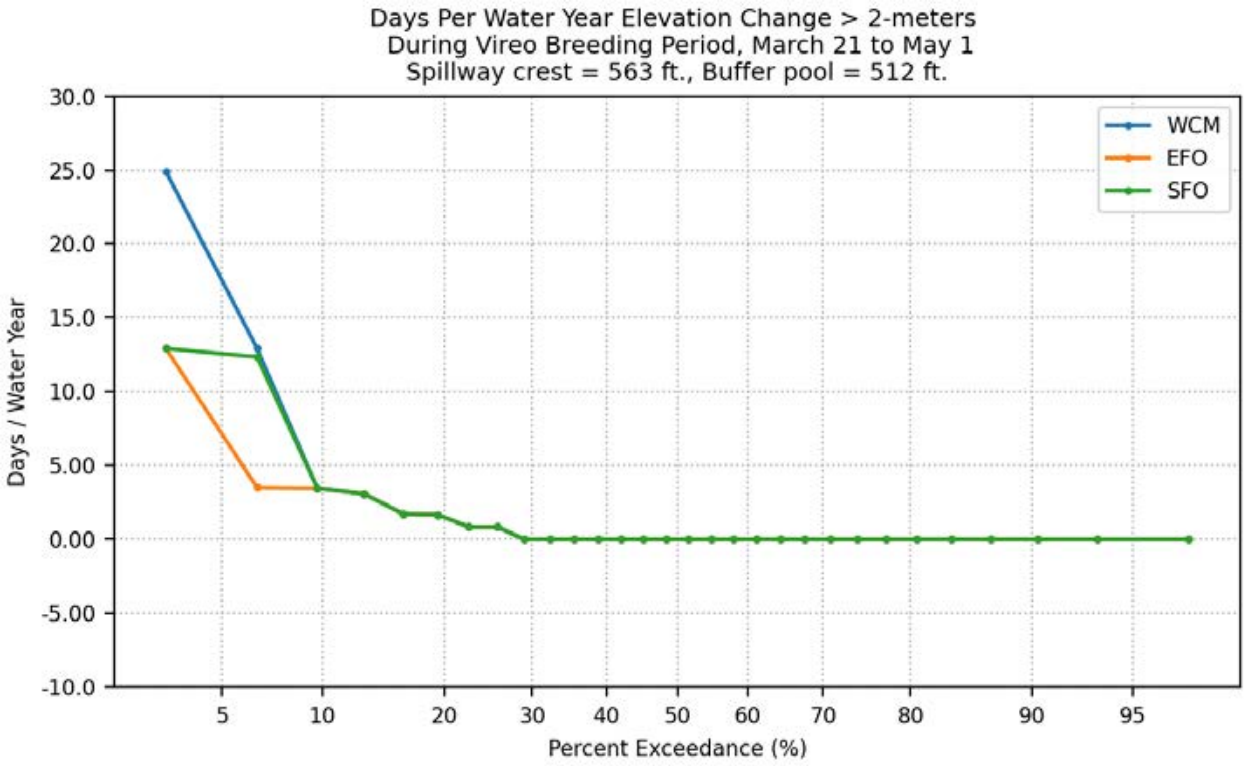

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

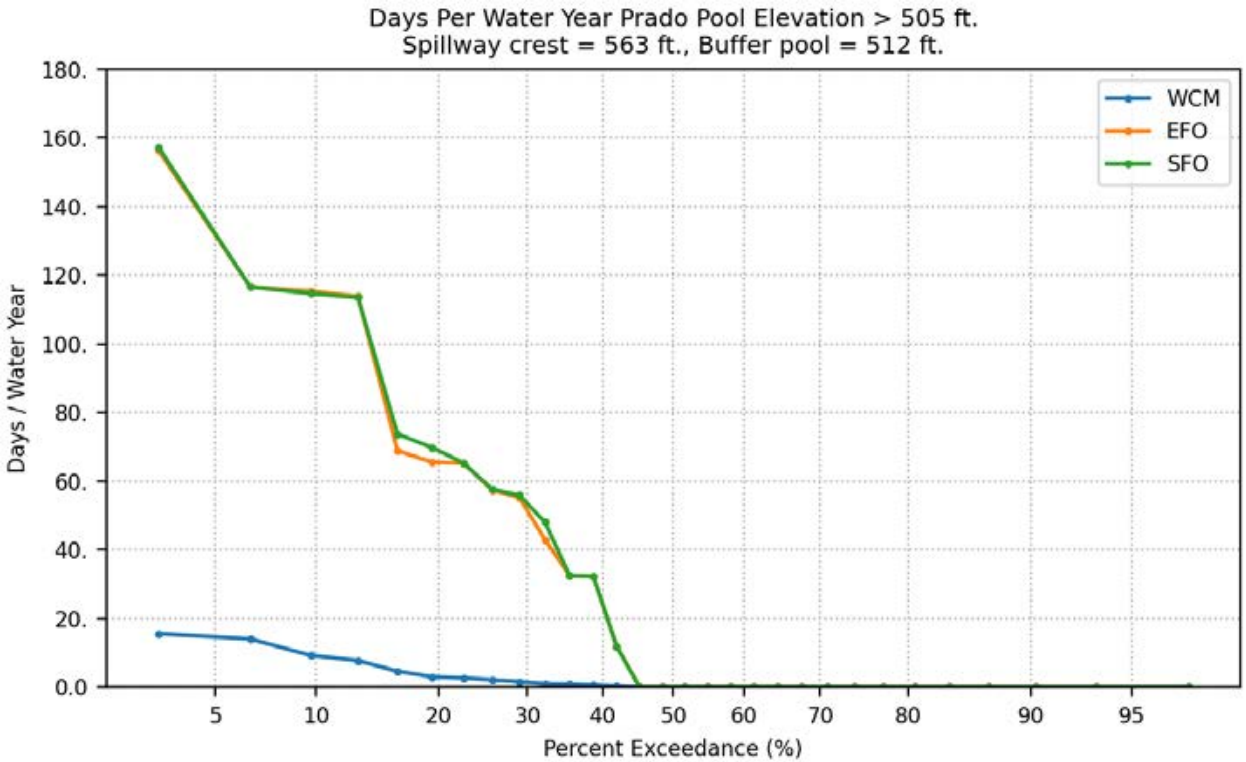

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

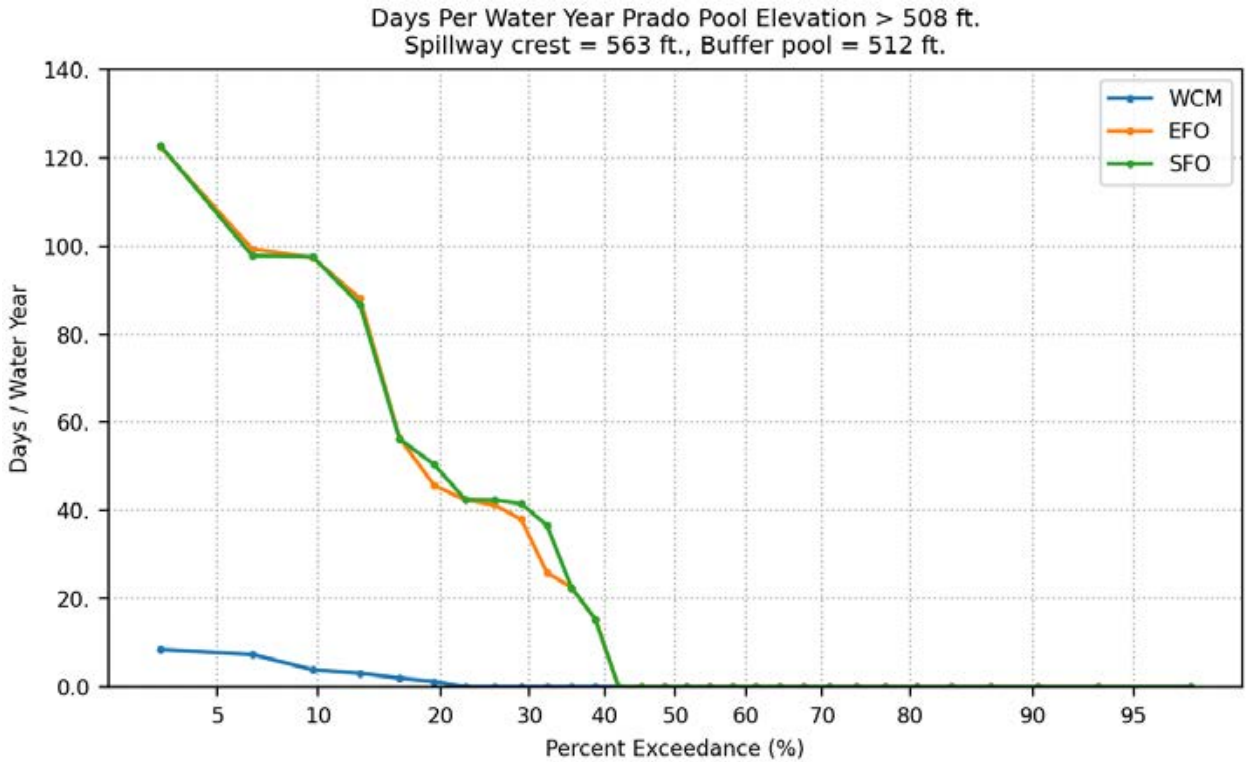

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 563 ft., Buffer pool = 510 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
0.0
0.5
1.0
1.5
2.0
2.5
5
10
20
30
40
50
60
70
80
90
95

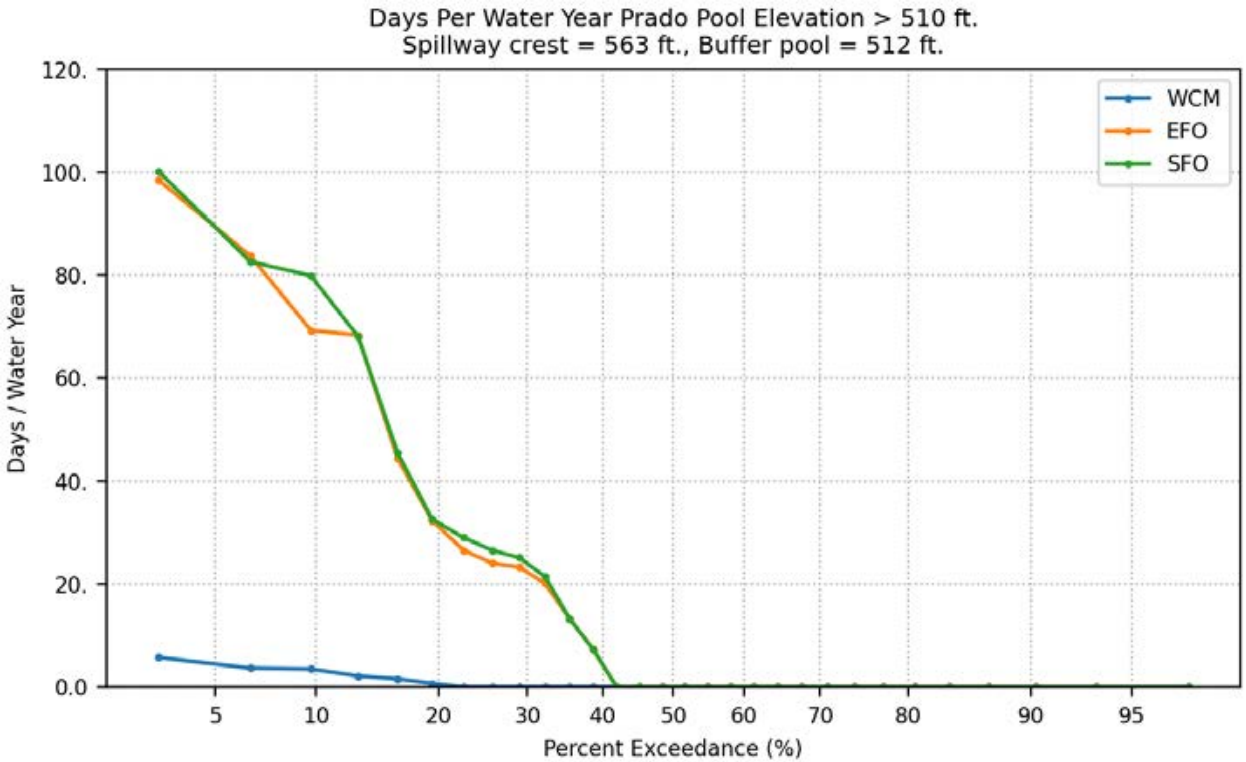

Groundwater Recharge Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 512 ft.
Volume / Water Year (1,000 acre-feet per water year)
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

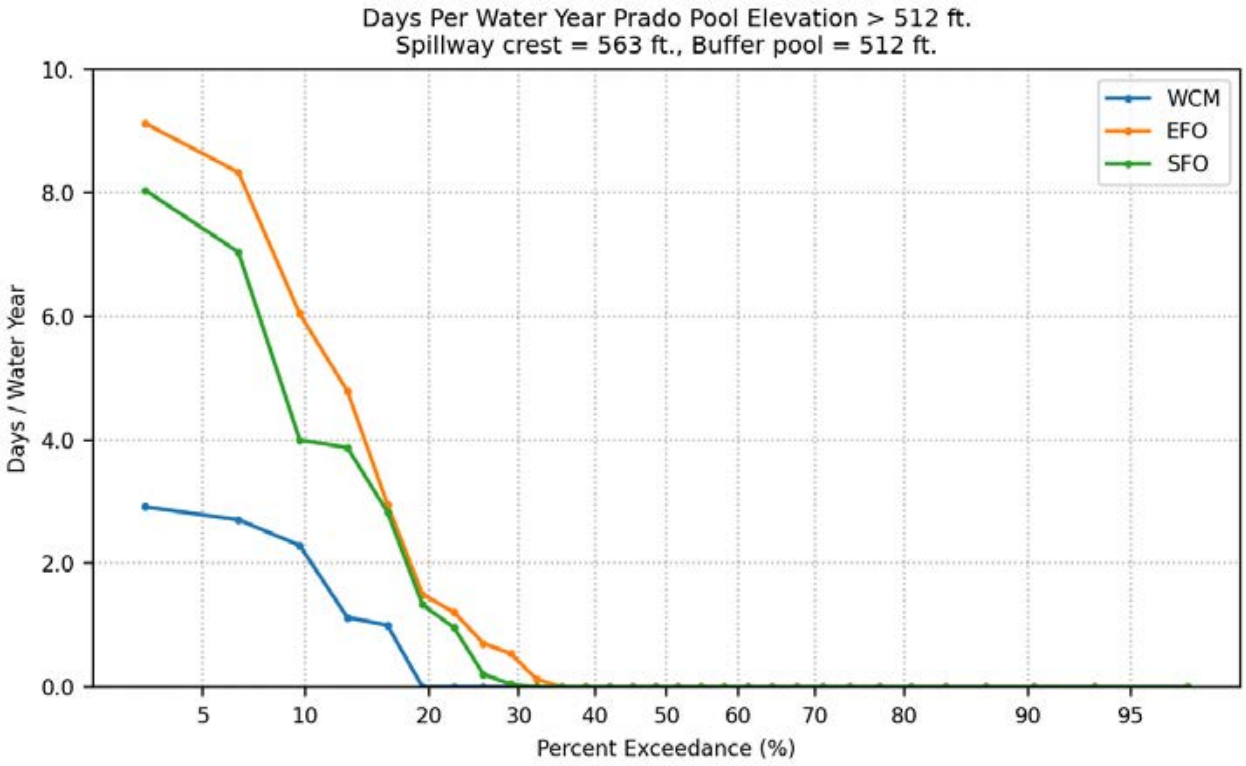

Santa Ana River Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 512 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

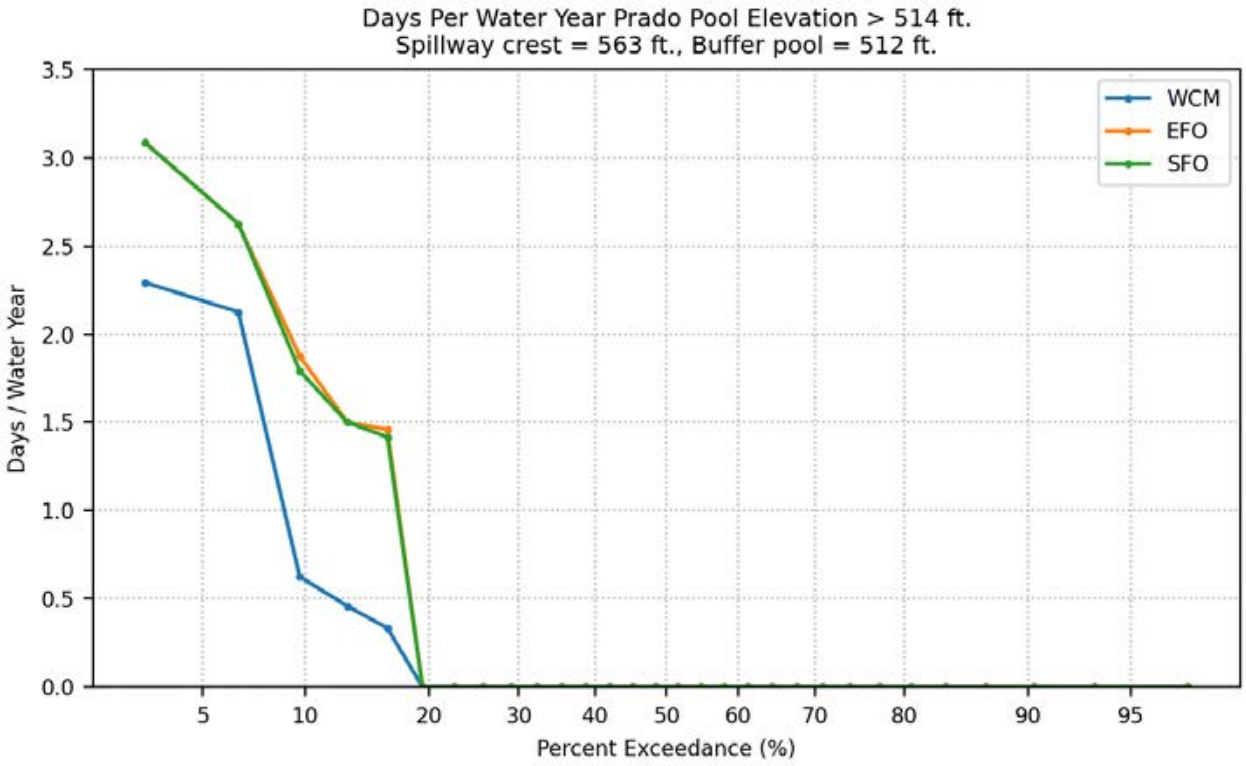

Days Per Water Year Elevation Change > 2-meters
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 563 ft., Buffer pool = 512 ft.
WCM
EFO
SFO
Days / Water Year
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)

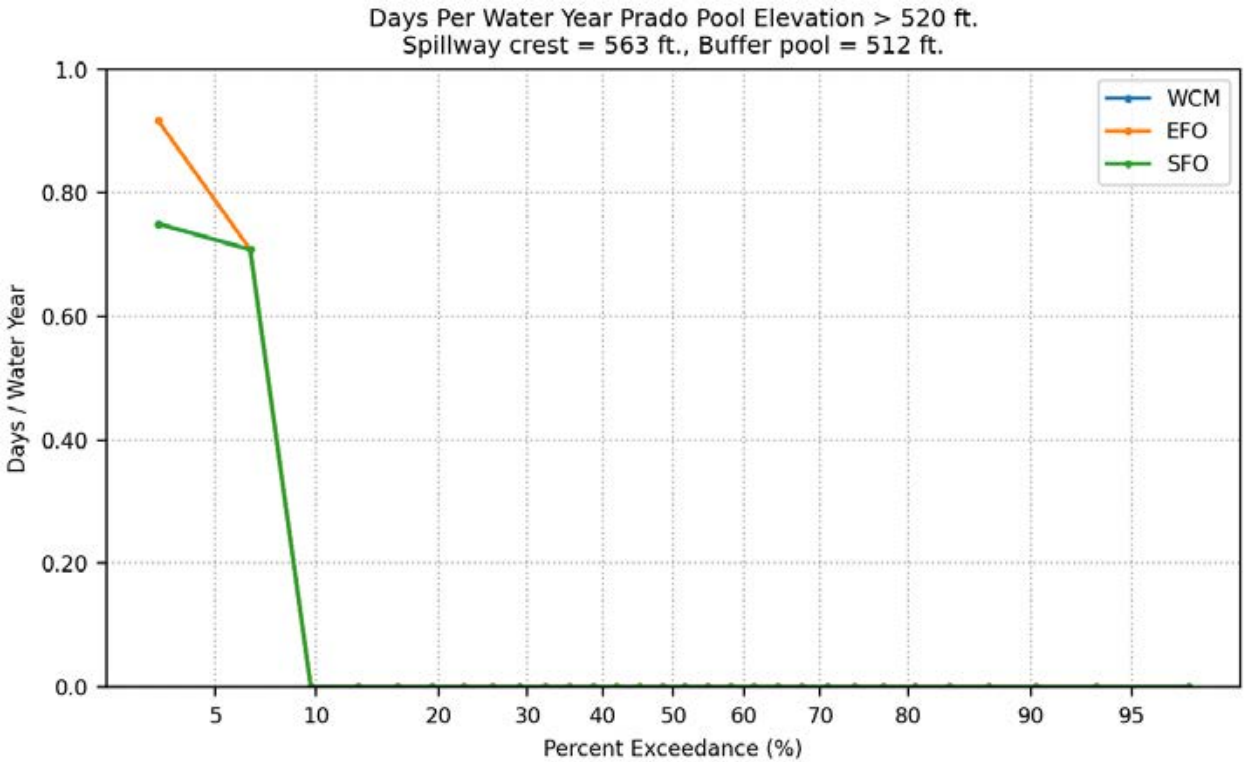

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
180.
160.
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

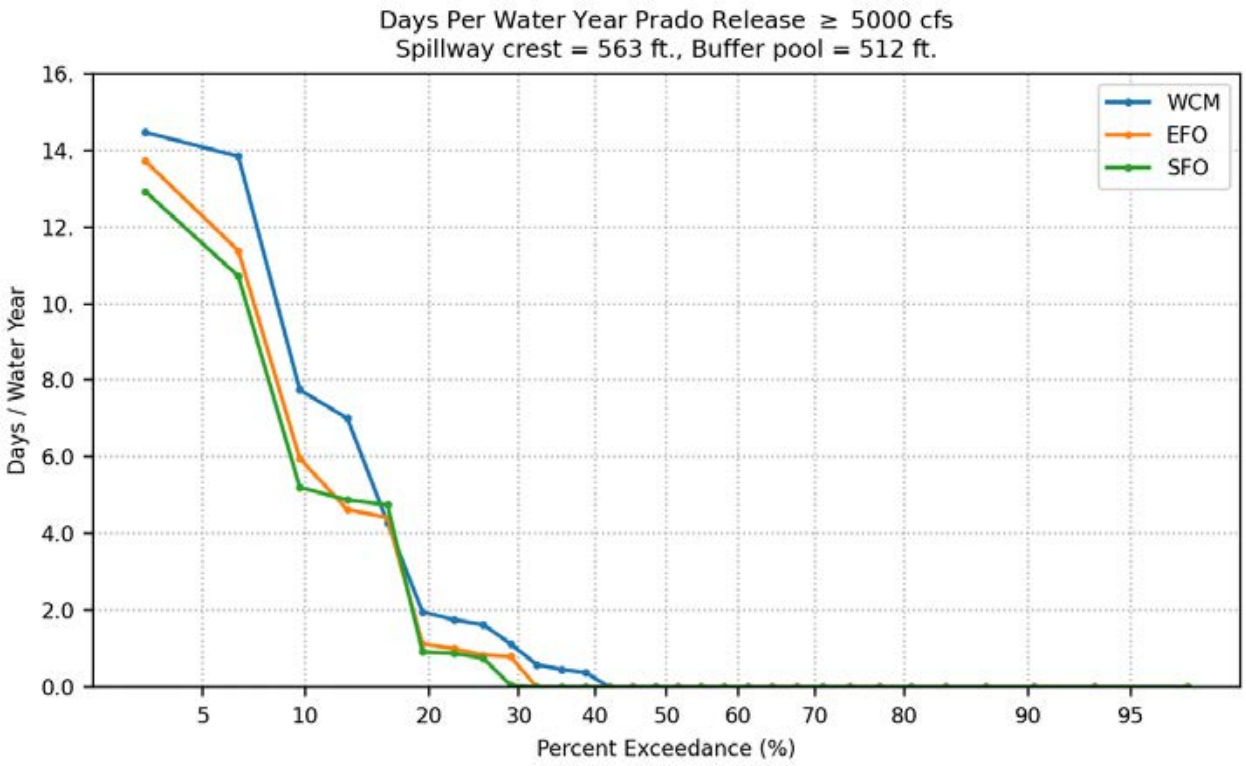

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

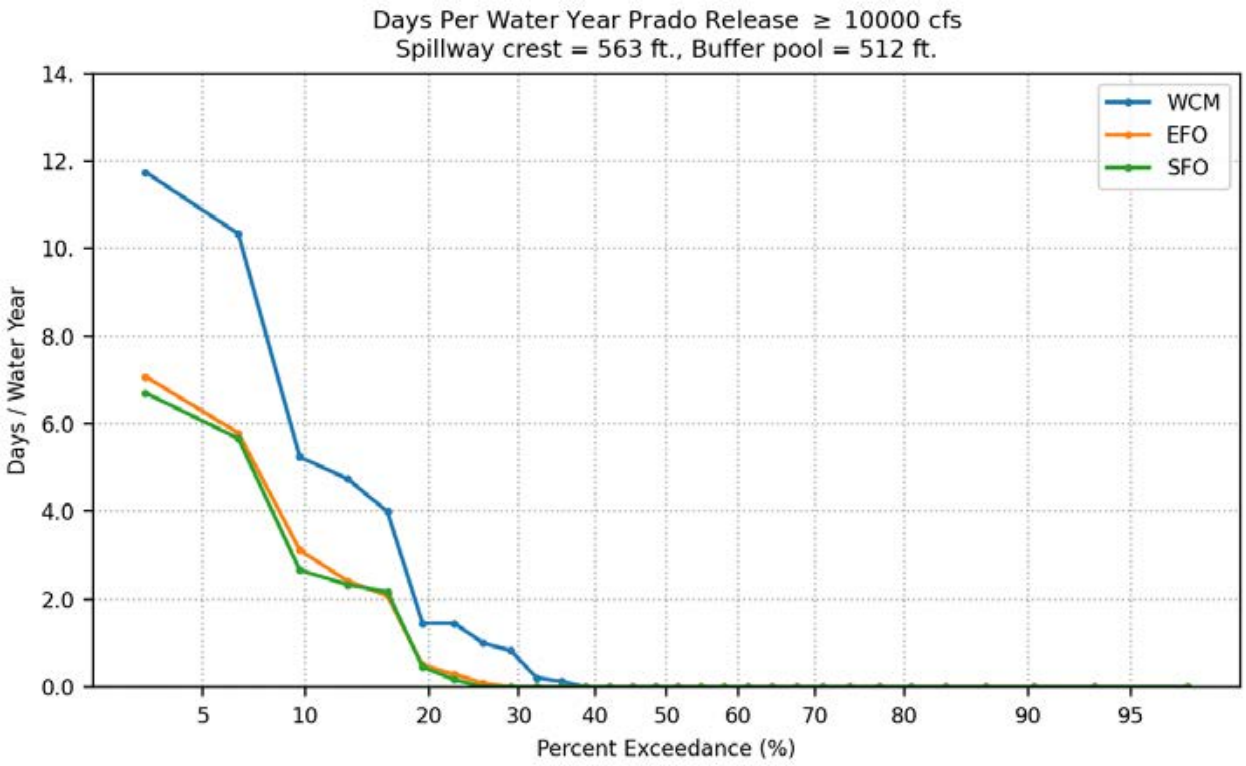

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

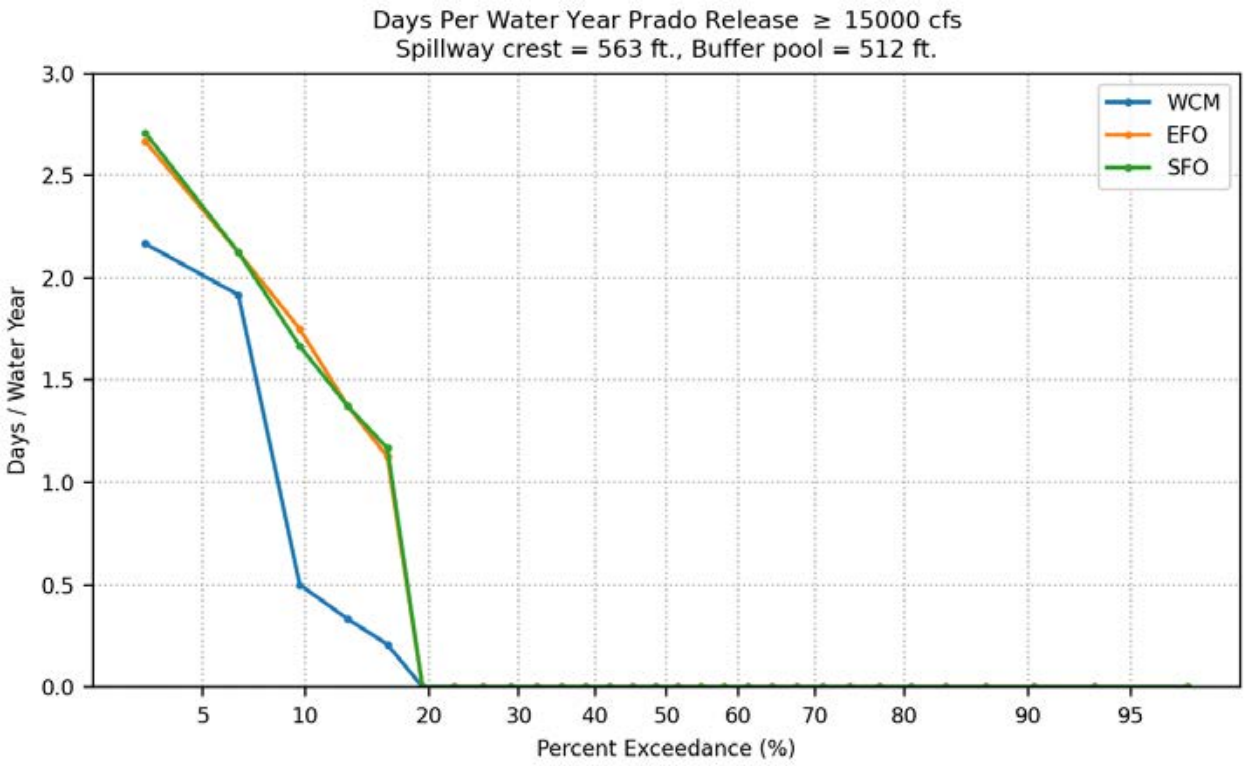

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

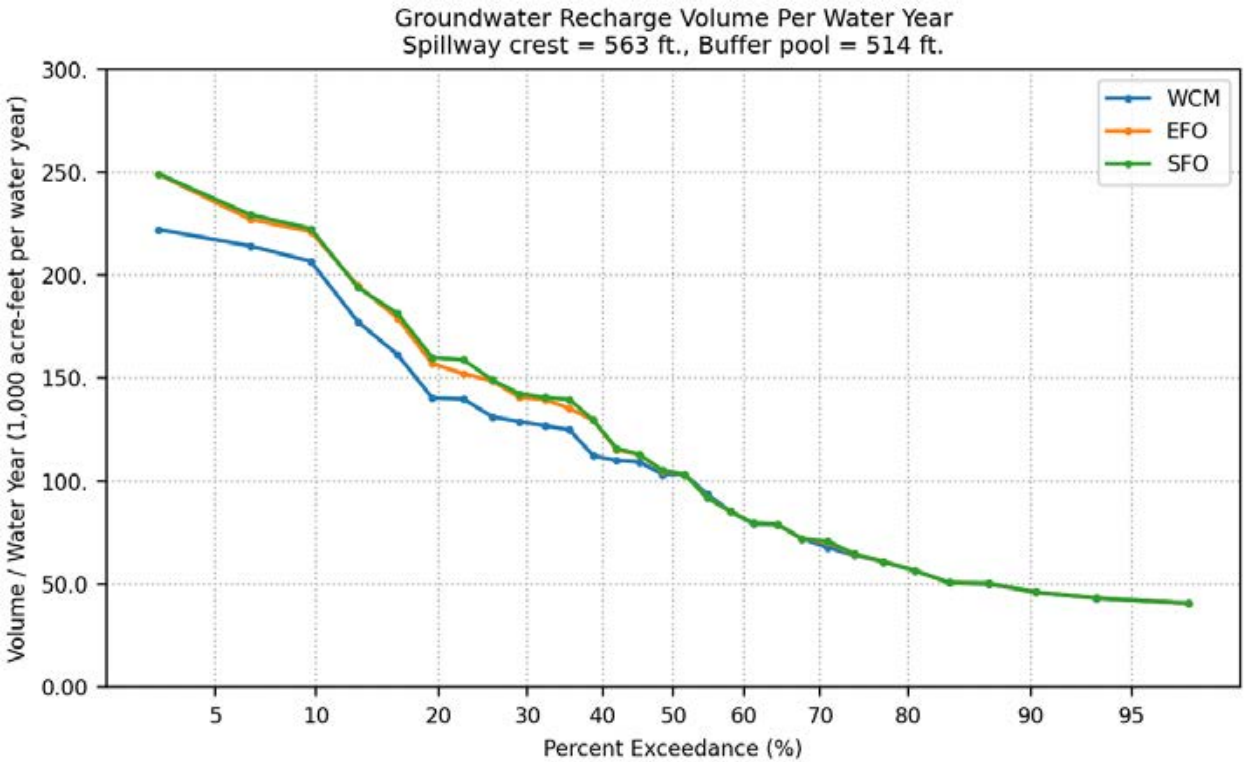

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
5
10
20
30
40
50
60
70
80
90
95

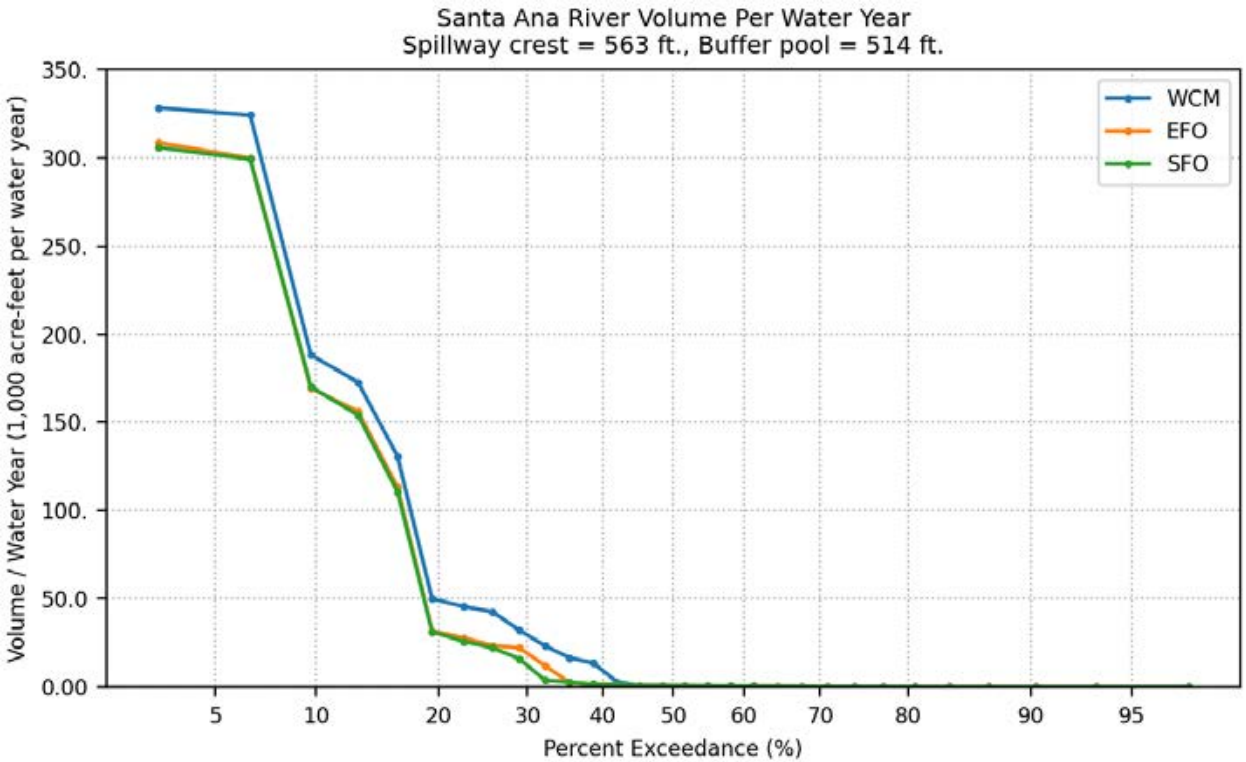

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
1.0
0.80
0.60
0.40
0.20
0.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

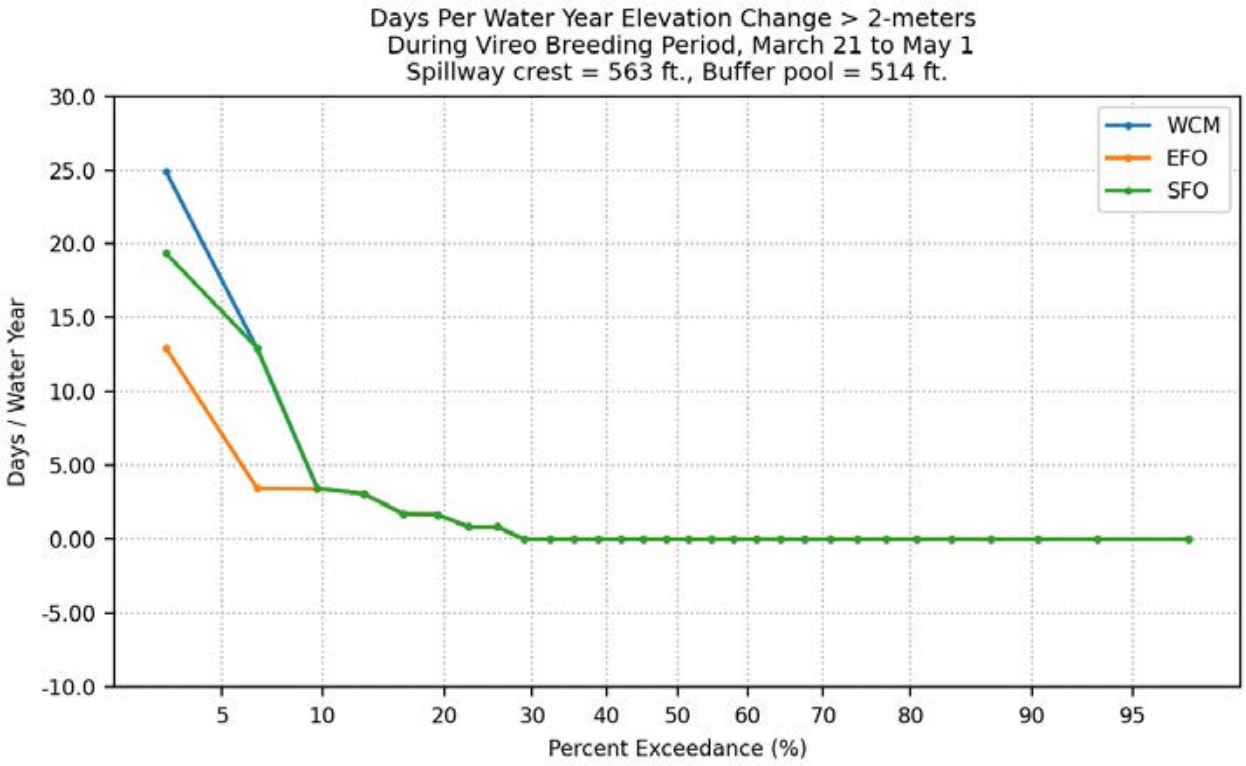

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

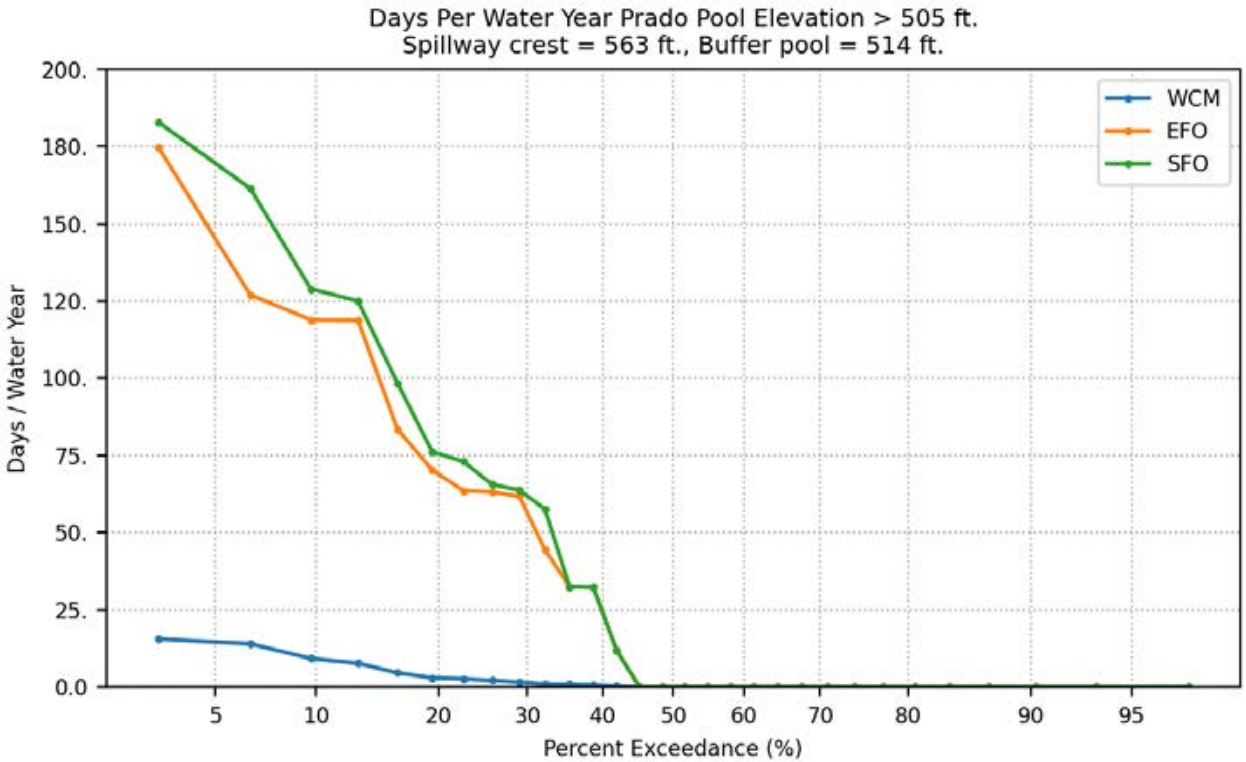

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

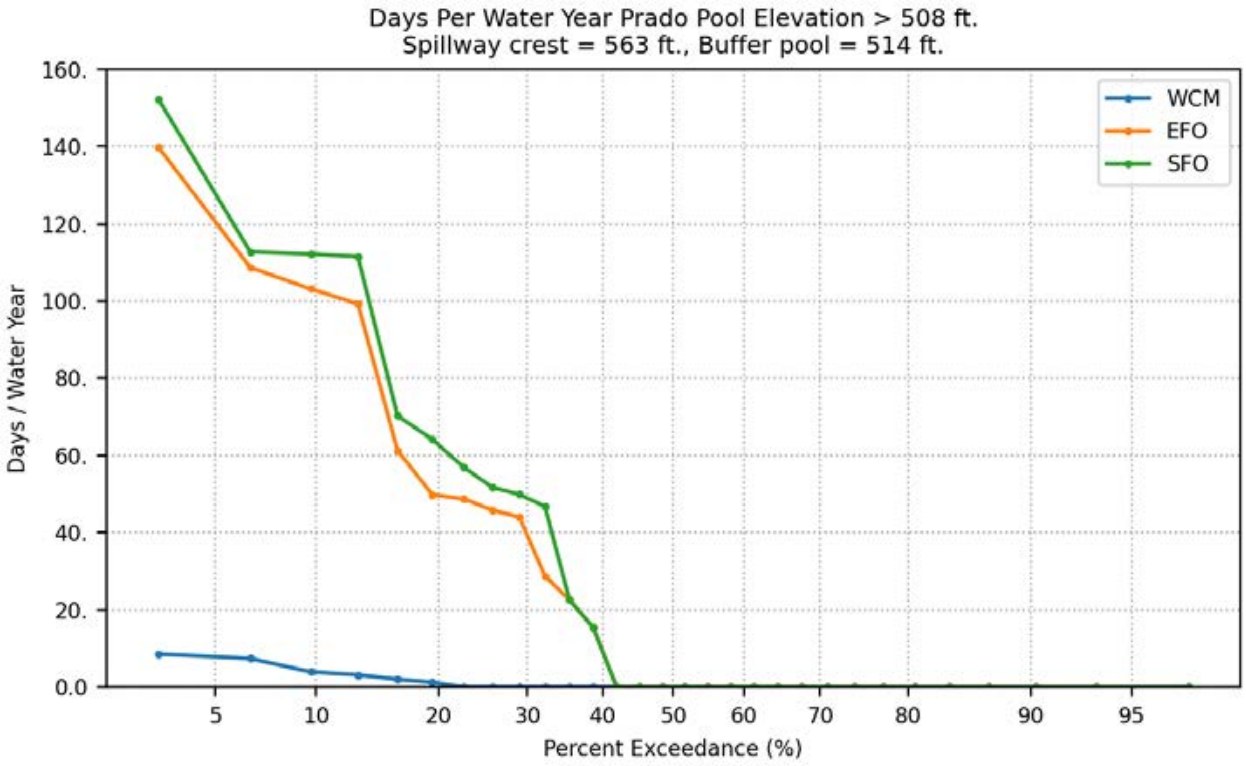

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 563 ft., Buffer pool = 512 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
20
30
40
50
60
70
80
90
95

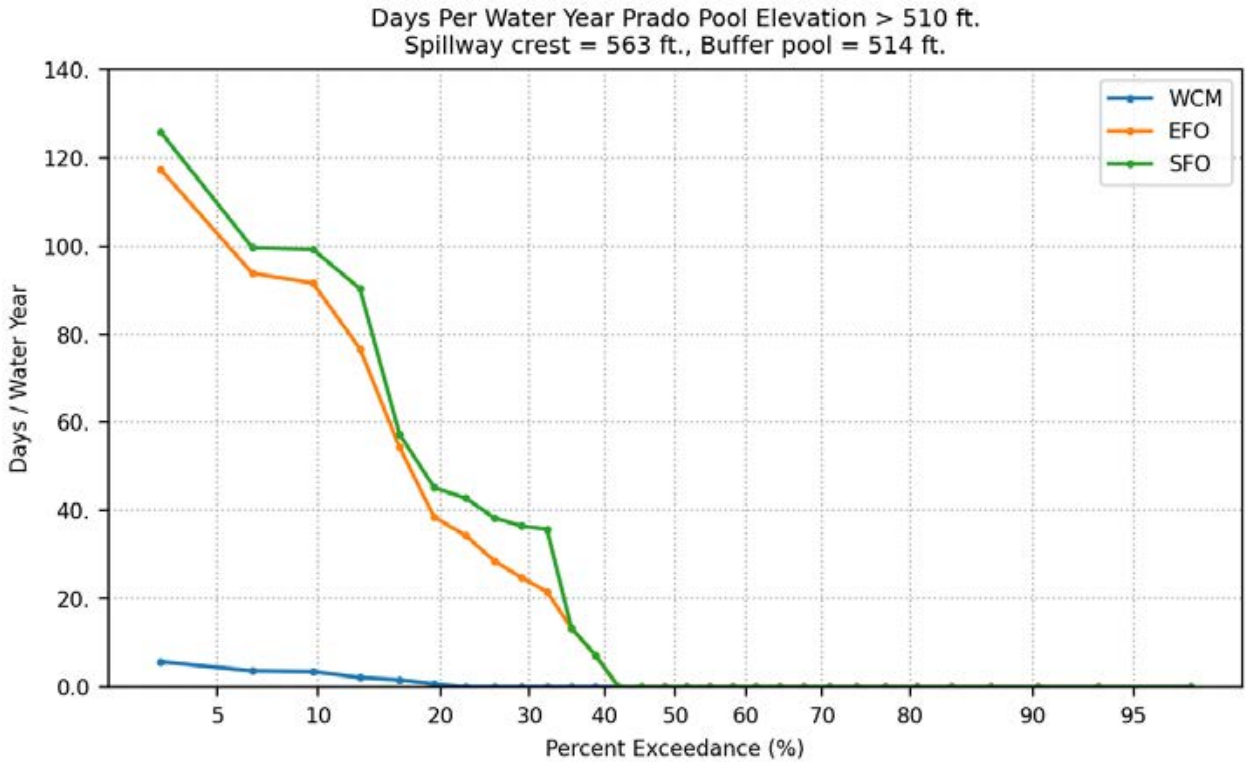

Groundwater Recharge Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 514 ft.
Volume / Water Year (1,000 acre-feet per water year)
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

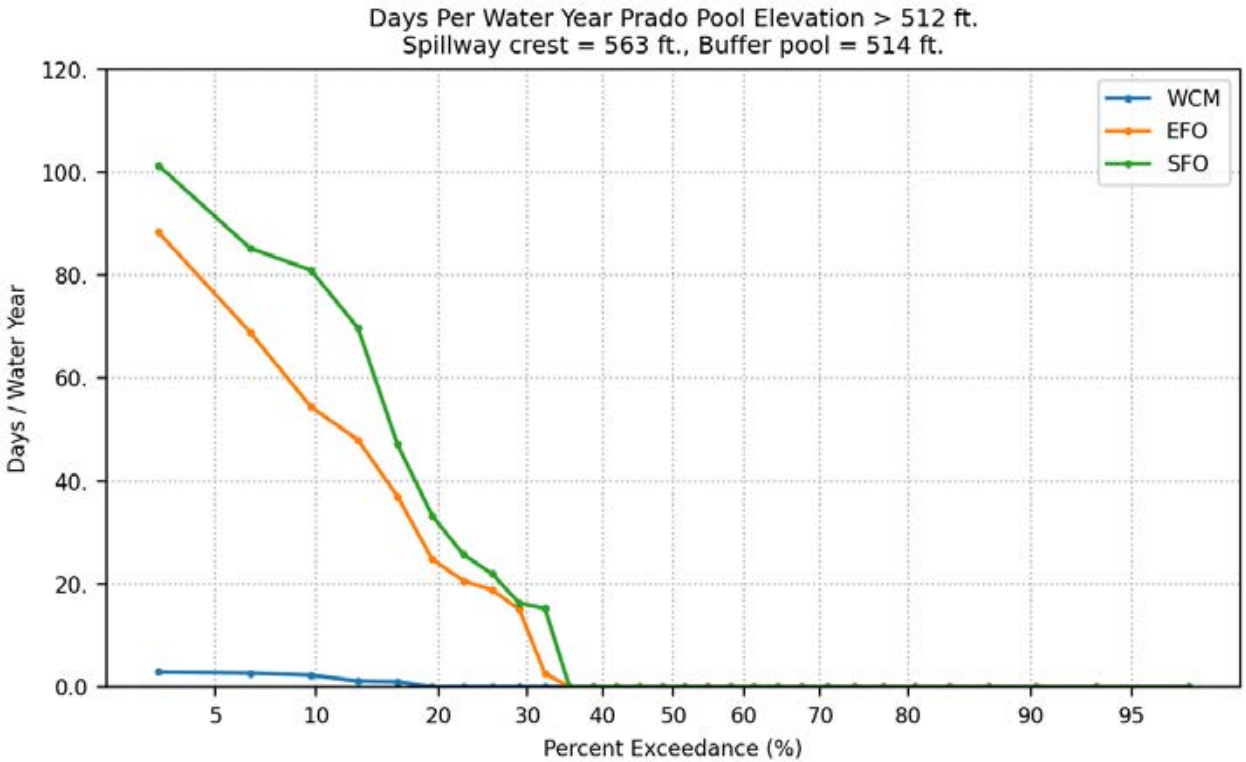

Santa Ana River Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 514 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

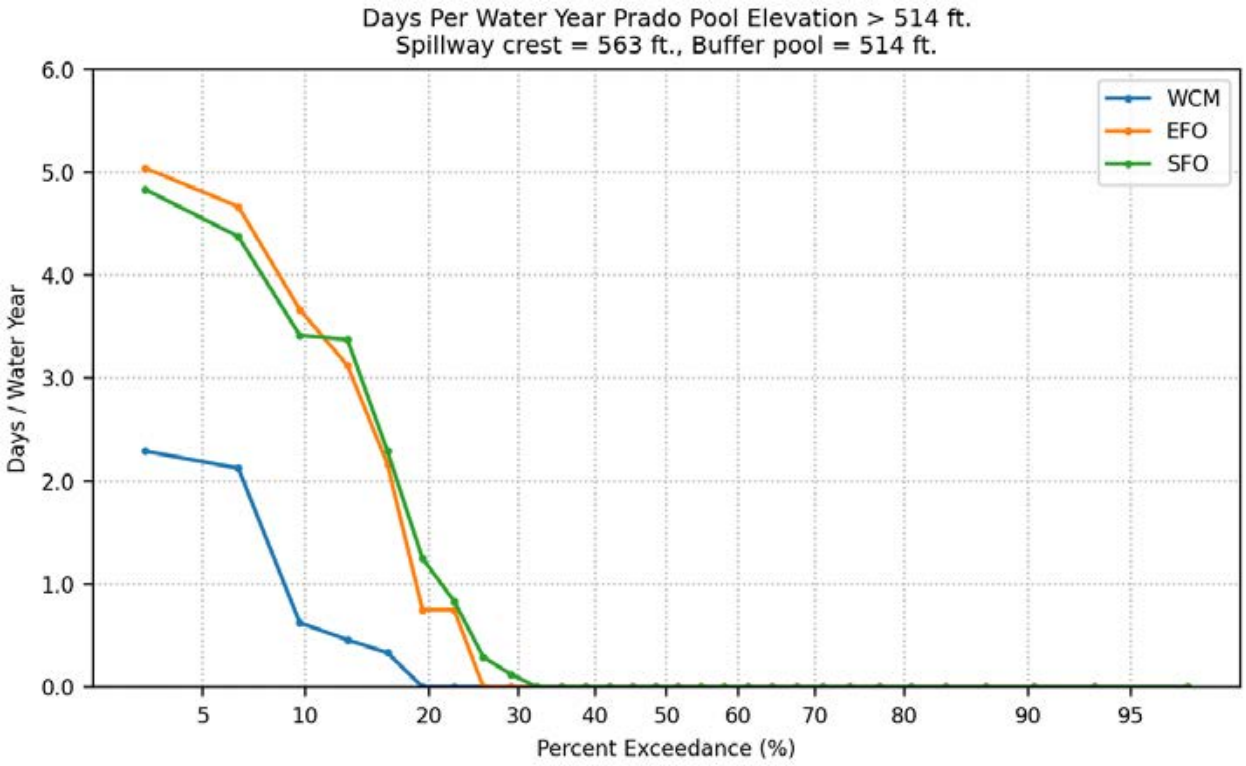

Days Per Water Year Elevation Change > 2-meters
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 563 ft., Buffer pool = 514 ft.
WCM
EFO
SFO
Days / Water Year
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)

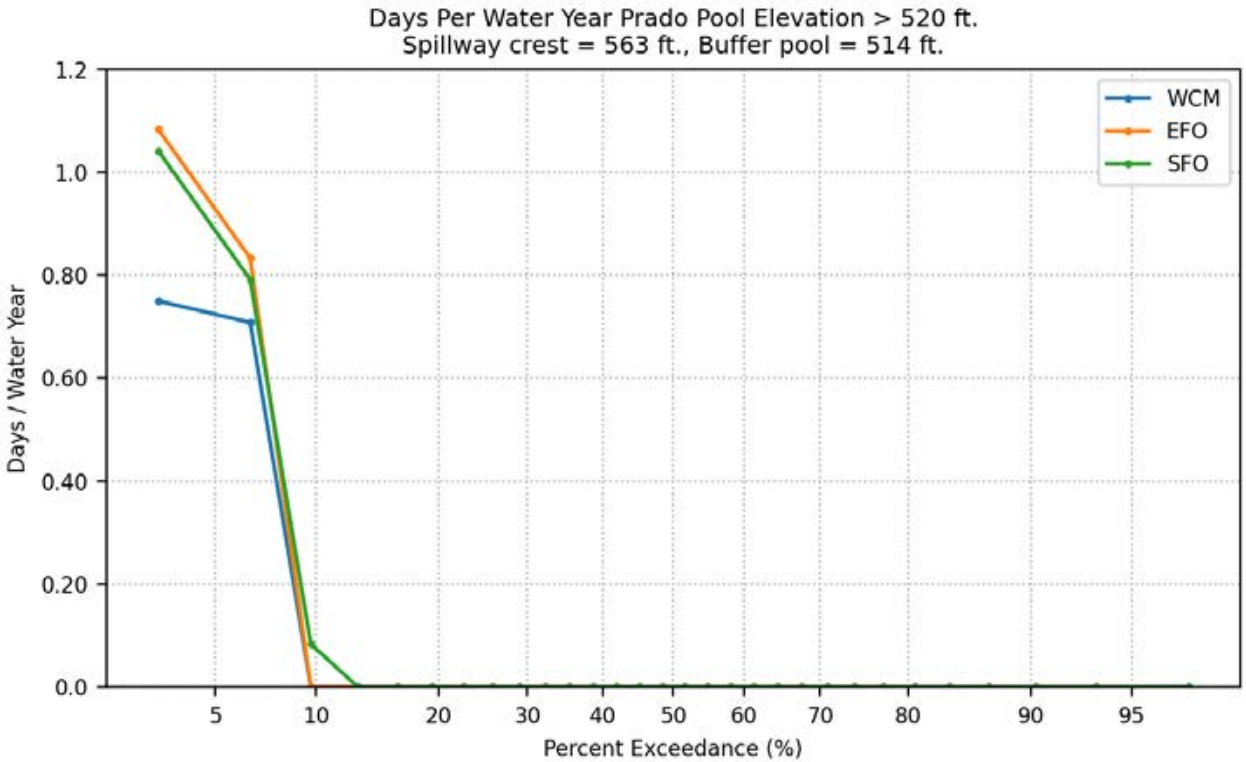

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
200.
180.
150.
120.
100.
75.
50.
25.
0.0
5
10
20
30
40
50
60
70
80
90
95

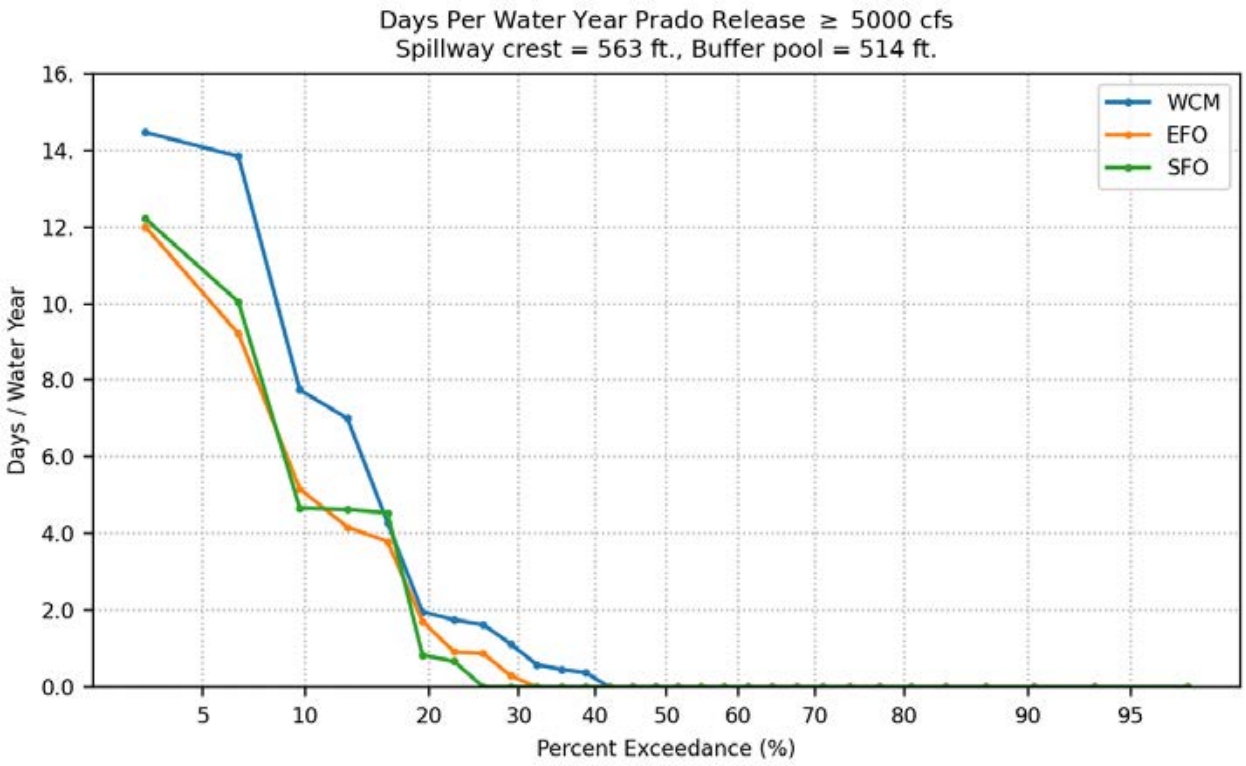

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
160.
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

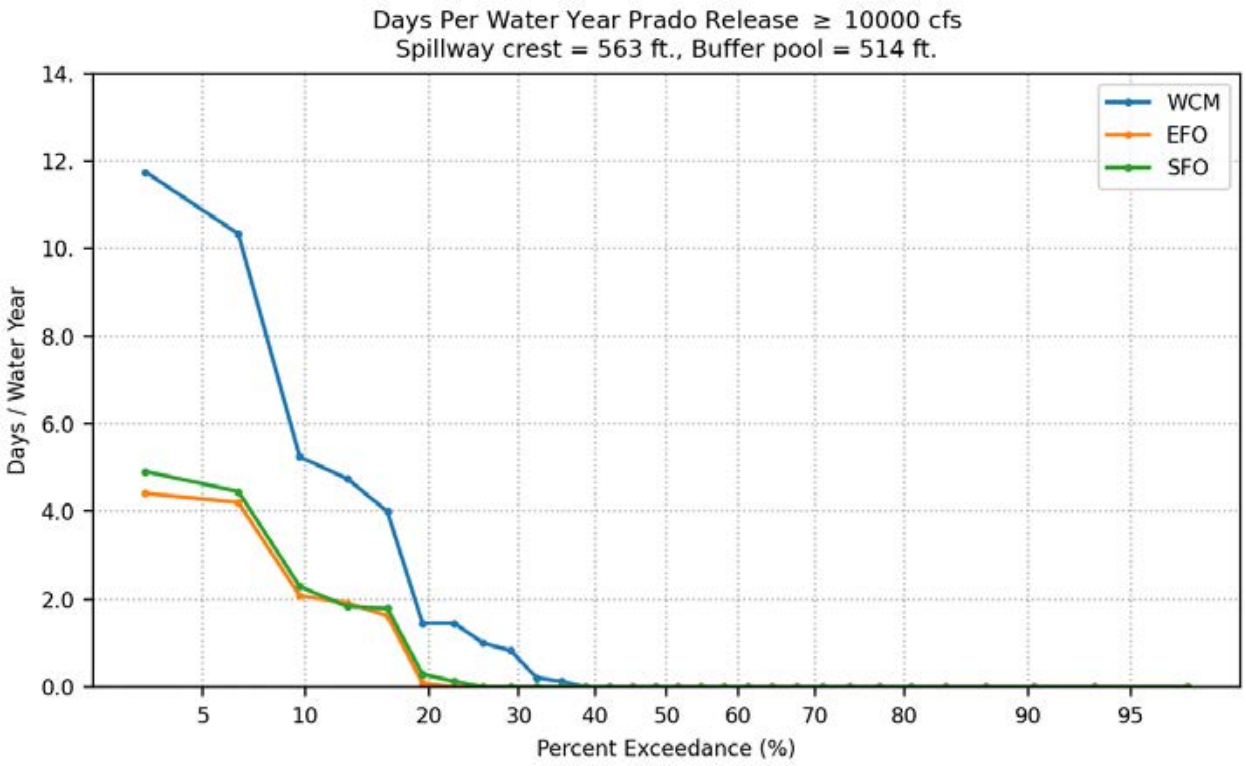

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

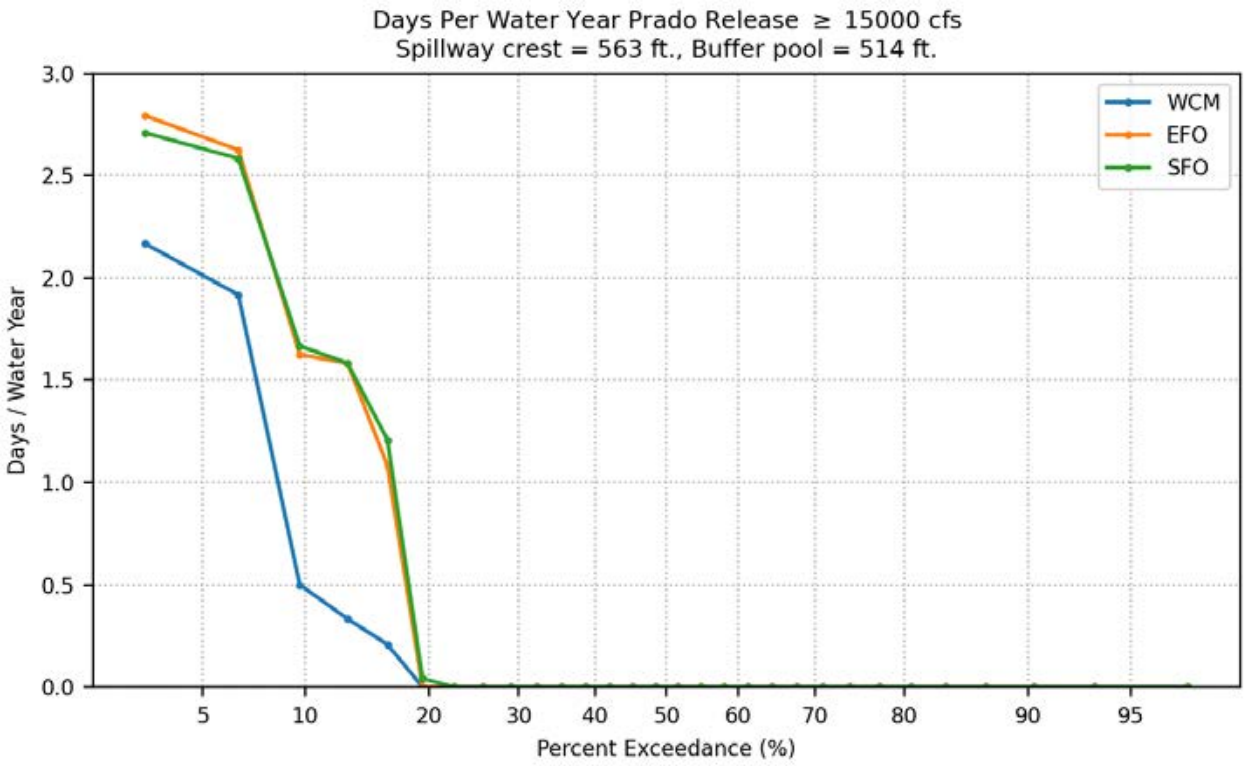

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95

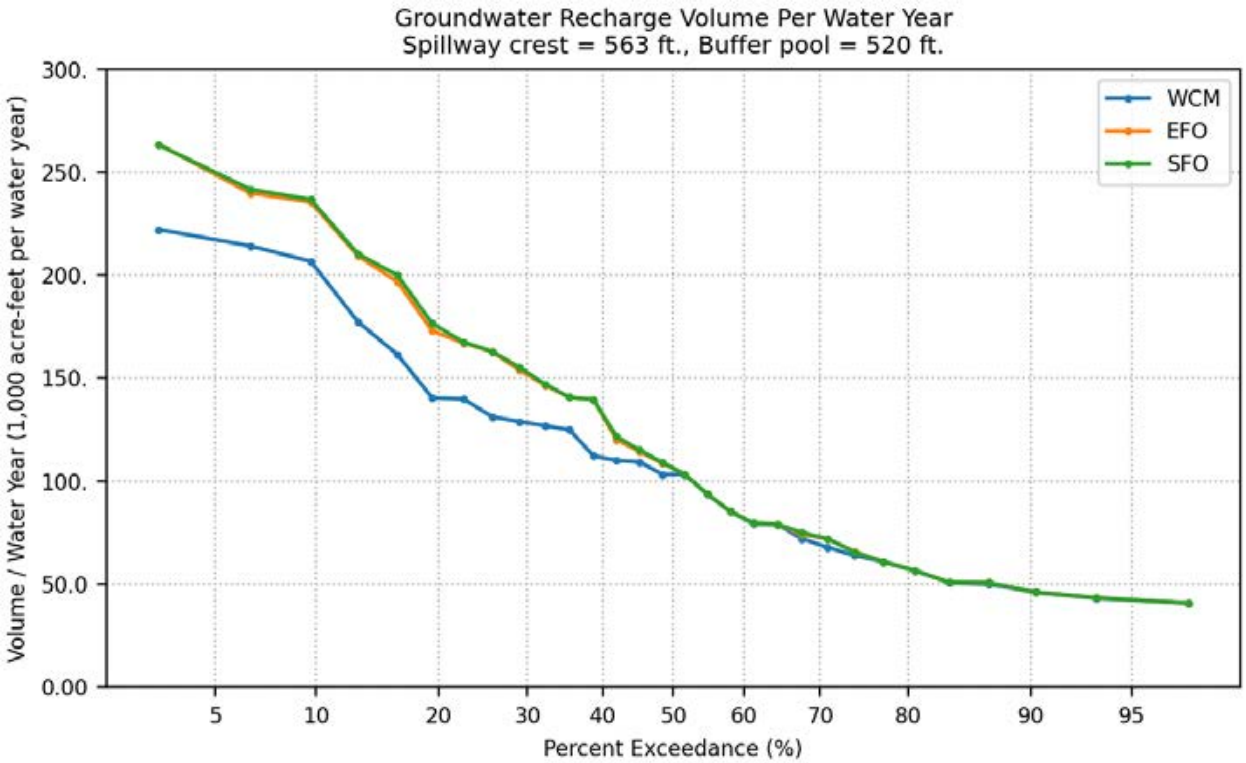

Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
0.0
1.0
2.0
3.0
4.0
5.0
6.0
5
10
20
30
40
50
60
70
80
90
95

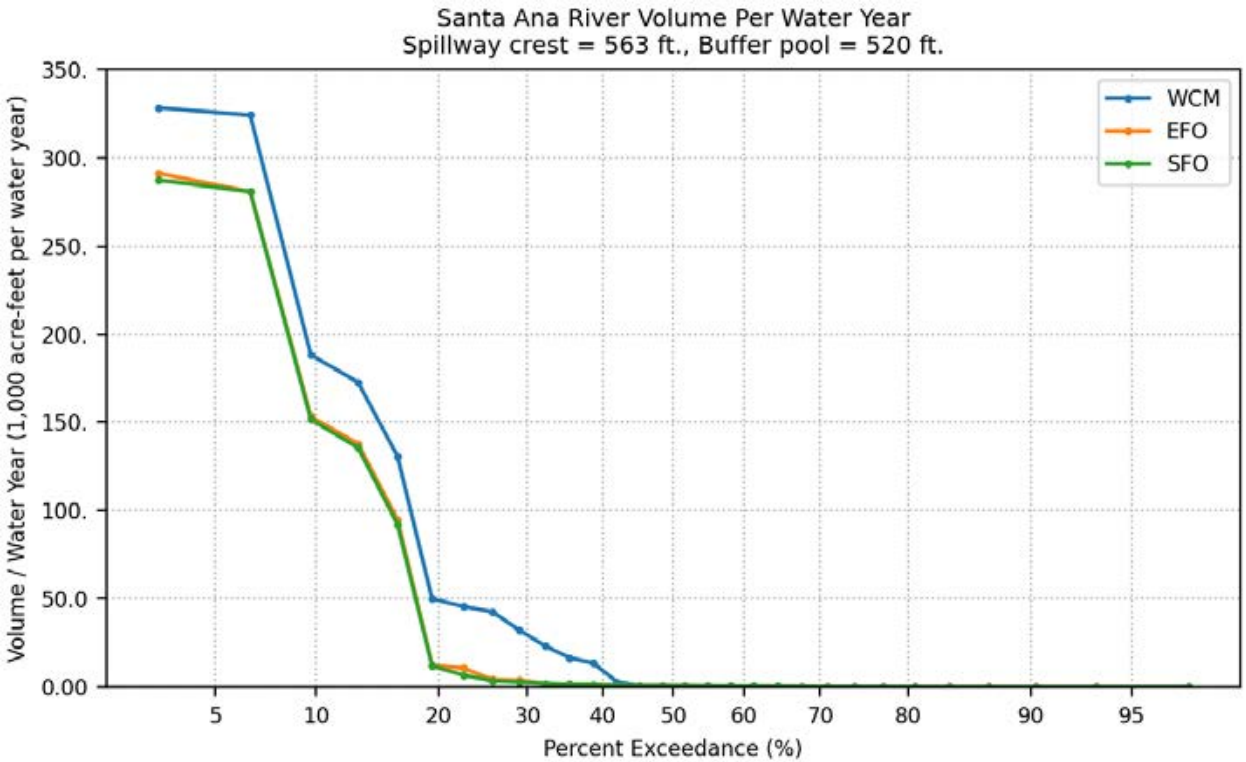

Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
1.2
1.0
0.80
0.60
0.40
0.20
0.0
5
10
20
30
40
50
60
70
80
90
95

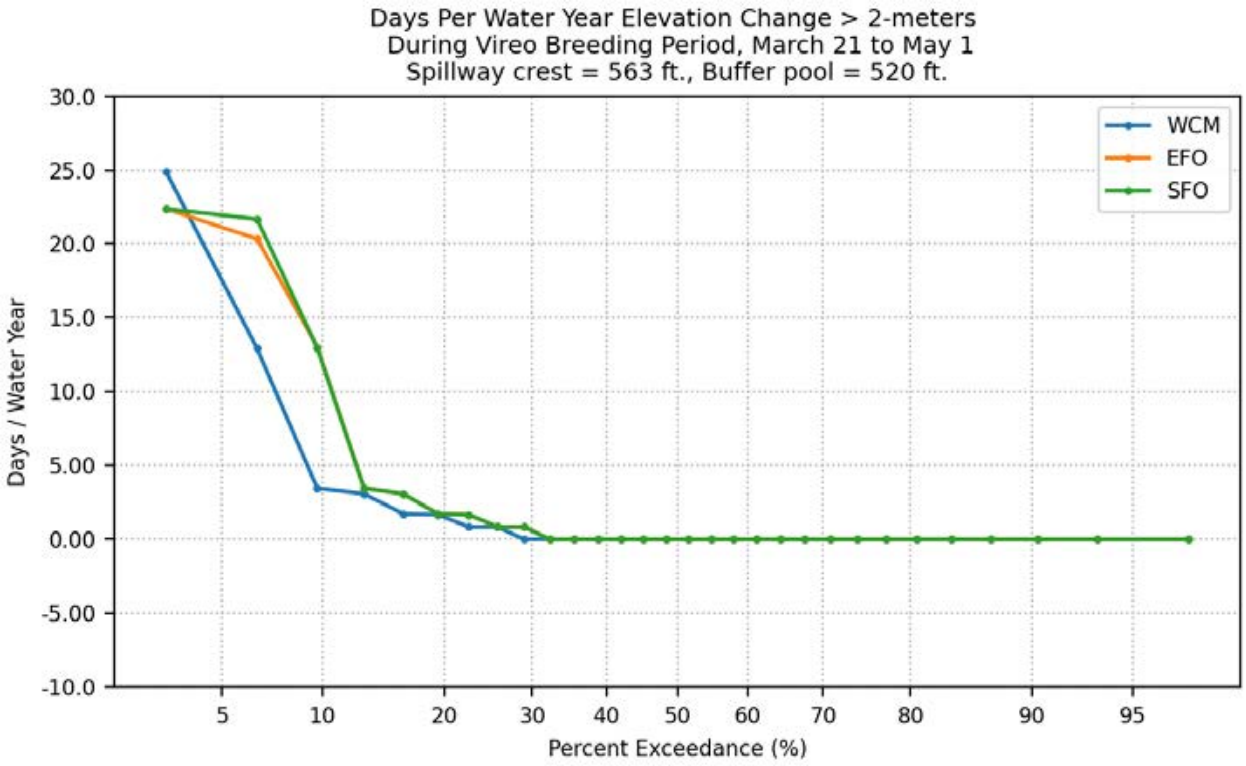

Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

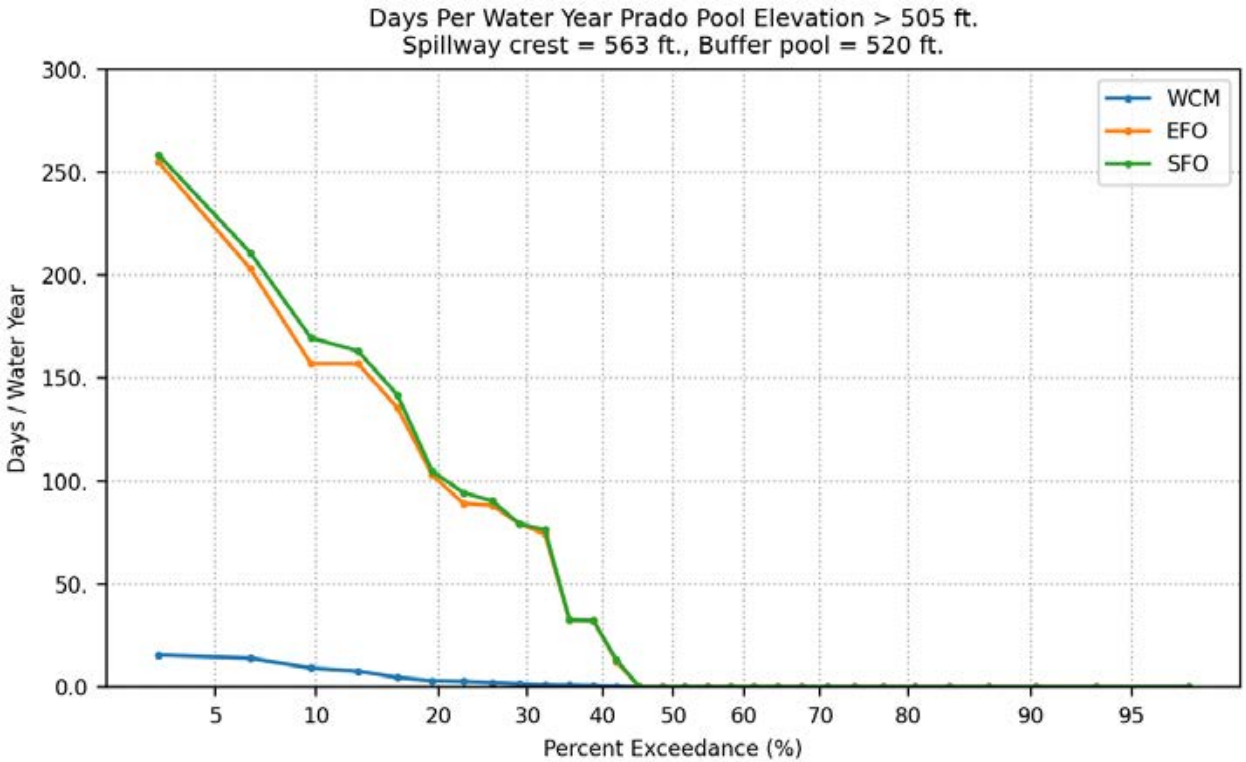

Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95

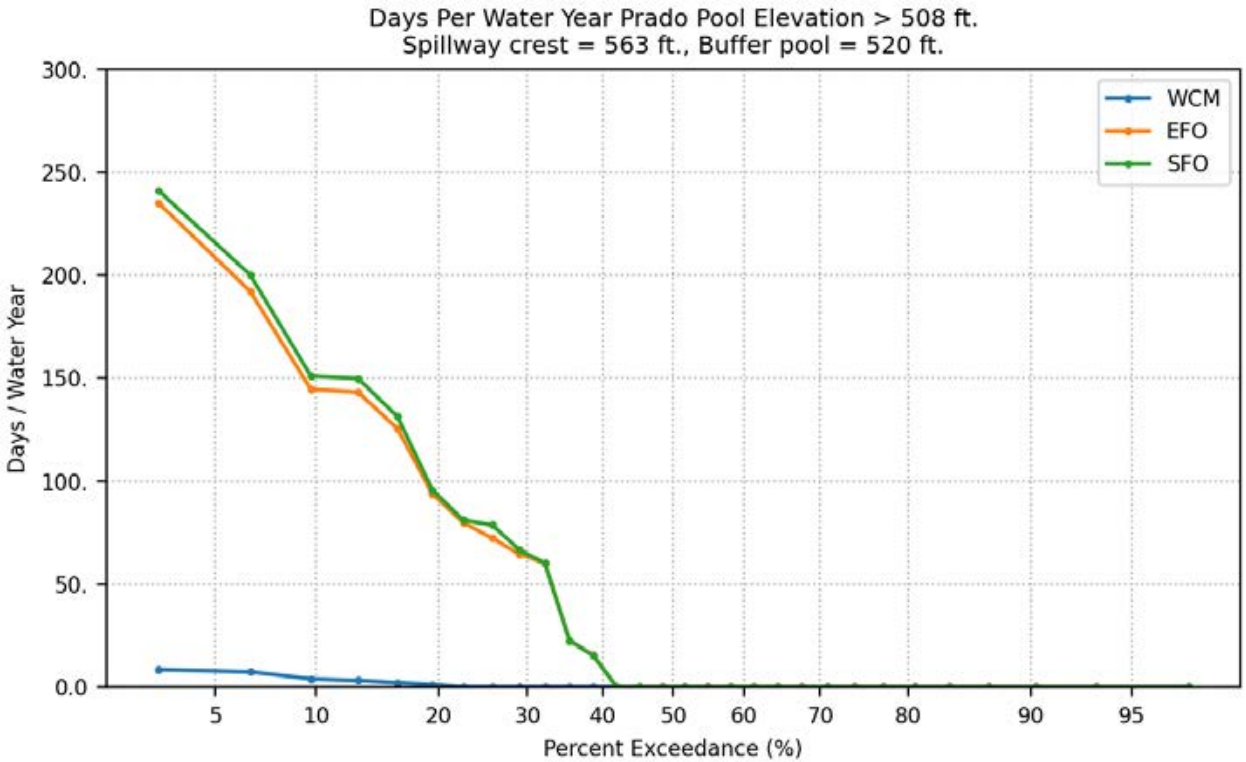

Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 563 ft., Buffer pool = 514 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
20
30
40
50
60
70
80
90
95

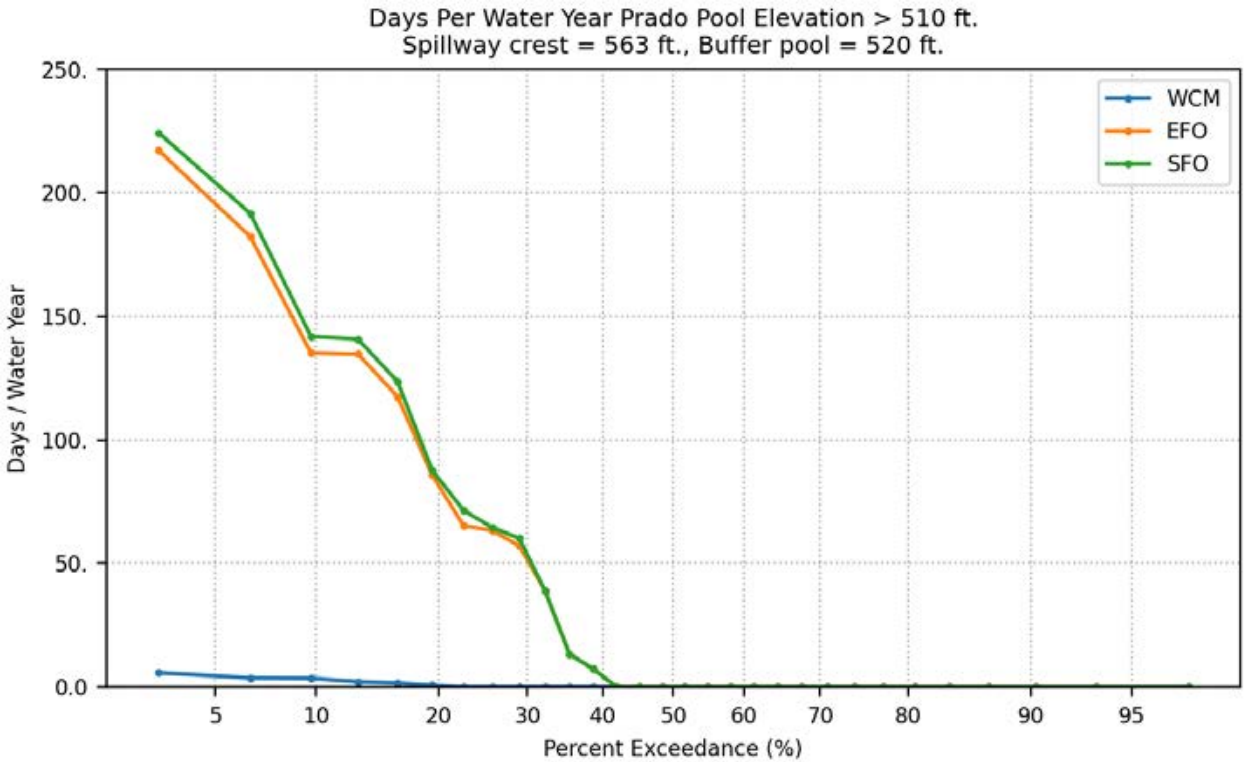

Groundwater Recharge Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 520 ft.
Volume / Water Year (1,000 acre-feet per water year)
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

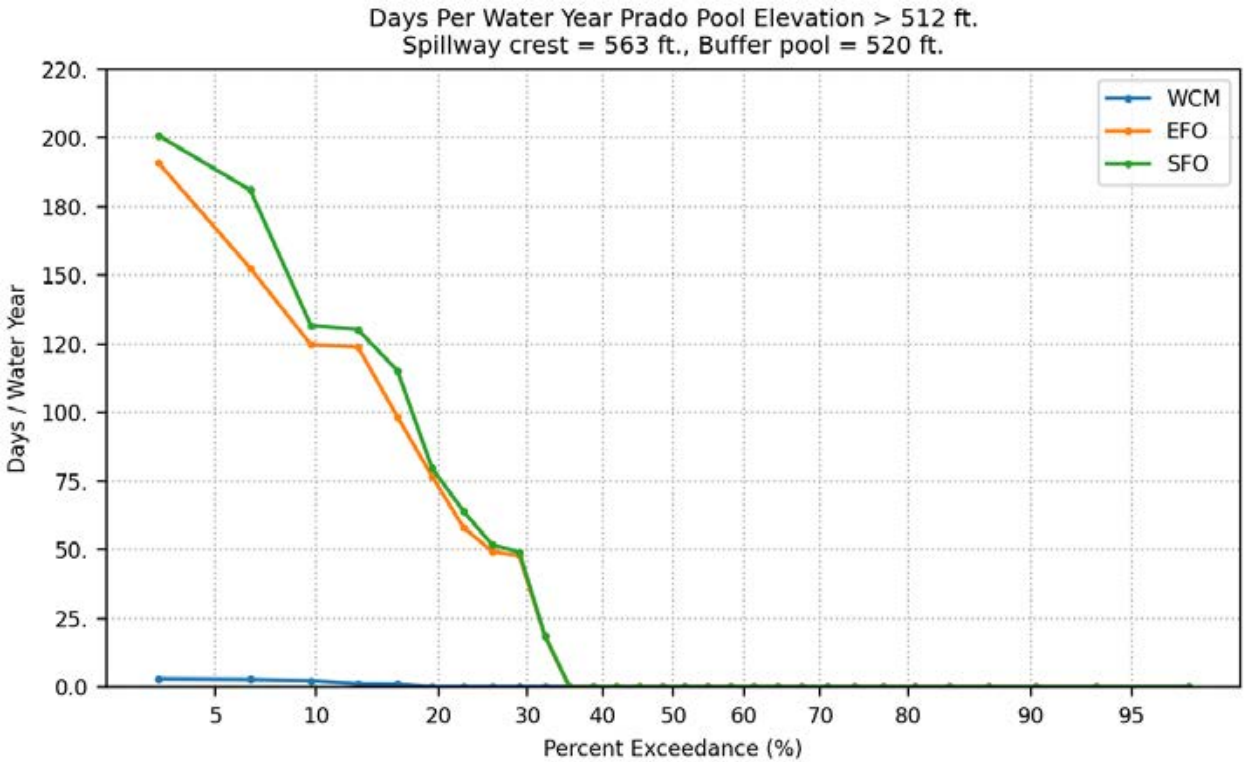

Santa Ana River Volume Per Water Year
Spillway crest = 563 ft., Buffer pool = 520 ft.
Volume / Water Year (1,000 acre-feet per water year)
350.
300.
250.
200.
150.
100.
50.0
0.00
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

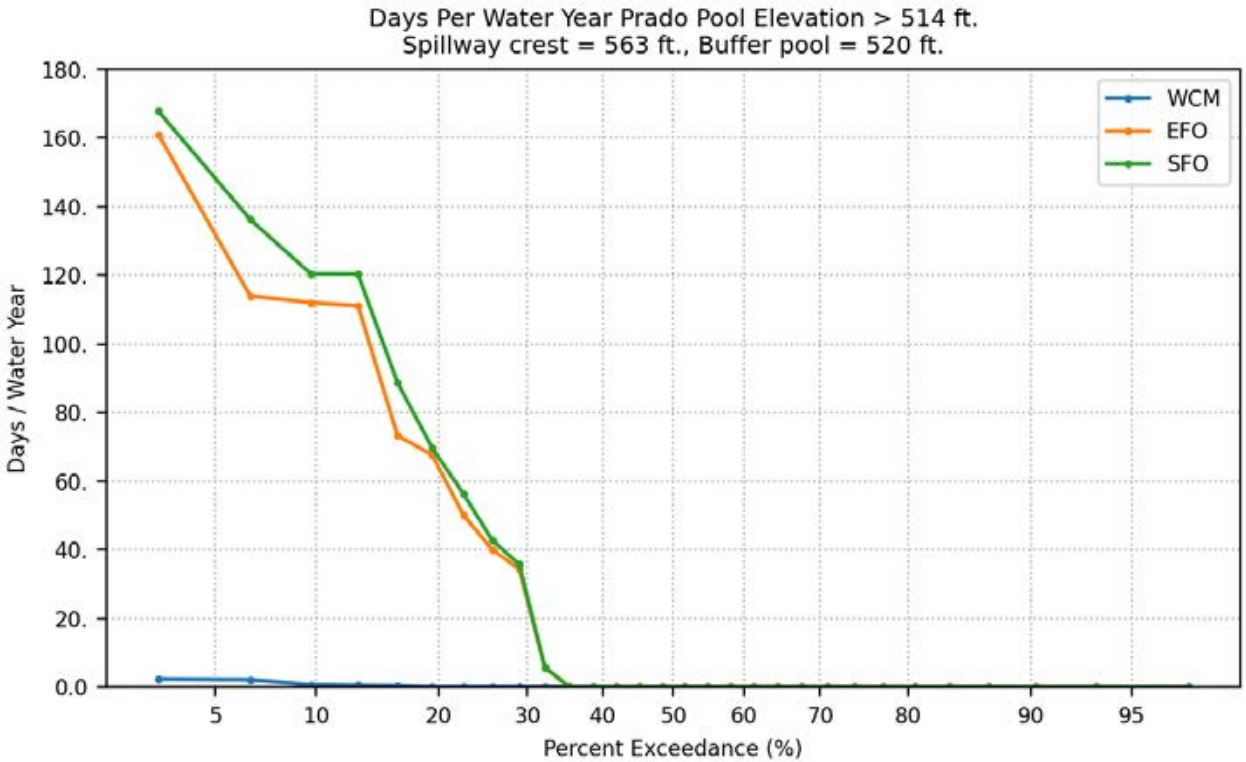

Days Per Water Year Elevation Change > 2-meters
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 563 ft., Buffer pool = 520 ft.
WCM
EFO
SFO
Days / Water Year
30.0
25.0
20.0
15.0
10.0
5.00
0.00
-5.00
-10.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)

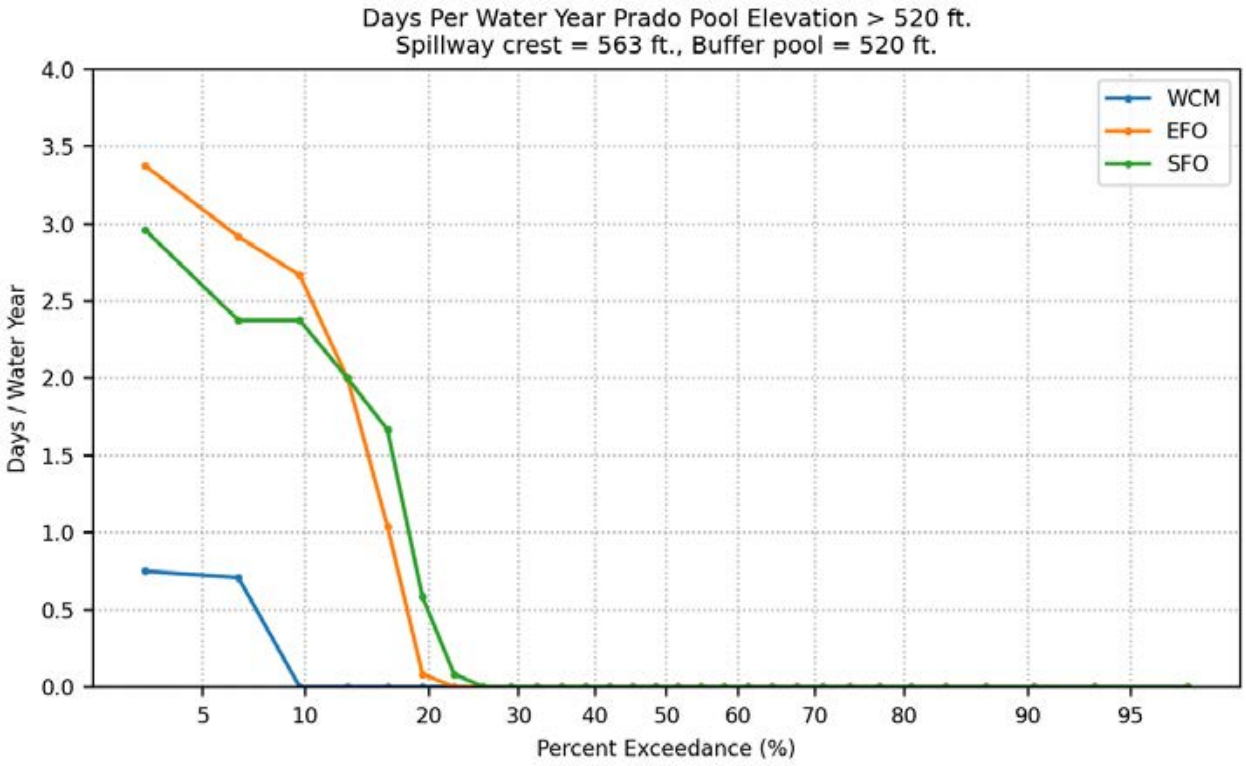

Days Per Water Year Prado Pool Elevation > 505 ft.
Spillway crest = 563 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
300.
250.
200.
150.
100.
50.
0.0
5
10
20
30
40
50
60
70
80
90
95

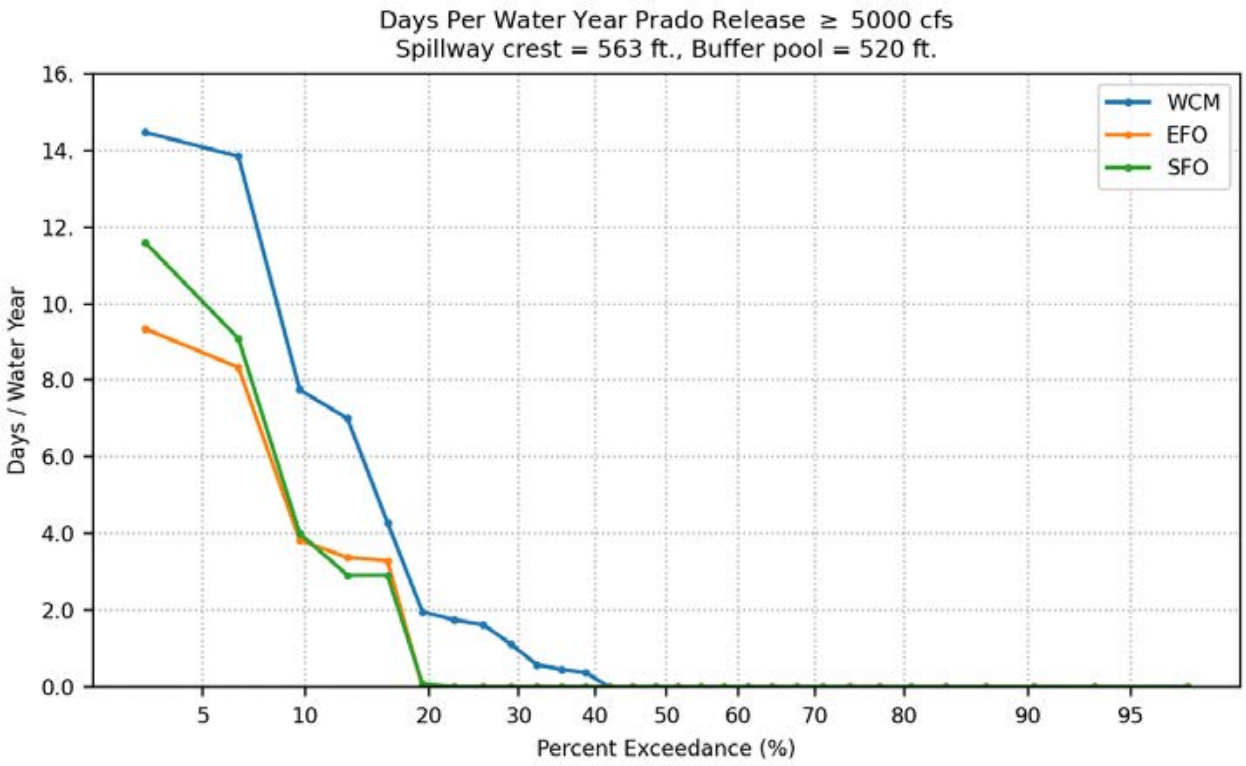

Days Per Water Year Prado Pool Elevation > 508 ft.
Spillway crest = 563 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
300.
250.
200.
150.
100.
50.
0.0
5
10
20
30
40
50
60
70
80
90
95

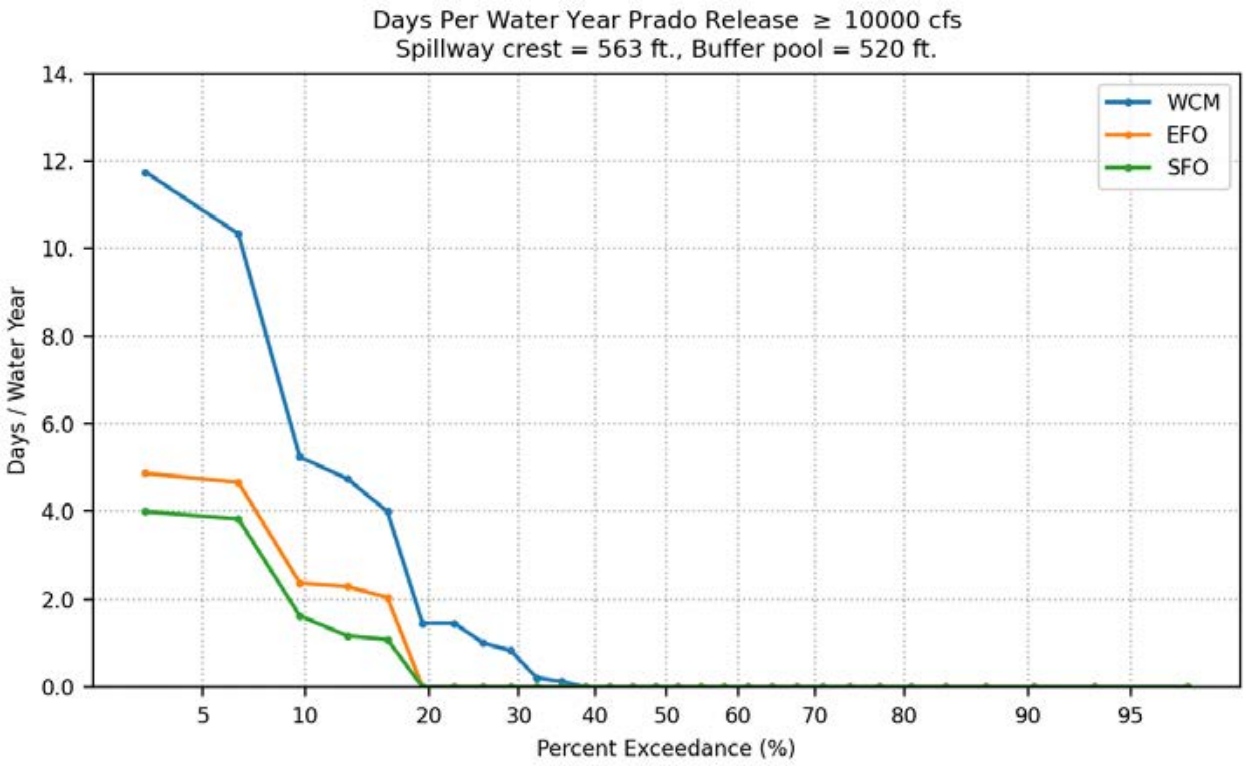

Days Per Water Year Prado Pool Elevation > 510 ft.
Spillway crest = 563 ft., Buffer pool = 520 ft.
Days / Water Year
250.
200.
150.
100.
50.
0.0
5
10
20
30
40
50
60
70
80
90
95
Percent Exceedance (%)
WCM
EFO
SFO

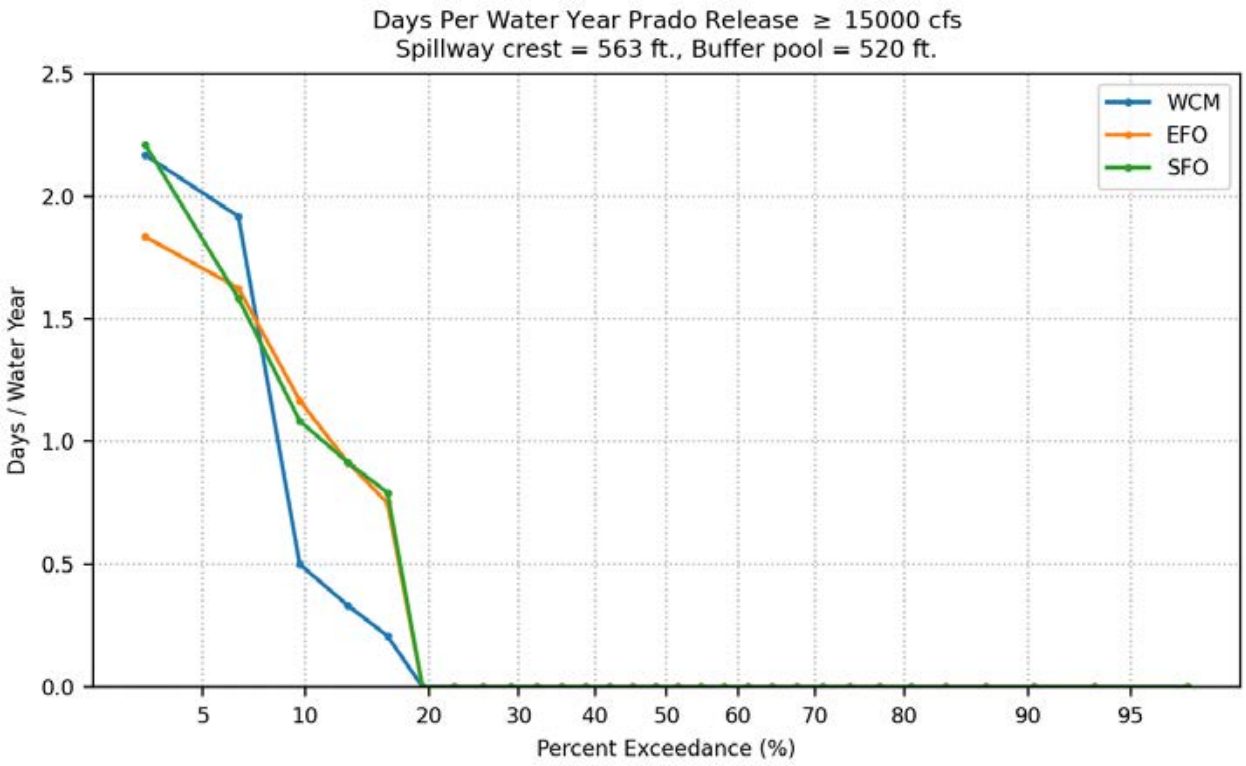

Days Per Water Year Prado Pool Elevation > 512 ft.
Spillway crest = 563 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
220.
200.
180.
150.
120.
100.
75.
50.
25.
0.0
5
10
20
30
40
50
60
70
80
90
95


Days Per Water Year Prado Pool Elevation > 514 ft.
Spillway crest = 563 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
180.
160.
140.
120.
100.
80.
60.
40.
20.
0.0
5
10
20
30
40
50
60
70
80
90
95


Days Per Water Year Prado Pool Elevation > 520 ft.
Spillway crest = 563 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
10
20
30
40
50
60
70
80
90
95


Days Per Water Year Prado Release ≥ 5000 cfs
Spillway crest = 563 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
16.
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95


Days Per Water Year Prado Release ≥ 10000 cfs
Spillway crest = 563 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
14.
12.
10.
8.0
6.0
4.0
2.0
0.0
5
10
20
30
40
50
60
70
80
90
95


Days Per Water Year Prado Release ≥ 15000 cfs
Spillway crest = 563 ft., Buffer pool = 520 ft.
Days / Water Year
Percent Exceedance (%)
WCM
EFO
SFO
0.0
0.5
1.0
1.5
2.0
2.5
5
10
20
30
40
50
60
70
80
90
95

APPENDIX B-5

HEMP Metrics – Bar Charts

- Average annual groundwater recharge (AAGR)
- Change in AAGR relative to WCM (baseline)

- Average annual Santa Anna River discharge (AASRD) to Pacific Ocean
- Change in AASRD relative to WCM (baseline)

- Average days/yr > 505’, 508’, 510’, 512’, 514’, 520’
- Change in days/yr > 505’, 508’, 510’, 512’, 514’, 520’ relative to WCM (baseline)

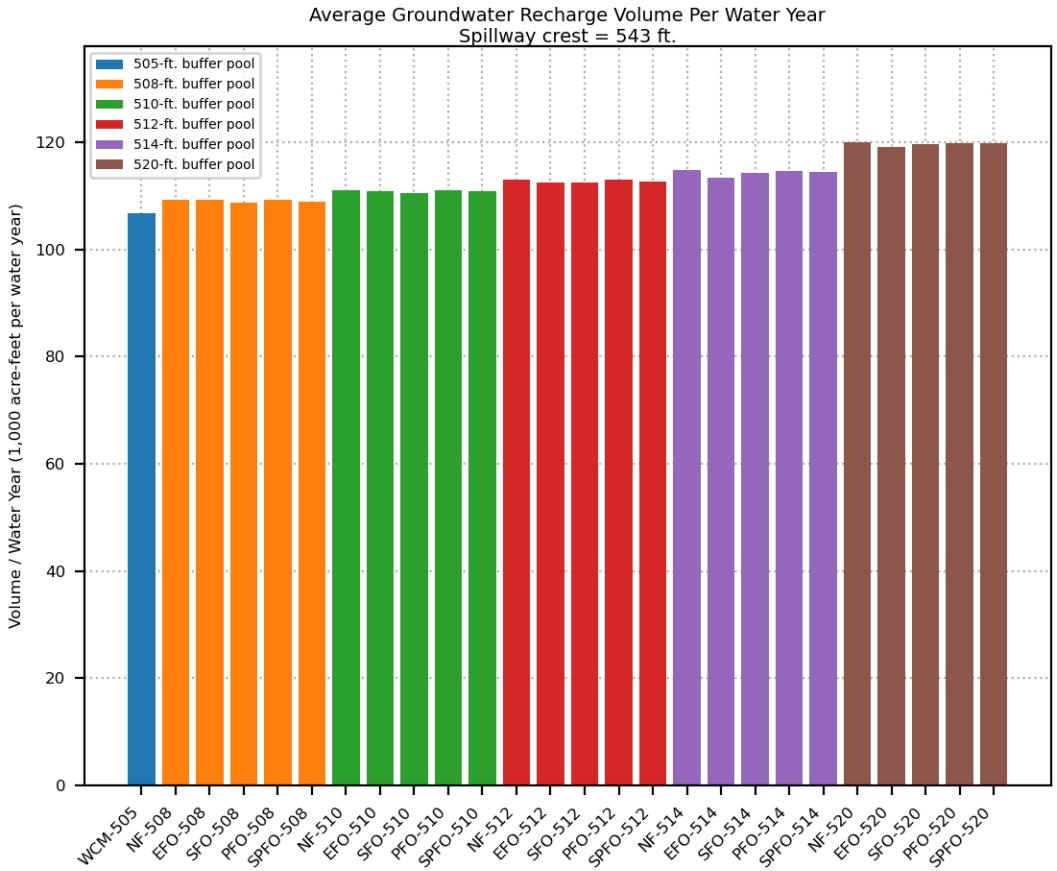
HEMP Metrics – Bar Charts

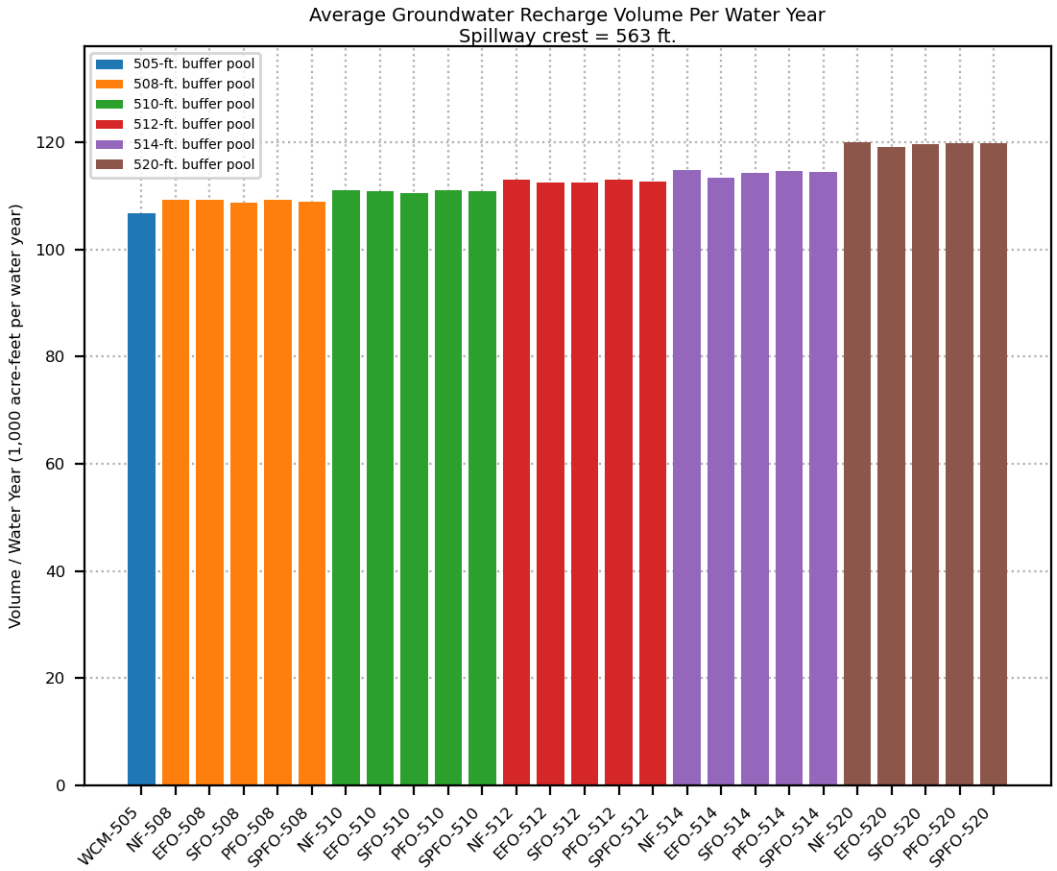
- Average days/yr > 5,000, 10,000, 15,000 cfs
- Change in days/yr > 5,000, 10,000, 15,000 cfs relative to WCM (baseline)

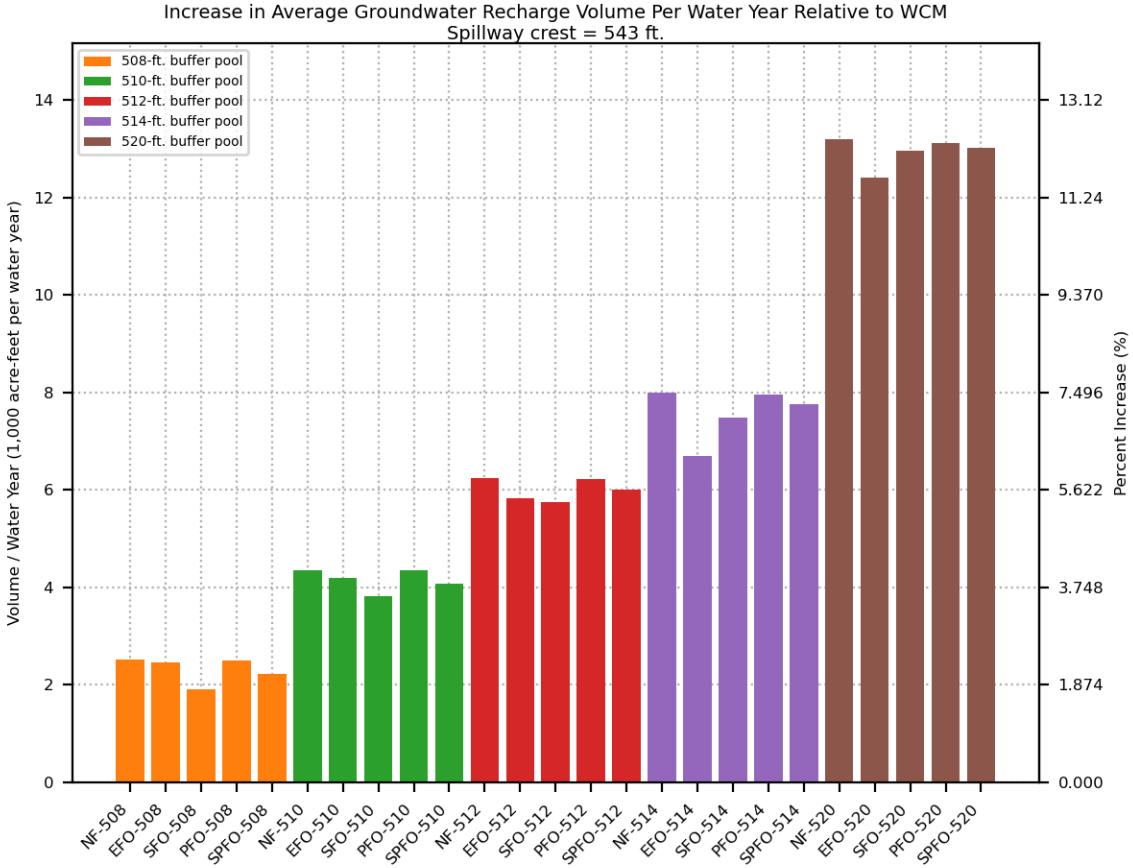
- Average days/yr > 1 meter pool rise during vireo nesting season (3/21-5/1)
- Change in days/yr > 1 meter pool rise during vireo nesting season (3/21–5/1) relative to WCM (baseline)

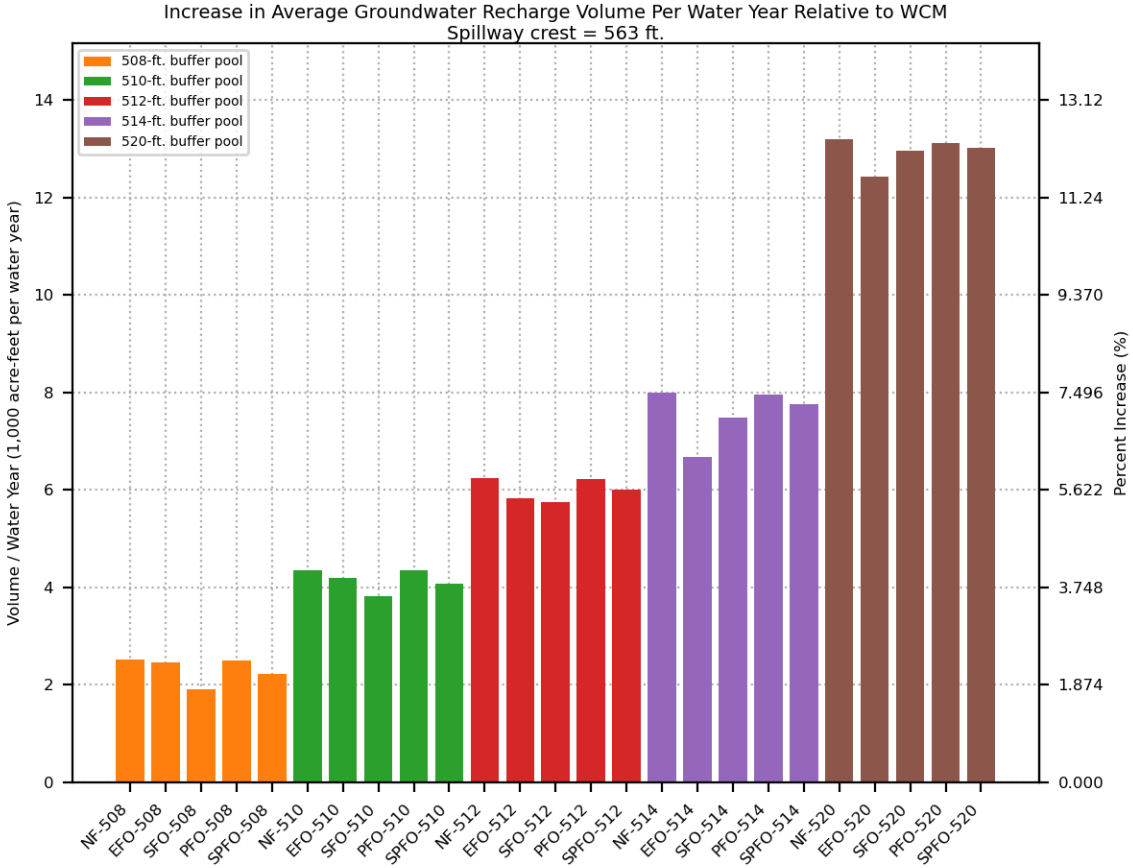
HEMP Metrics – Bar Charts

- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’, 510’, 512’, 514’, 520’
- WCP alternatives across X Axis


Average Groundwater Recharge Volume Per Water Year
Spillway crest = 543 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Volume / Water Year (1,000 acre-feet per water year)
0
20
40
60
80
100
120
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Average Groundwater Recharge Volume Per Water Year
Spillway crest = 563 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Volume / Water Year (1,000 acre-feet per water year)
0
20
40
60
80
100
120
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Increase in Average Groundwater Recharge Volume Per Water Year Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Volume / Water Year (1,000 acre-feet per water year)
Percent Increase (%)
0
2
4
6
8
10
12
14
0.000
1.874
3.748
5.622
7.496
9.370
11.24
13.12
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Increase in Average Groundwater Recharge Volume Per Water Year Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Volume / Water Year (1,000 acre-feet per water year)
Percent Increase (%)
0
2
4
6
8
10
12
14
0.000
1.874
3.748
5.622
7.496
9.370
11.24
13.12
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
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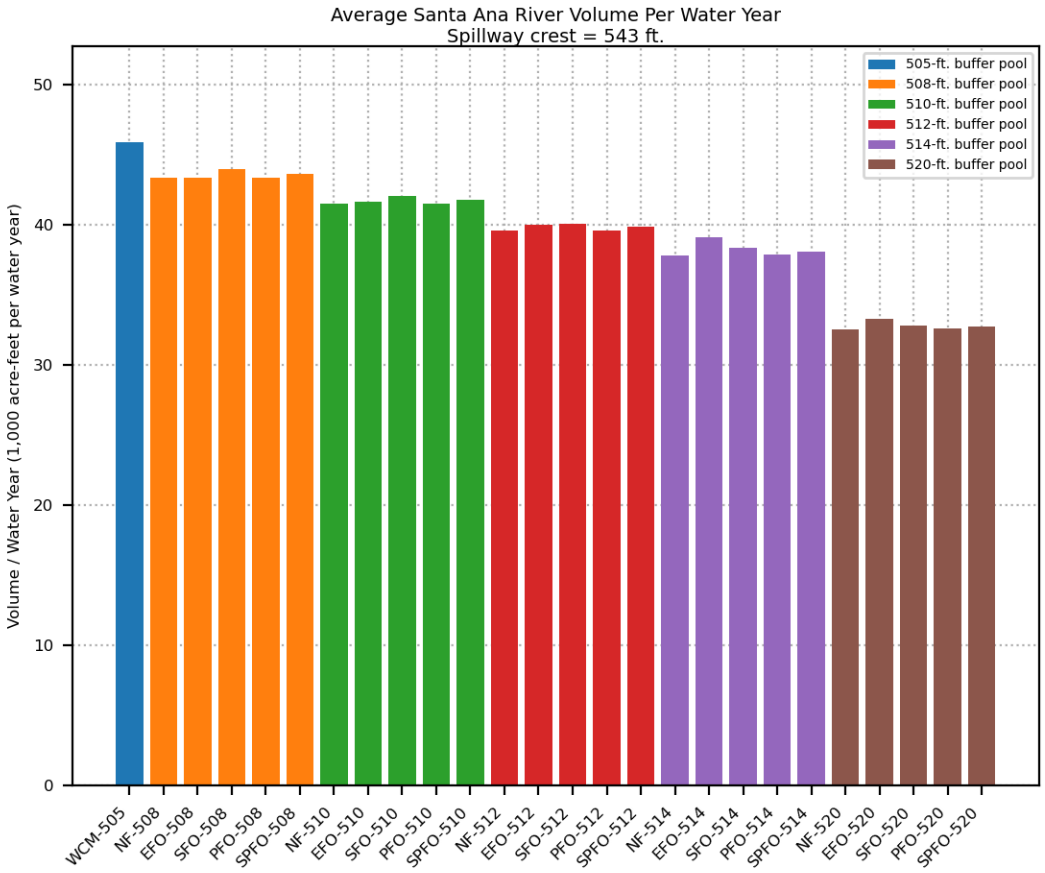
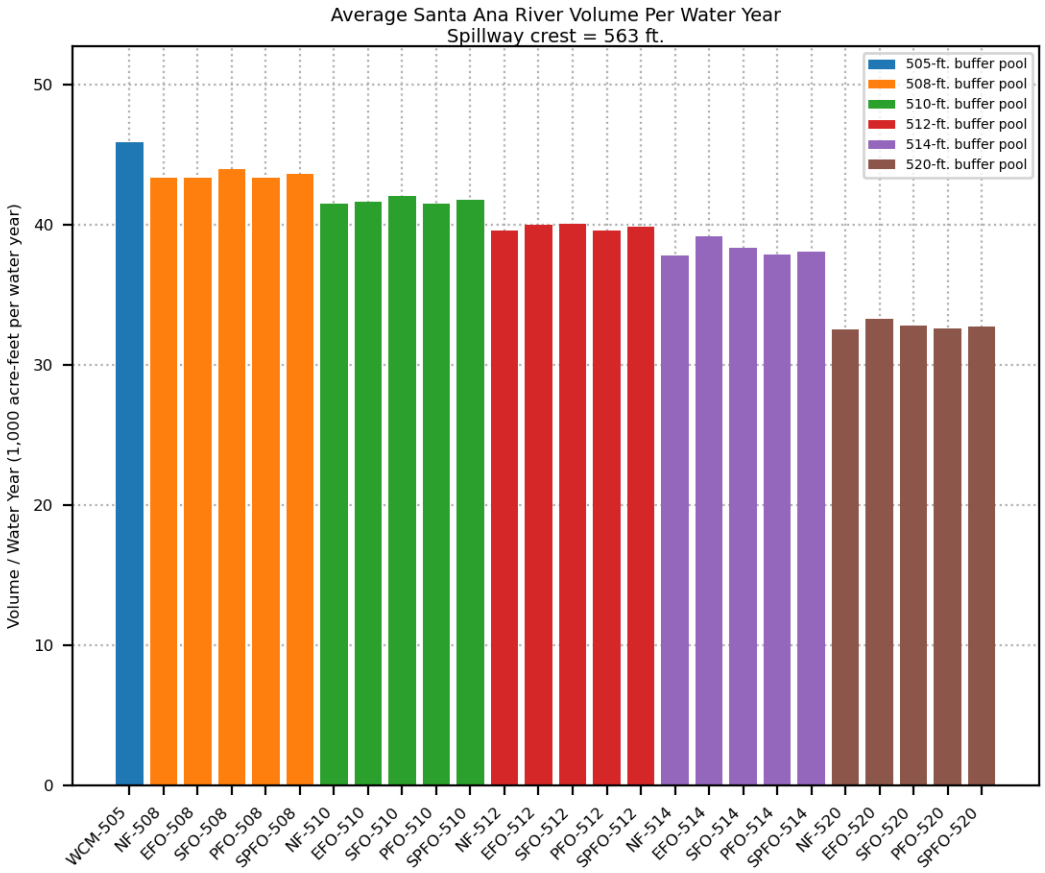
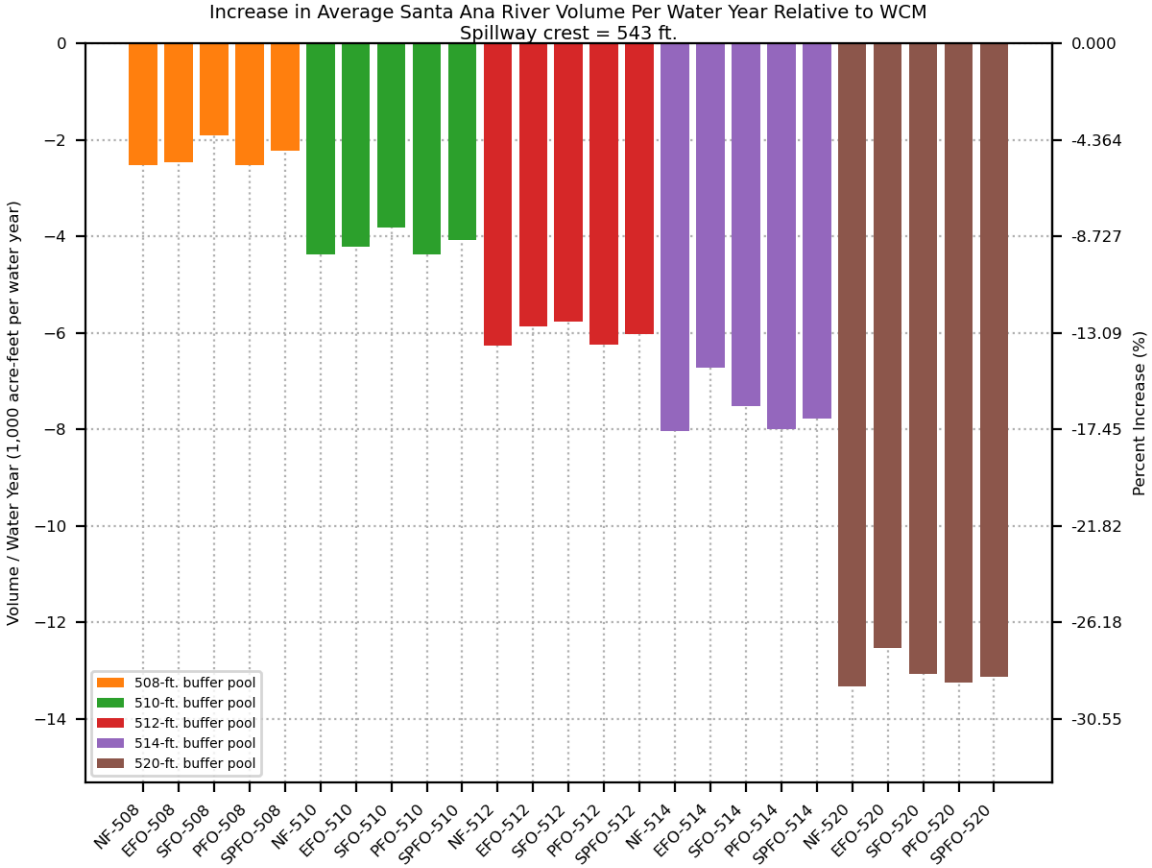
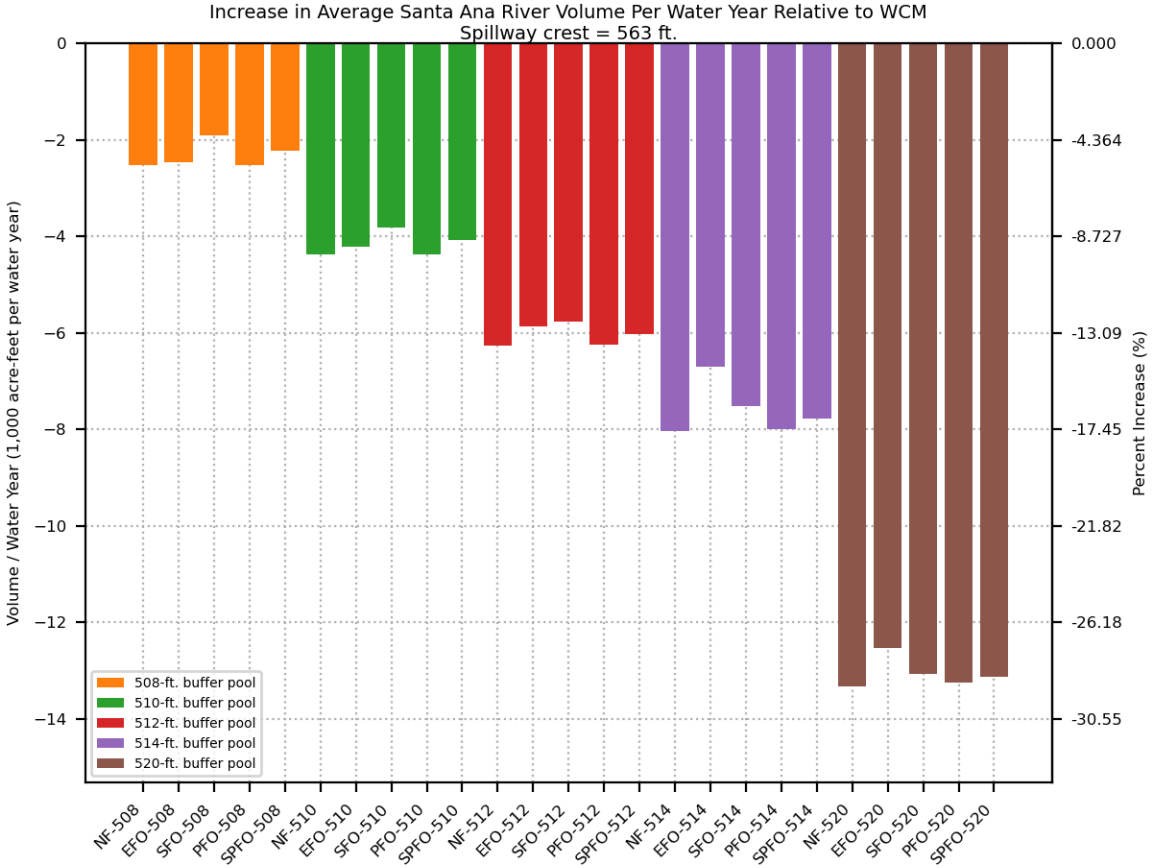
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Average Santa Ana River Volume Per Water Year
Spillway crest = 543 ft.
Volume / Water Year (1,000 acre-feet per water year)
0
10
20
30
40
50
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Average Santa Ana River Volume Per Water Year
Spillway crest = 563 ft.
Volume / Water Year (1,000 acre-feet per water year)
0
10
20
30
40
50
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Increase in Average Santa Ana River Volume Per Water Year Relative to WCM
Spillway crest = 543 ft.
Volume / Water Year (1,000 acre-feet per water year)
Percent Increase (%)
0
−2
−4
−6
−8
−10
−12
−14
0.000
-4.364
-8.727
-13.09
-17.45
-21.82
-26.18
-30.55
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Increase in Average Santa Ana River Volume Per Water Year Relative to WCM
Spillway crest = 563 ft.
Volume / Water Year (1,000 acre-feet per water year)
Percent Increase (%)
0
−2
−4
−6
−8
−10
−12
−14
0.000
-4.364
-8.727
-13.09
-17.45
-21.82
-26.18
-30.55
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
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SFO-514
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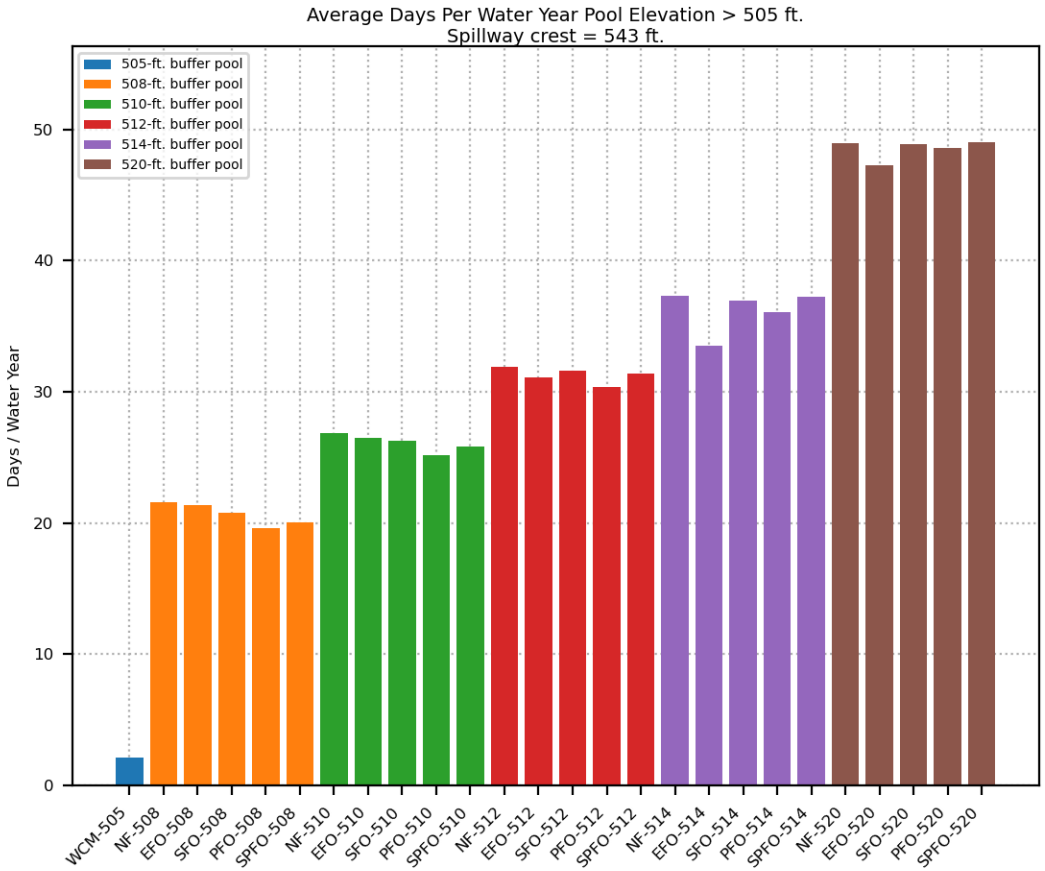
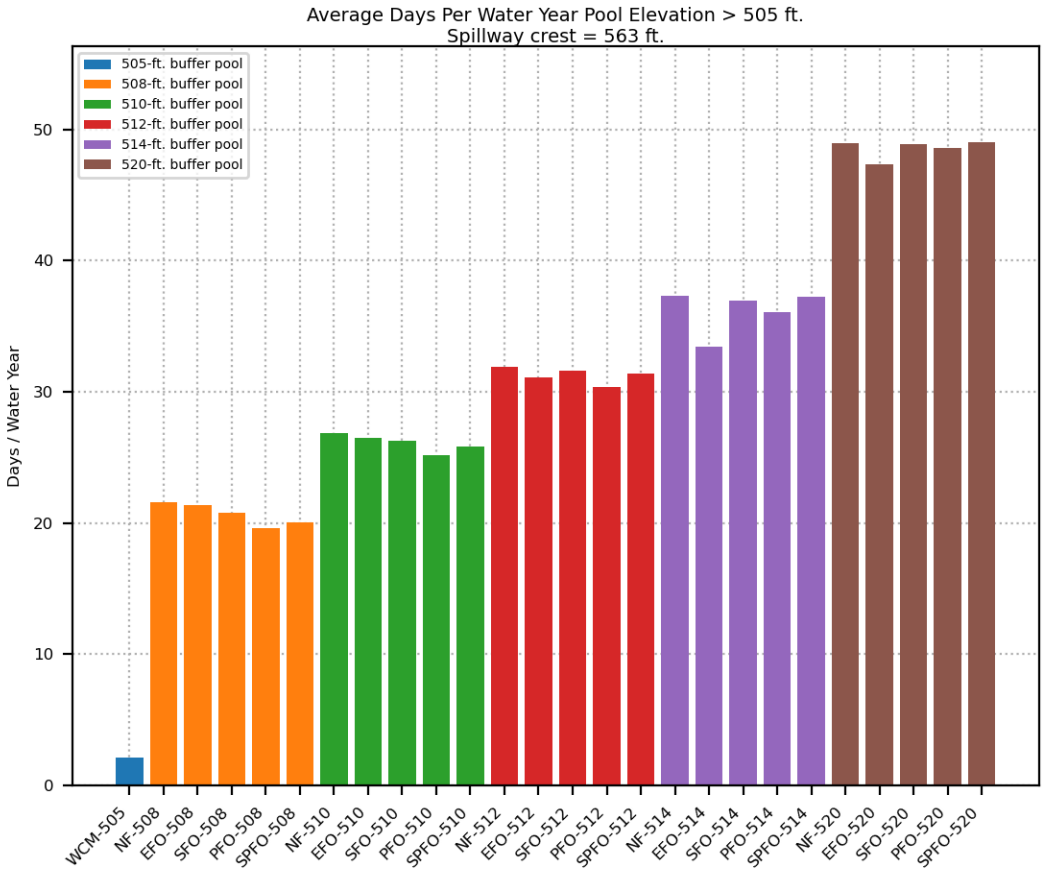
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Average Days Per Water Year Pool Elevation > 505 ft.
Spillway crest = 543 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0
10
20
30
40
50
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Average Days Per Water Year Pool Elevation > 505 ft.
Spillway crest = 563 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0
10
20
30
40
50
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
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SFO-514
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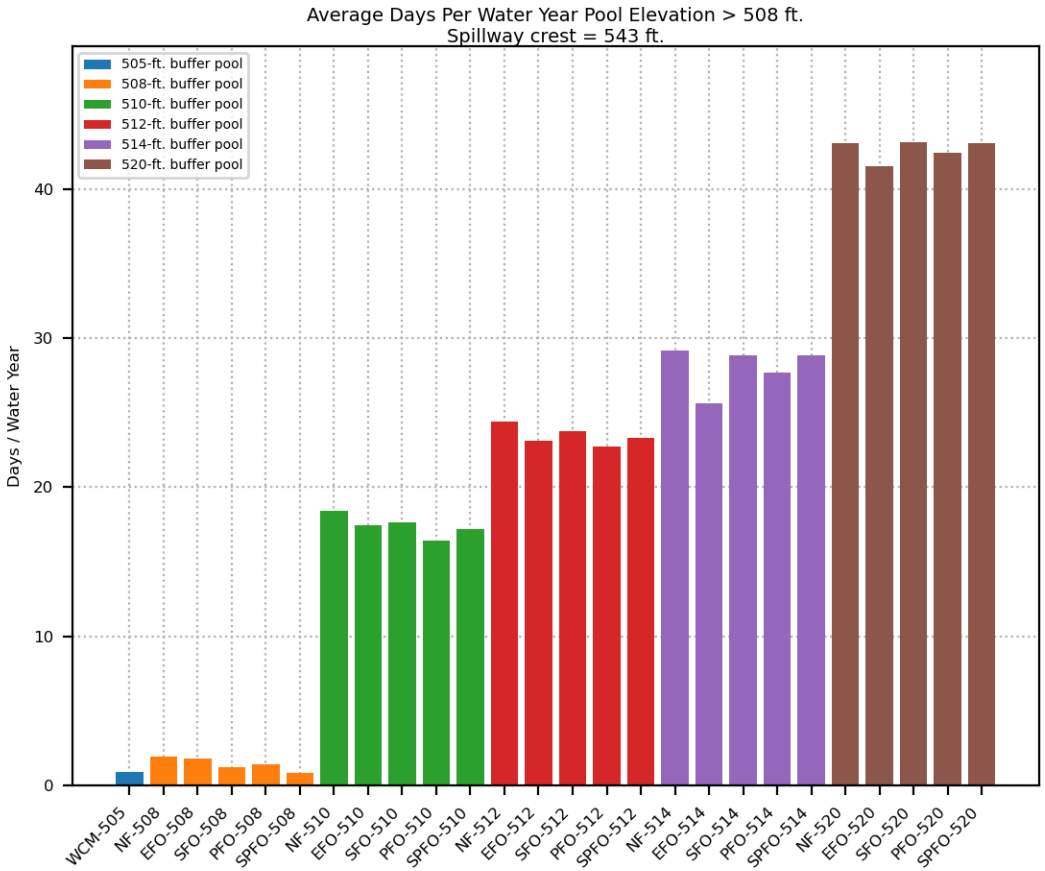
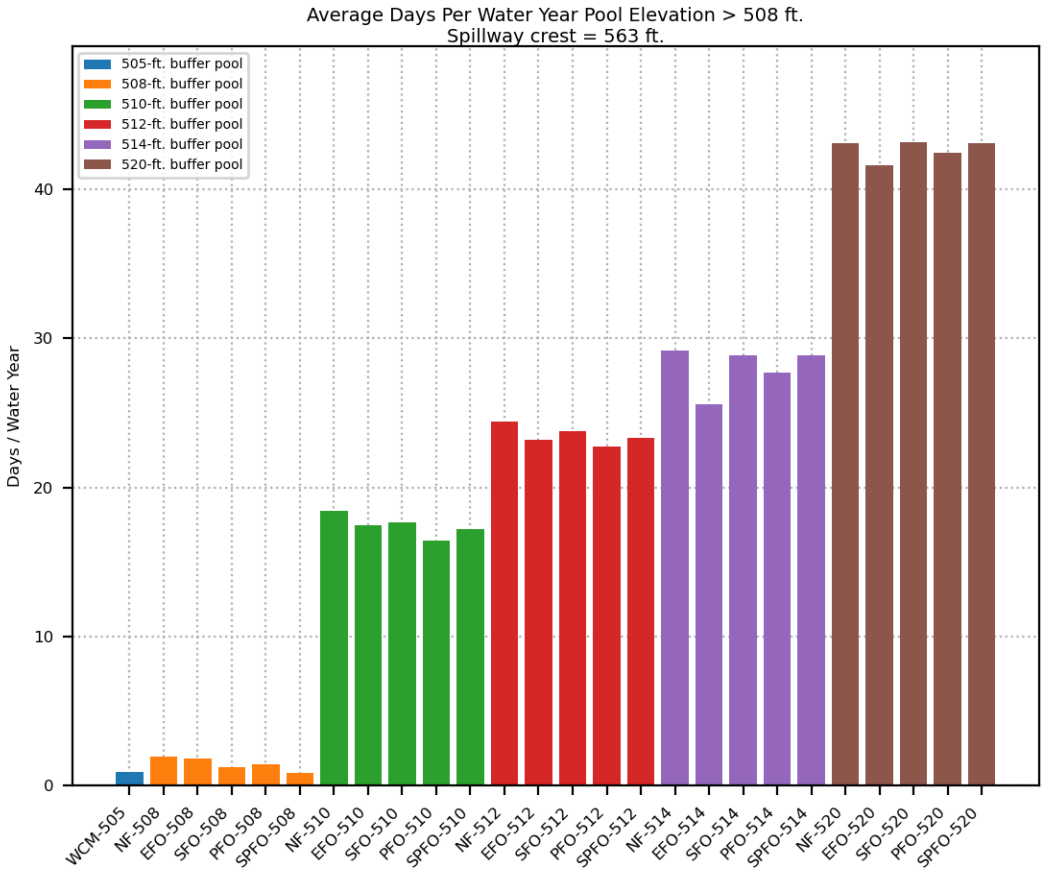
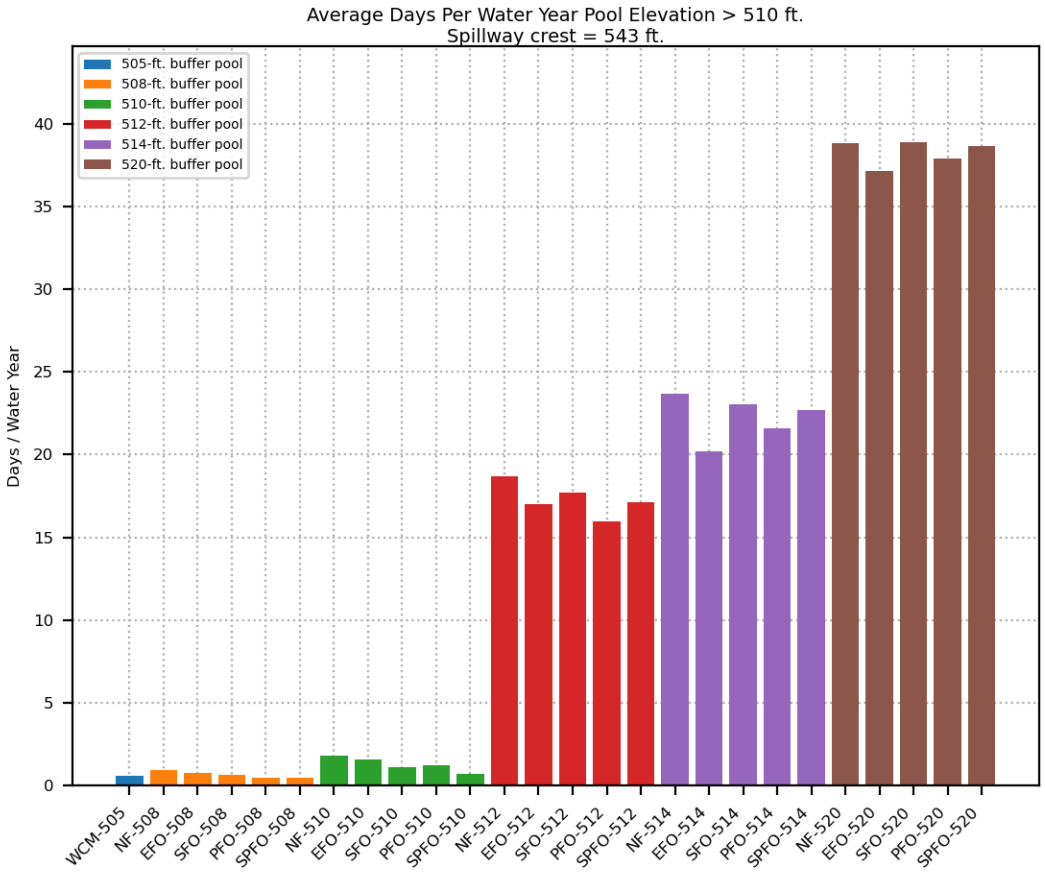
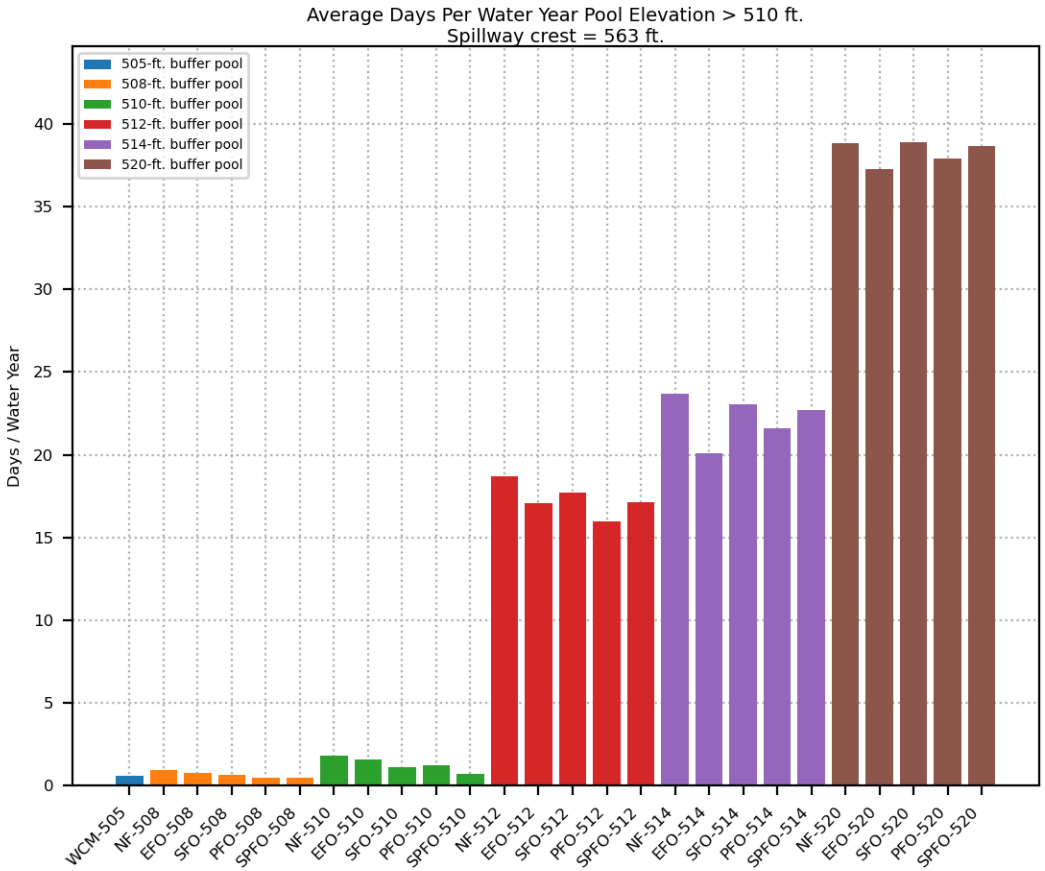
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Average Days Per Water Year Pool Elevation > 508 ft.
Spillway crest = 543 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0
10
20
30
40
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Average Days Per Water Year Pool Elevation > 508 ft.
Spillway crest = 563 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0
10
20
30
40
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Average Days Per Water Year Pool Elevation > 510 ft.
Spillway crest = 543 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0
5
10
15
20
25
30
35
40
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Average Days Per Water Year Pool Elevation > 510 ft.
Spillway crest = 563 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0
5
10
15
20
25
30
35
40
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
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SFO-514
PFO-514
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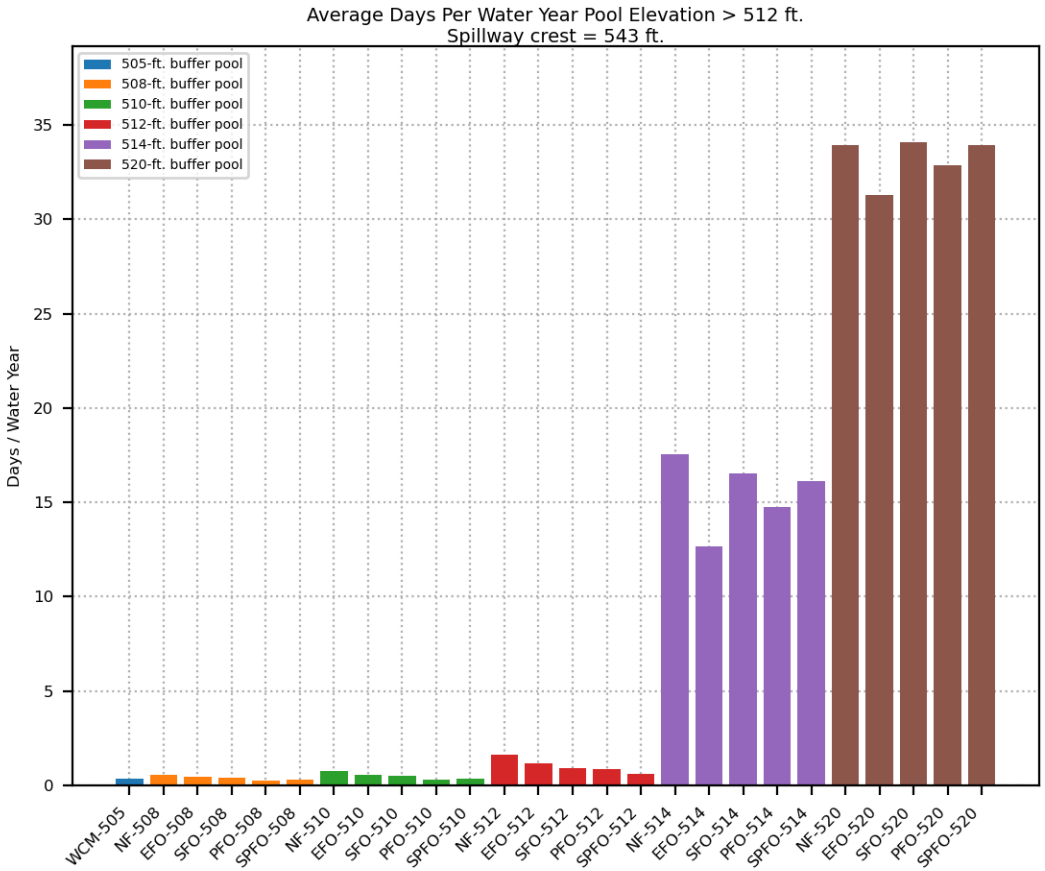
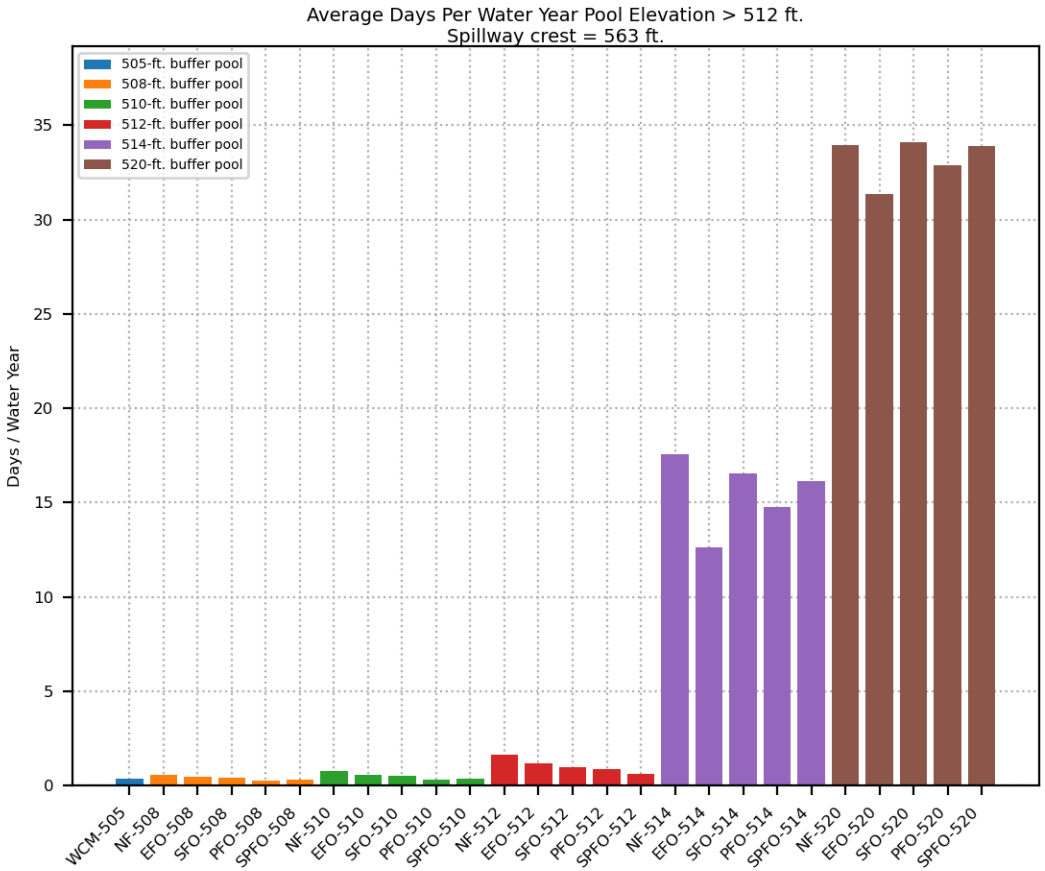
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Average Days Per Water Year Pool Elevation > 512 ft.
Spillway crest = 543 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0
5
10
15
20
25
30
35
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Average Days Per Water Year Pool Elevation > 512 ft.
Spillway crest = 563 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0
5
10
15
20
25
30
35
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
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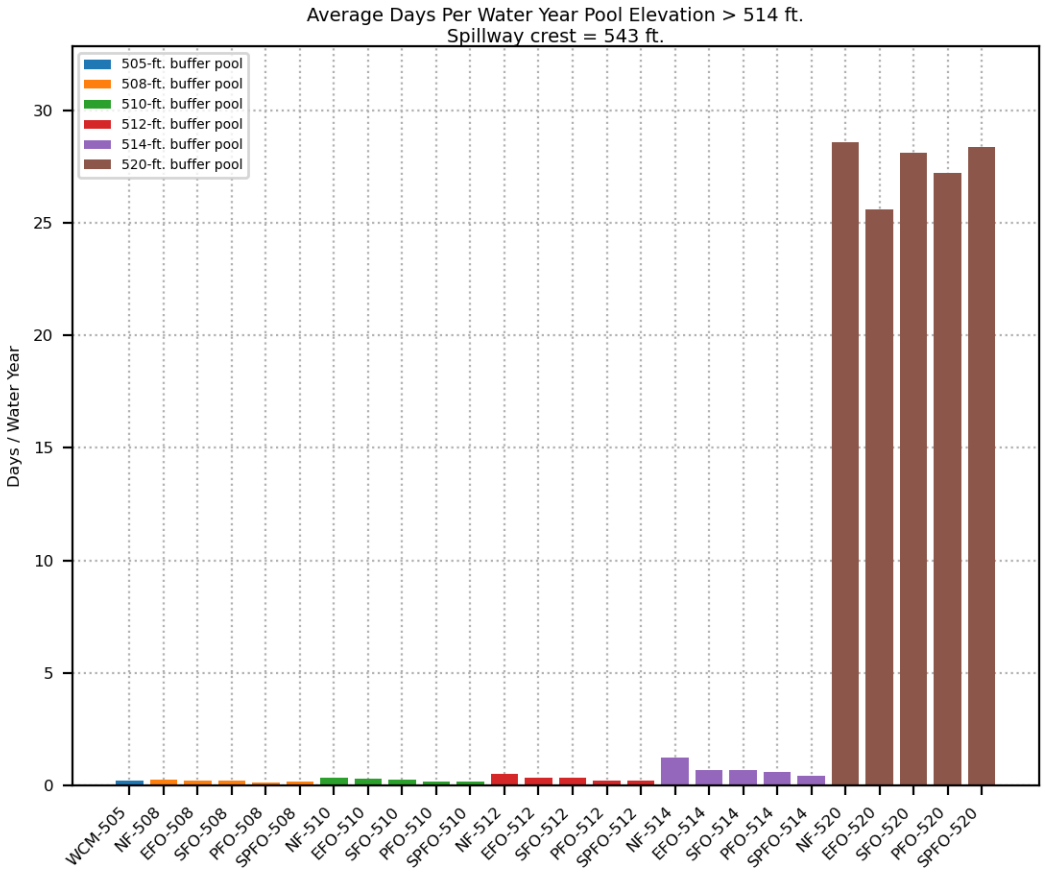
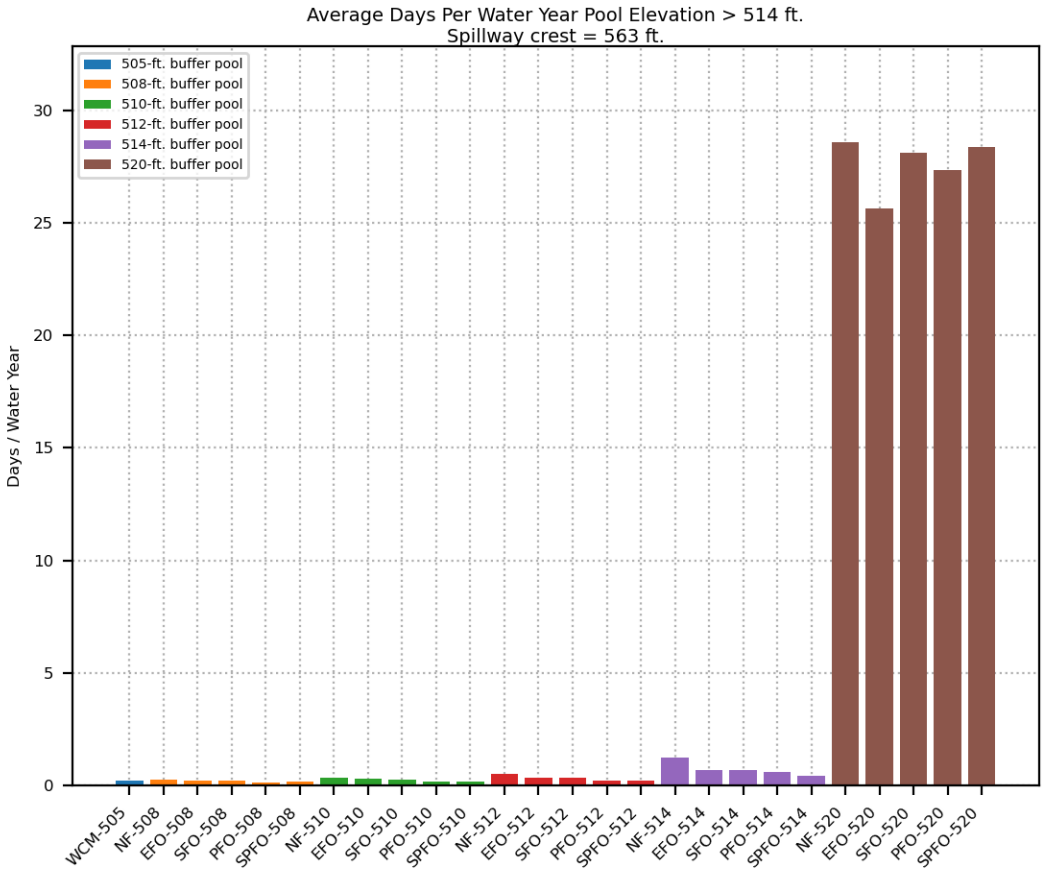
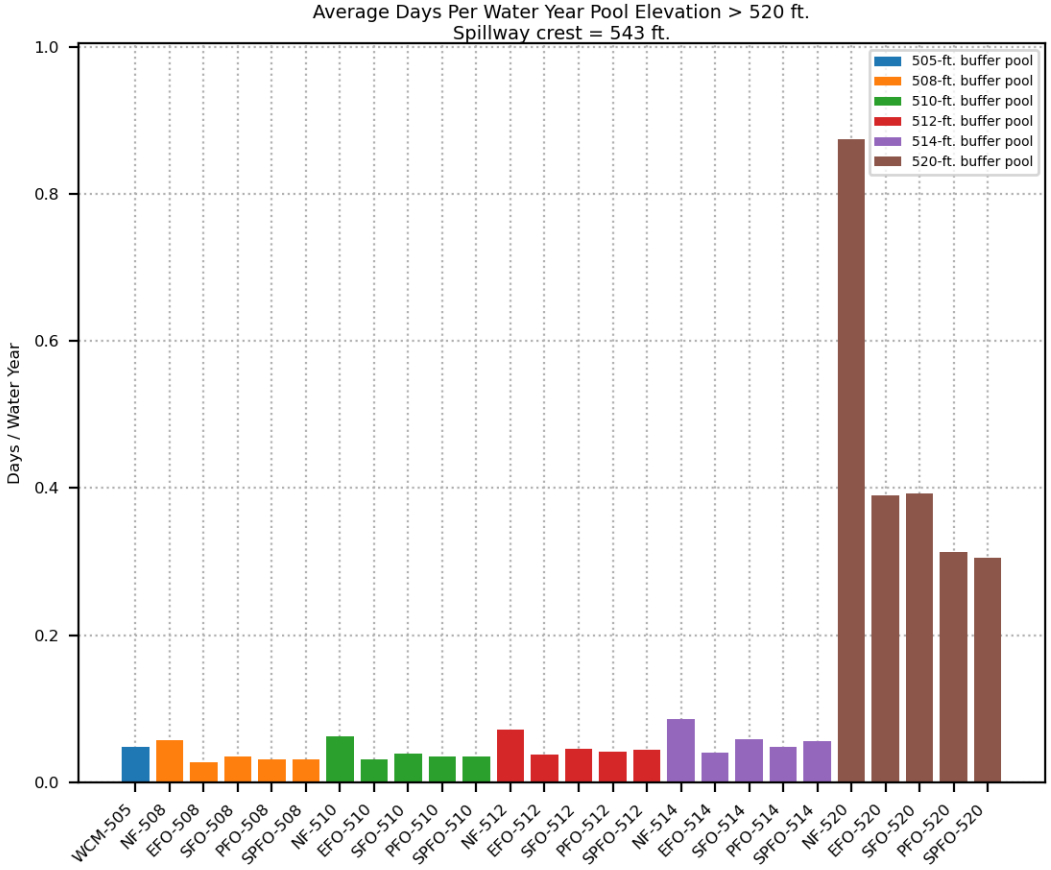
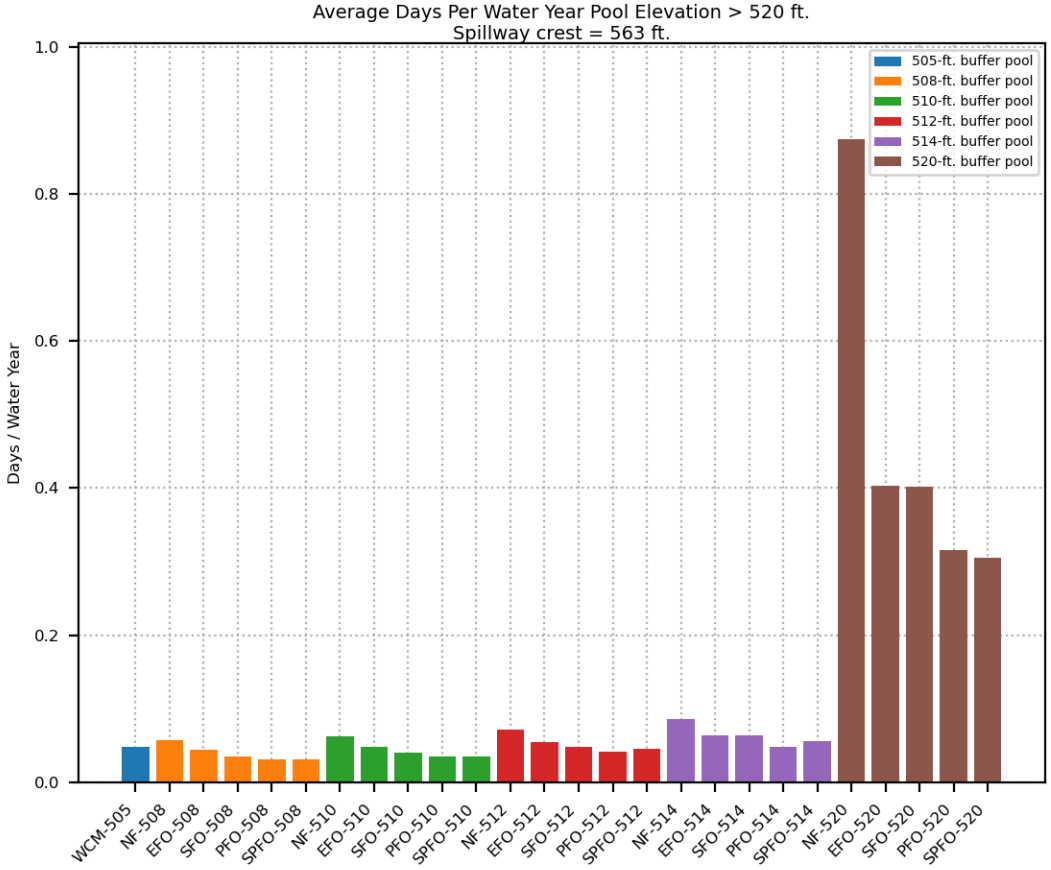
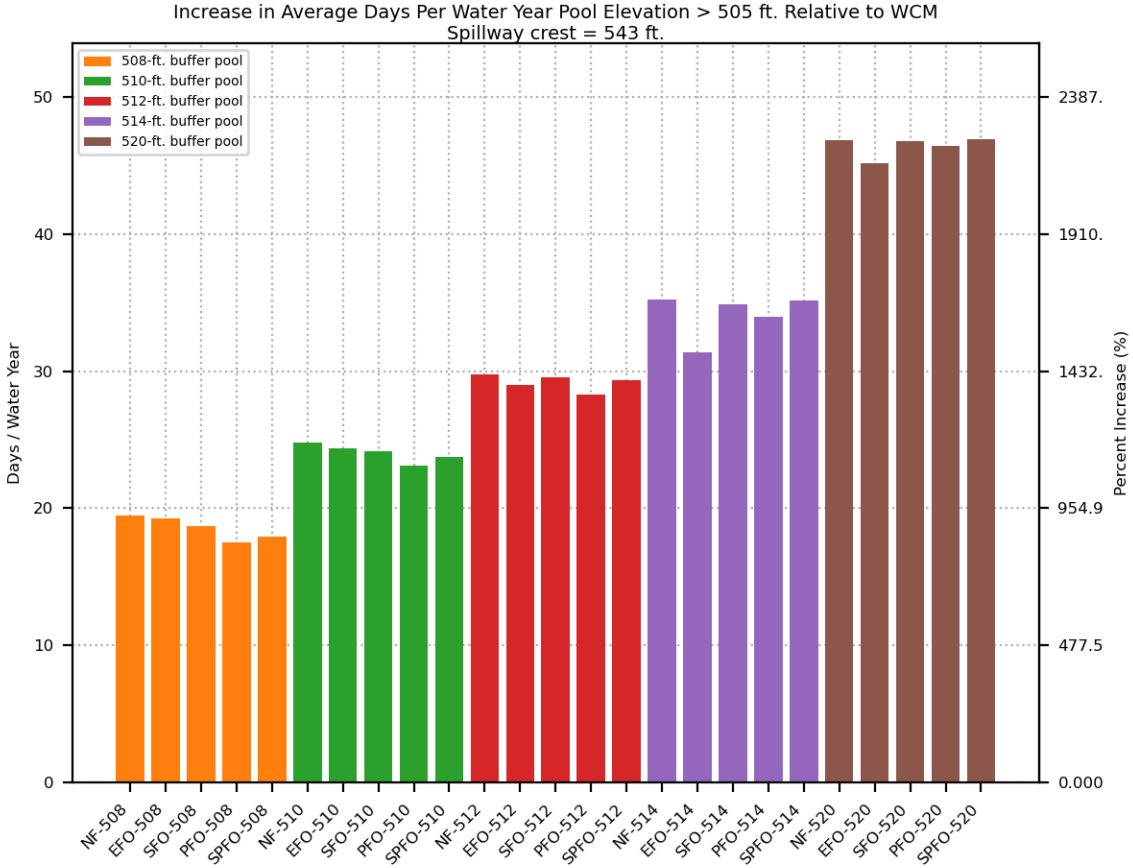
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

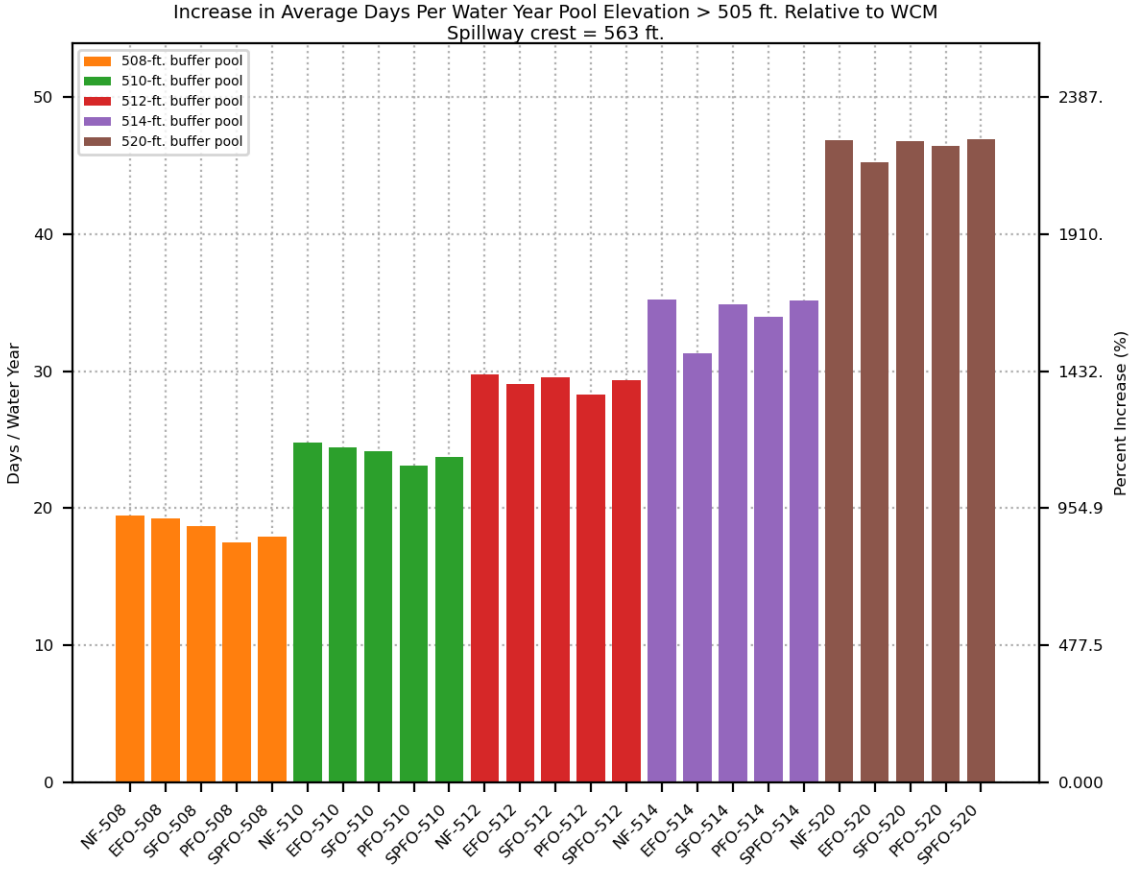

Average Days Per Water Year Pool Elevation > 514 ft.
Spillway crest = 543 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0
5
10
15
20
25
30
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Average Days Per Water Year Pool Elevation > 514 ft.
Spillway crest = 563 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0
5
10
15
20
25
30
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Average Days Per Water Year Pool Elevation > 520 ft.
Spillway crest = 543 ft.
Days / Water Year
1.0
0.8
0.6
0.4
0.2
0.0
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Average Days Per Water Year Pool Elevation > 520 ft.
Spillway crest = 563 ft.
Days / Water Year
1.0
0.8
0.6
0.4
0.2
0.0
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Increase in Average Days Per Water Year Pool Elevation > 505 ft. Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
10
20
30
40
50
0.000
477.5
954.9
1432.
1910.
2387.
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Increase in Average Days Per Water Year Pool Elevation > 505 ft. Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
10
20
30
40
50
0.000
477.5
954.9
1432.
1910.
2387.
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
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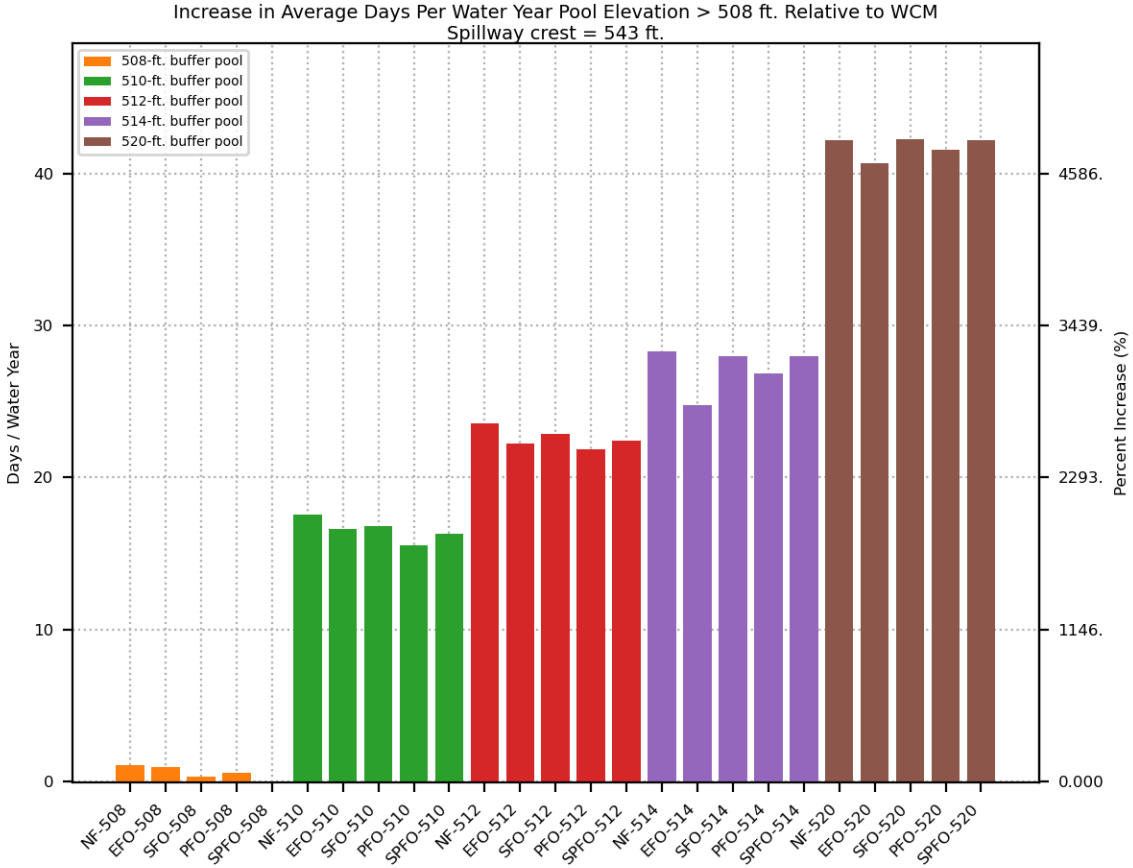
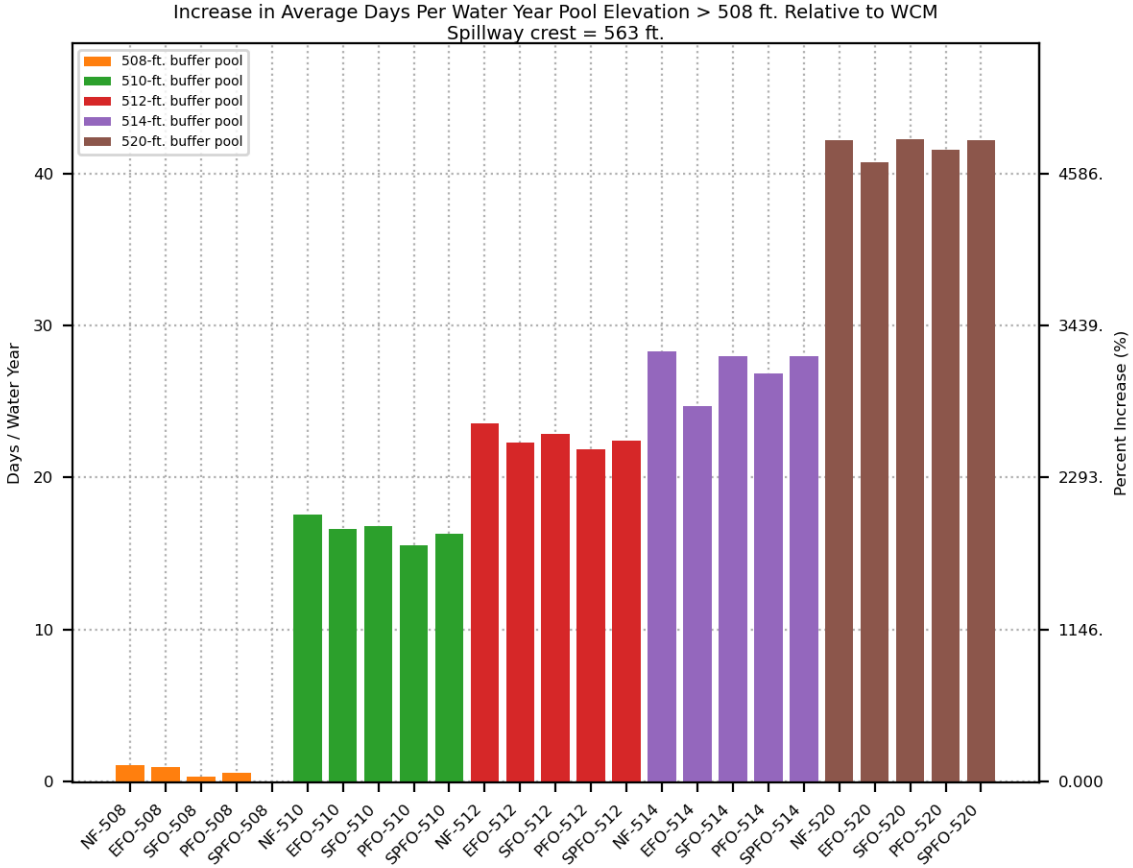
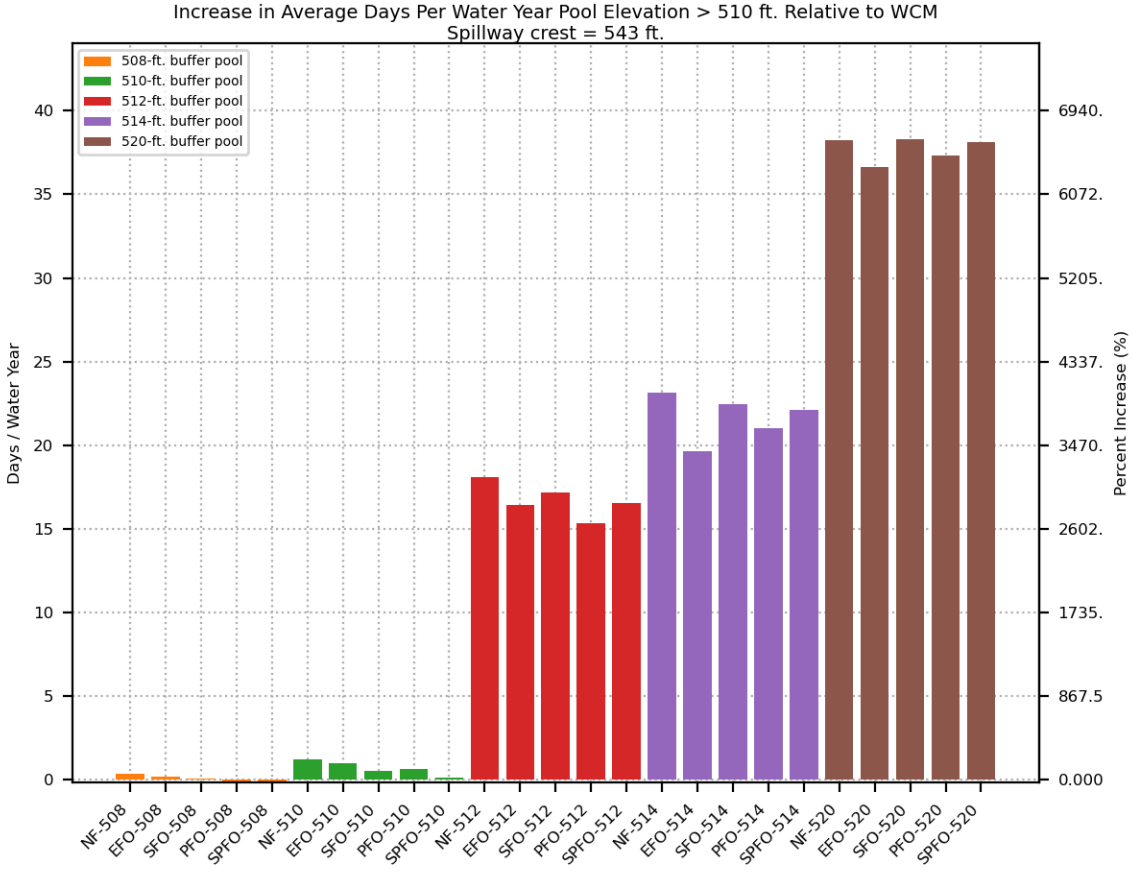
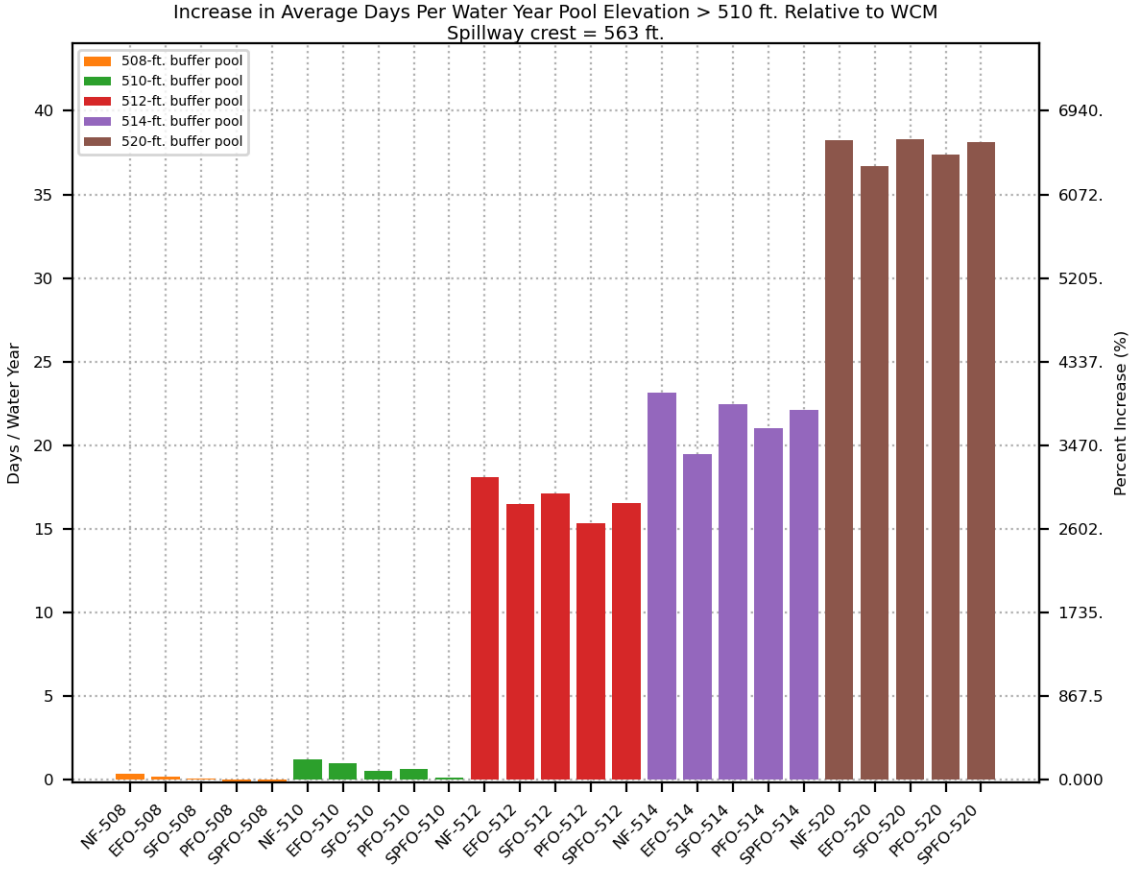
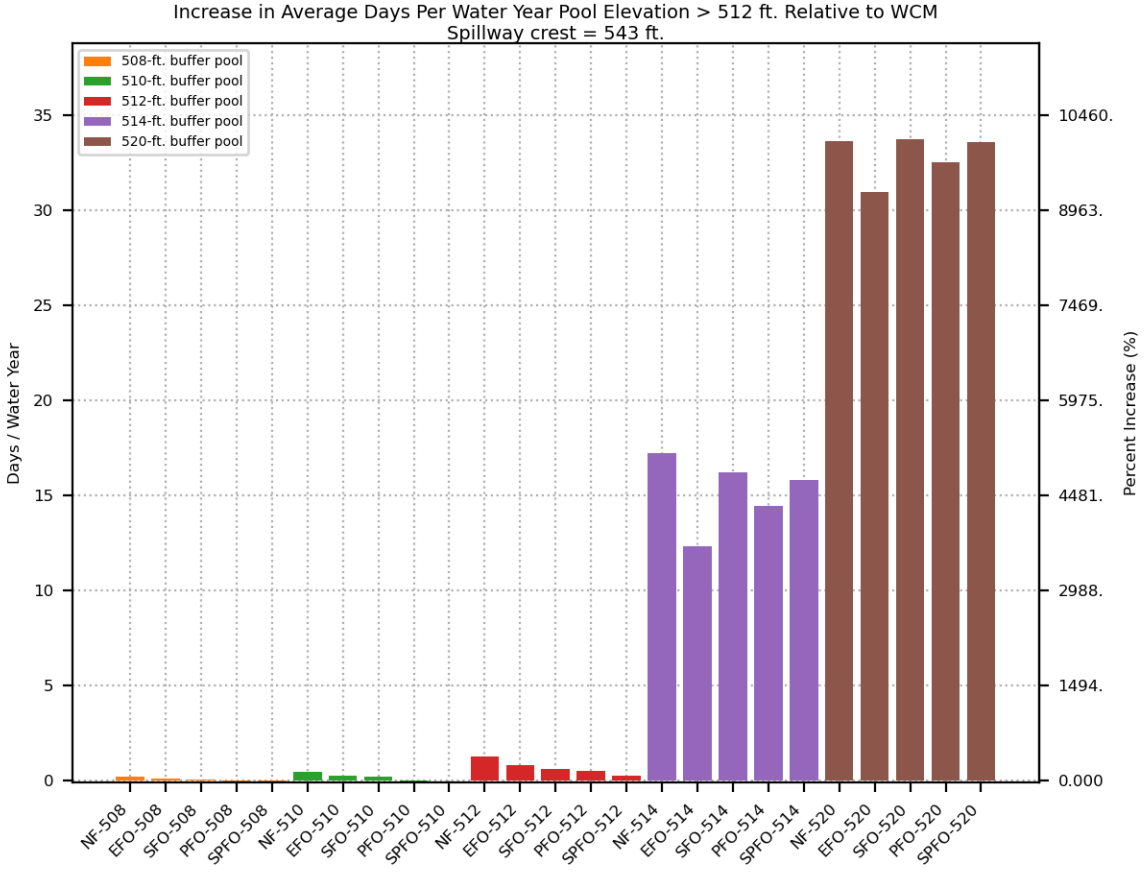
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

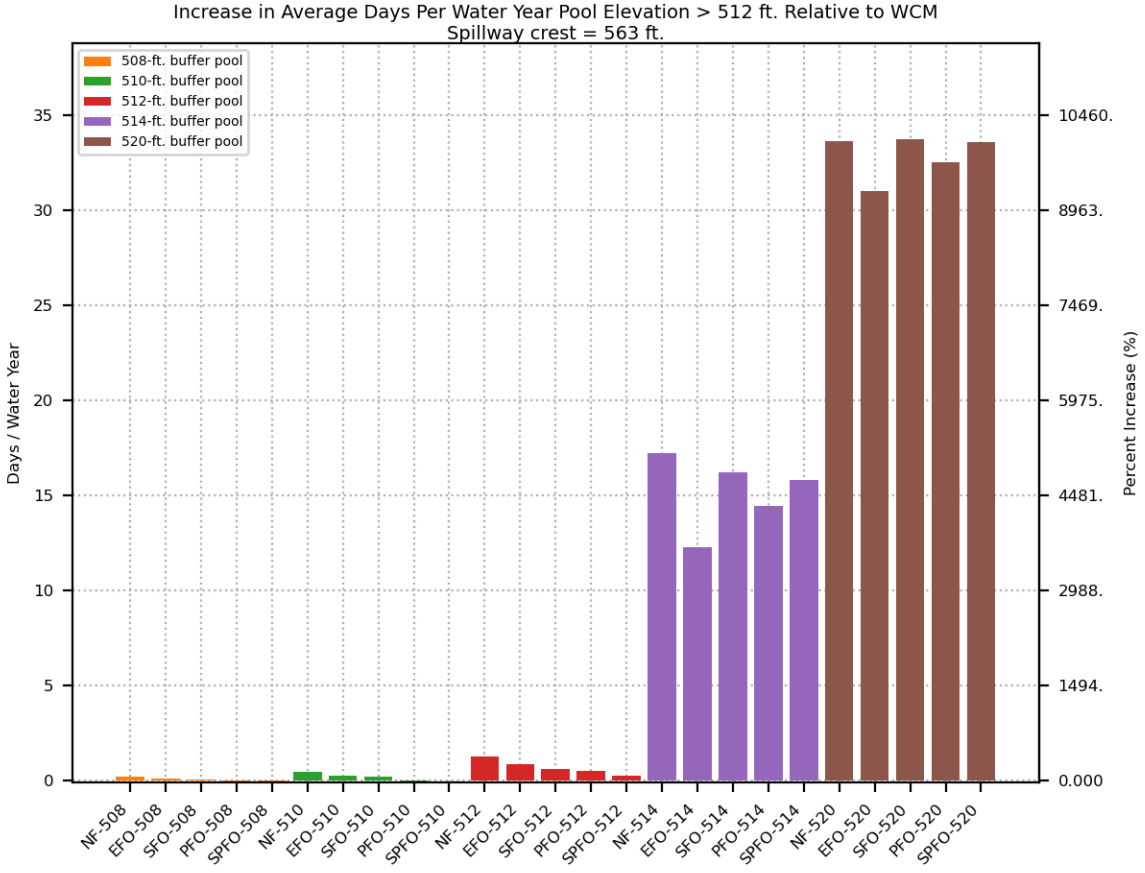

Increase in Average Days Per Water Year Pool Elevation > 508 ft. Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
10
20
30
40
0.000
1146.
2293.
3439.
4586.
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

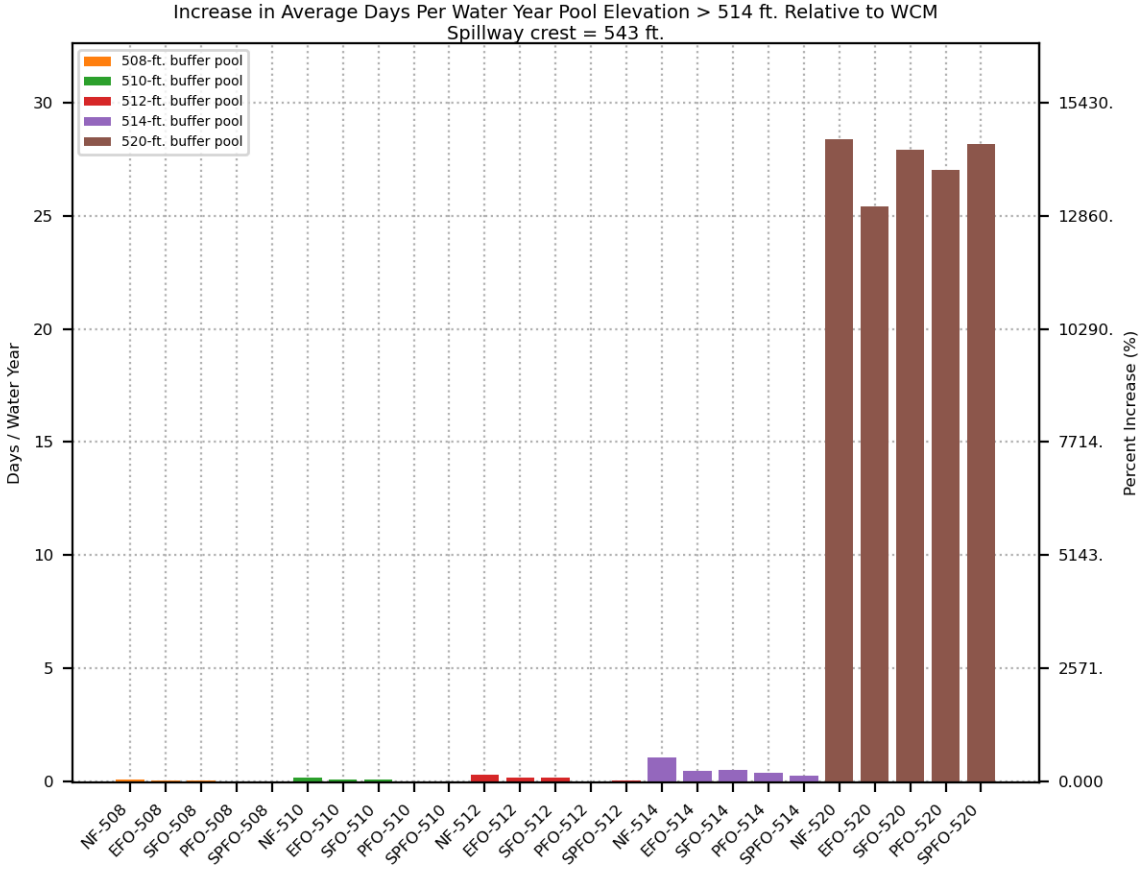

Increase in Average Days Per Water Year Pool Elevation > 508 ft. Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
10
20
30
40
0.000
1146.
2293.
3439.
4586.
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

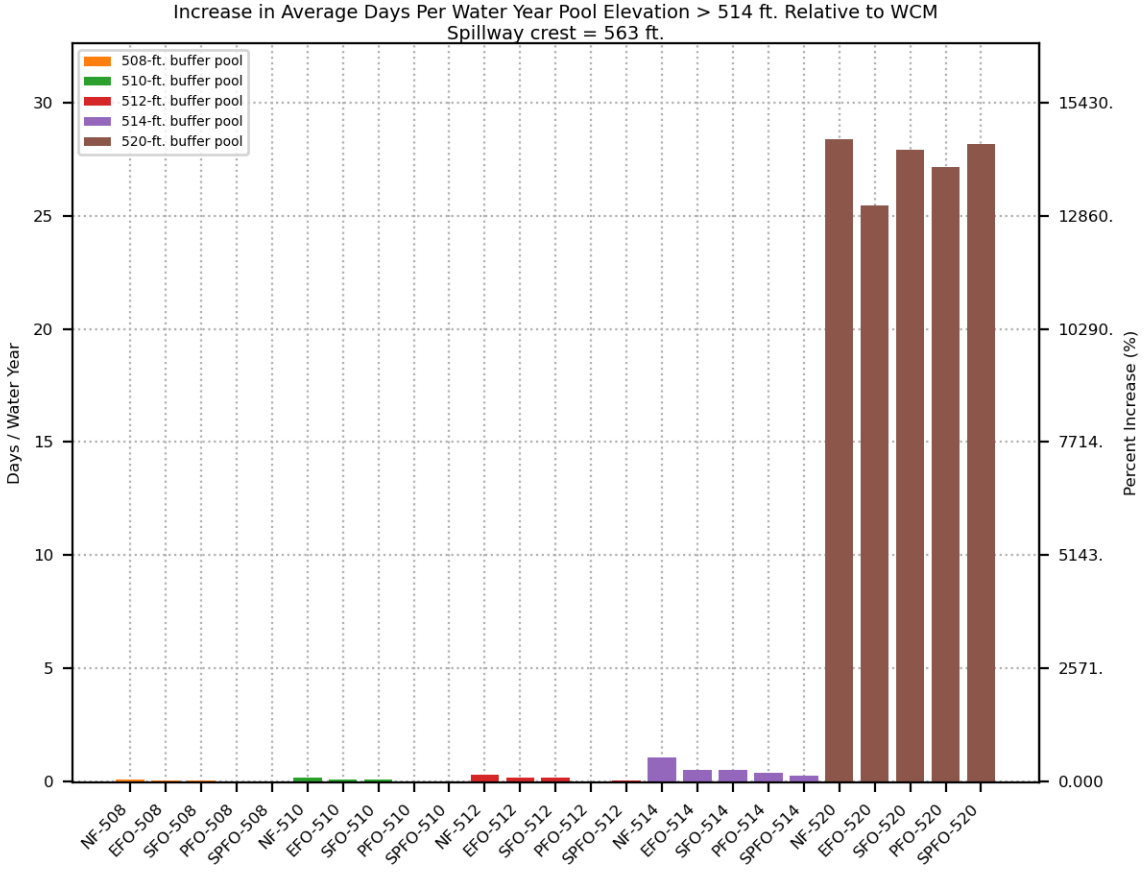

Increase in Average Days Per Water Year Pool Elevation > 510 ft. Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
5
10
15
20
25
30
35
40
0.000
867.5
1735.
2602.
3470.
4337.
5205.
6072.
6940.
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

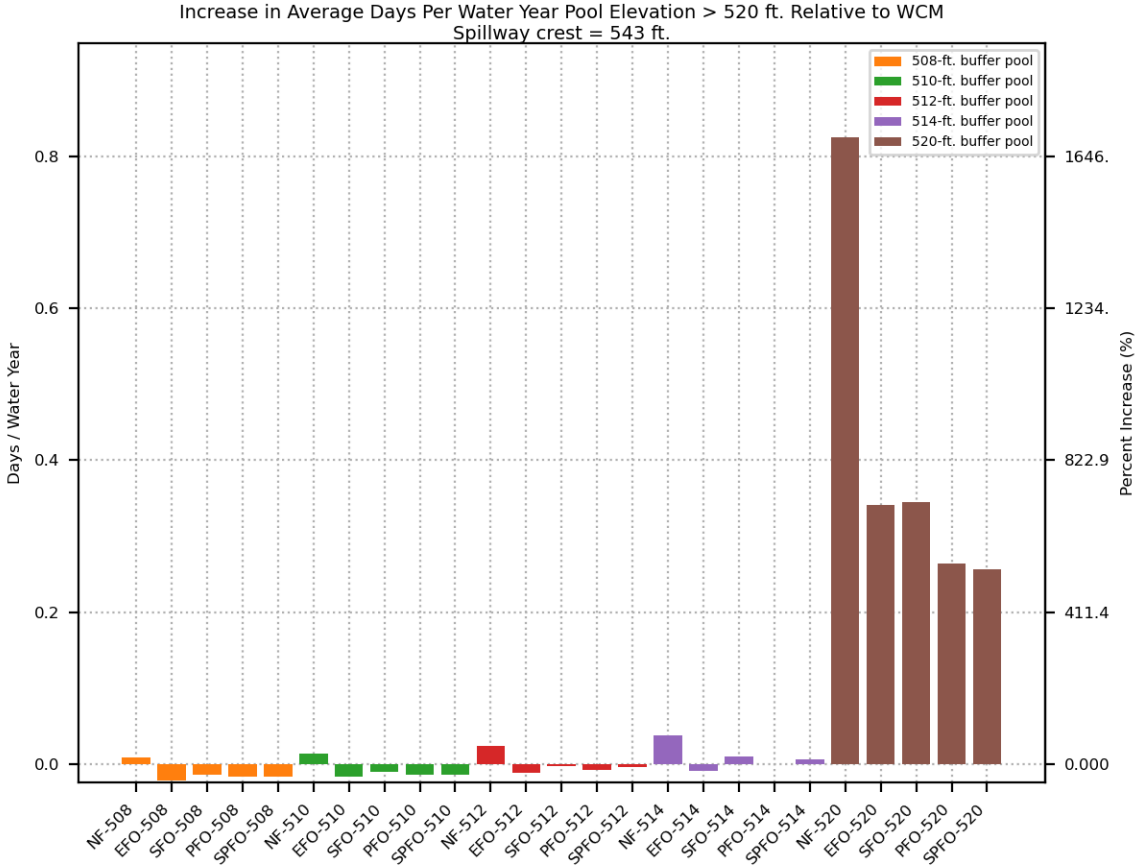

Increase in Average Days Per Water Year Pool Elevation > 510 ft. Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
5
10
15
20
25
30
35
40
0.000
867.5
1735.
2602.
3470.
4337.
5205.
6072.
6940.
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

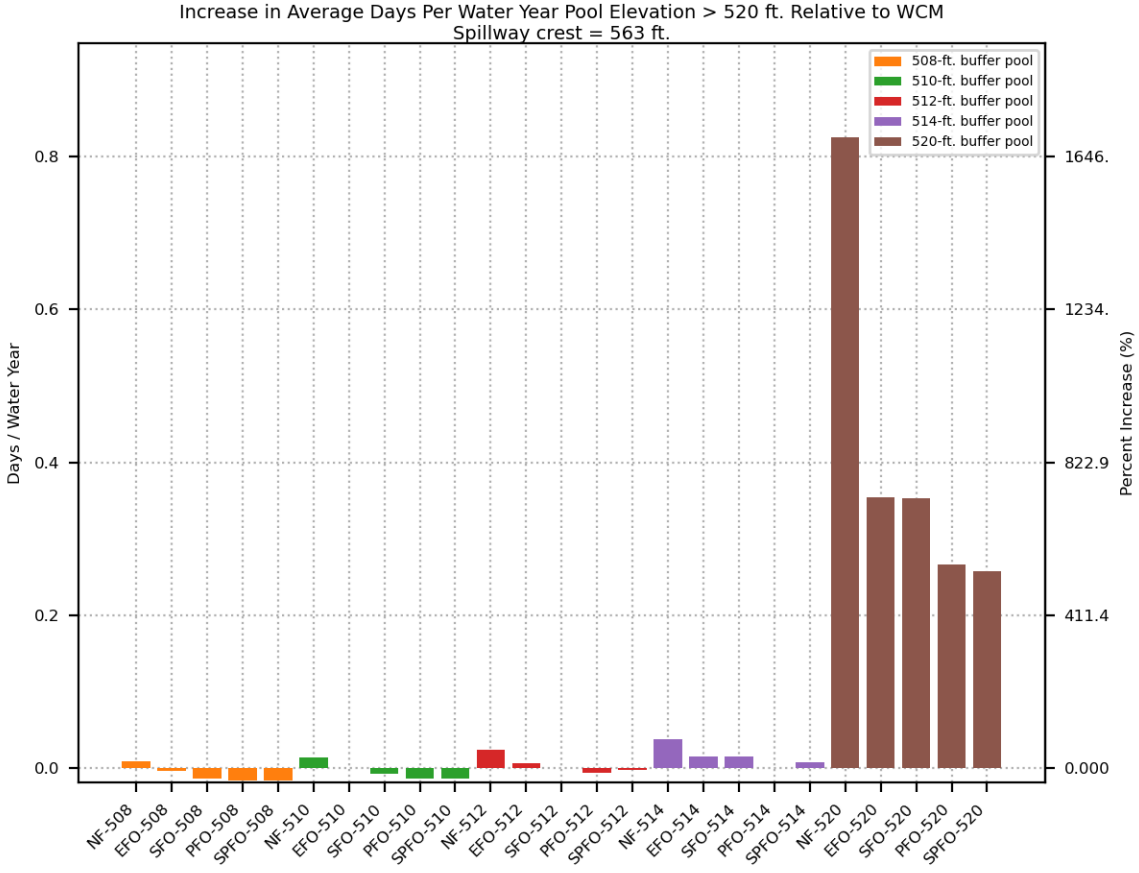

Increase in Average Days Per Water Year Pool Elevation > 512 ft. Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
5
10
15
20
25
30
35
0.000
1494.
2988.
4481.
5975.
7469.
8963.
10460.
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

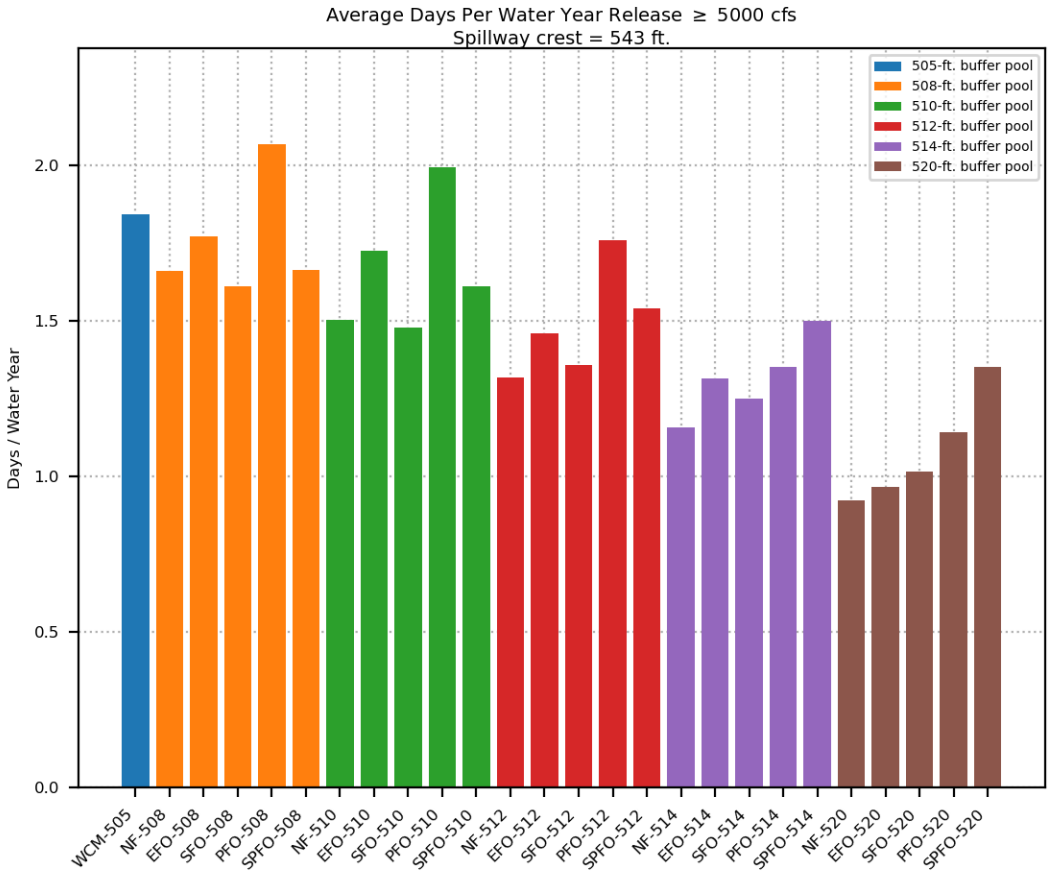

Increase in Average Days Per Water Year Pool Elevation > 512 ft. Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
5
10
15
20
25
30
35
0.000
1494.
2988.
4481.
5975.
7469.
8963.
10460.
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

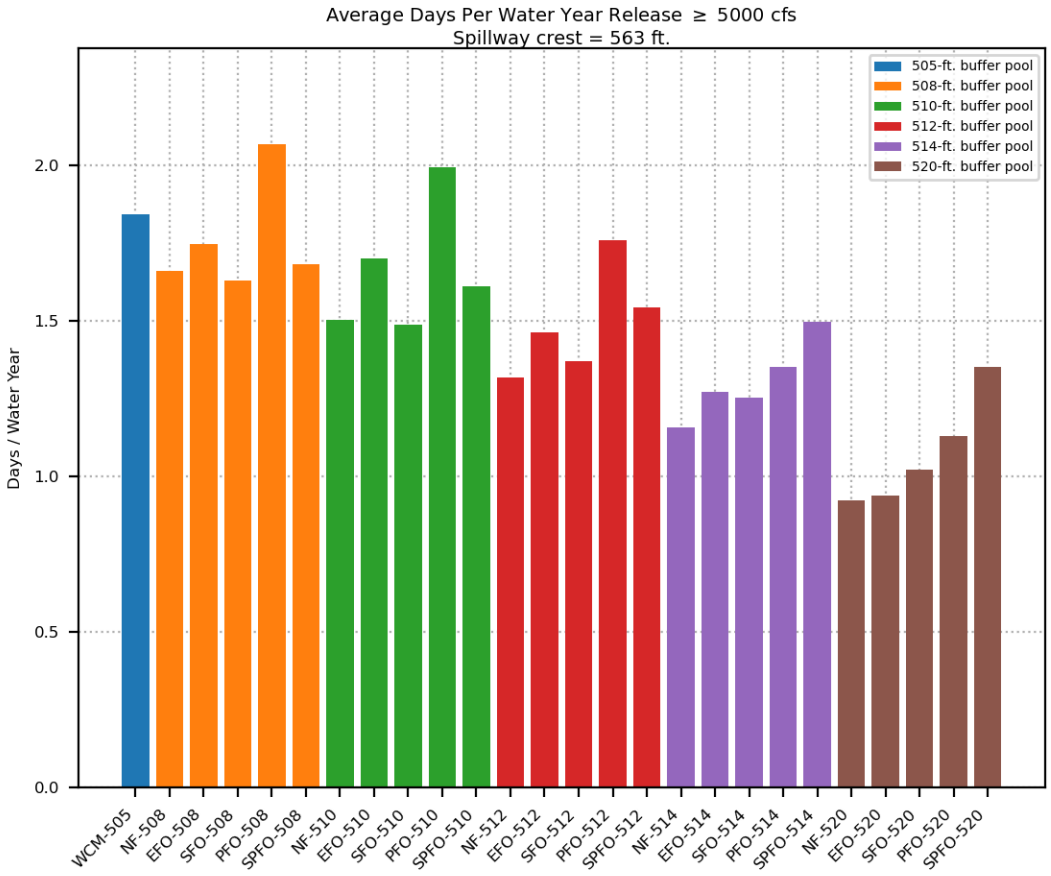

Increase in Average Days Per Water Year Pool Elevation > 514 ft. Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
5
10
15
20
25
30
0.000
2571.
5143.
7714.
10290.
12860.
15430.
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

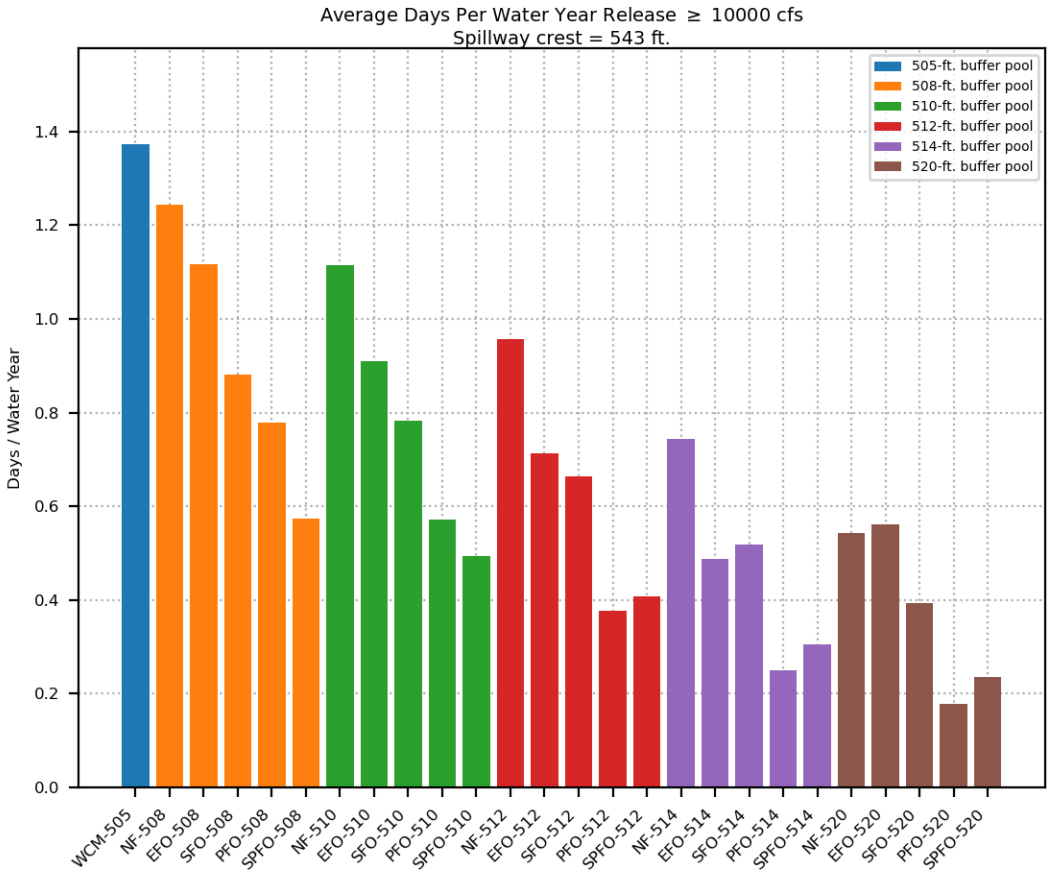

Increase in Average Days Per Water Year Pool Elevation > 514 ft. Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
5
10
15
20
25
30
0.000
2571.
5143.
7714.
10290.
12860.
15430.
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

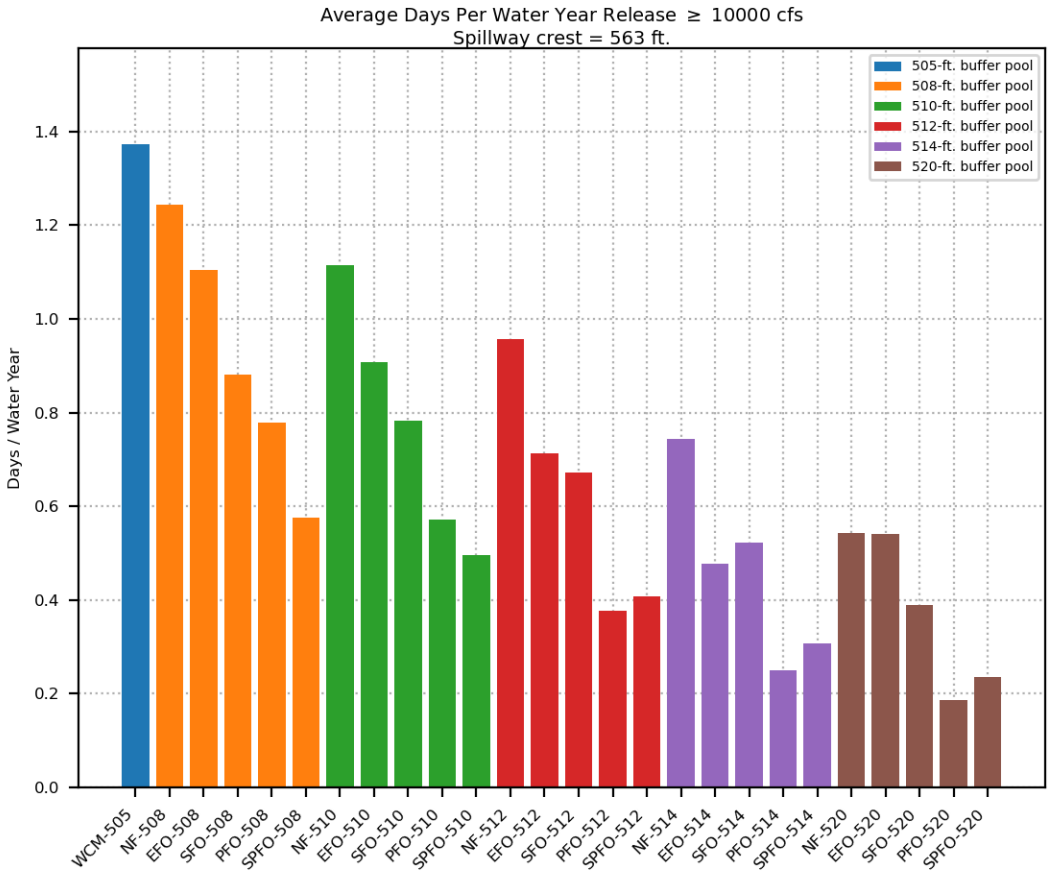

Increase in Average Days Per Water Year Pool Elevation > 520 ft. Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0.0
0.2
0.4
0.6
0.8
0.000
411.4
822.9
1234.
1646.
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

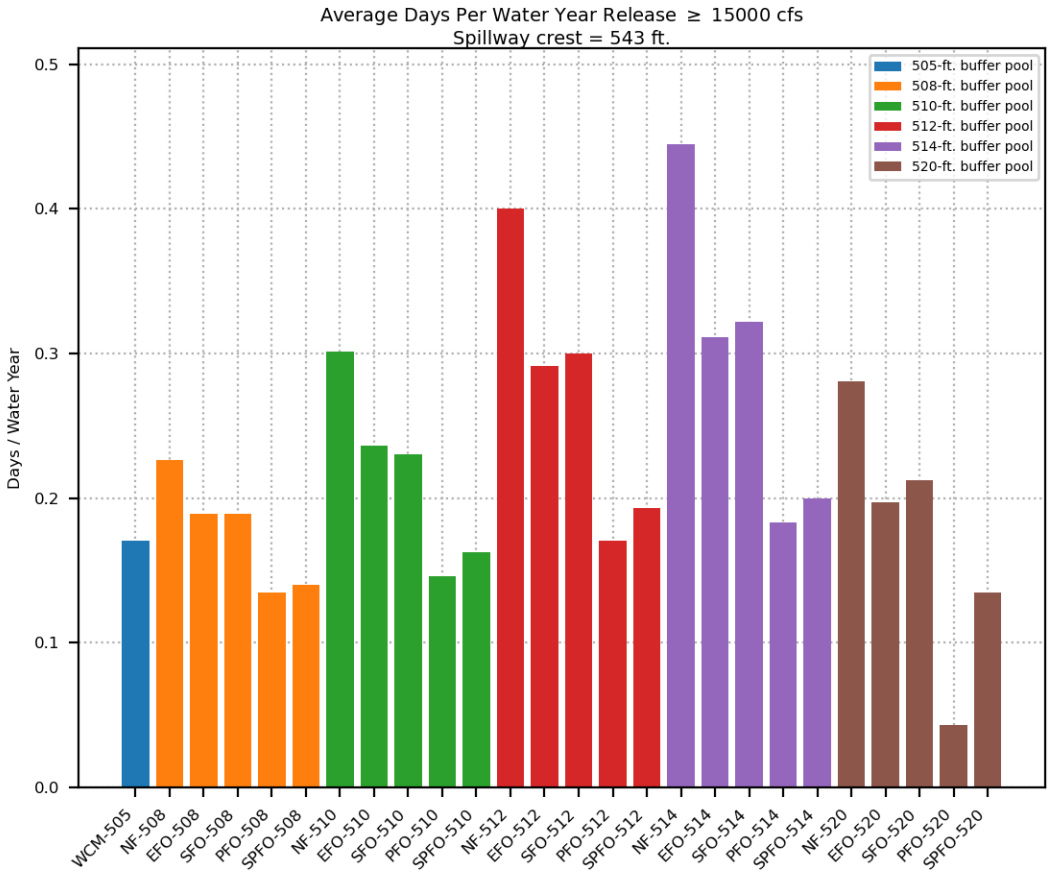

Increase in Average Days Per Water Year Pool Elevation > 520 ft. Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0.0
0.2
0.4
0.6
0.8
Percent Increase (%)
0.000
411.4
822.9
1234.
1646.
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

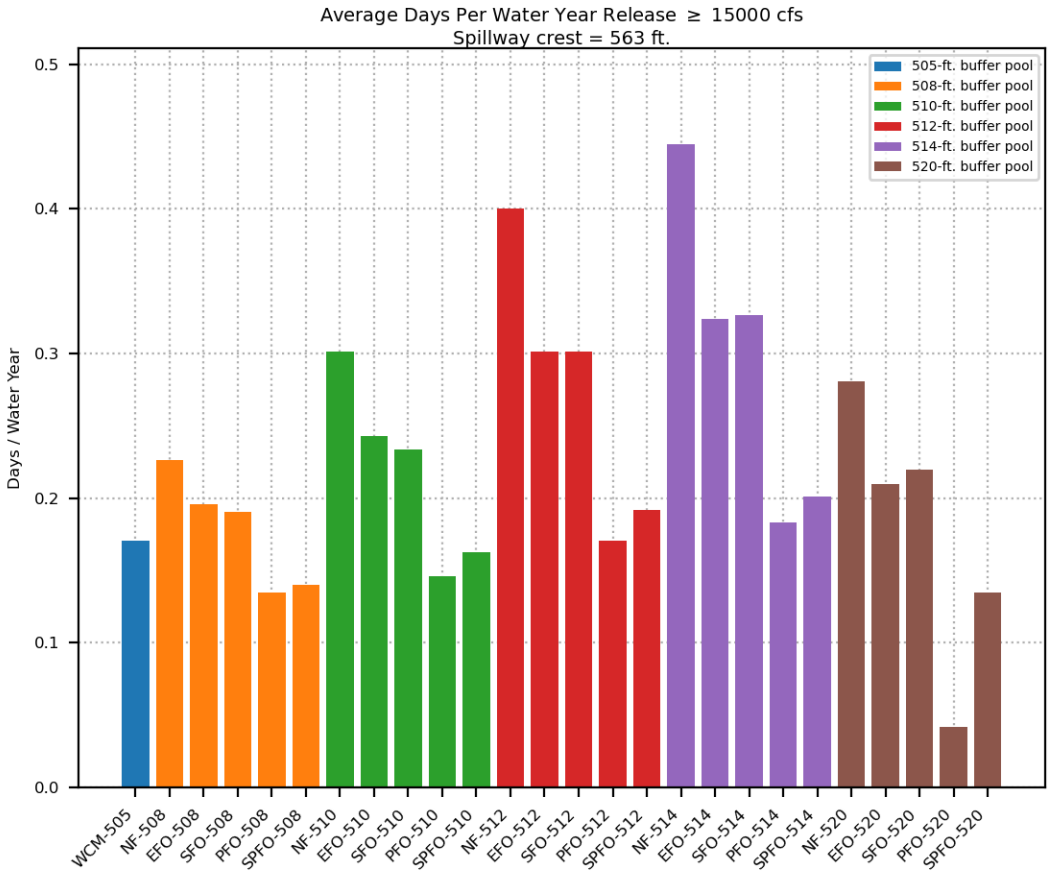

Average Days Per Water Year Release ≥ 5000 cfs
Spillway crest = 543 ft.
Days / Water Year
0.0
0.5
1.0
1.5
2.0
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

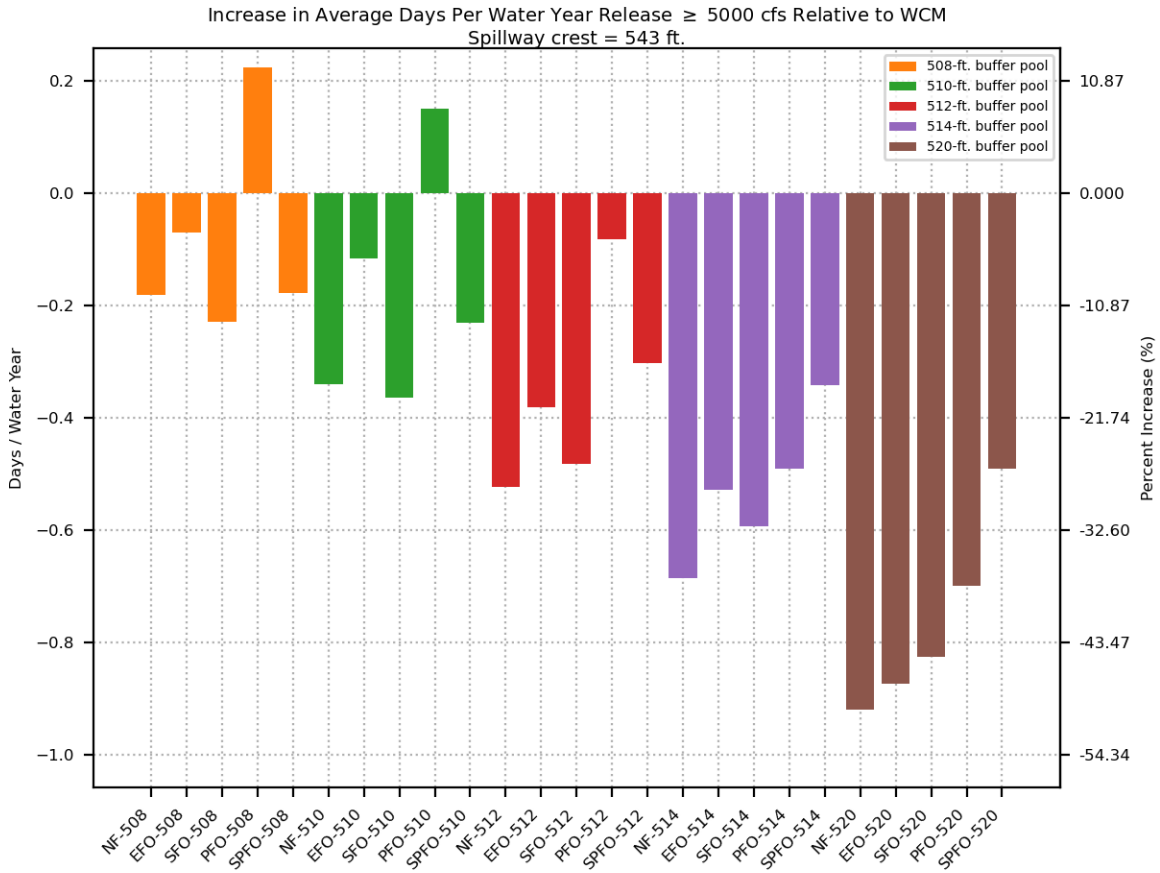

Average Days Per Water Year Release ≥ 5000 cfs
Spillway crest = 563 ft.
Days / Water Year
0.0
0.5
1.0
1.5
2.0
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

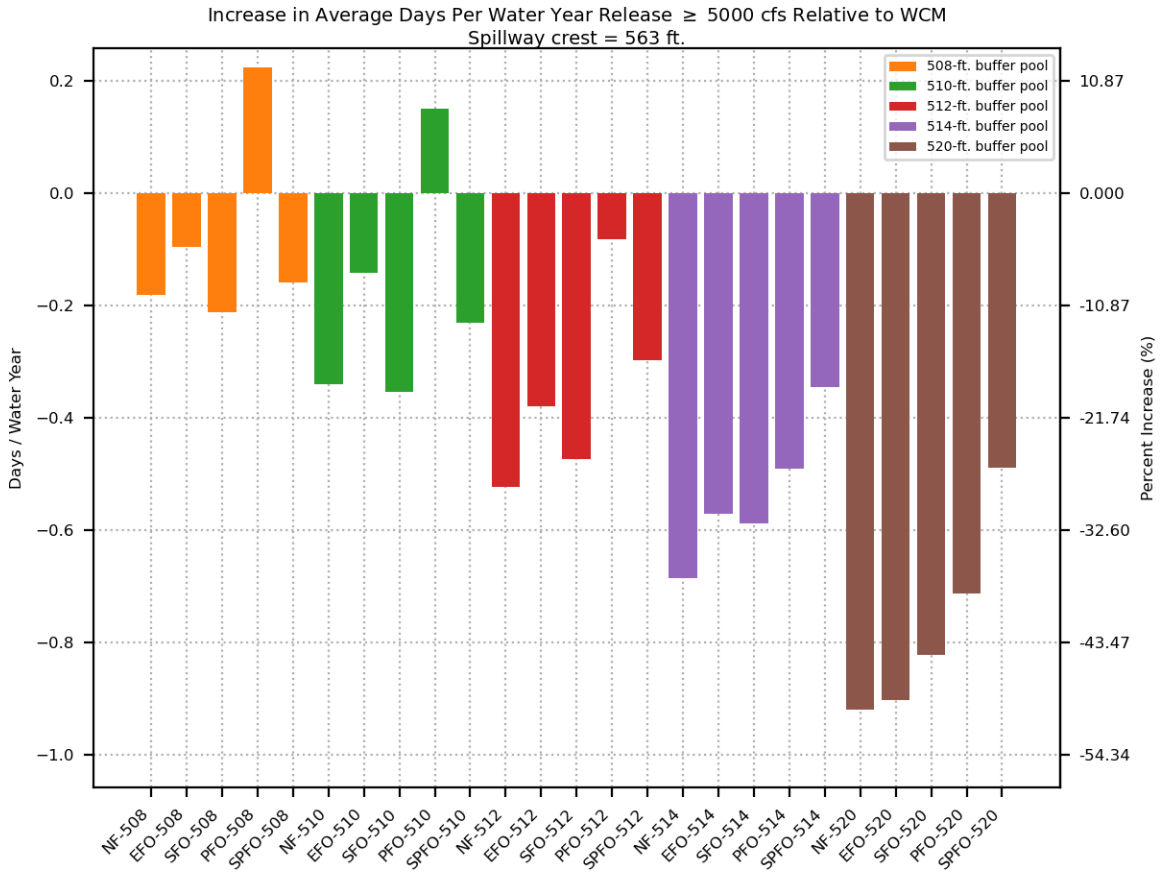

Average Days Per Water Year Release ≥ 10000 cfs
Spillway crest = 543 ft.
Days / Water Year
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

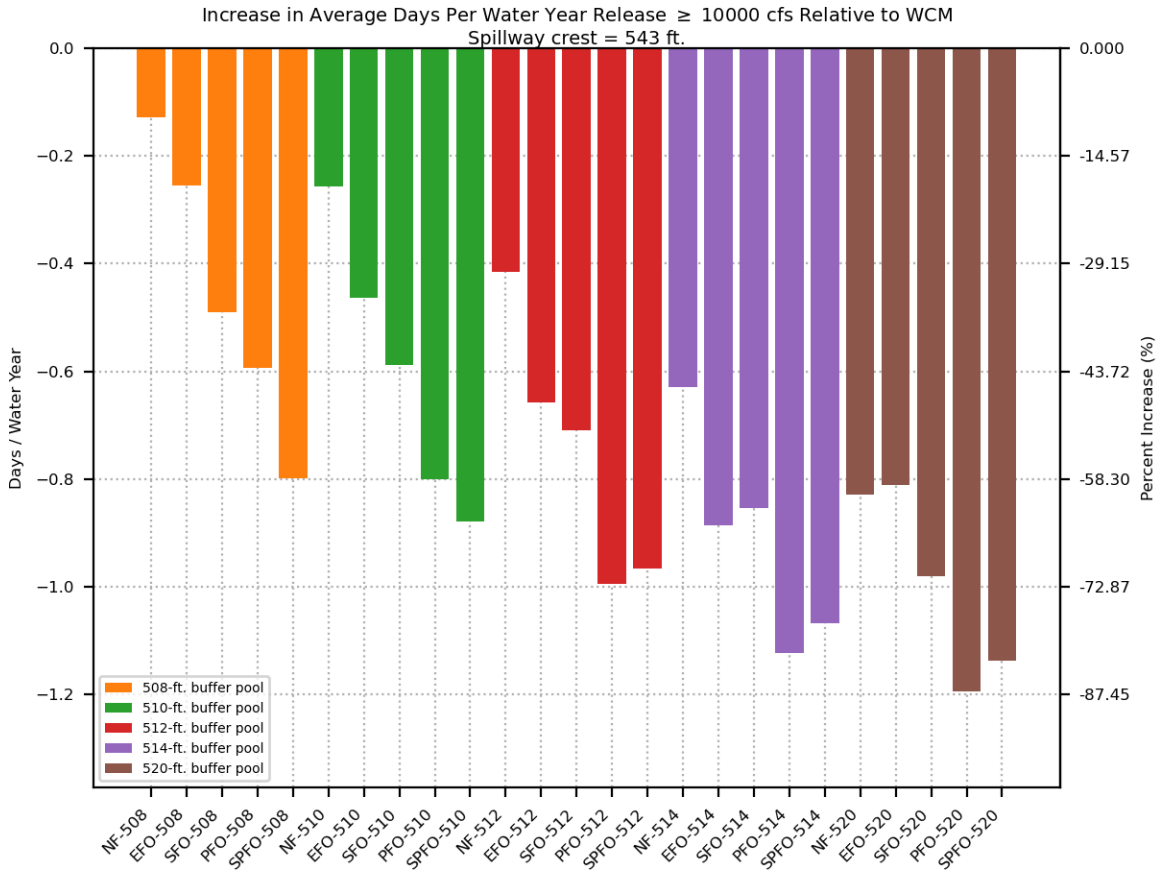

Average Days Per Water Year Release ≥ 10000 cfs
Spillway crest = 563 ft.
Days / Water Year
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

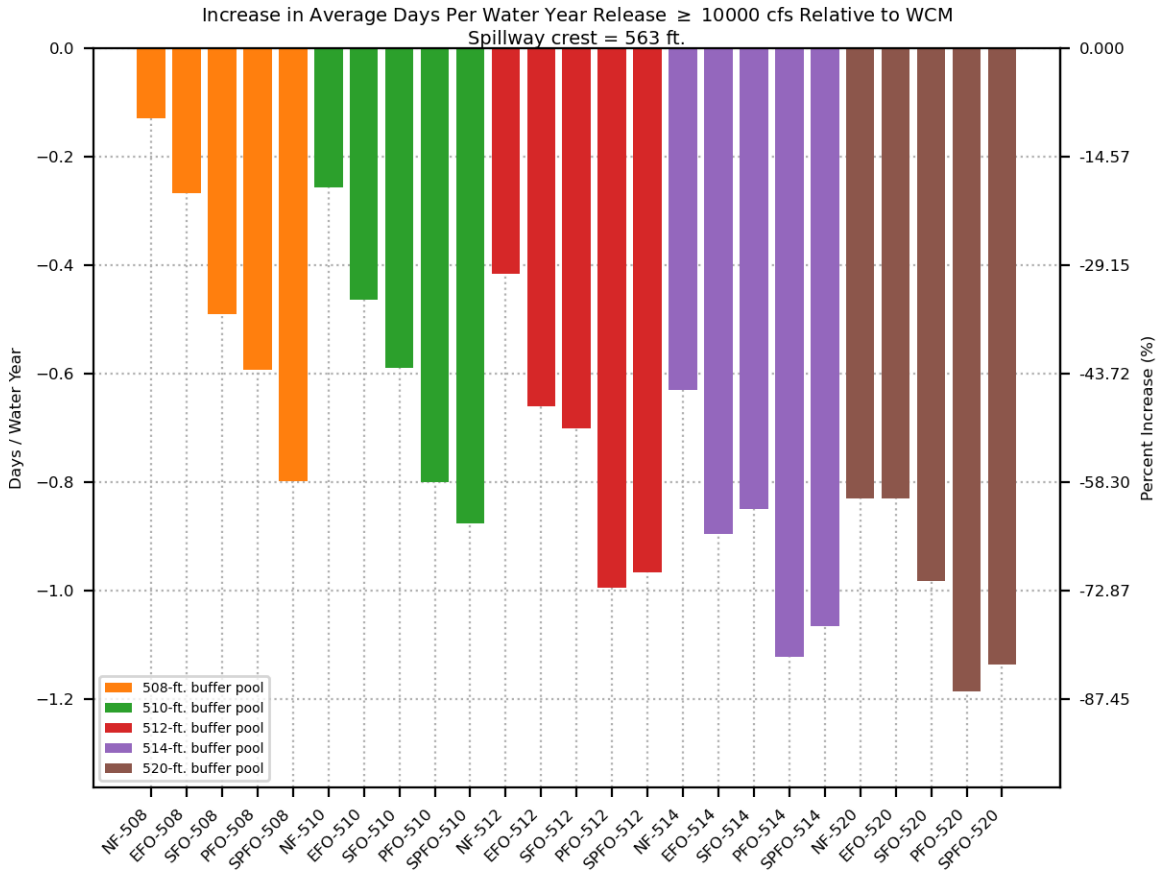

Average Days Per Water Year Release ≥ 15000 cfs
Spillway crest = 543 ft.
Days / Water Year
0.0
0.1
0.2
0.3
0.4
0.5
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

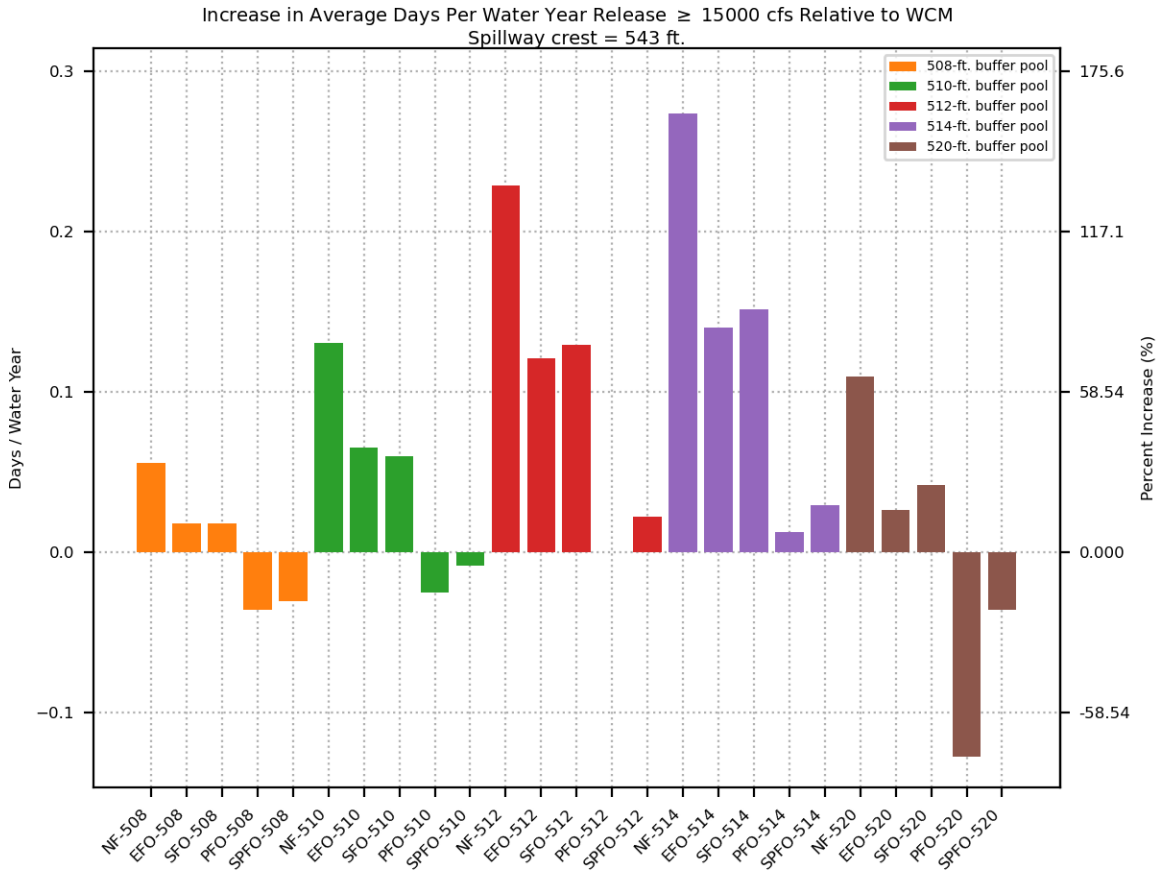

Average Days Per Water Year Release ≥ 15000 cfs
Spillway crest = 563 ft.
Days / Water Year
0.0
0.1
0.2
0.3
0.4
0.5
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

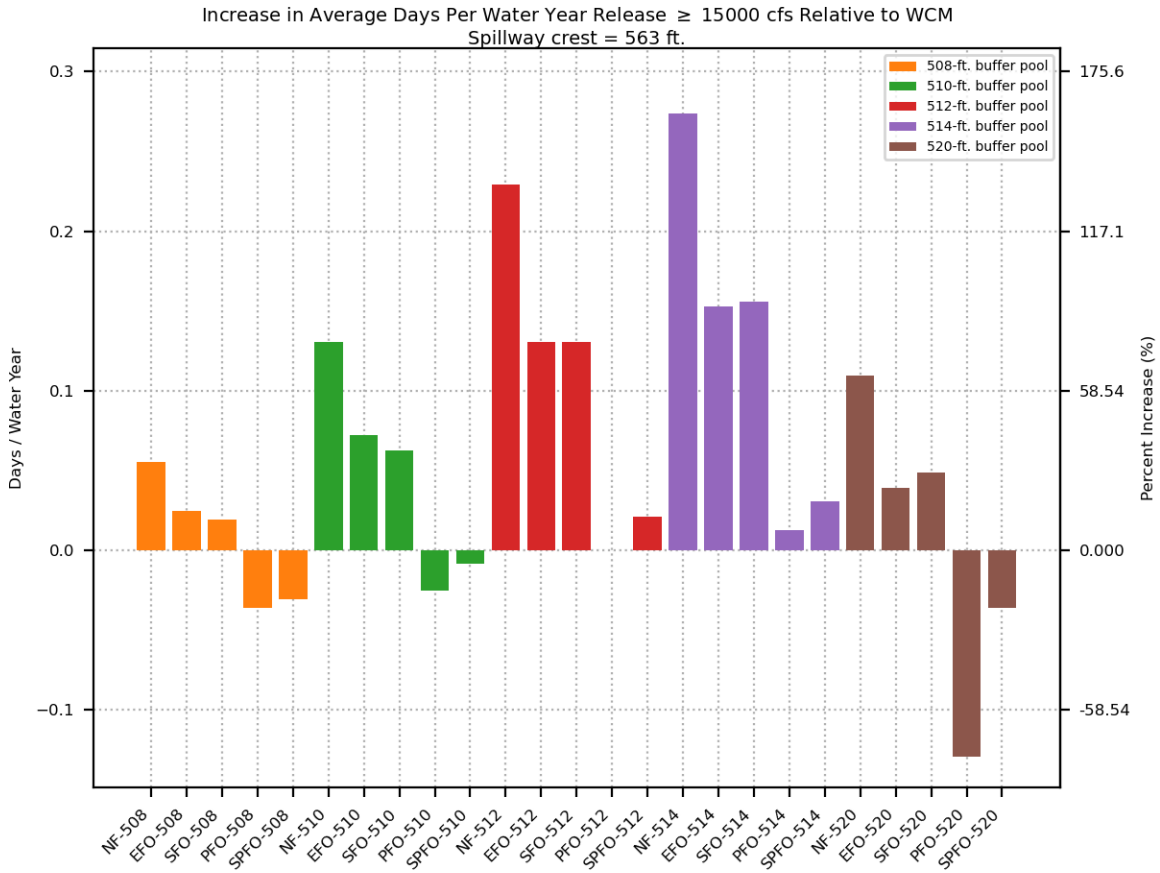

Increase in Average Days Per Water Year Release ≥ 5000 cfs Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
10.87
0.000
-10.87
-21.74
-32.60
-43.47
-54.34
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

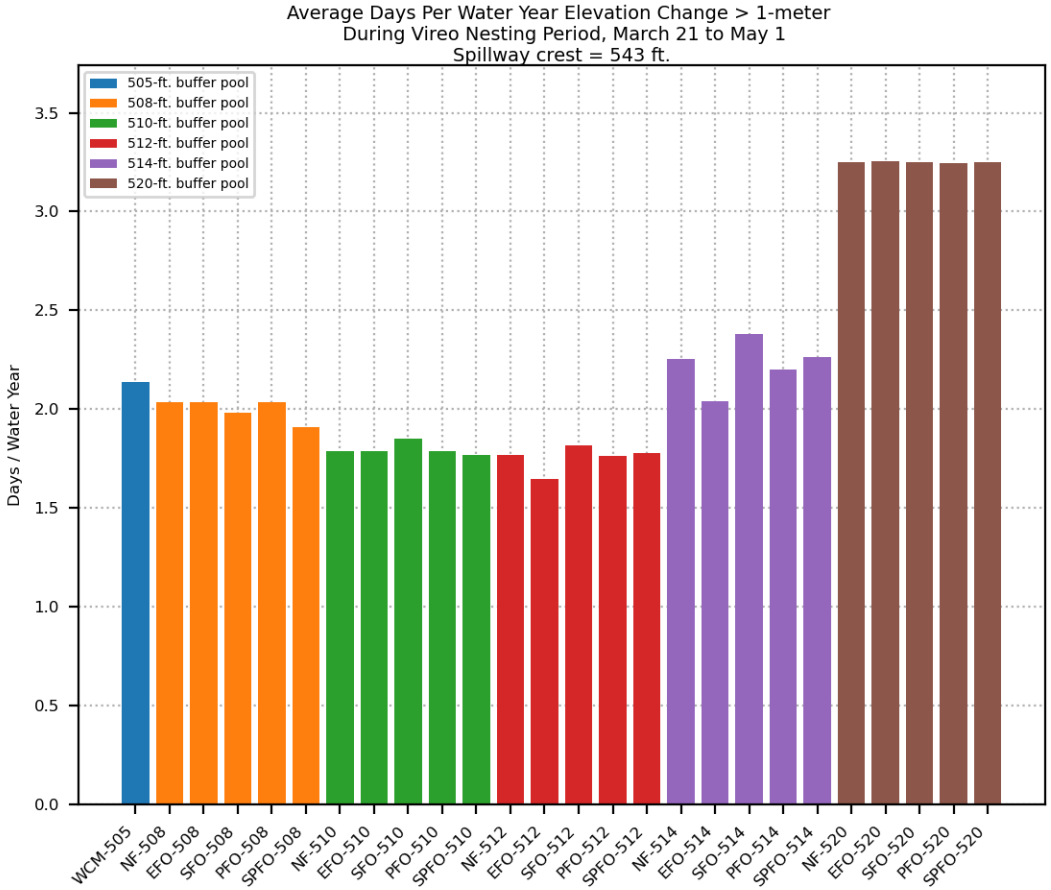

Increase in Average Days Per Water Year Release ≥ 5000 cfs Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
10.87
0.000
-10.87
-21.74
-32.60
-43.47
-54.34
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

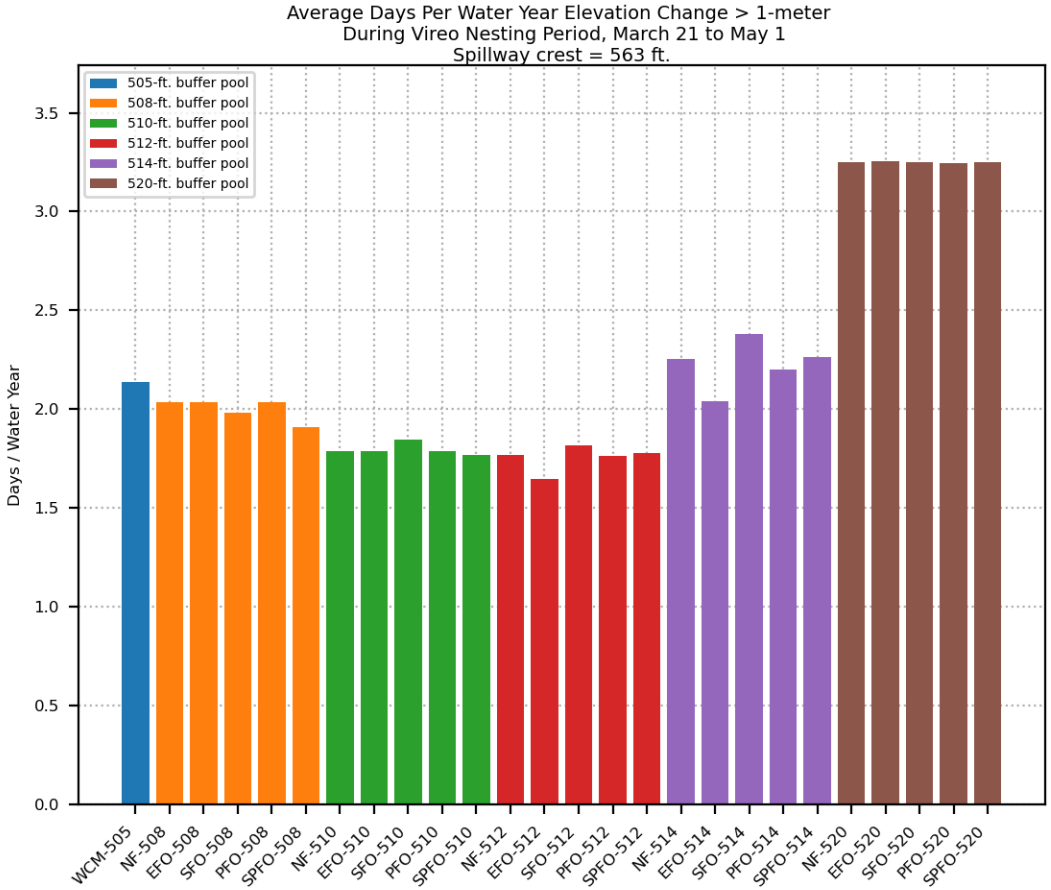

Increase in Average Days Per Water Year Release ≥ 10000 cfs Relative to WCM
Spillway crest = 543 ft.
Days / Water Year
Percent Increase (%)
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
0.000
-14.57
-29.15
-43.72
-58.30
-72.87
-87.45
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

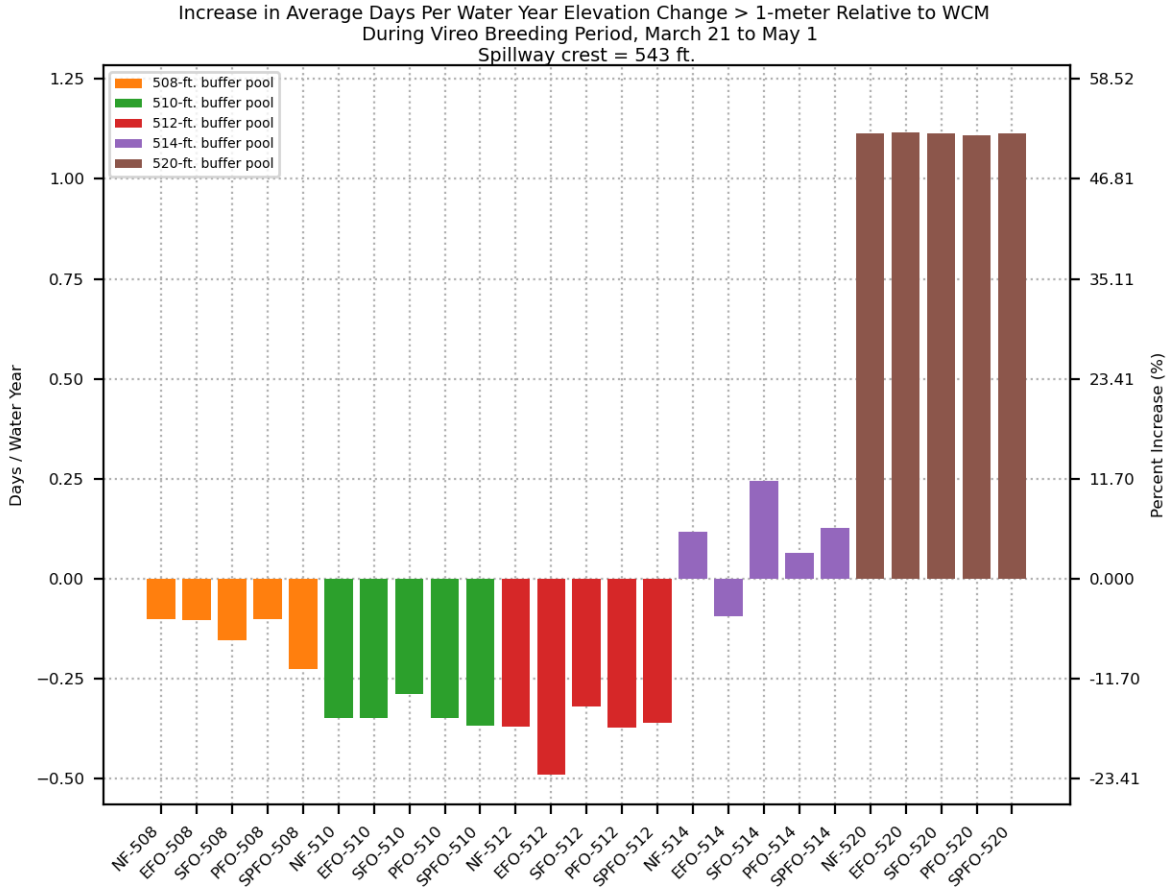

Increase in Average Days Per Water Year Release ≥ 10000 cfs Relative to WCM
Spillway crest = 563 ft.
Days / Water Year
Percent Increase (%)
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
0.000
-14.57
-29.15
-43.72
-58.30
-72.87
-87.45
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

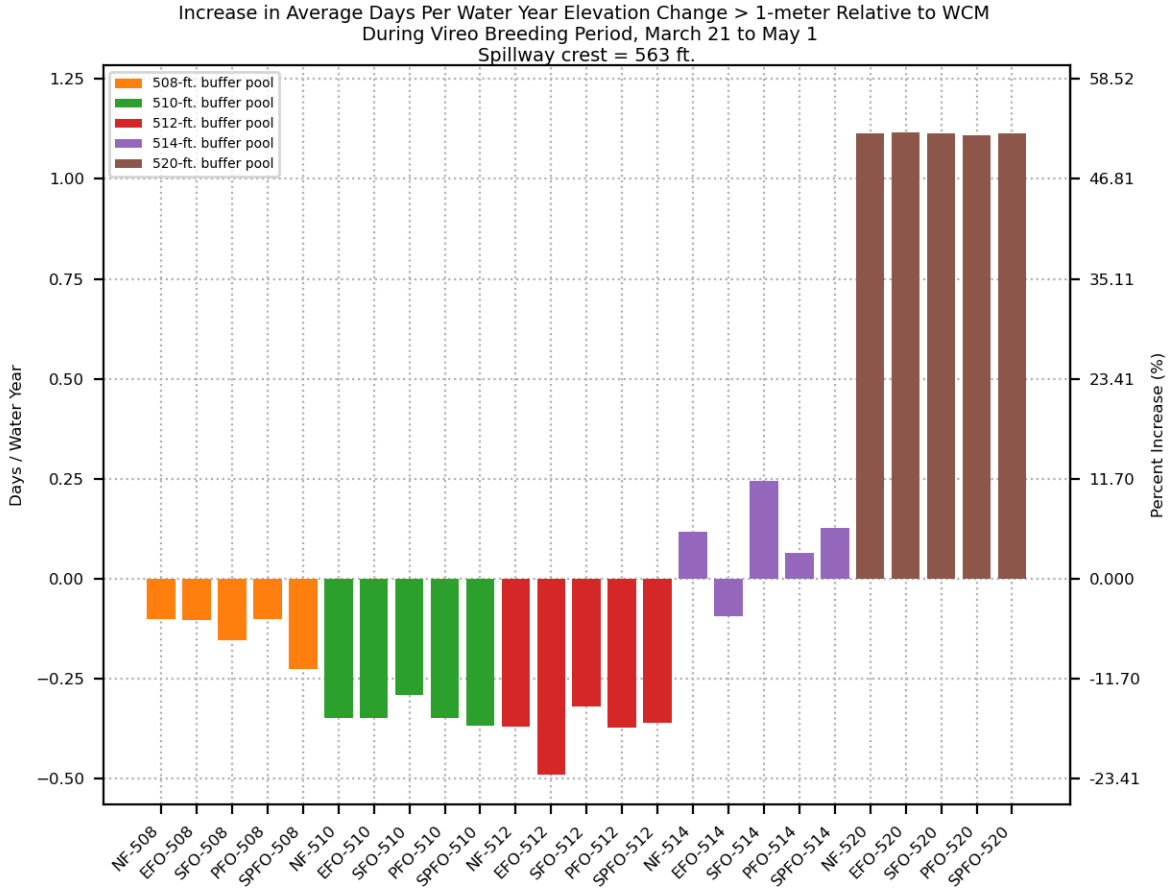

Increase in Average Days Per Water Year Release ≥ 15000 cfs Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0.3
0.2
0.1
0.0
−0.1
175.6
117.1
58.54
0.000
-58.54
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Increase in Average Days Per Water Year Release ≥ 15000 cfs Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0.3
0.2
0.1
0.0
−0.1
175.6
117.1
58.54
0.000
-58.54
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Average Days Per Water Year Elevation Change > 1-meter
During Vireo Nesting Period, March 21 to May 1
Spillway crest = 543 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Average Days Per Water Year Elevation Change > 1-meter
During Vireo Nesting Period, March 21 to May 1
Spillway crest = 563 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Increase in Average Days Per Water Year Elevation Change > 1-meter Relative to WCM
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
1.25
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
58.52
46.81
35.11
23.41
11.70
0.000
-11.70
-23.41
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520


Increase in Average Days Per Water Year Elevation Change > 1-meter Relative to WCM
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
1.25
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
58.52
46.81
35.11
23.41
11.70
0.000
-11.70
-23.41
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514
NF-520
EFO-520
SFO-520
PFO-520
SPFO-520

HEMP Metrics – Bar Charts (No 520)

- Average annual groundwater recharge (AAGR)
- Change in AAGR relative to WCM (baseline)

- Average annual Santa Anna River discharge (AASRD) to Pacific Ocean
- Change in AASRD relative to WCM (baseline)

- Average days/yr > 505’, 508’, 510’, 512’, 514’, 520’
- Change in days/yr > 505’, 508’, 510’, 512’, 514’, 520’ relative to WCM (baseline)

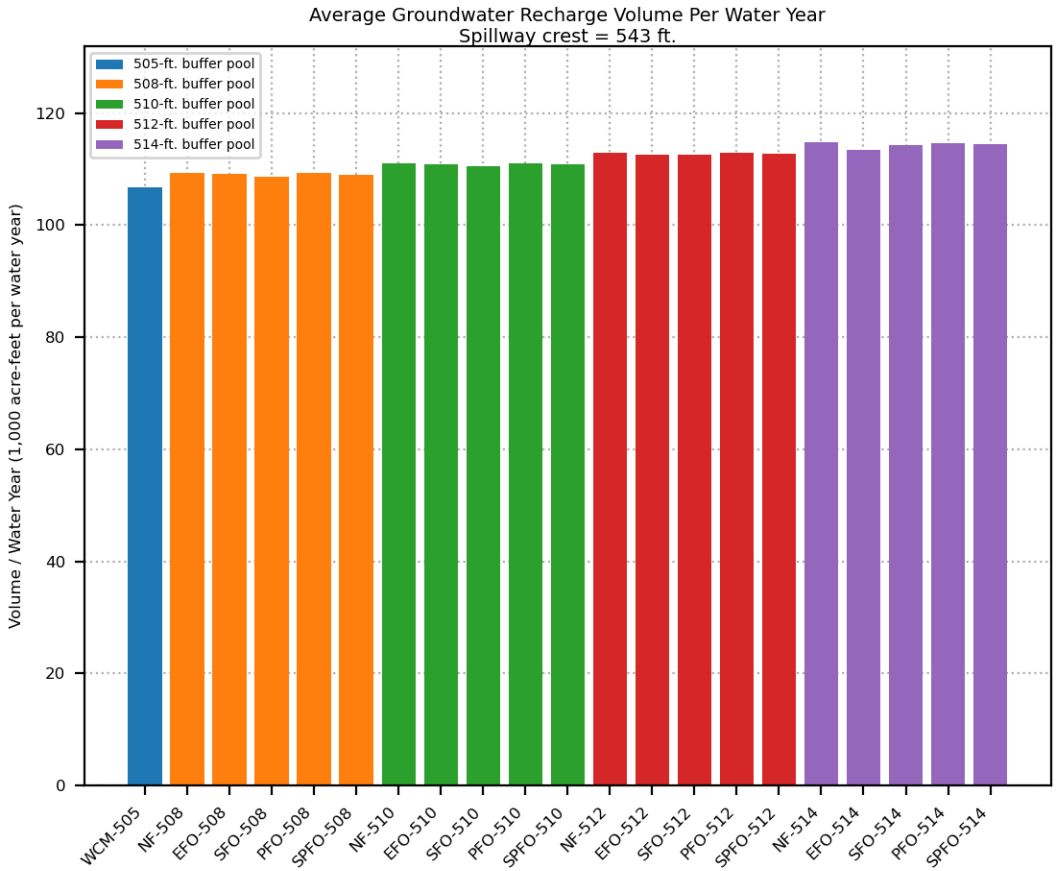
HEMP Metrics – Bar Charts (No 520)

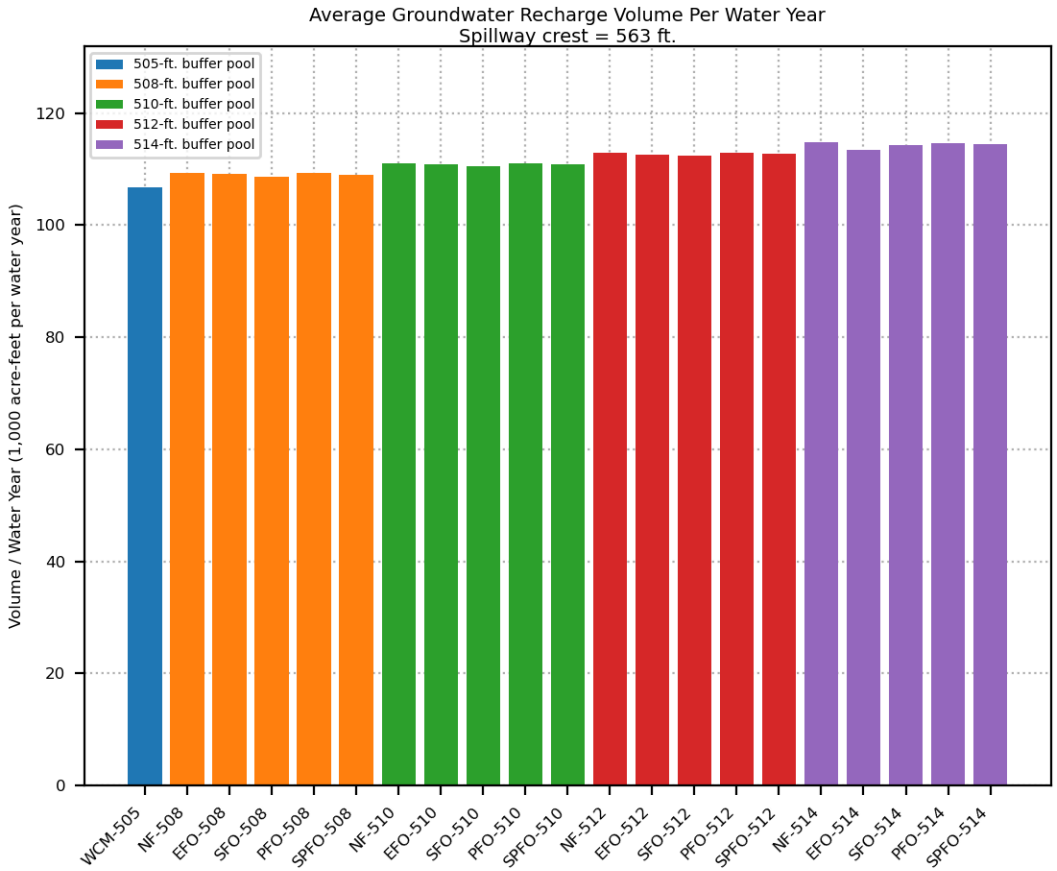
- Average days/yr > 5,000, 10,000, 15,000 cfs
- Change in days/yr > 5,000, 10,000, 15,000 cfs relative to WCM (baseline)

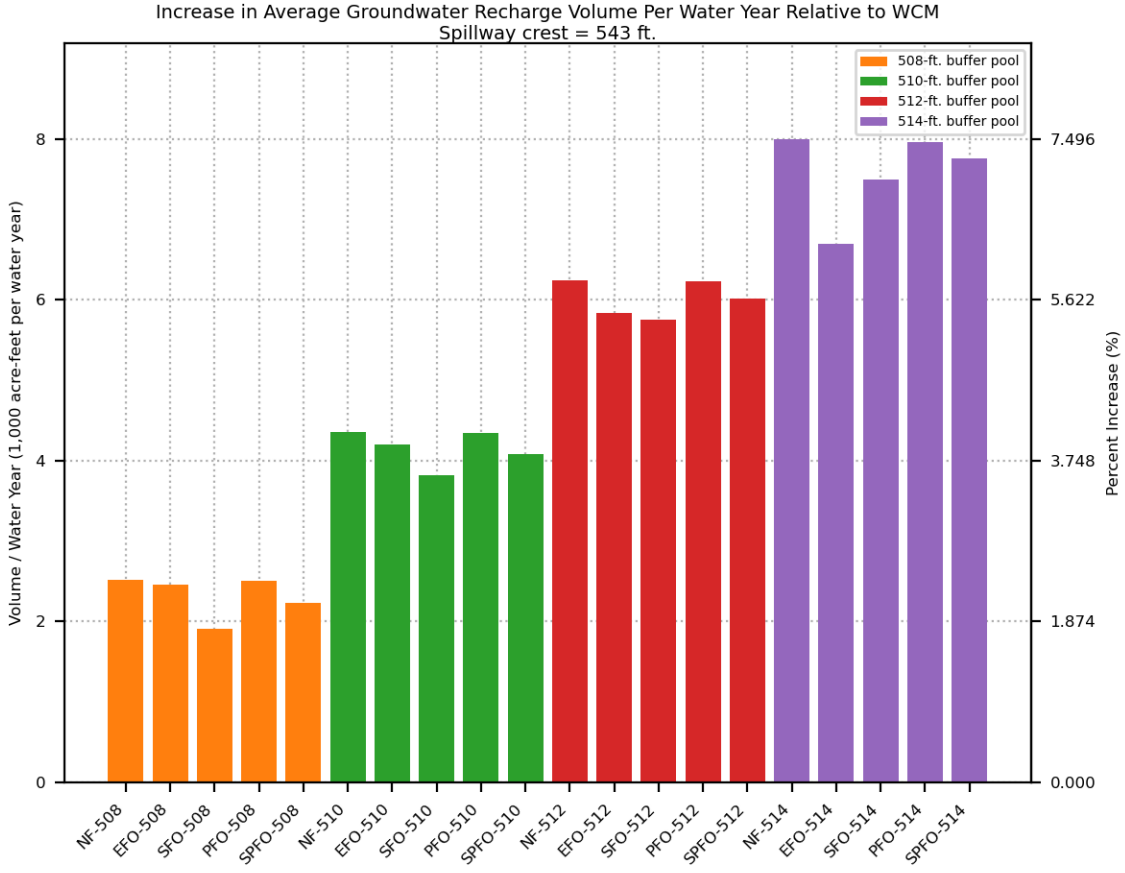
- Average days/yr > 1 meter pool rise during vireo nesting season (3/21-5/1)
- Change in days/yr > 1 meter pool rise during vireo nesting season (3/21–5/1) relative to WCM (baseline)

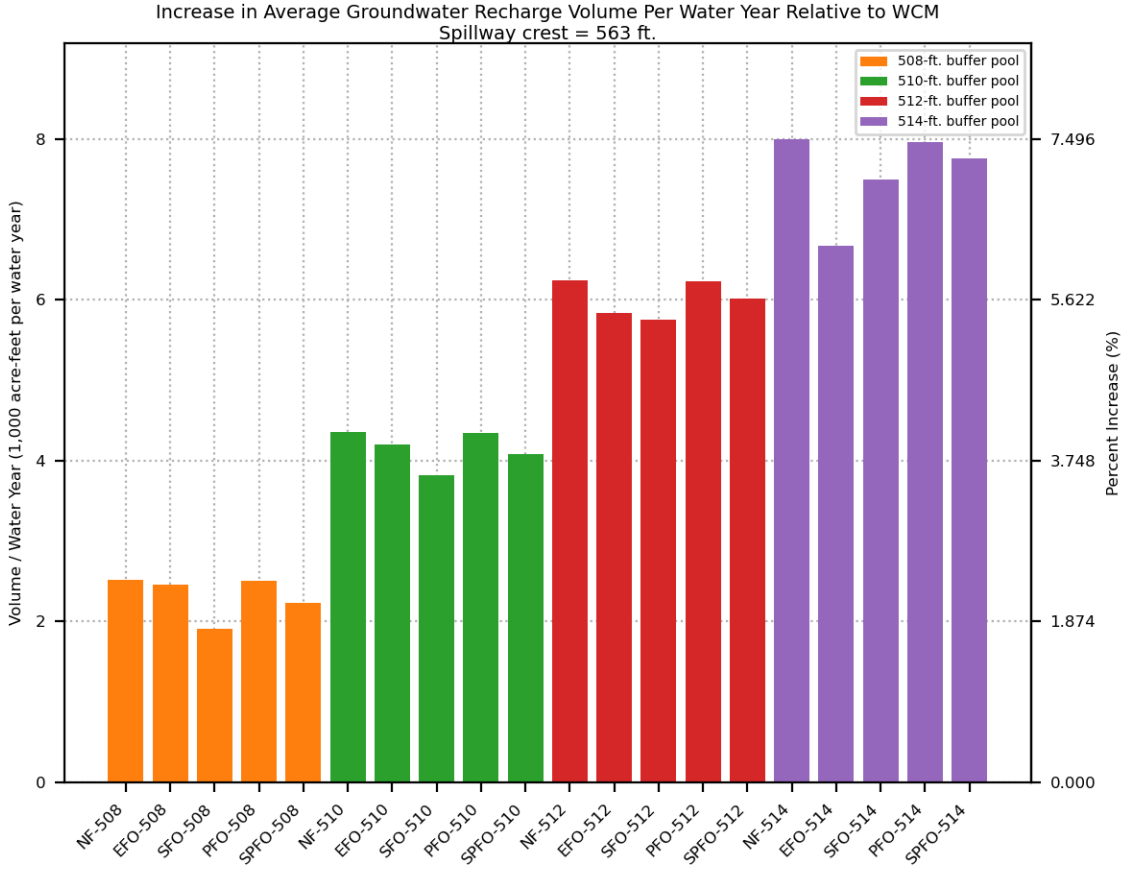
HEMP Metrics – Bar Charts (No 520)

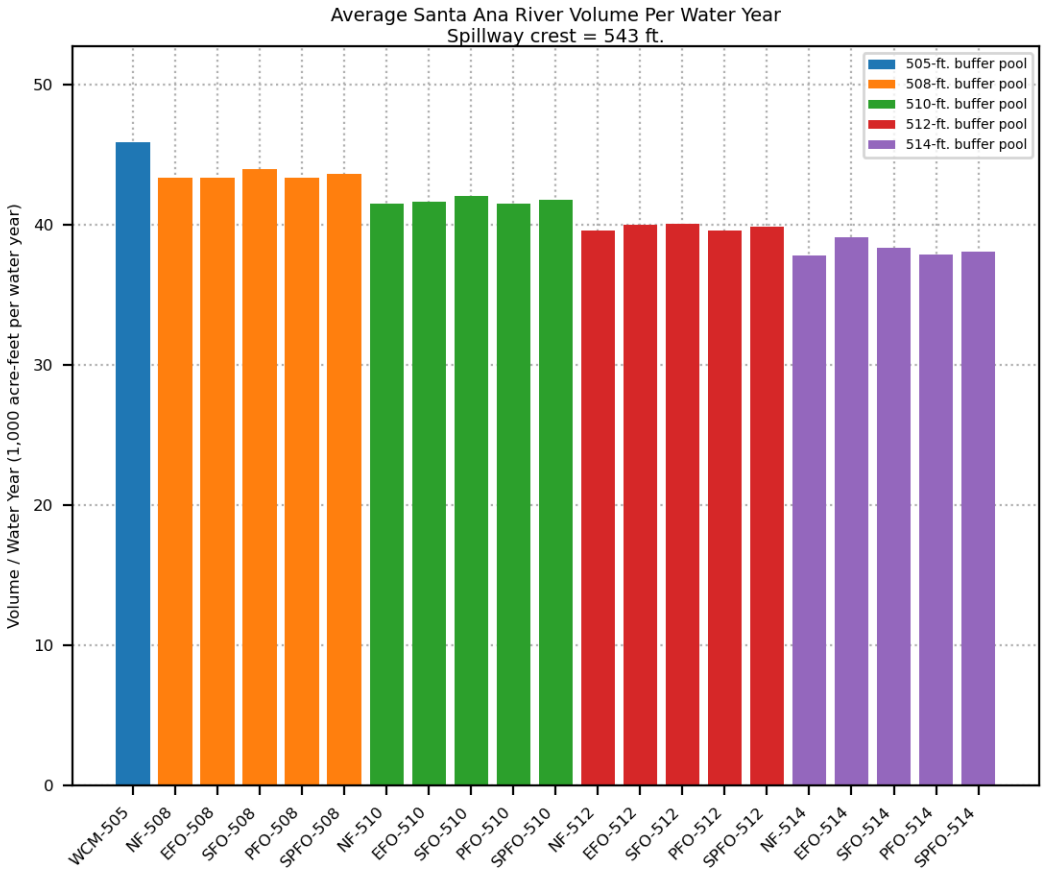
- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’, 510’, 512’, 514’
- WCP alternatives across X Axis

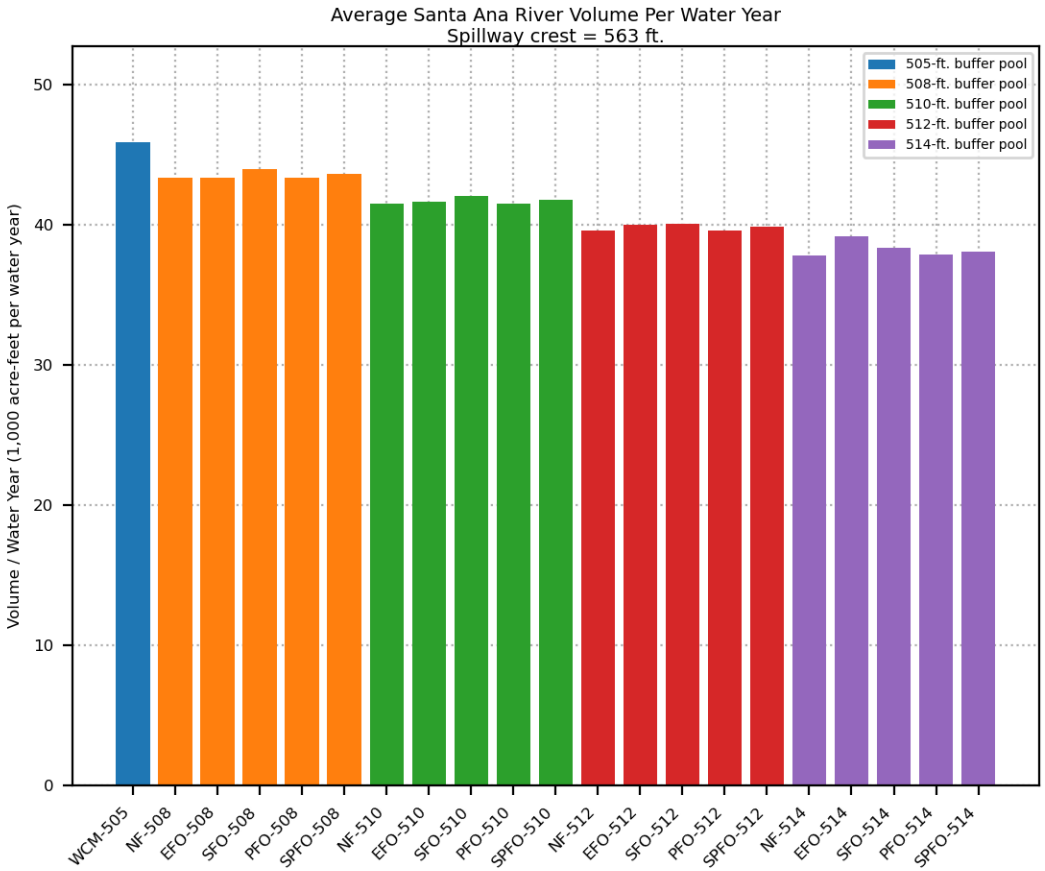

Average Groundwater Recharge Volume Per Water Year
Spillway crest = 543 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Volume / Water Year (1,000 acre-feet per water year)
0
20
40
60
80
100
120
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514

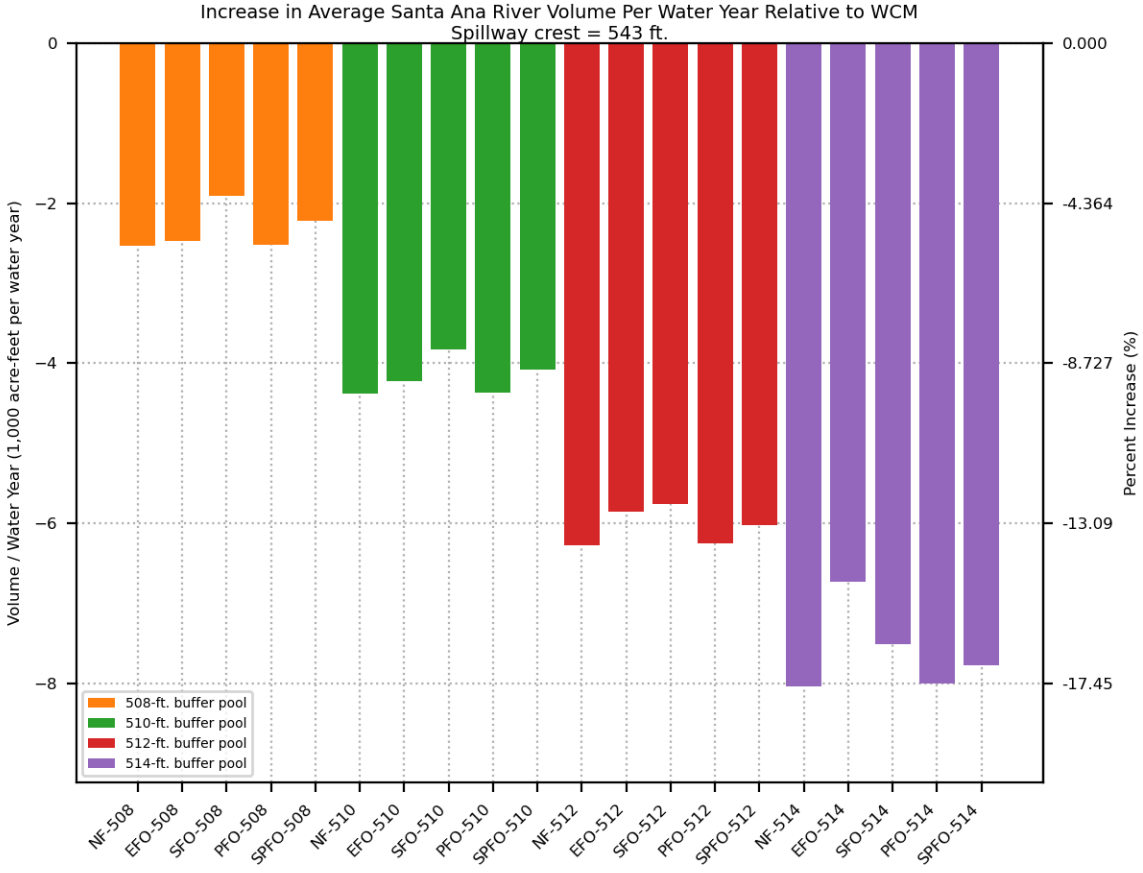

Average Groundwater Recharge Volume Per Water Year
Spillway crest = 563 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Volume / Water Year (1,000 acre-feet per water year)
0
20
40
60
80
100
120
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514

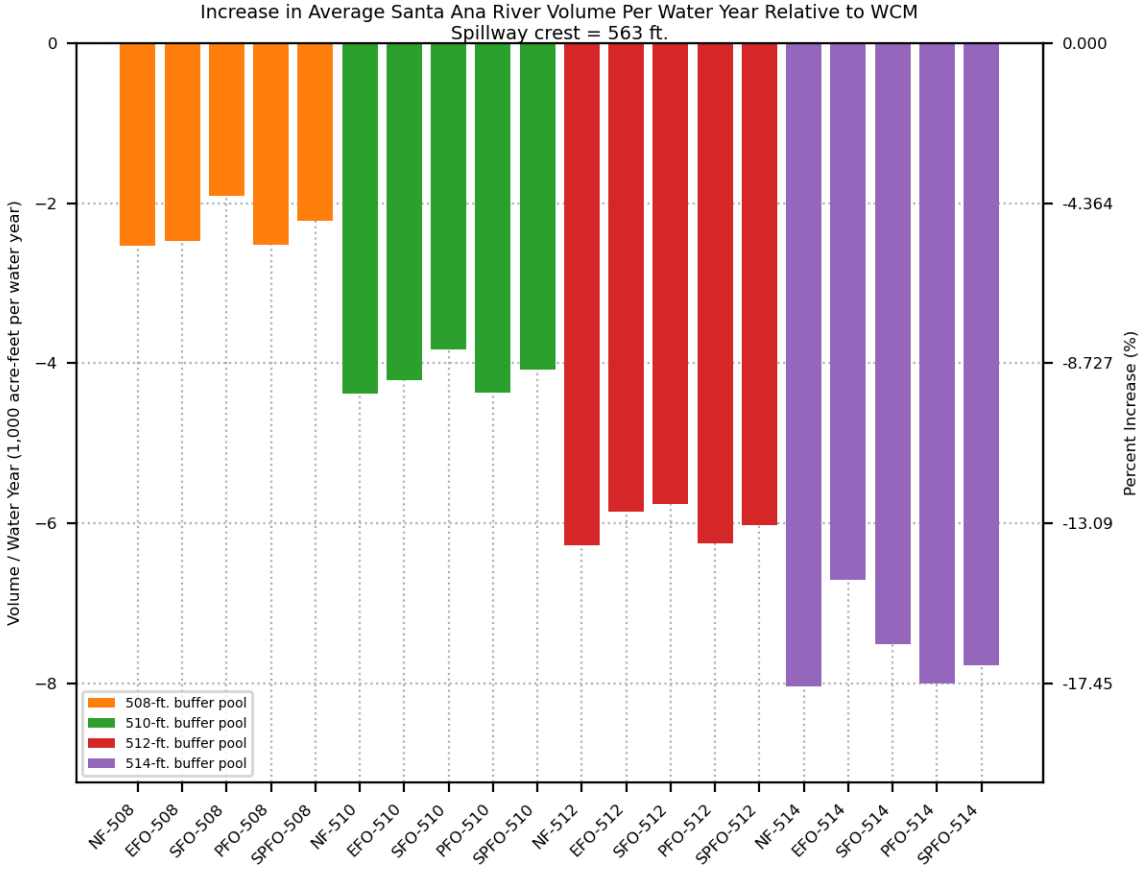

Increase in Average Groundwater Recharge Volume Per Water Year Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Volume / Water Year (1,000 acre-feet per water year)
Percent Increase (%)
0
2
4
6
8
0.000
1.874
3.748
5.622
7.496
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514

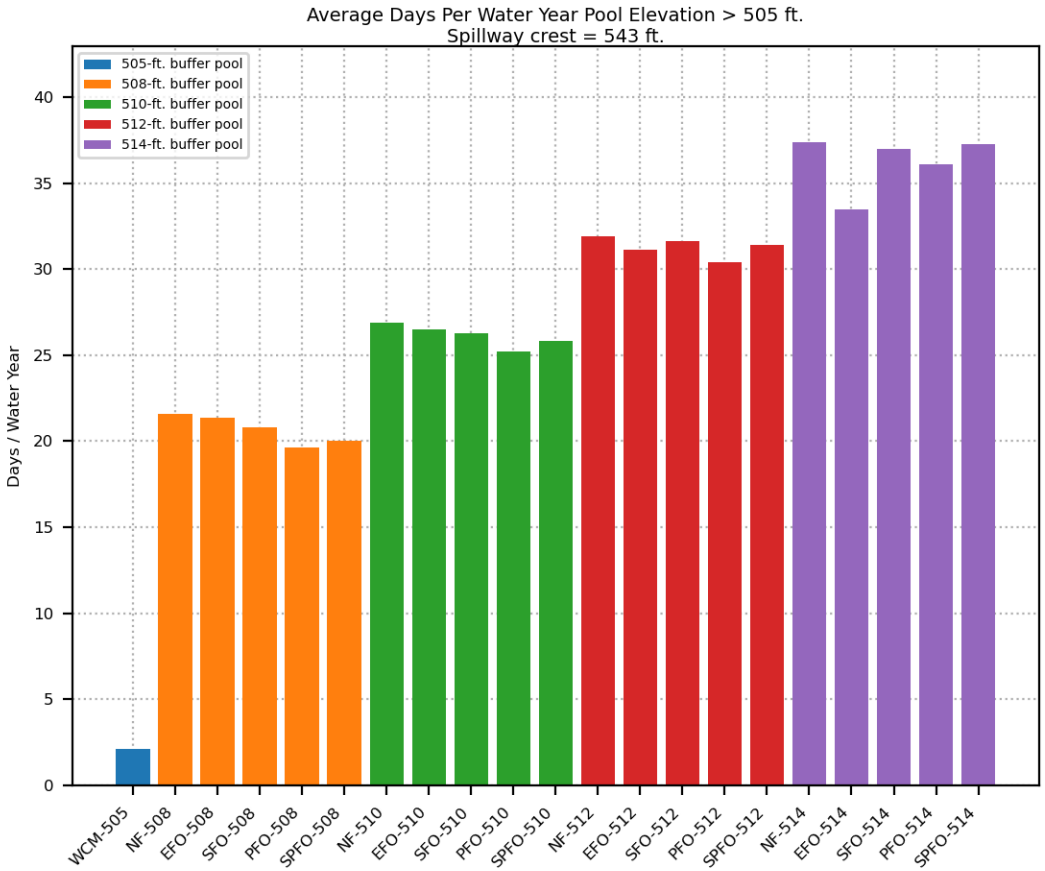

Increase in Average Groundwater Recharge Volume Per Water Year Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Volume / Water Year (1,000 acre-feet per water year)
Percent Increase (%)
0
2
4
6
8
0.000
1.874
3.748
5.622
7.496
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514

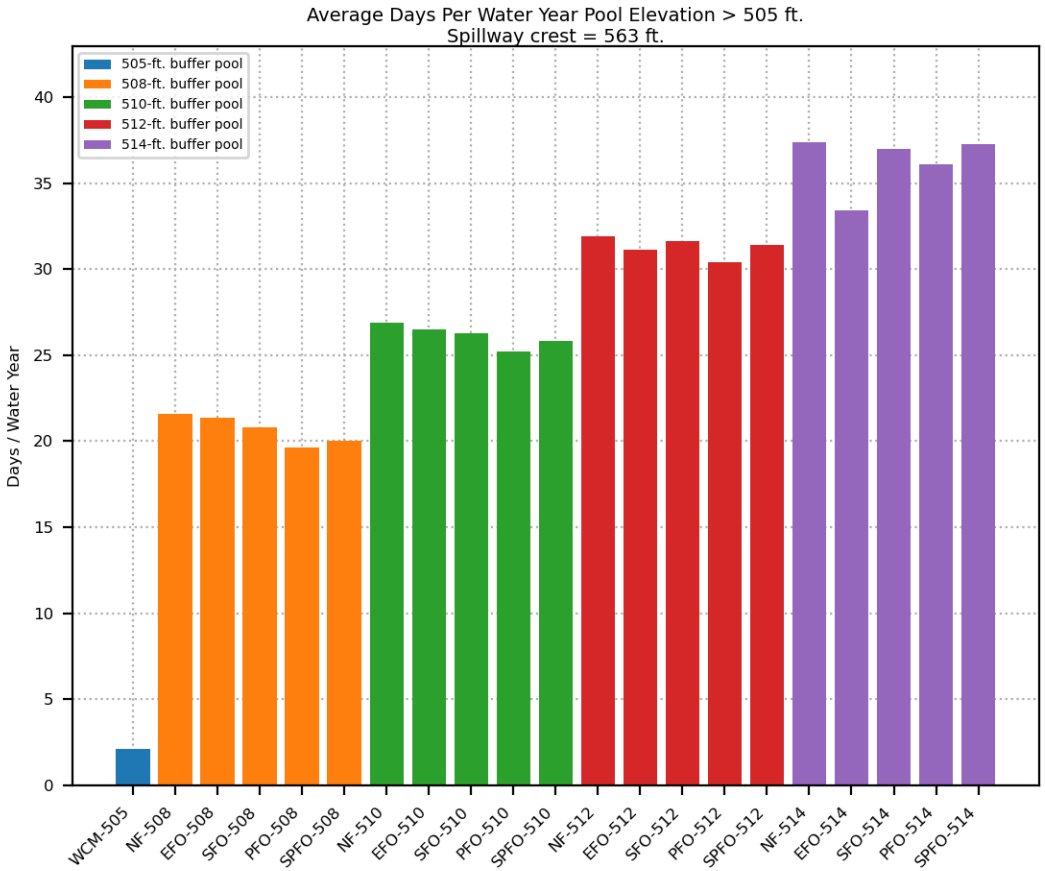

Average Santa Ana River Volume Per Water Year
Spillway crest = 543 ft.
Volume / Water Year (1,000 acre-feet per water year)
0
10
20
30
40
50
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514

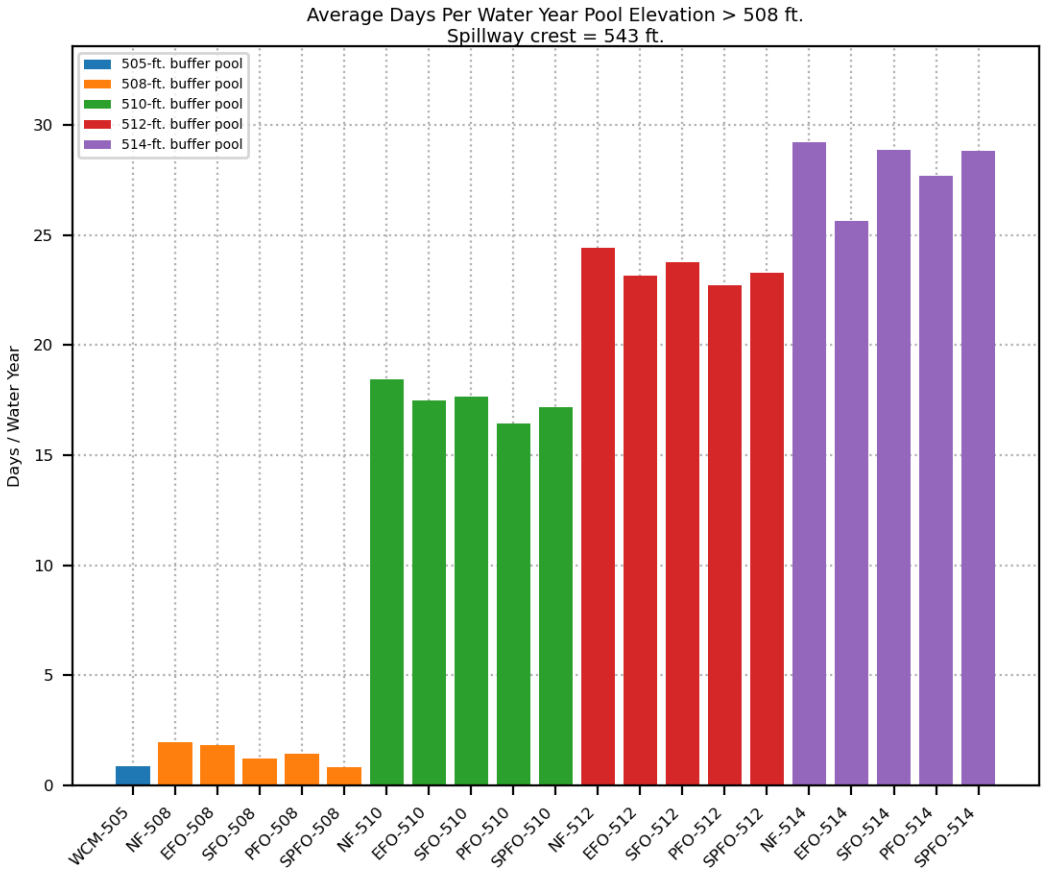

Average Santa Ana River Volume Per Water Year
Spillway crest = 563 ft.
Volume / Water Year (1,000 acre-feet per water year)
0
10
20
30
40
50
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514

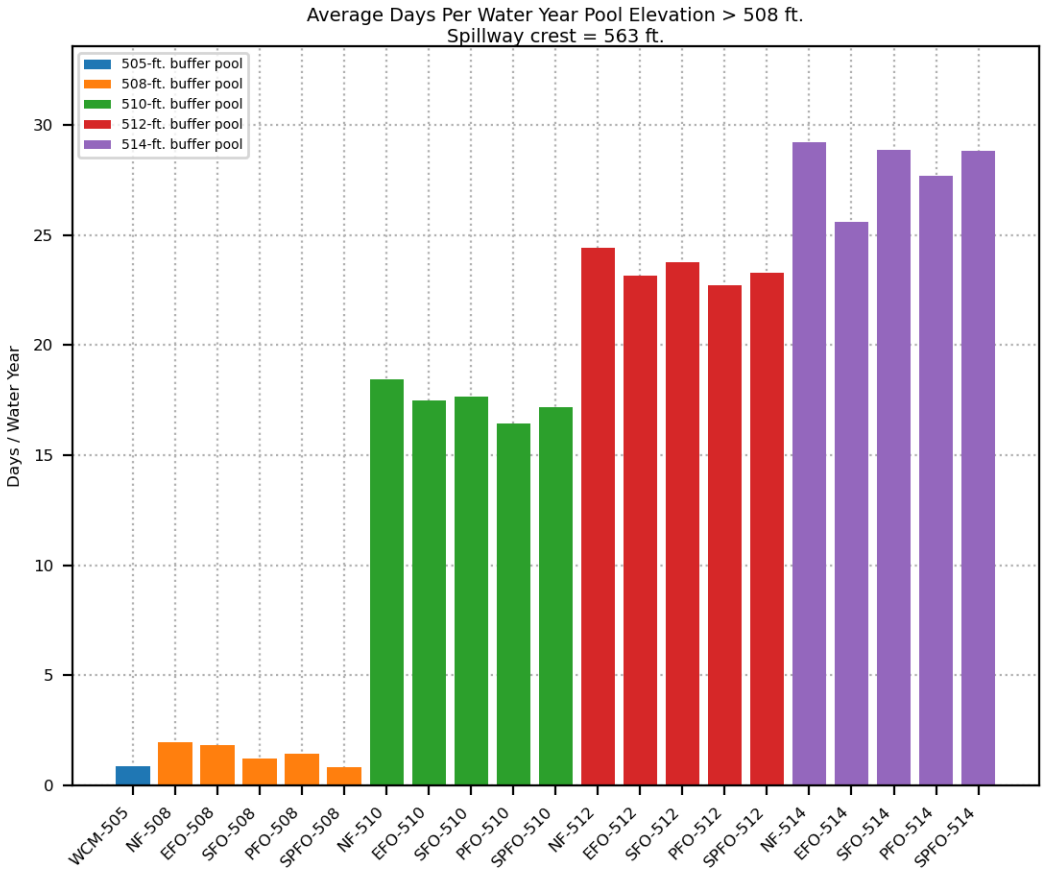

Increase in Average Santa Ana River Volume Per Water Year Relative to WCM
Spillway crest = 543 ft.
Volume / Water Year (1,000 acre-feet per water year)
Percent Increase (%)
0
−2
−4
−6
−8
0.000
-4.364
-8.727
-13.09
-17.45
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514

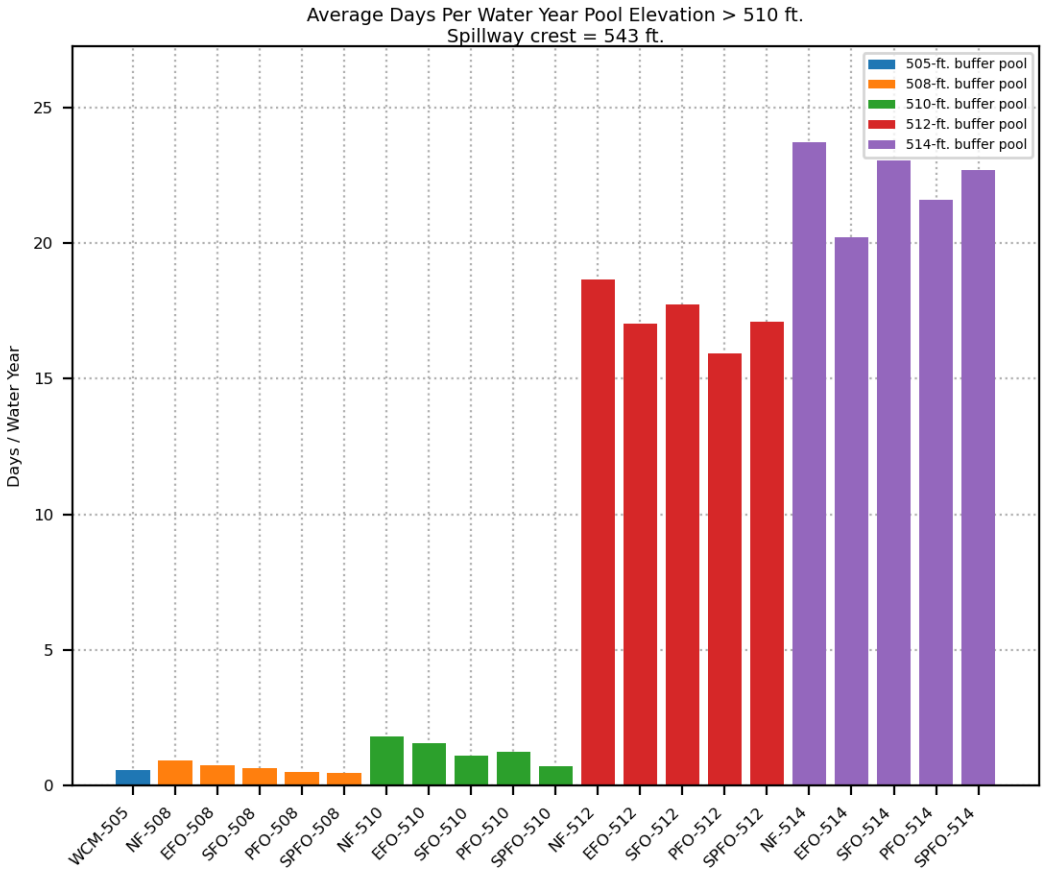

Increase in Average Santa Ana River Volume Per Water Year Relative to WCM
Spillway crest = 563 ft.
Volume / Water Year (1,000 acre-feet per water year)
Percent Increase (%)
0
−2
−4
−6
−8
0.000
-4.364
-8.727
-13.09
-17.45
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Average Days Per Water Year Pool Elevation > 505 ft.
Spillway crest = 543 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
0
5
10
15
20
25
30
35
40
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Average Days Per Water Year Pool Elevation > 505 ft.
Spillway crest = 563 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
0
5
10
15
20
25
30
35
40
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Average Days Per Water Year Pool Elevation > 508 ft.
Spillway crest = 543 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
0
5
10
15
20
25
30
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Average Days Per Water Year Pool Elevation > 508 ft.
Spillway crest = 563 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
0
5
10
15
20
25
30
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Average Days Per Water Year Pool Elevation > 510 ft.
Spillway crest = 543 ft.
Days / Water Year
0
5
10
15
20
25
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
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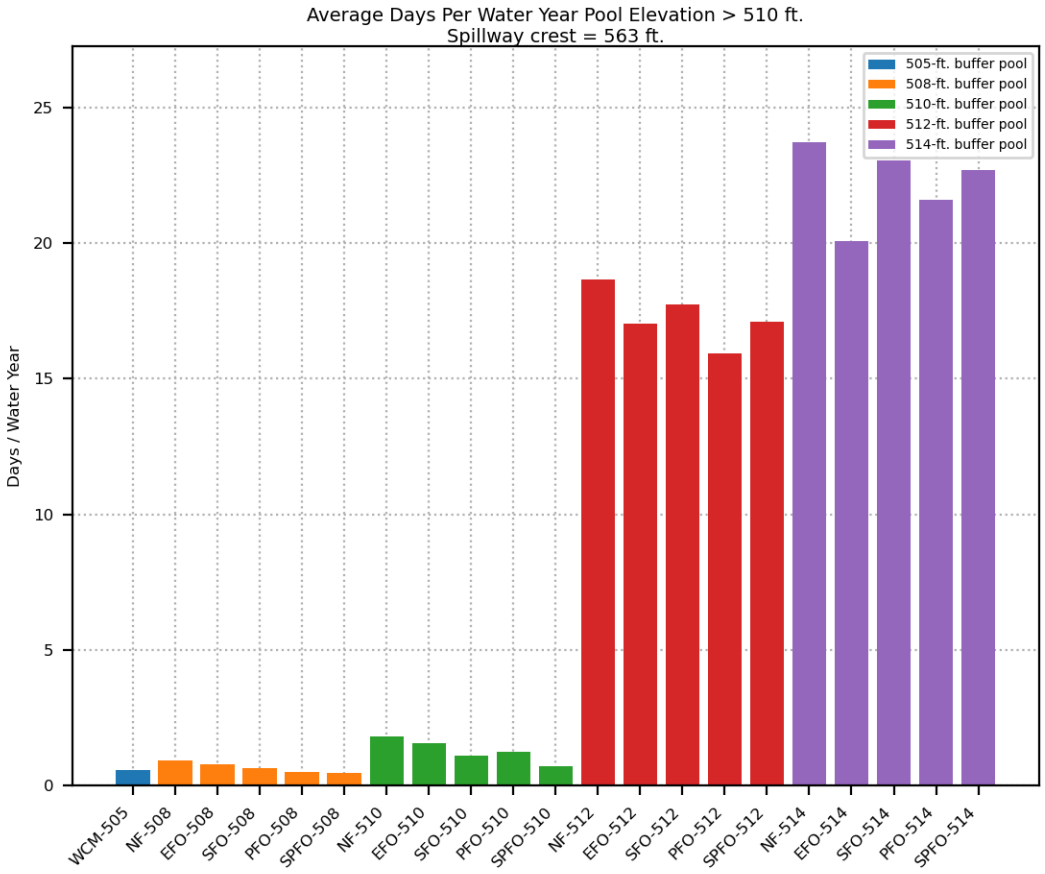
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Average Days Per Water Year Pool Elevation > 510 ft.
Spillway crest = 563 ft.
Days / Water Year
0
5
10
15
20
25
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
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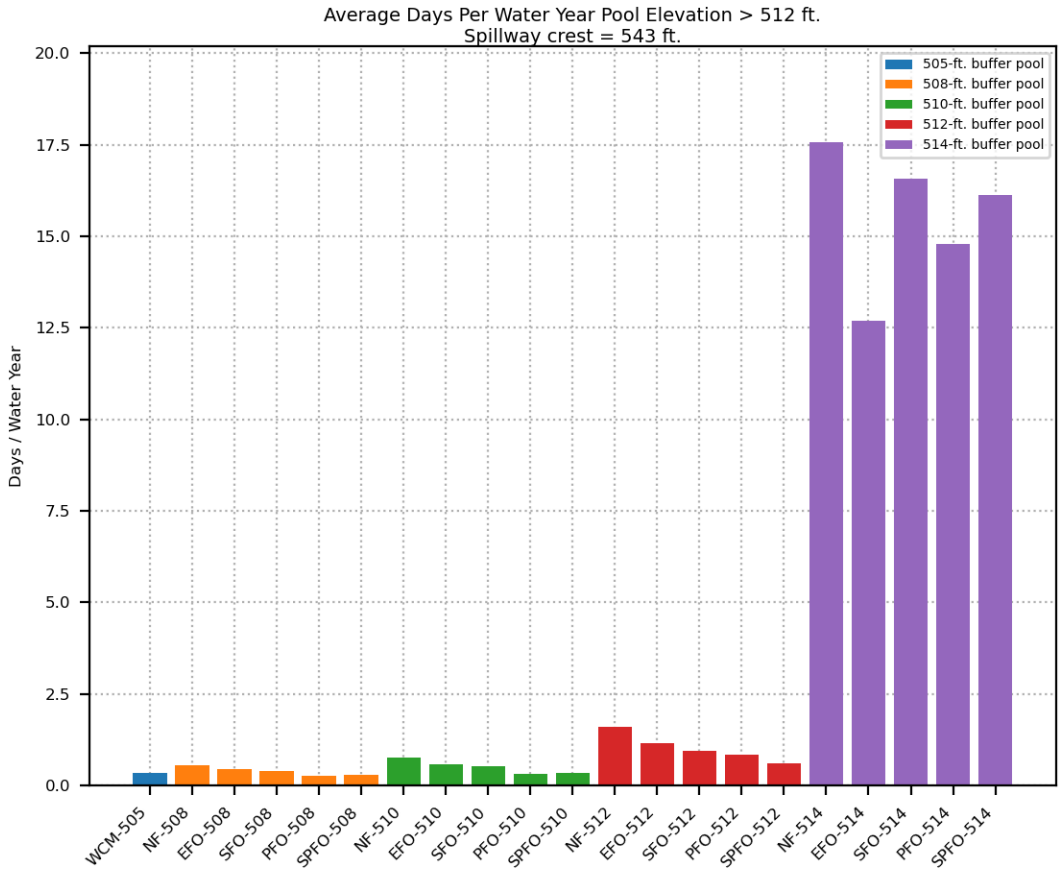
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Average Days Per Water Year Pool Elevation > 512 ft.
Spillway crest = 543 ft.
Days / Water Year
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
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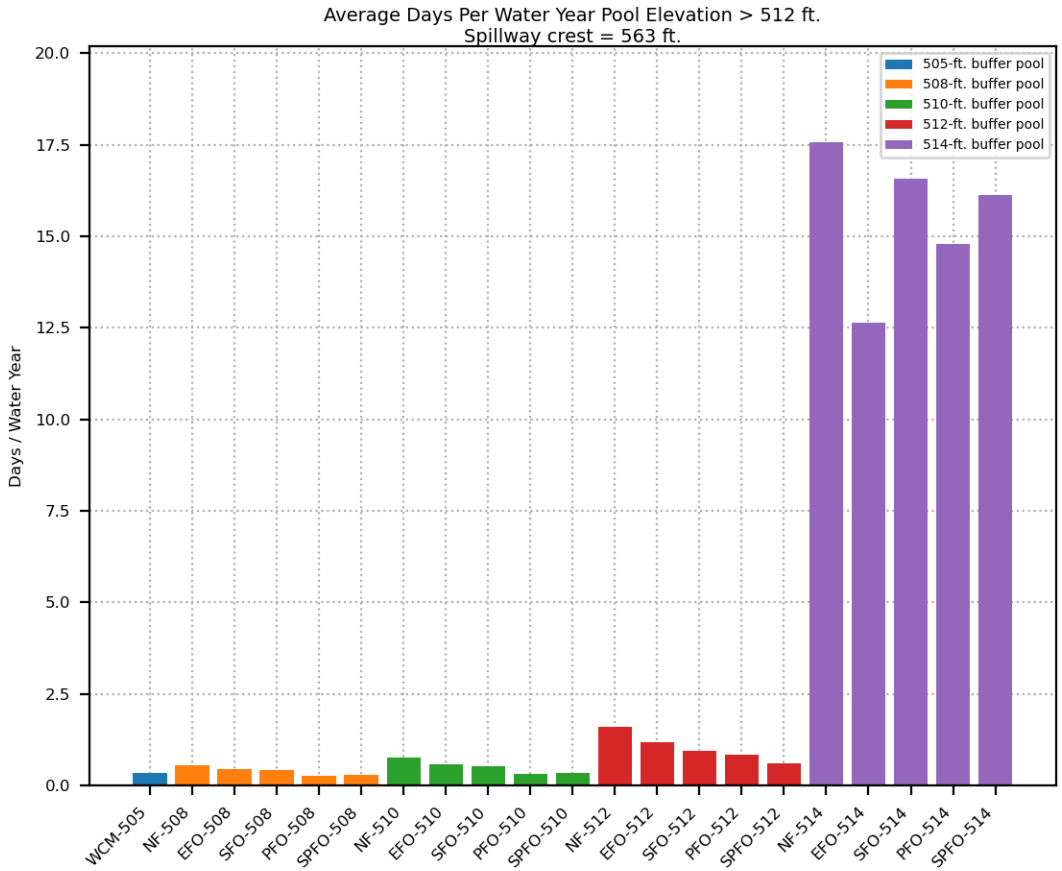
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Average Days Per Water Year Pool Elevation > 512 ft.
Spillway crest = 563 ft.
Days / Water Year
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
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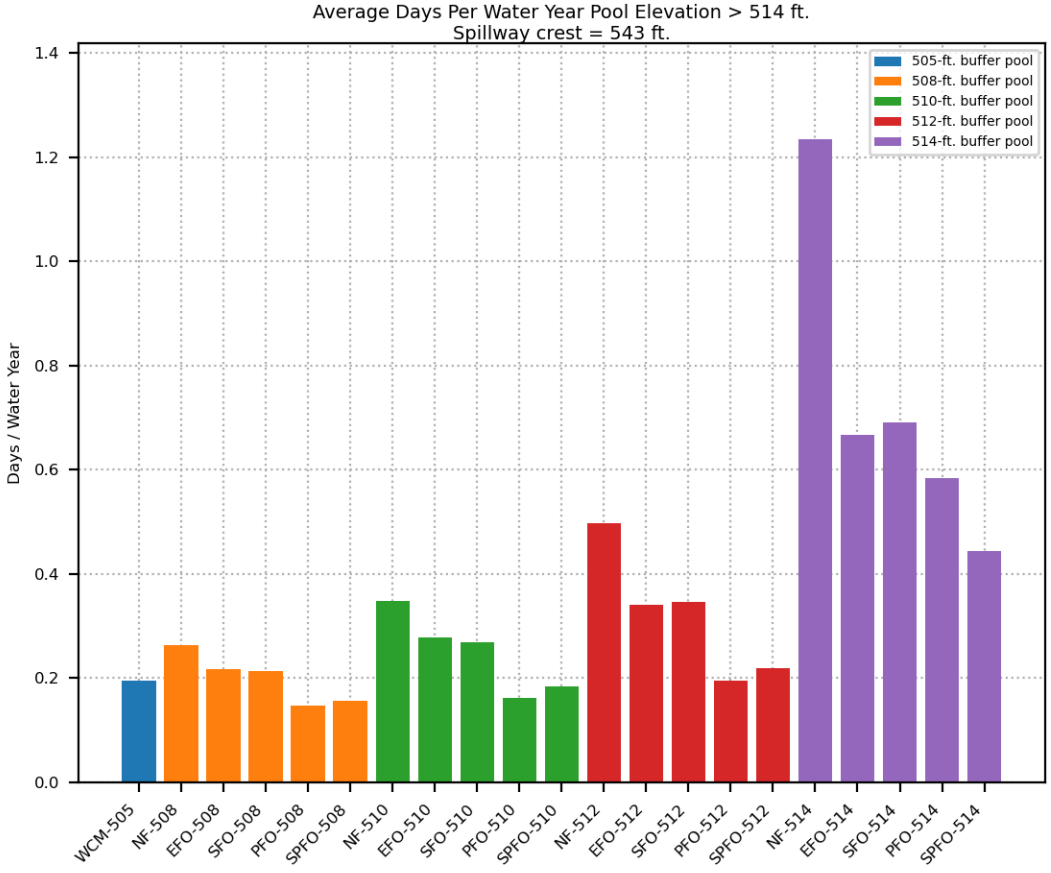
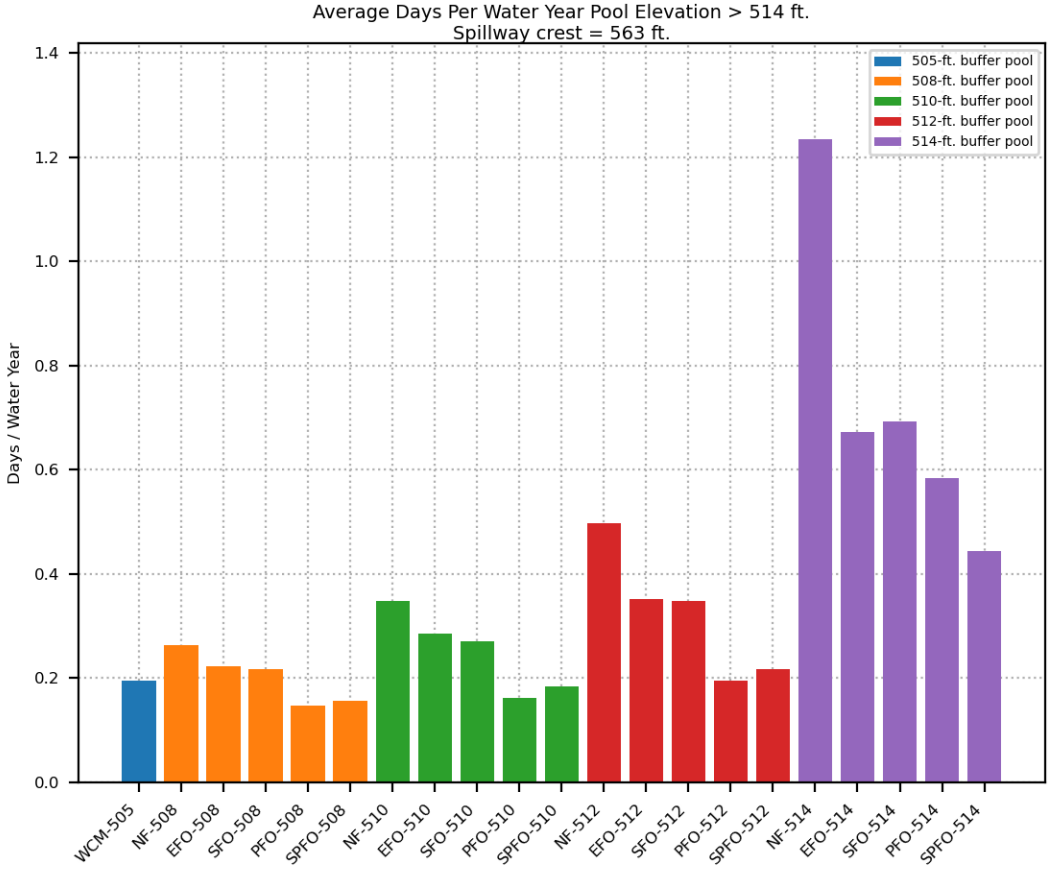
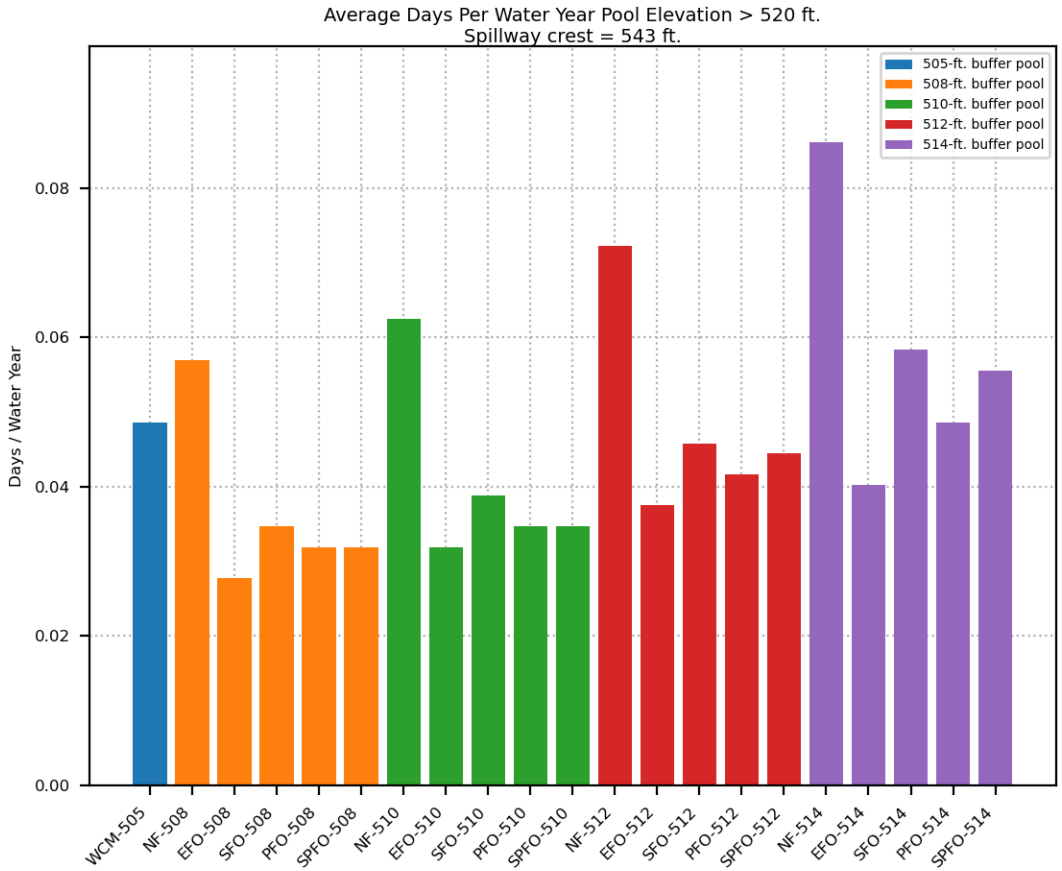
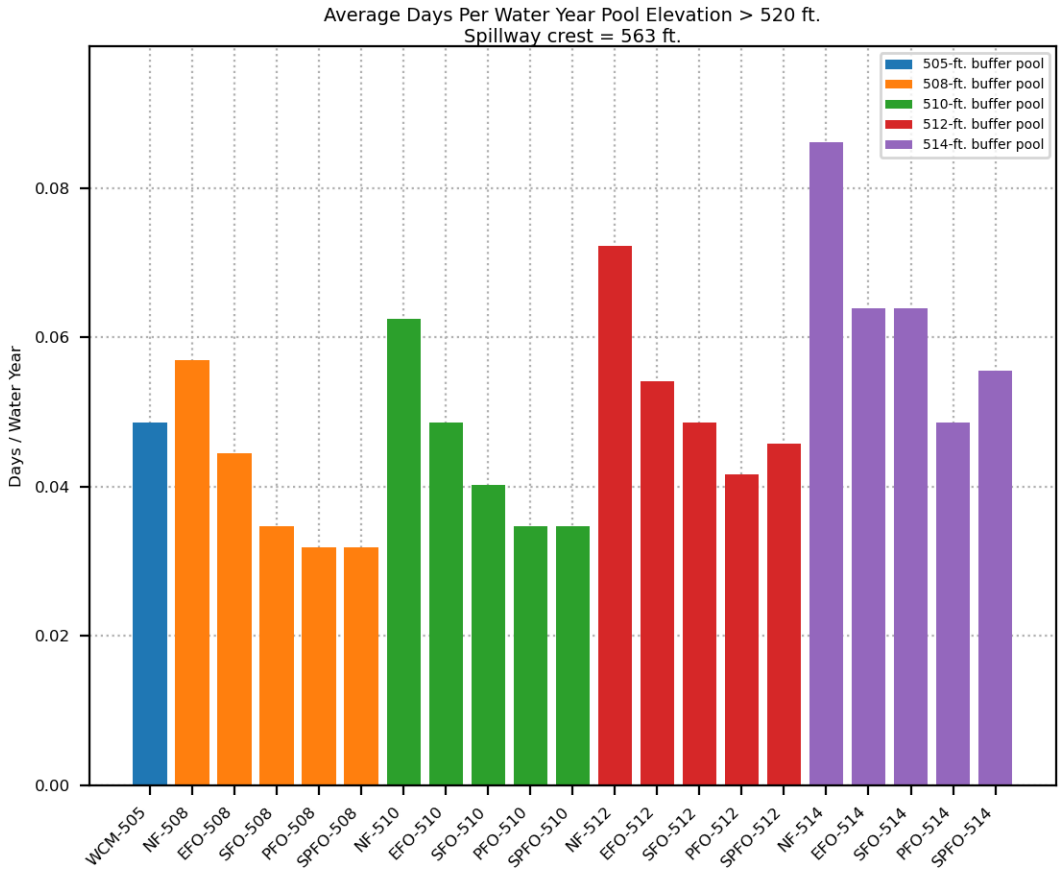
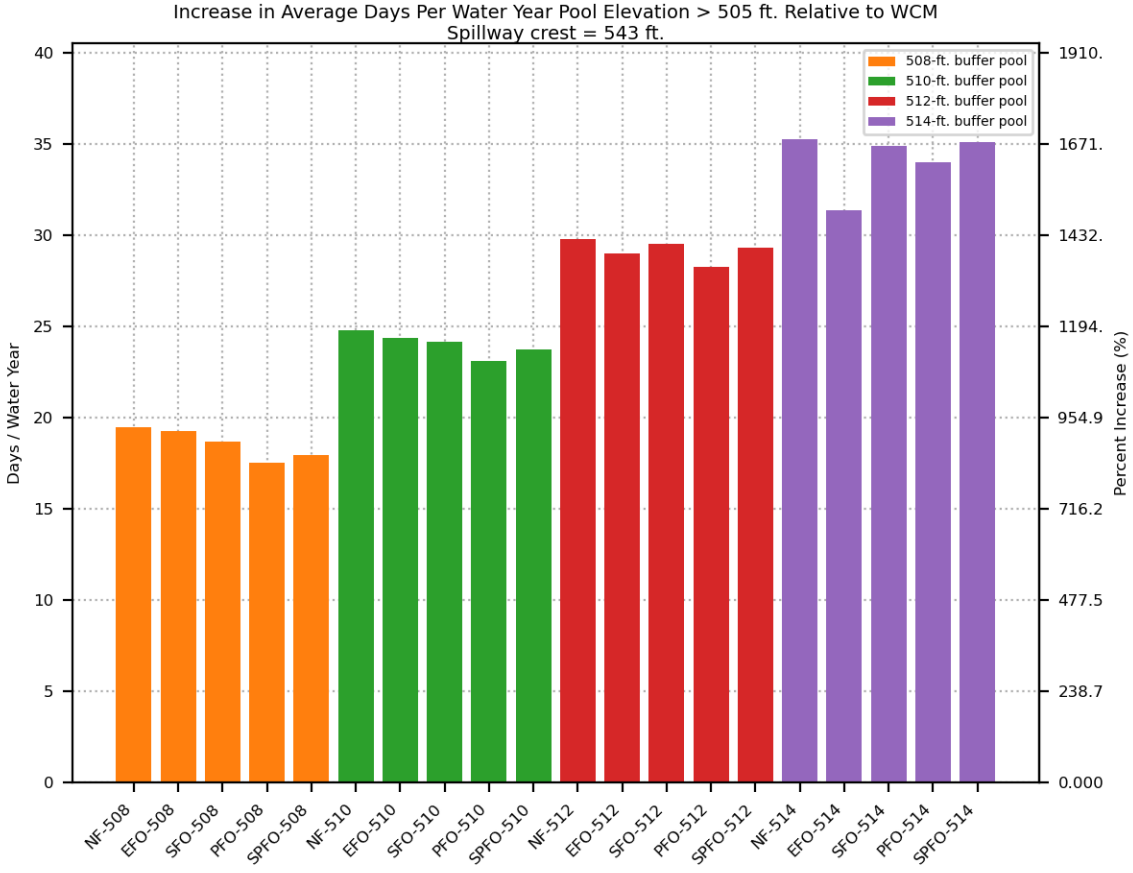
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514

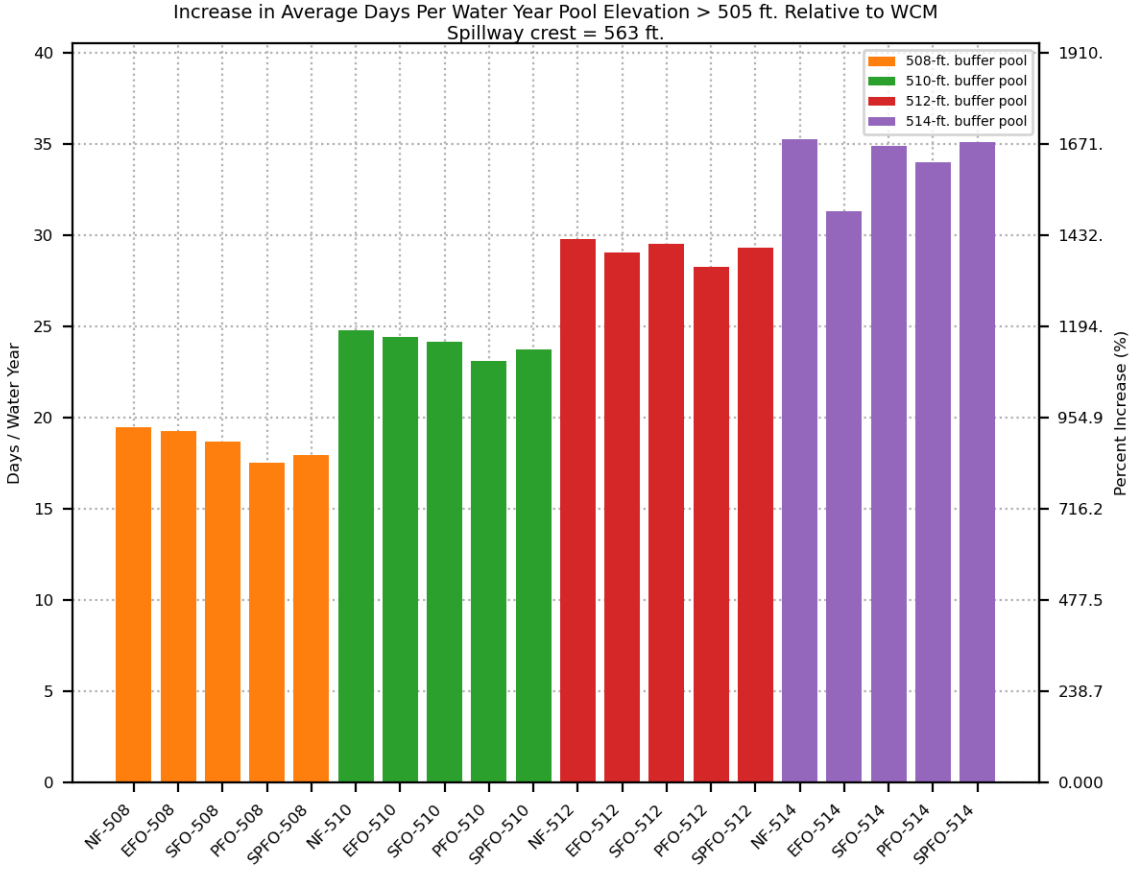

Average Days Per Water Year Pool Elevation > 514 ft.
Spillway crest = 543 ft.
Days / Water Year
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514

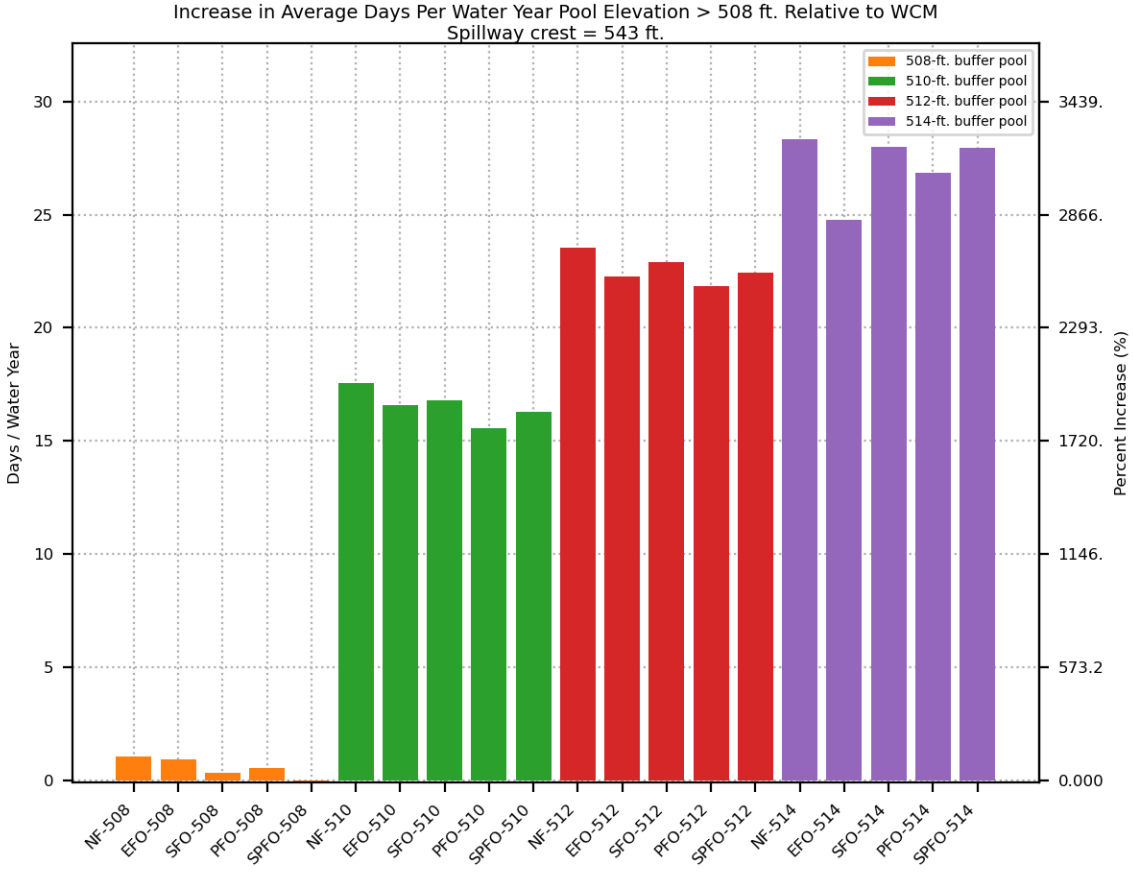

Average Days Per Water Year Pool Elevation > 514 ft.
Spillway crest = 563 ft.
Days / Water Year
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514

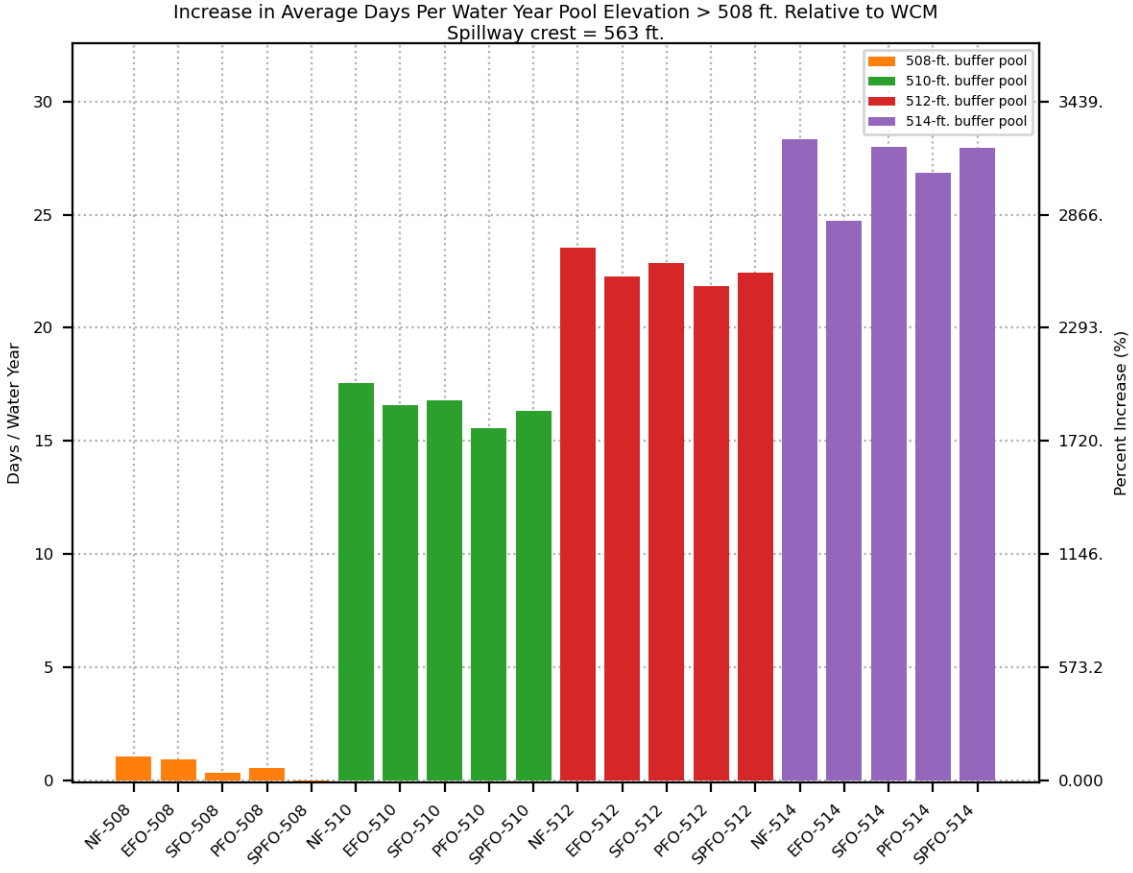

Average Days Per Water Year Pool Elevation > 520 ft.
Spillway crest = 543 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
0.00
0.02
0.04
0.06
0.08
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514

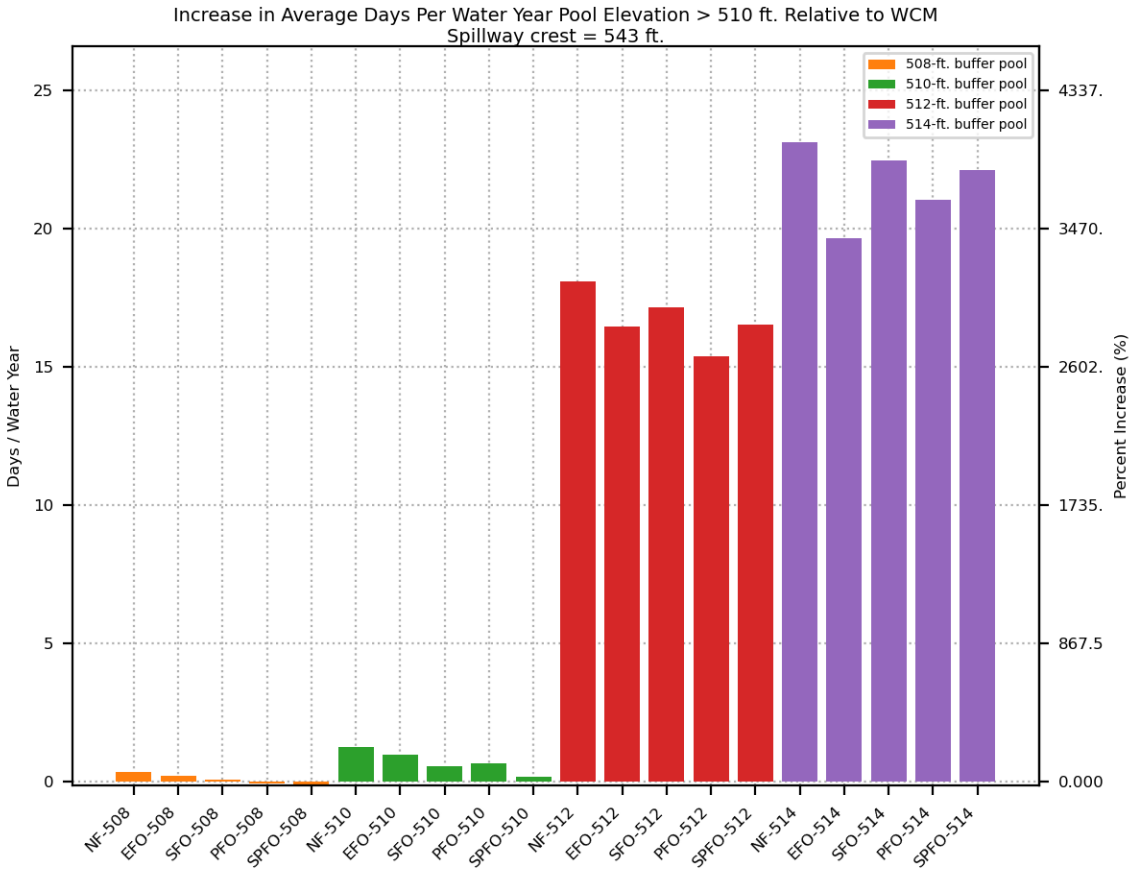

Average Days Per Water Year Pool Elevation > 520 ft.
Spillway crest = 563 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
0.00
0.02
0.04
0.06
0.08
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514

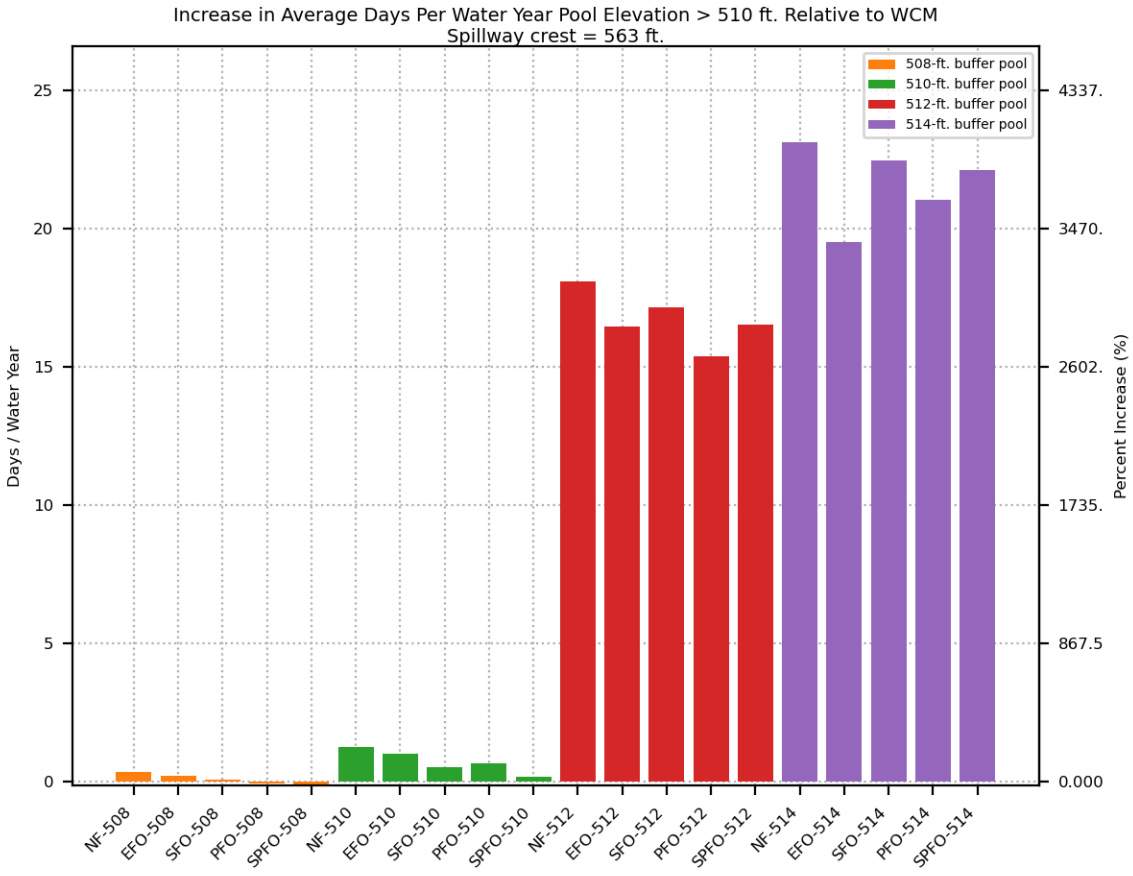

Increase in Average Days Per Water Year Pool Elevation > 505 ft. Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
5
10
15
20
25
30
35
40
0.000
238.7
477.5
716.2
954.9
1194.
1432.
1671.
1910.
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514

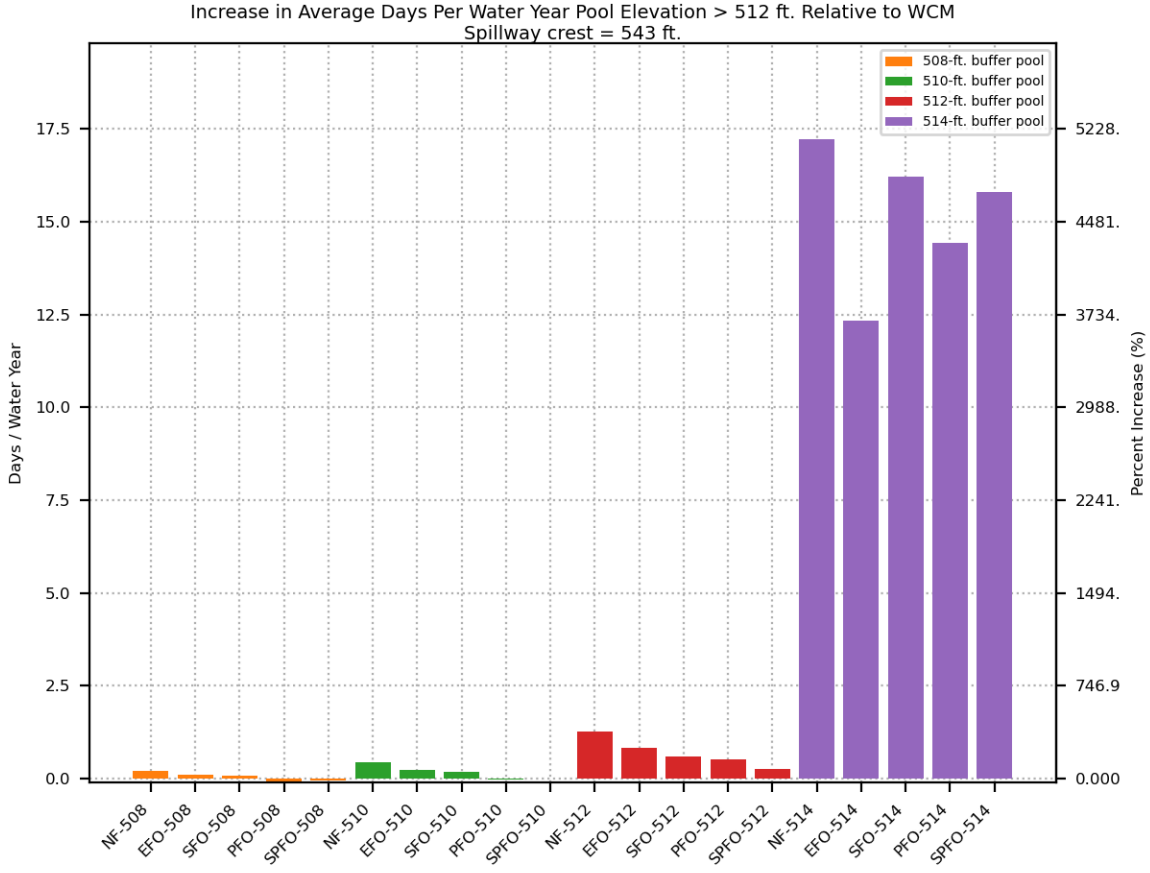

Increase in Average Days Per Water Year Pool Elevation > 505 ft. Relative to WCM
Spillway crest = 563 ft.
Days / Water Year
Percent Increase (%)
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
0
5
10
15
20
25
30
35
40
0.000
238.7
477.5
716.2
954.9
1194.
1432.
1671.
1910.
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514

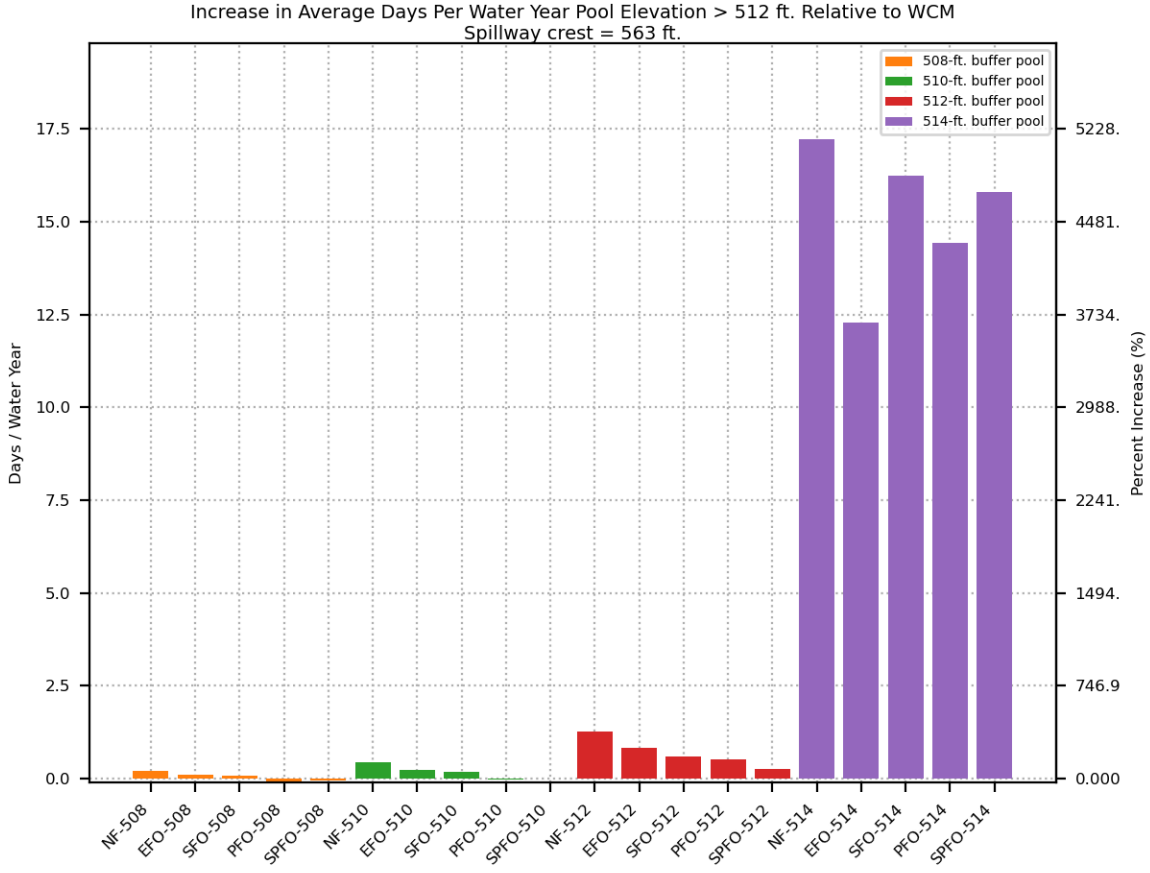

Increase in Average Days Per Water Year Pool Elevation > 508 ft. Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
5
10
15
20
25
30
0.000
573.2
1146.
1720.
2293.
2866.
3439.
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514

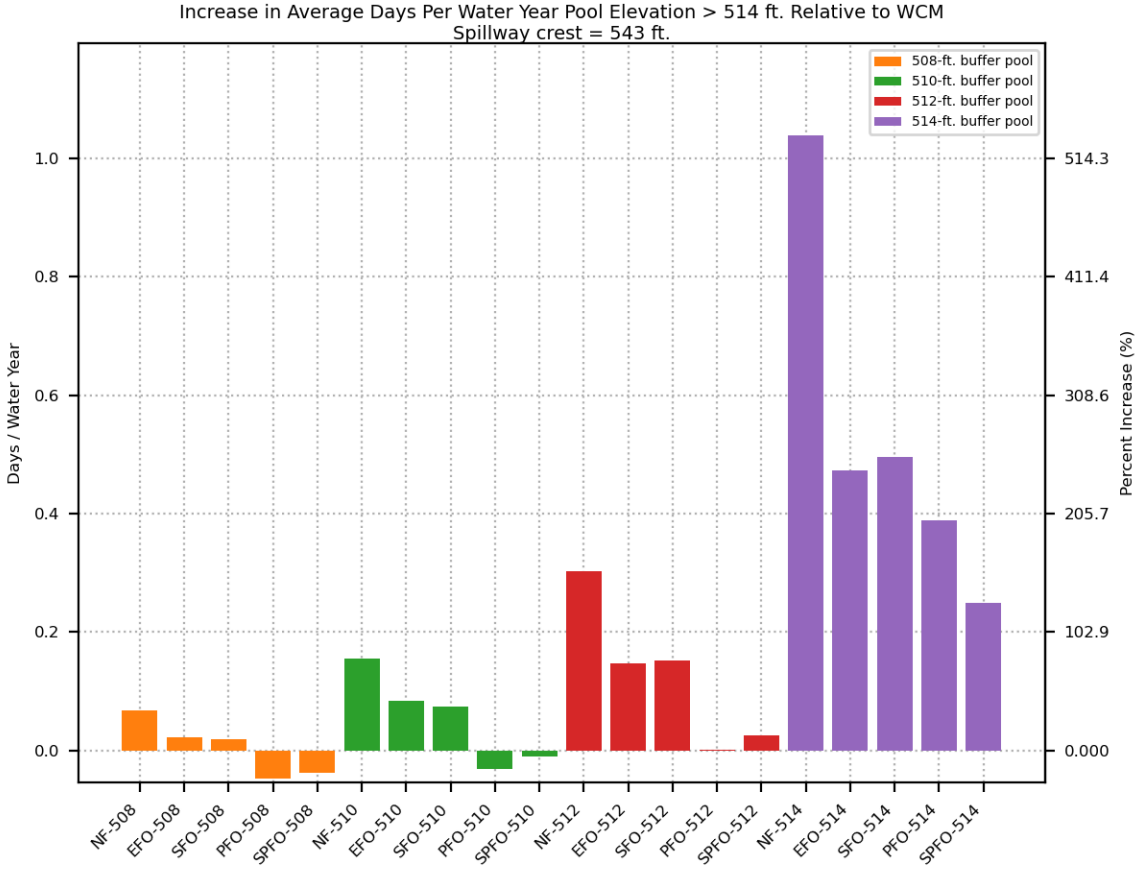

Increase in Average Days Per Water Year Pool Elevation > 508 ft. Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
5
10
15
20
25
30
0.000
573.2
1146.
1720.
2293.
2866.
3439.
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514

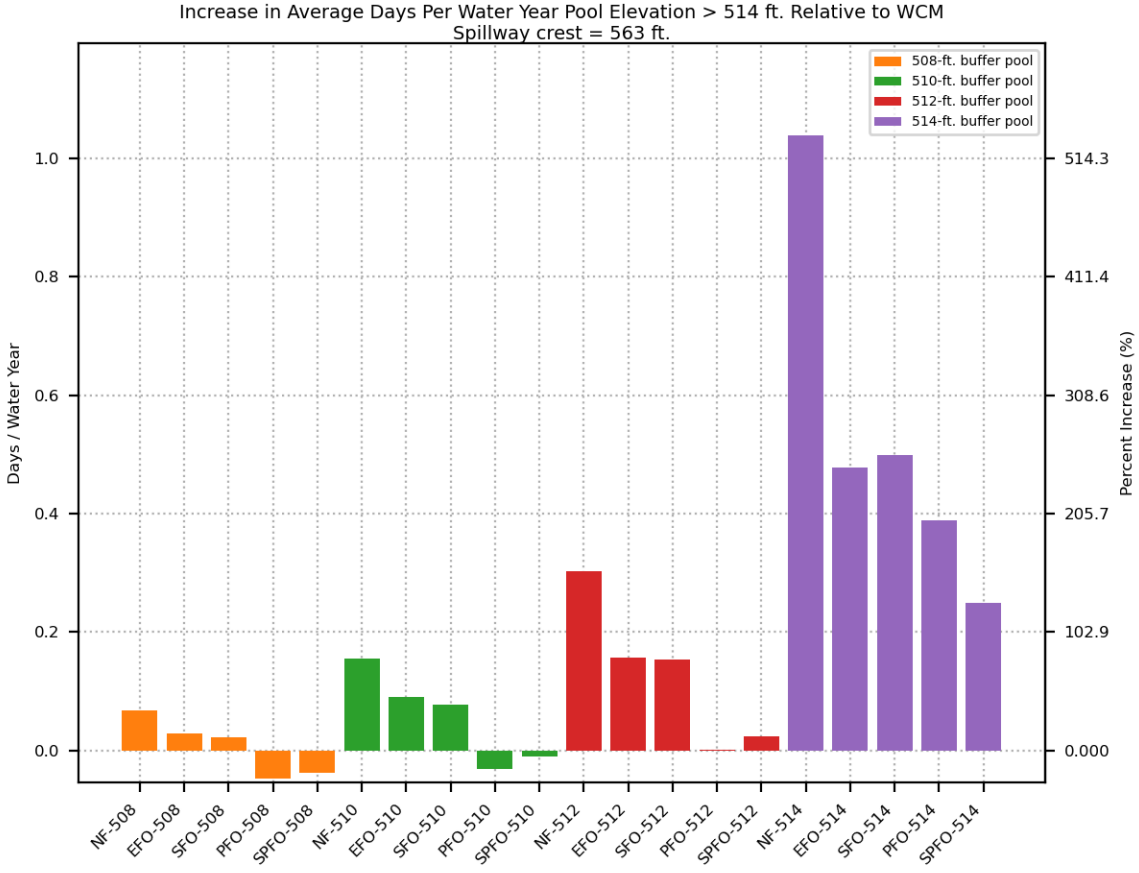

Increase in Average Days Per Water Year Pool Elevation > 510 ft. Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
5
10
15
20
25
0.000
867.5
1735.
2602.
3470.
4337.
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514

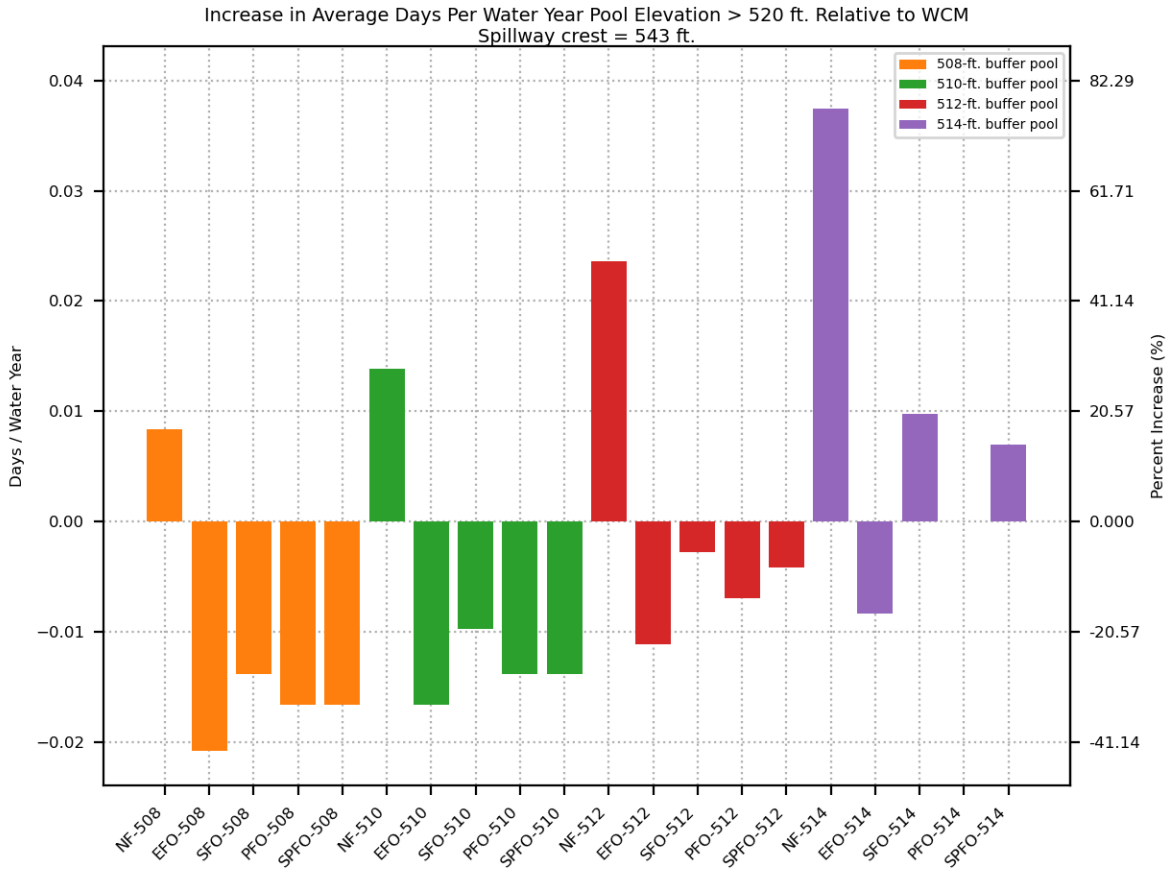

Increase in Average Days Per Water Year Pool Elevation > 510 ft. Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
5
10
15
20
25
0.000
867.5
1735.
2602.
3470.
4337.
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514

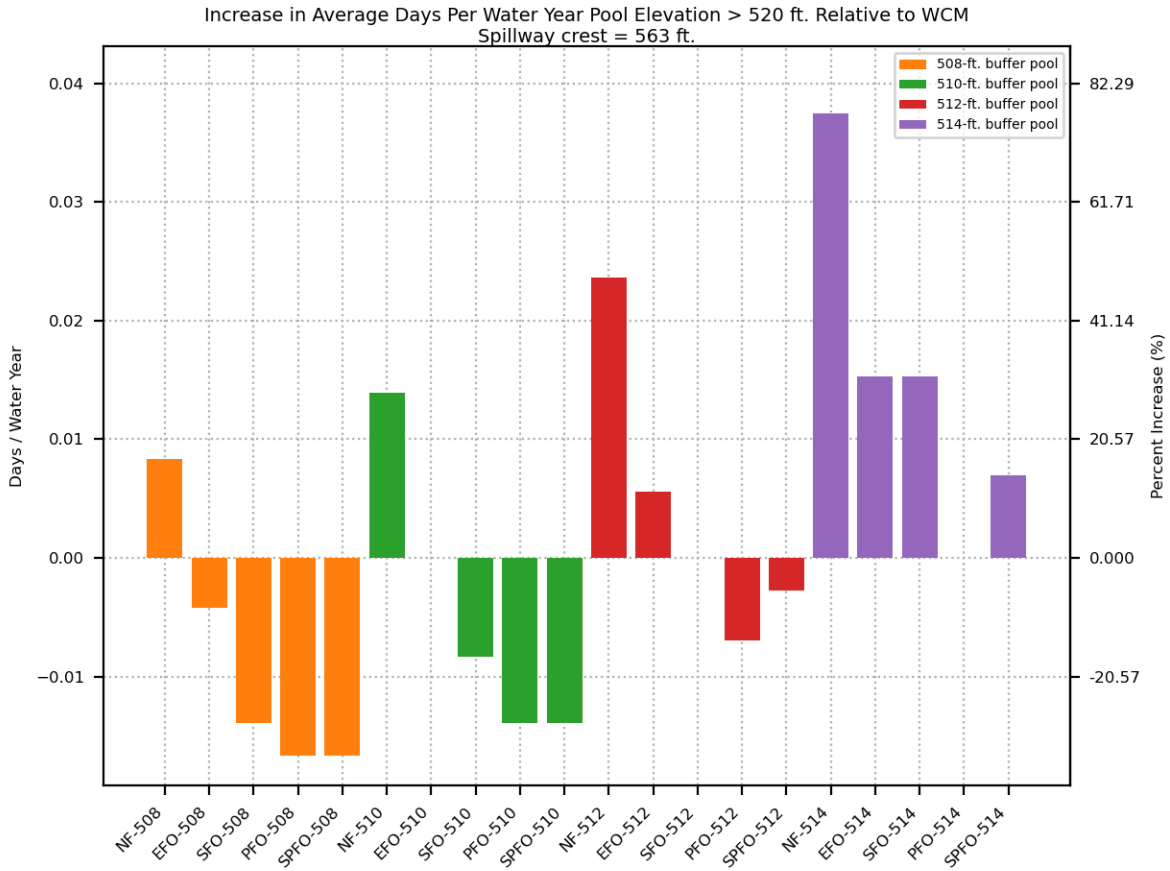

Increase in Average Days Per Water Year Pool Elevation > 512 ft. Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
Percent Increase (%)
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
0.000
746.9
1494.
2241.
2988.
3734.
4481.
5228.
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514

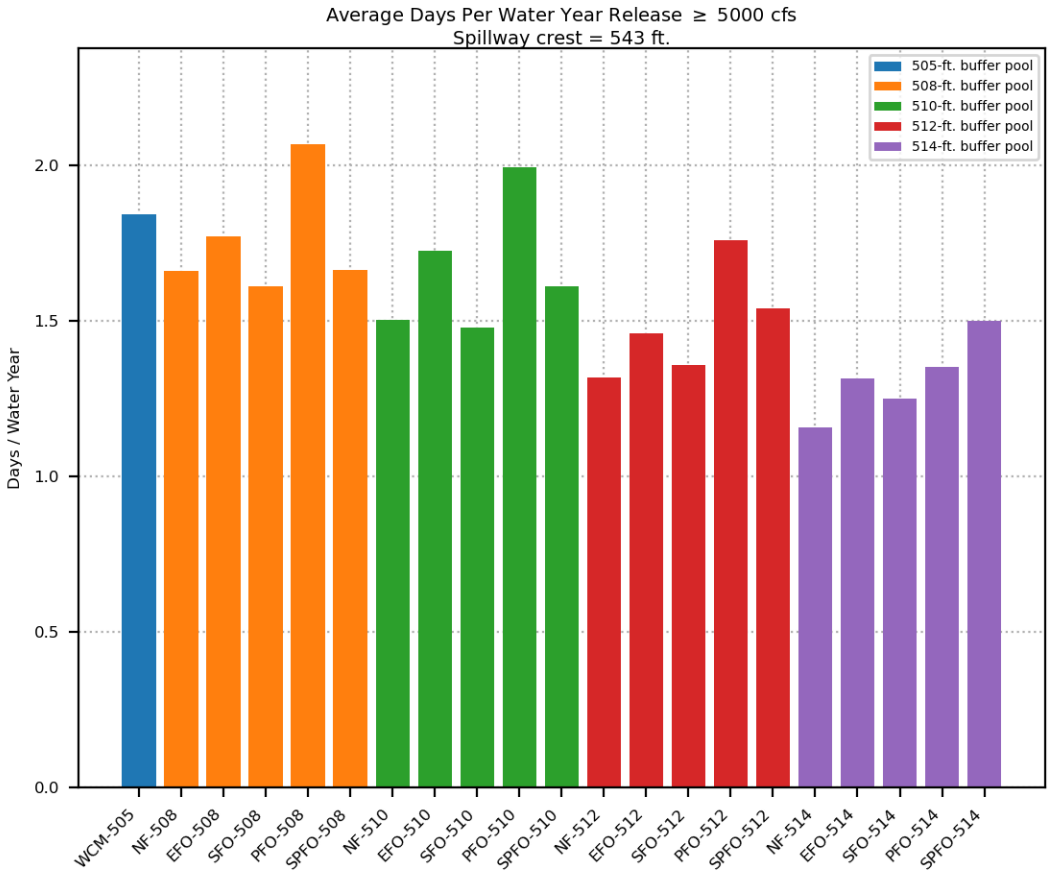

Increase in Average Days Per Water Year Pool Elevation > 512 ft. Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
Percent Increase (%)
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
0.000
746.9
1494.
2241.
2988.
3734.
4481.
5228.
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514

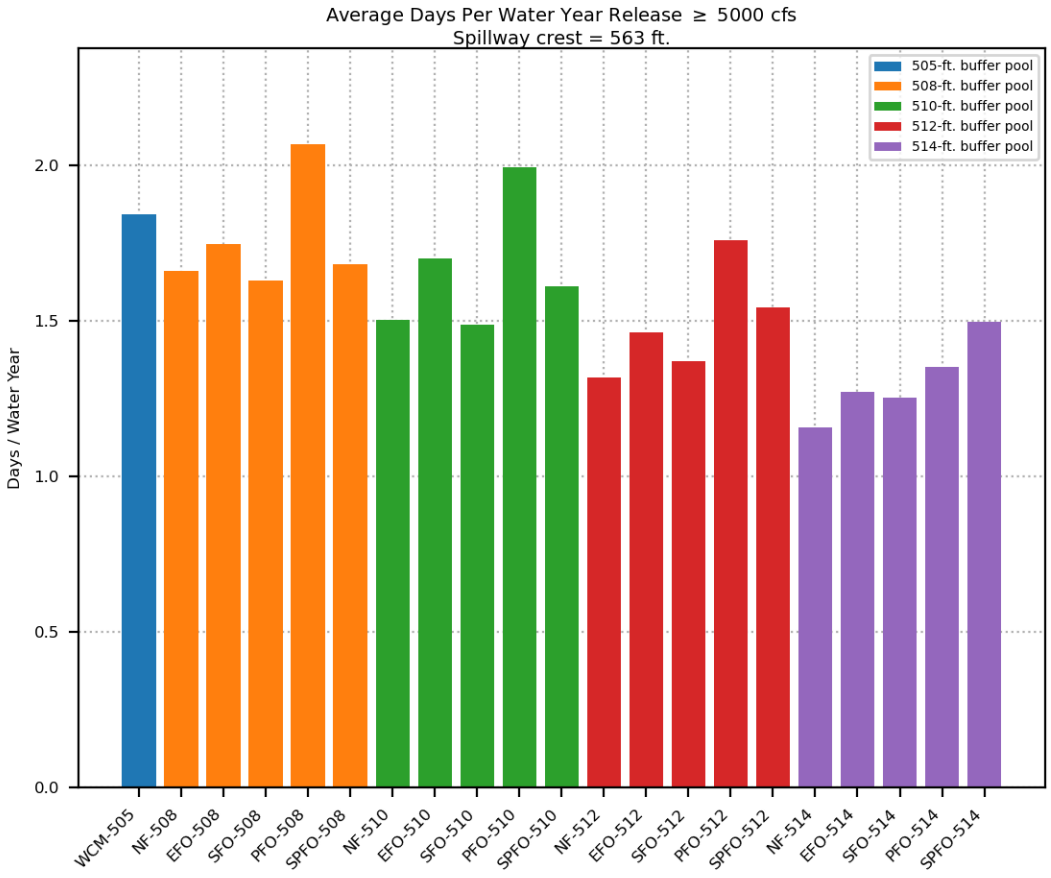

Increase in Average Days Per Water Year Pool Elevation > 514 ft. Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
Percent Increase (%)
0.0
0.2
0.4
0.6
0.8
1.0
0.000
102.9
205.7
308.6
411.4
514.3
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Increase in Average Days Per Water Year Pool Elevation > 514 ft. Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
Percent Increase (%)
0.0
0.2
0.4
0.6
0.8
1.0
0.000
102.9
205.7
308.6
411.4
514.3
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Increase in Average Days Per Water Year Pool Elevation > 520 ft. Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
Percent Increase (%)
0.04
0.03
0.02
0.01
0.00
−0.01
−0.02
82.29
61.71
41.14
20.57
0.000
-20.57
-41.14
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Increase in Average Days Per Water Year Pool Elevation > 520 ft. Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
Percent Increase (%)
0.04
0.03
0.02
0.01
0.00
−0.01
82.29
61.71
41.14
20.57
0.000
-20.57
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Average Days Per Water Year Release ≥ 5000 cfs
Spillway crest = 543 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
0.0
0.5
1.0
1.5
2.0
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Average Days Per Water Year Release ≥ 5000 cfs
Spillway crest = 563 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
0.0
0.5
1.0
1.5
2.0
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
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PFO-512
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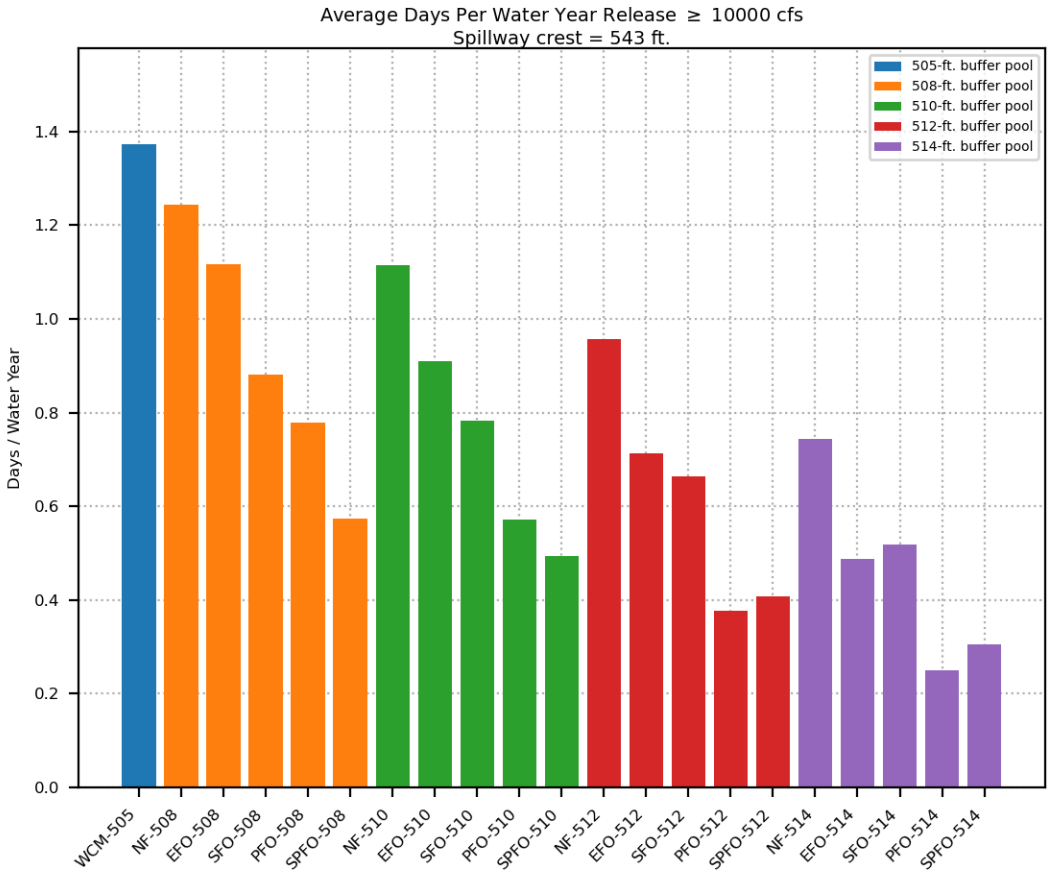
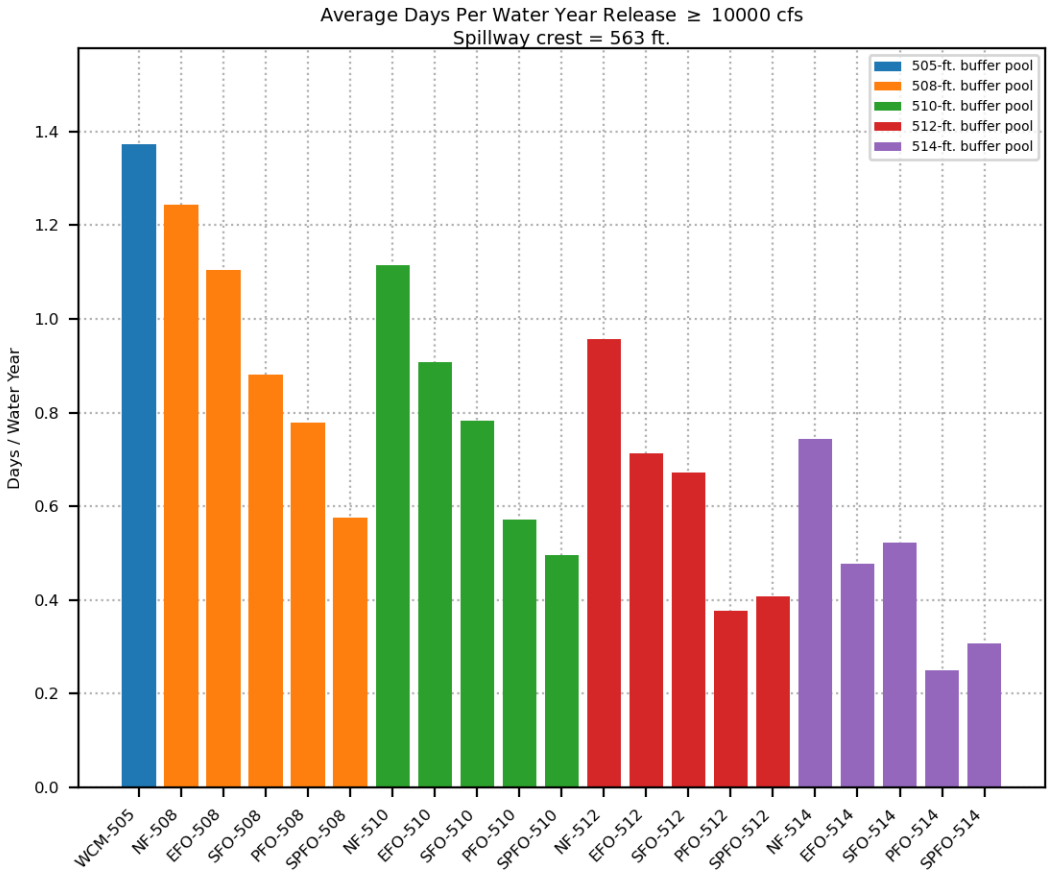
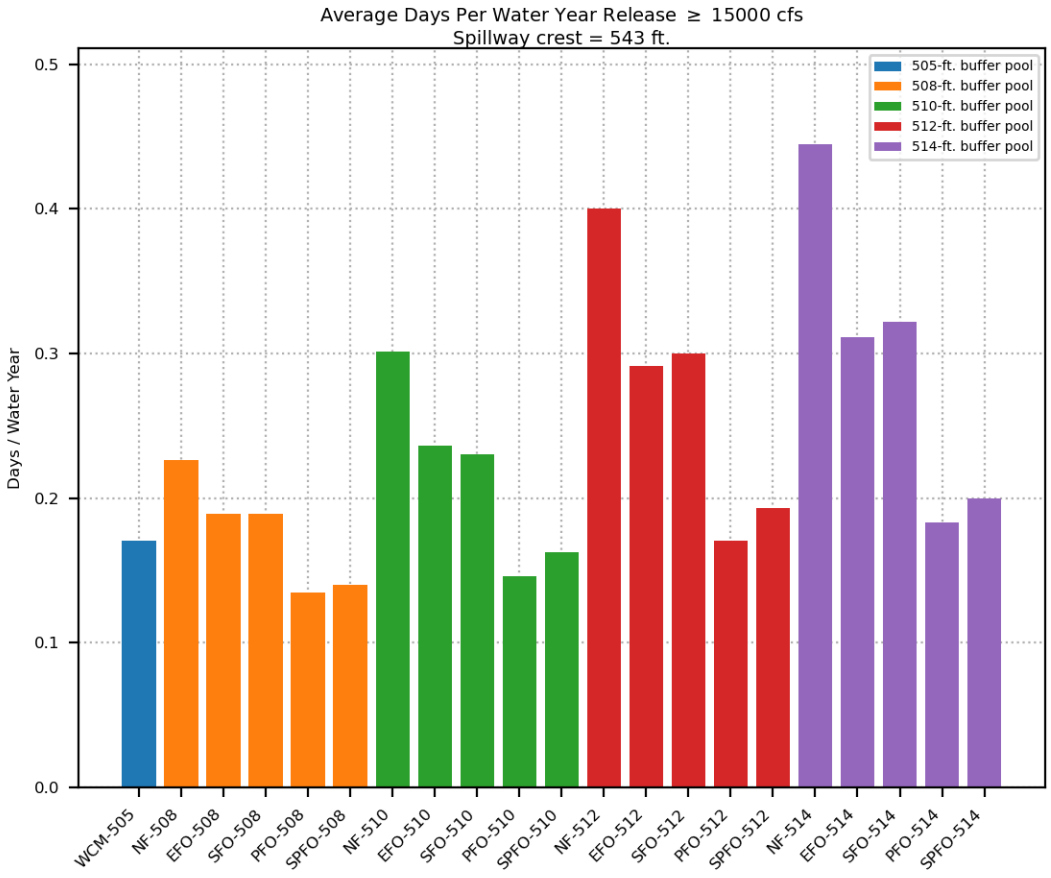
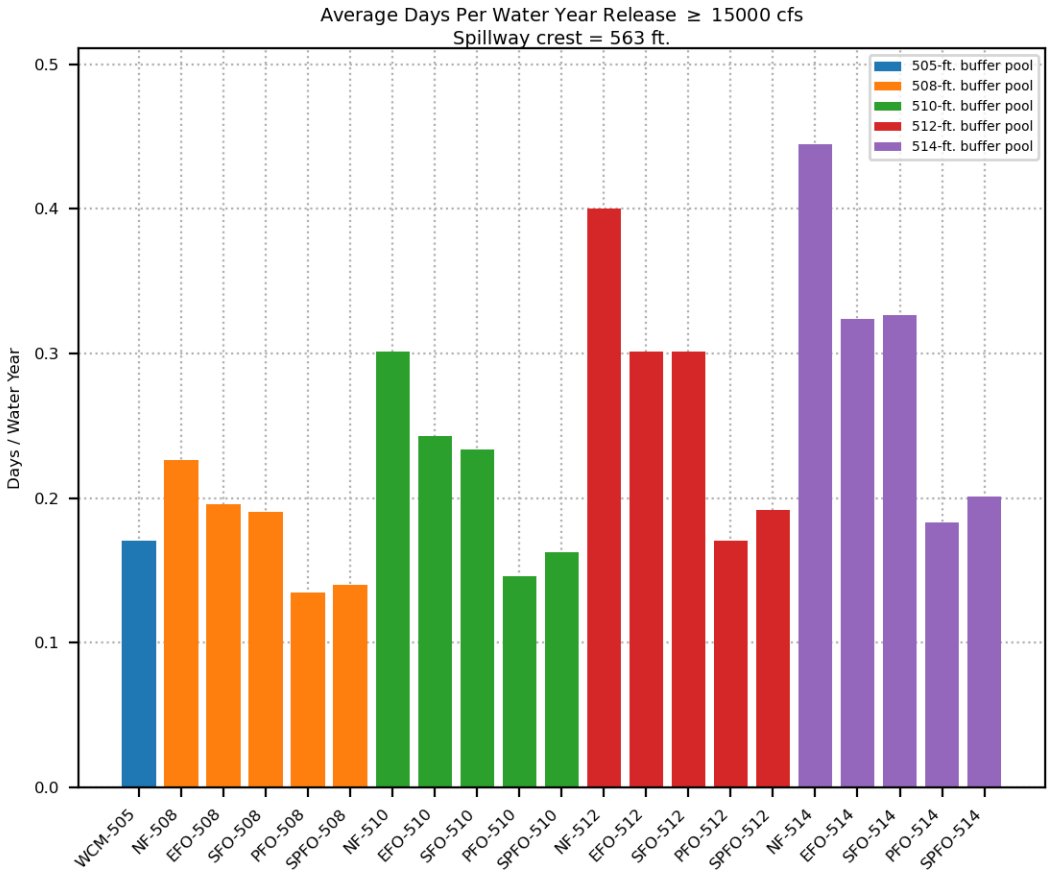
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Average Days Per Water Year Release ≥ 10000 cfs
Spillway crest = 543 ft.
Days / Water Year
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Average Days Per Water Year Release ≥ 10000 cfs
Spillway crest = 563 ft.
Days / Water Year
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Average Days Per Water Year Release ≥ 15000 cfs
Spillway crest = 543 ft.
Days / Water Year
0.0
0.1
0.2
0.3
0.4
0.5
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Average Days Per Water Year Release ≥ 15000 cfs
Spillway crest = 563 ft.
Days / Water Year
0.0
0.1
0.2
0.3
0.4
0.5
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
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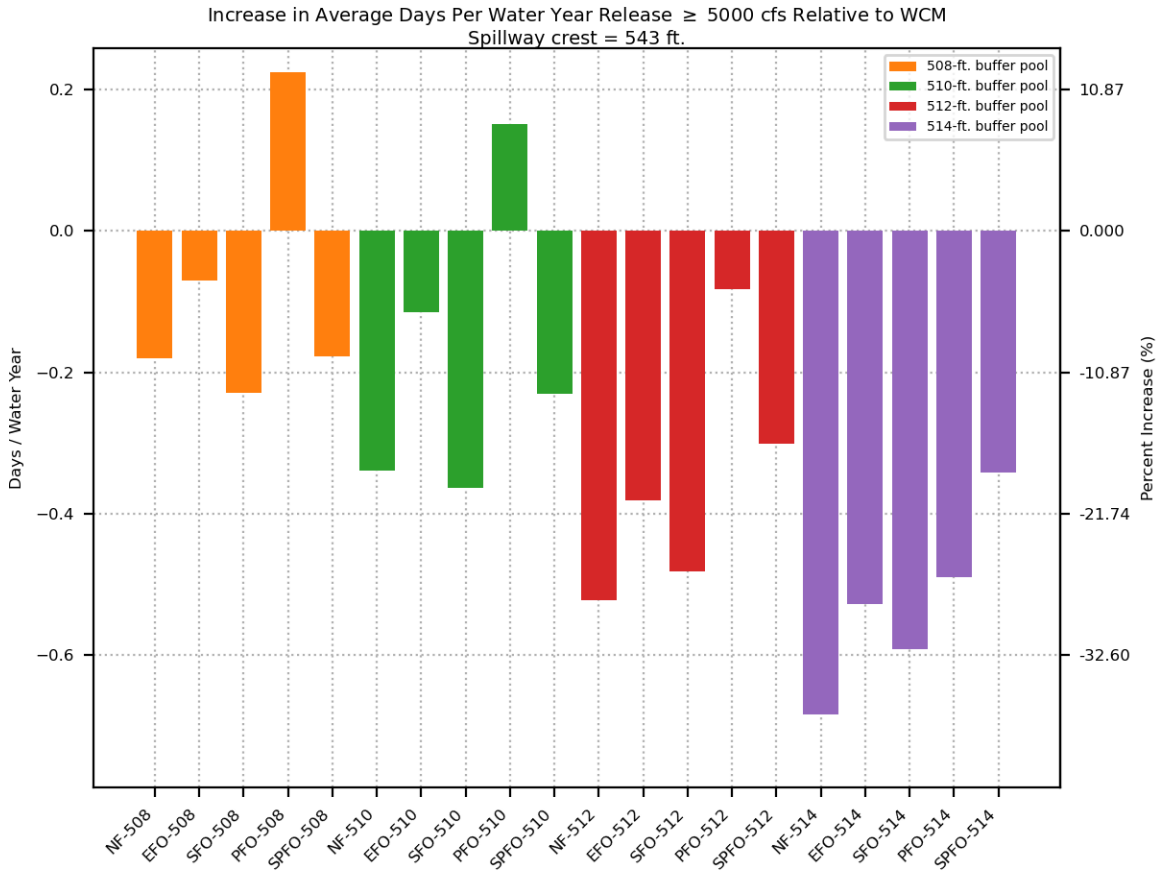
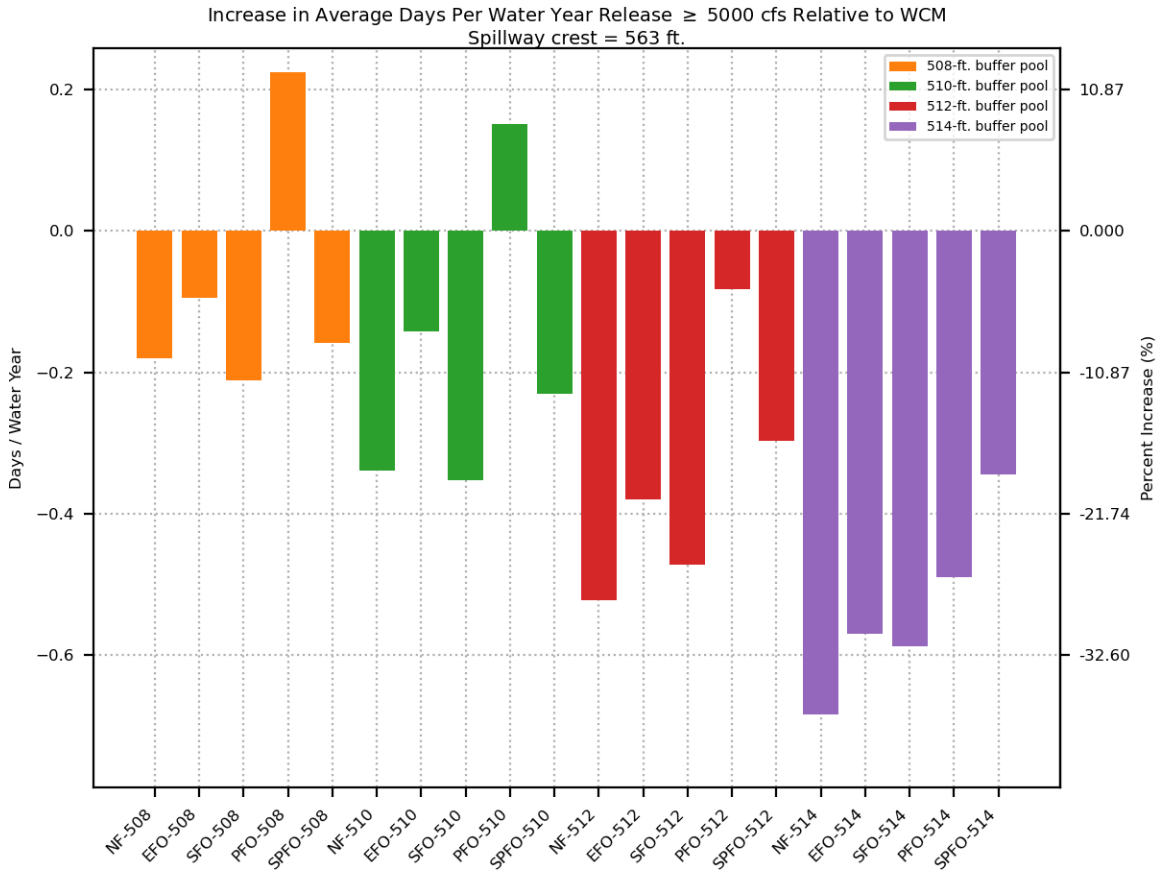
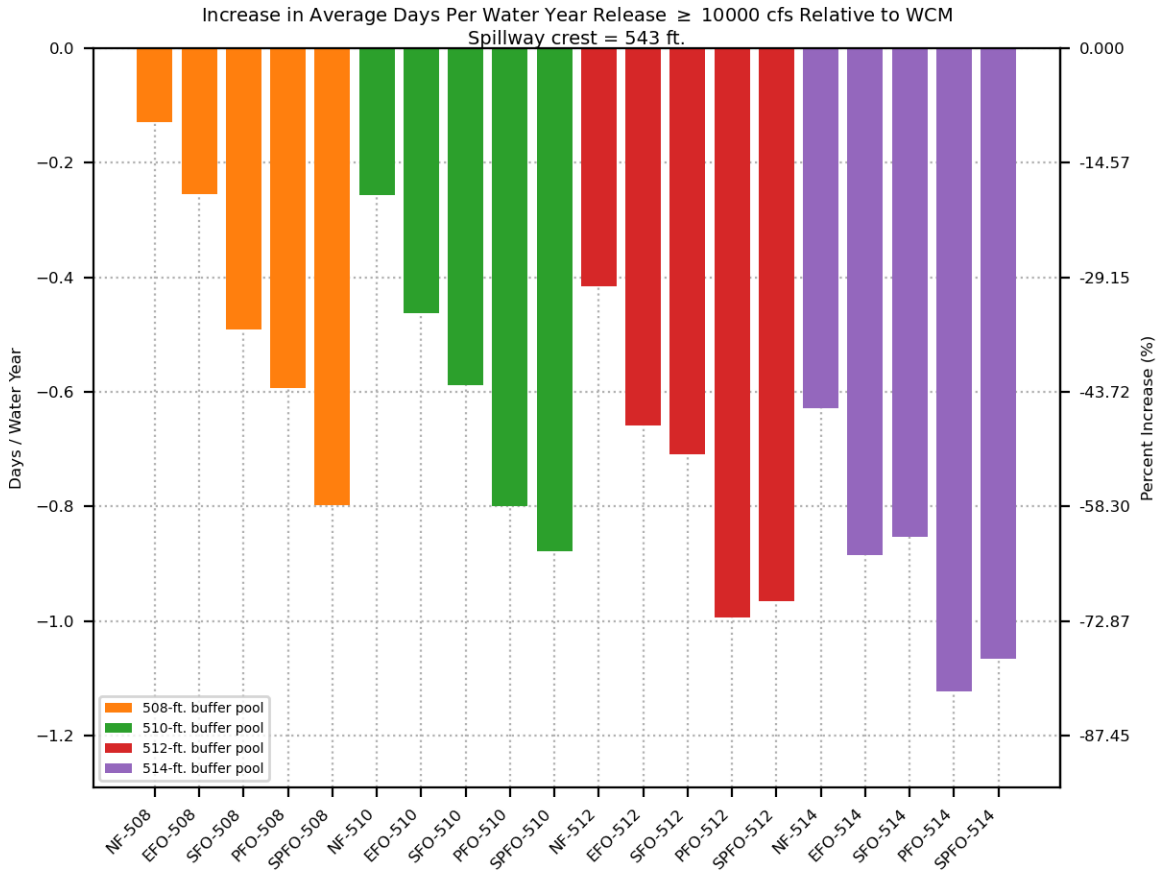
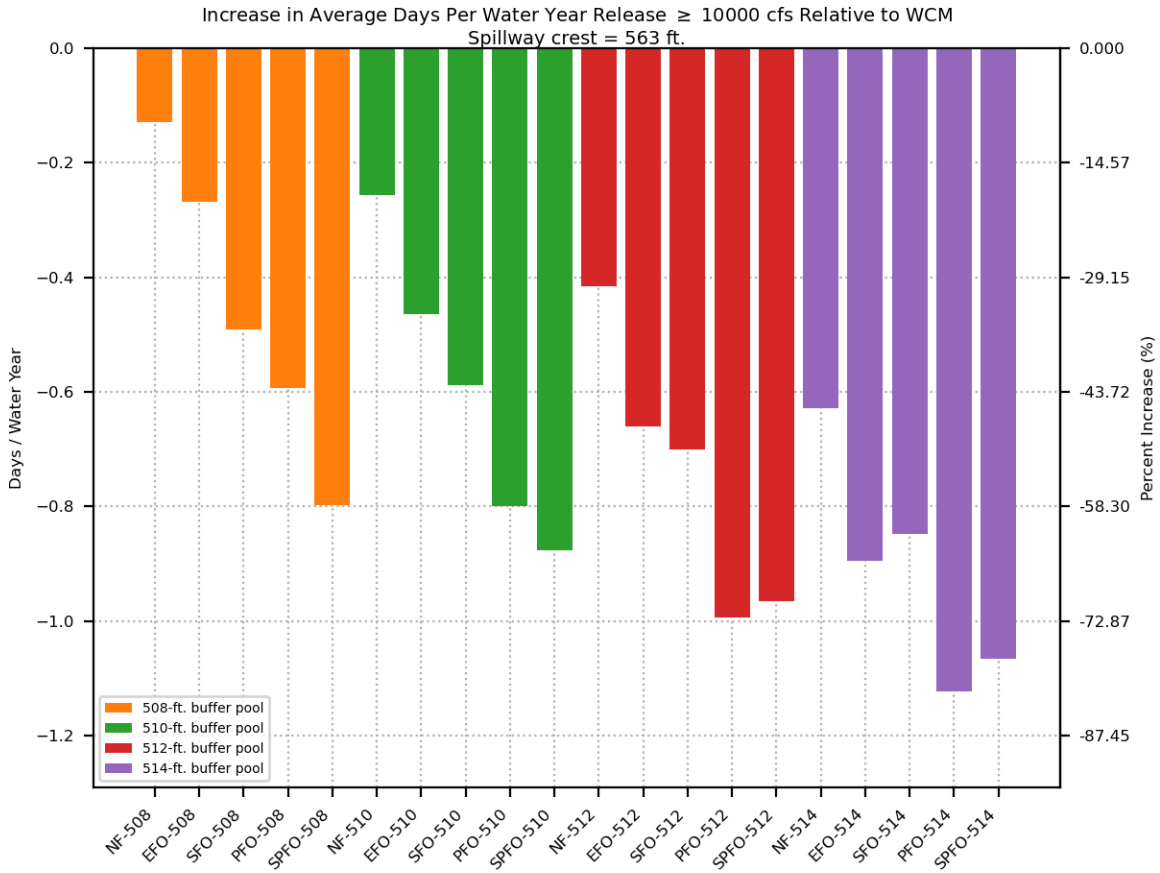
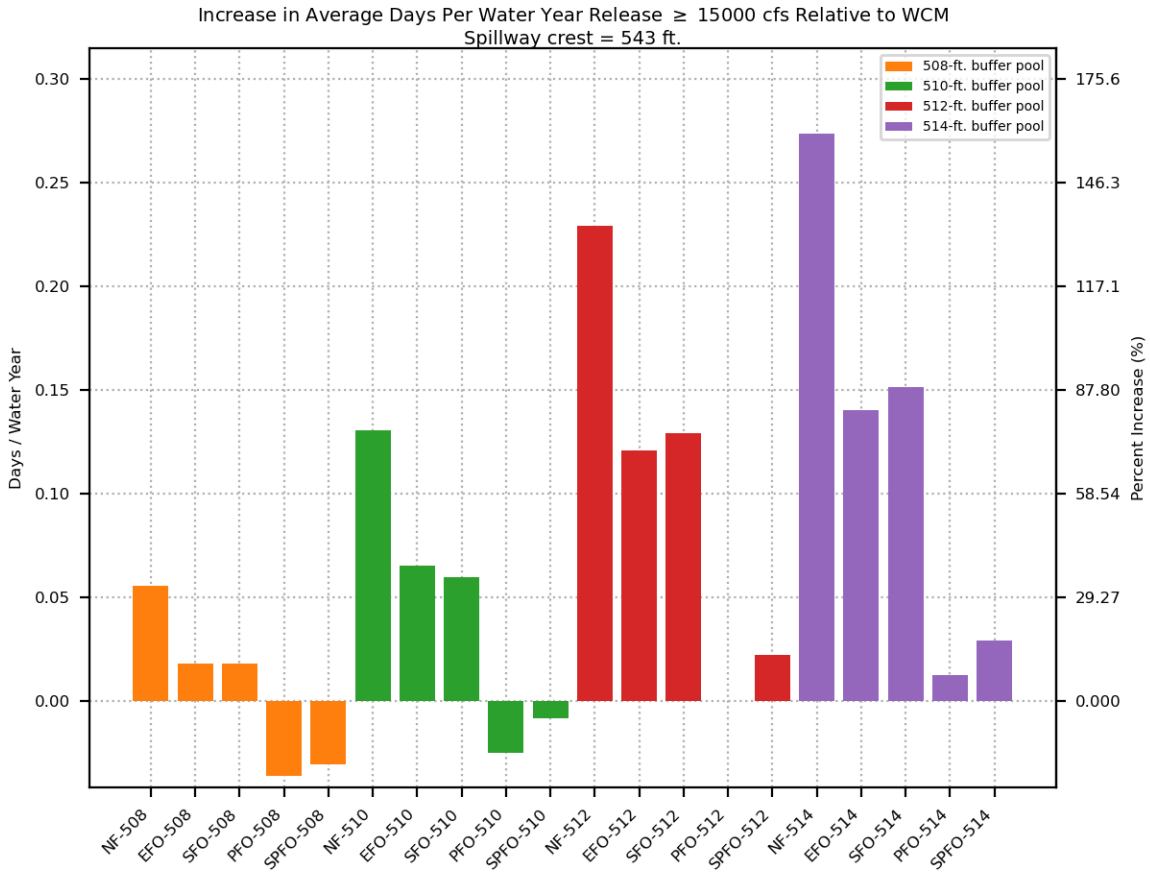
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514

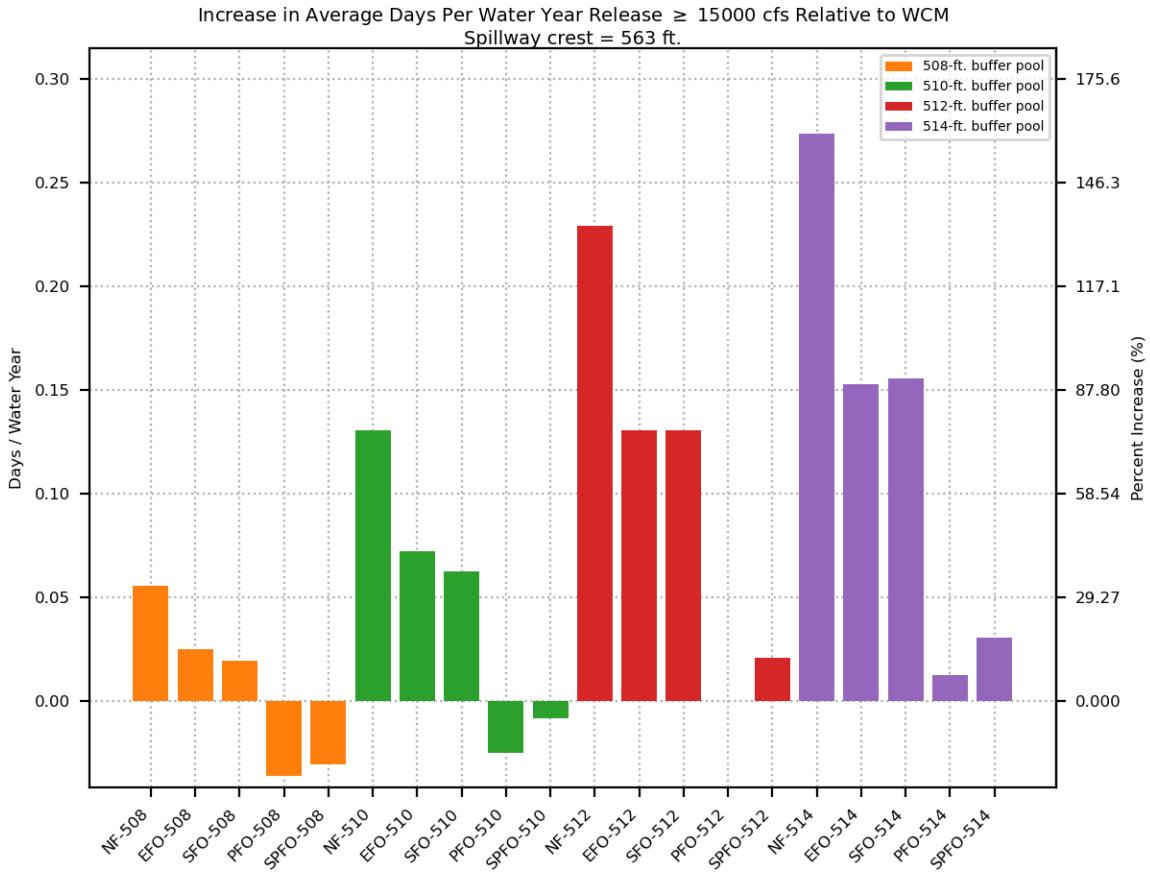

Increase in Average Days Per Water Year Release ≥ 5000 cfs Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
Percent Increase (%)
0.2
0.0
−0.2
−0.4
−0.6
10.87
0.000
-10.87
-21.74
-32.60
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Increase in Average Days Per Water Year Release ≥ 5000 cfs Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
Percent Increase (%)
0.2
0.0
−0.2
−0.4
−0.6
10.87
0.000
-10.87
-21.74
-32.60
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Increase in Average Days Per Water Year Release ≥ 10000 cfs Relative to WCM
Spillway crest = 543 ft.
Days / Water Year
Percent Increase (%)
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
0.000
-14.57
-29.15
-43.72
-58.30
-72.87
-87.45
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Increase in Average Days Per Water Year Release ≥ 10000 cfs Relative to WCM
Spillway crest = 563 ft.
Days / Water Year
Percent Increase (%)
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
0.000
-14.57
-29.15
-43.72
-58.30
-72.87
-87.45
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Increase in Average Days Per Water Year Release ≥ 15000 cfs Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
Percent Increase (%)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
175.6
146.3
117.1
87.80
58.54
29.27
0.000
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Increase in Average Days Per Water Year Release ≥ 15000 cfs Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
Percent Increase (%)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
175.6
146.3
117.1
87.80
58.54
29.27
0.000
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
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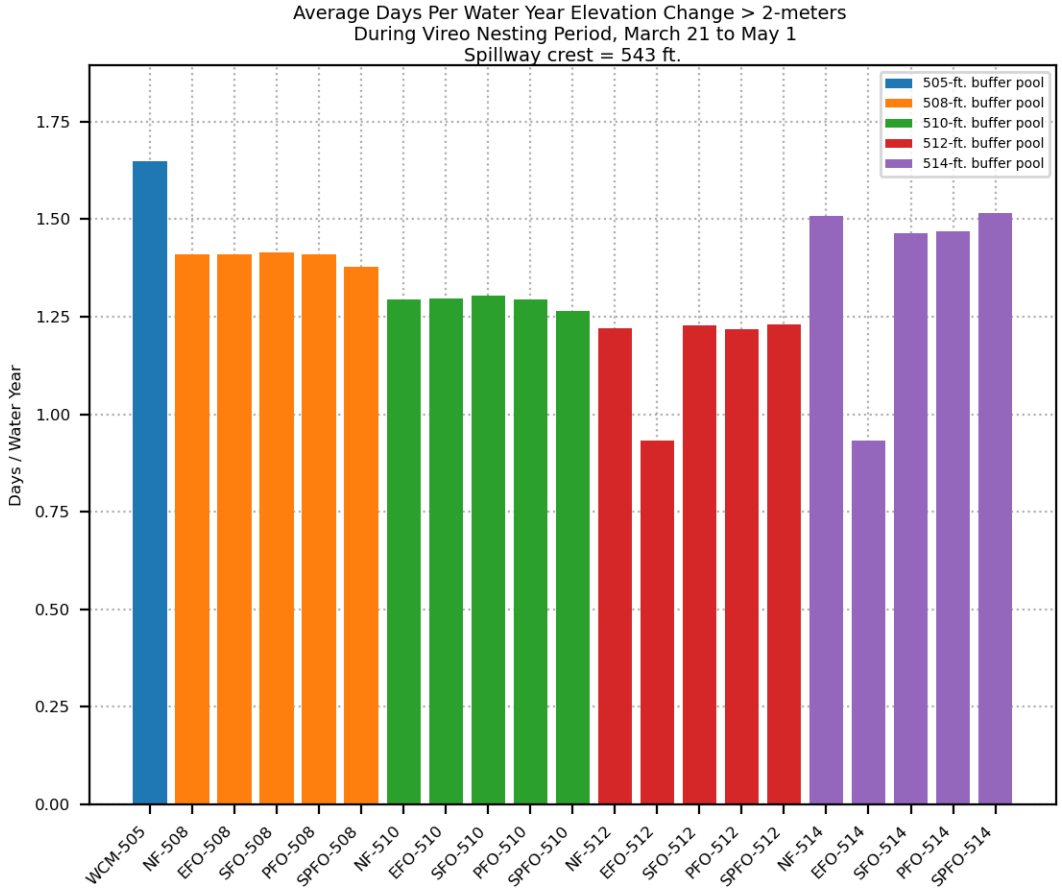
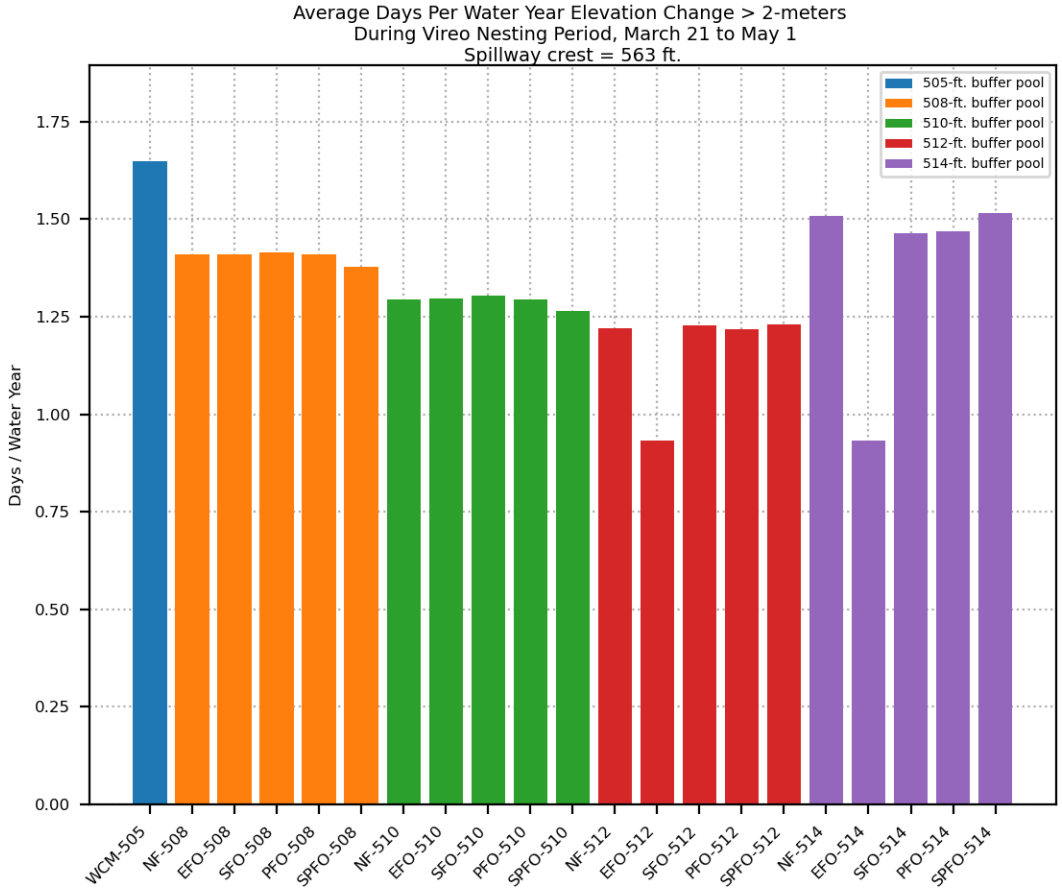
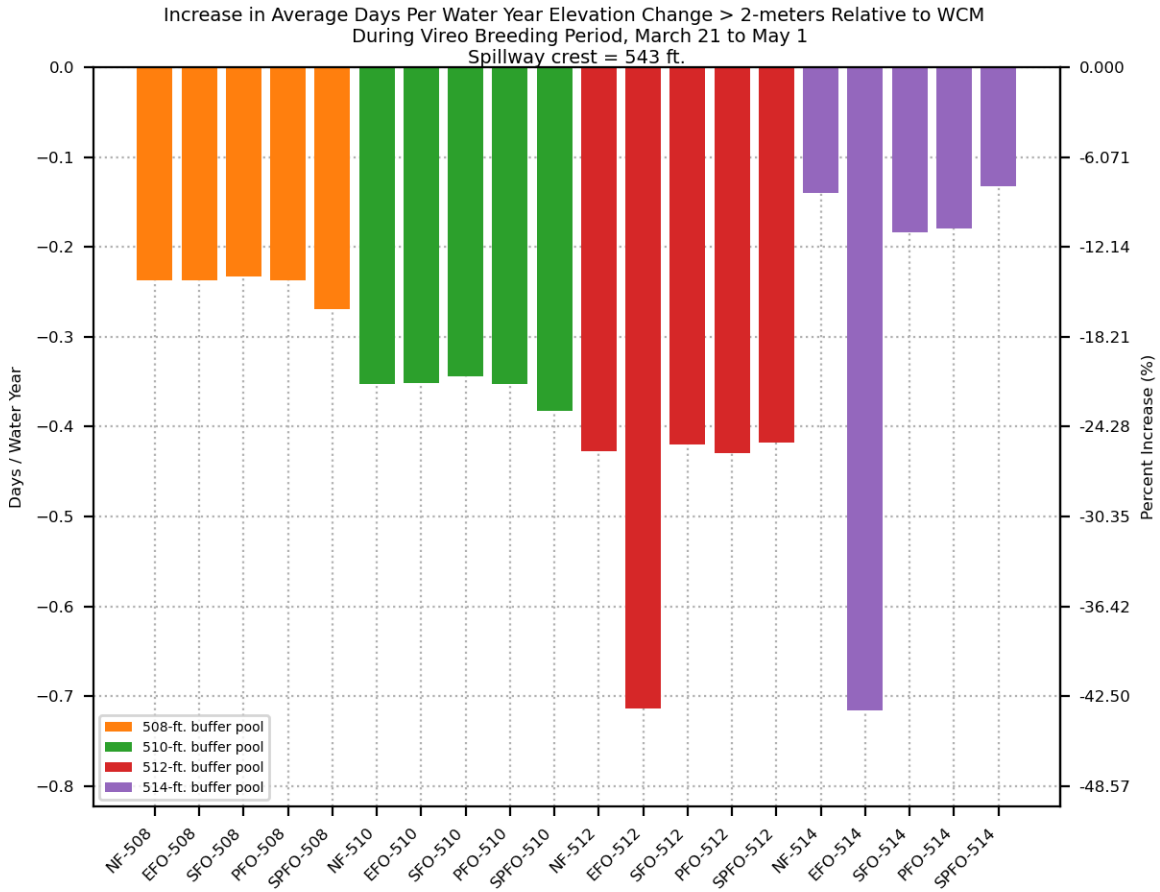
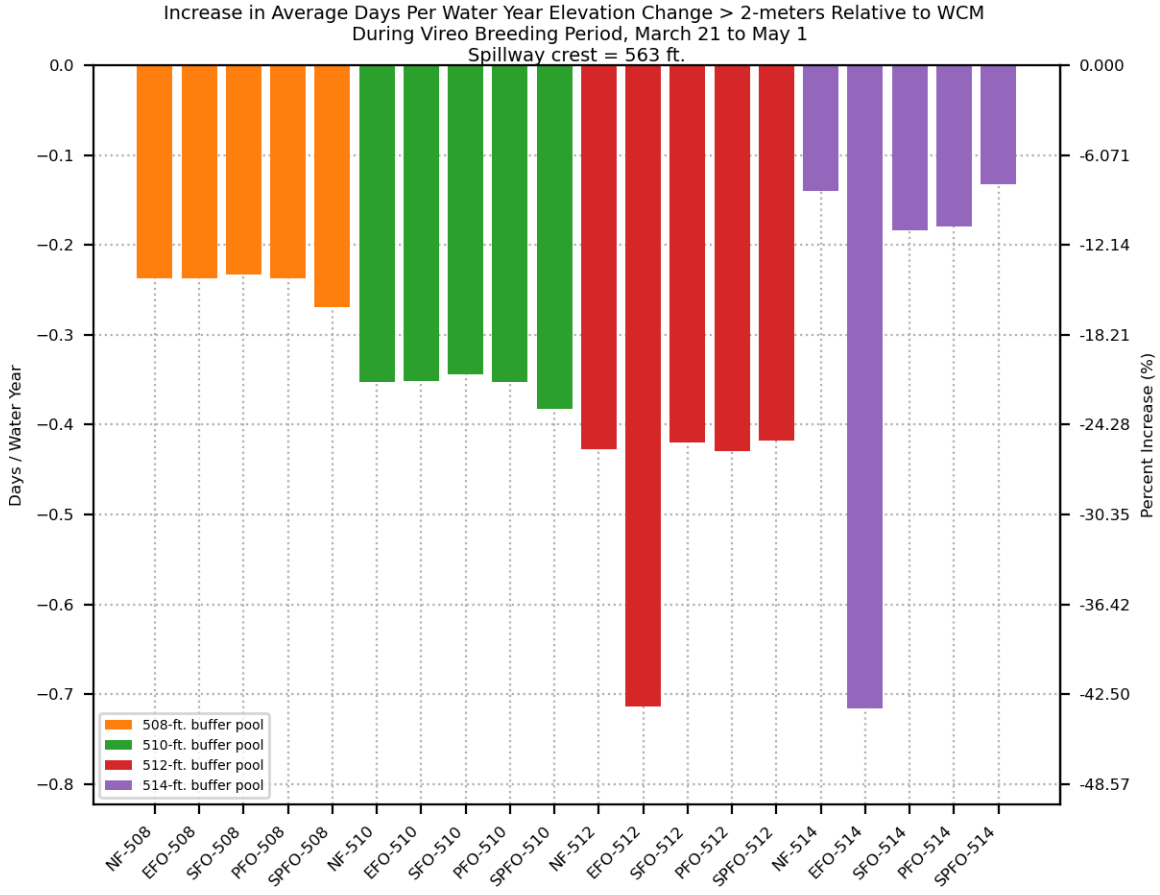
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Average Days Per Water Year Elevation Change > 2-meters
During Vireo Nesting Period, March 21 to May 1
Spillway crest = 543 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Average Days Per Water Year Elevation Change > 2-meters
During Vireo Nesting Period, March 21 to May 1
Spillway crest = 563 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
Days / Water Year
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
WCM-505
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Increase in Average Days Per Water Year Elevation Change > 2-meters Relative to WCM
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 543 ft.
Days / Water Year
Percent Increase (%)
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
−0.6
−0.7
−0.8
0.000
-6.071
-12.14
-18.21
-24.28
-30.35
-36.42
-42.50
-48.57
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514


Increase in Average Days Per Water Year Elevation Change > 2-meters Relative to WCM
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 563 ft.
Days / Water Year
Percent Increase (%)
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
−0.6
−0.7
−0.8
0.000
-6.071
-12.14
-18.21
-24.28
-30.35
-36.42
-42.50
-48.57
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
NF-508
EFO-508
SFO-508
PFO-508
SPFO-508
NF-510
EFO-510
SFO-510
PFO-510
SPFO-510
NF-512
EFO-512
SFO-512
PFO-512
SPFO-512
NF-514
EFO-514
SFO-514
PFO-514
SPFO-514

HEMP Metrics – Bar Charts (No PF No NF)

- Average annual groundwater recharge (AAGR)
- Change in AAGR relative to WCM (baseline)

- Average annual Santa Anna River discharge (AASRD) to Pacific Ocean
- Change in AASRD relative to WCM (baseline)

- Average days/yr > 505’, 508’, 510’, 512’, 514’, 520’
- Change in days/yr > 505’, 508’, 510’, 512’, 514’, 520’ relative to WCM (baseline)

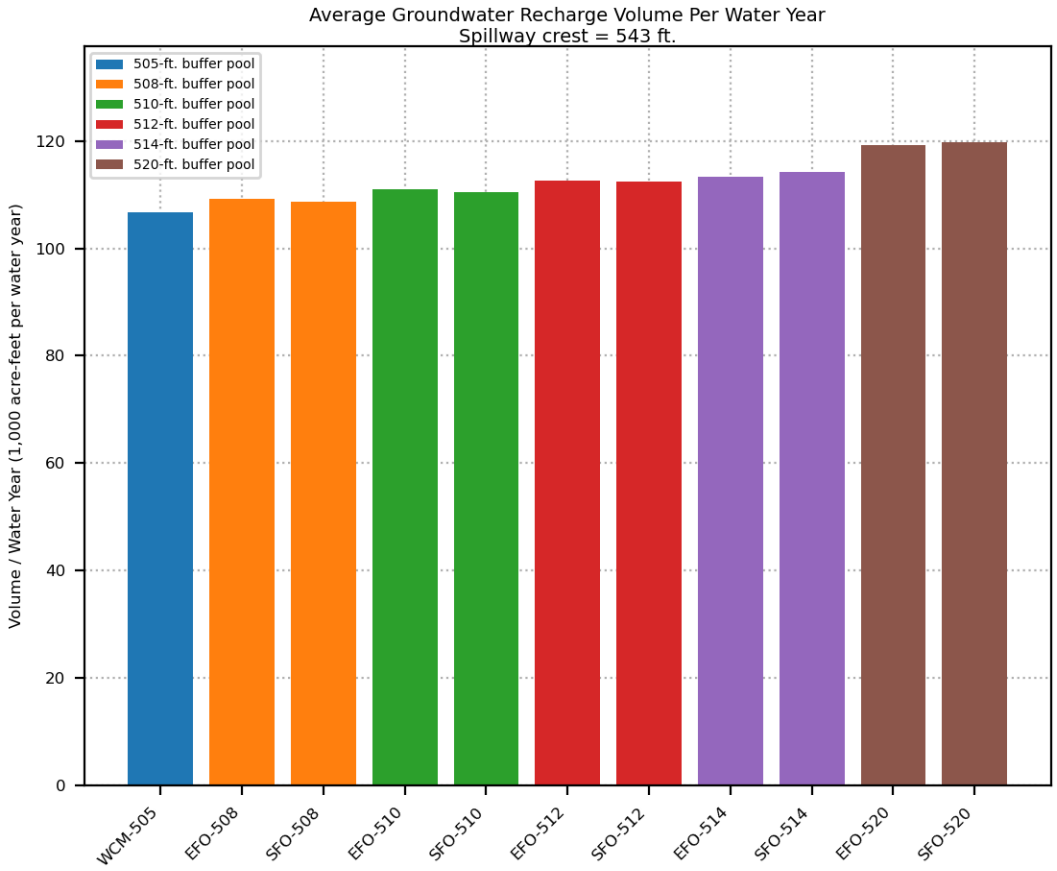
HEMP Metrics – Bar Charts (No PF No NF)

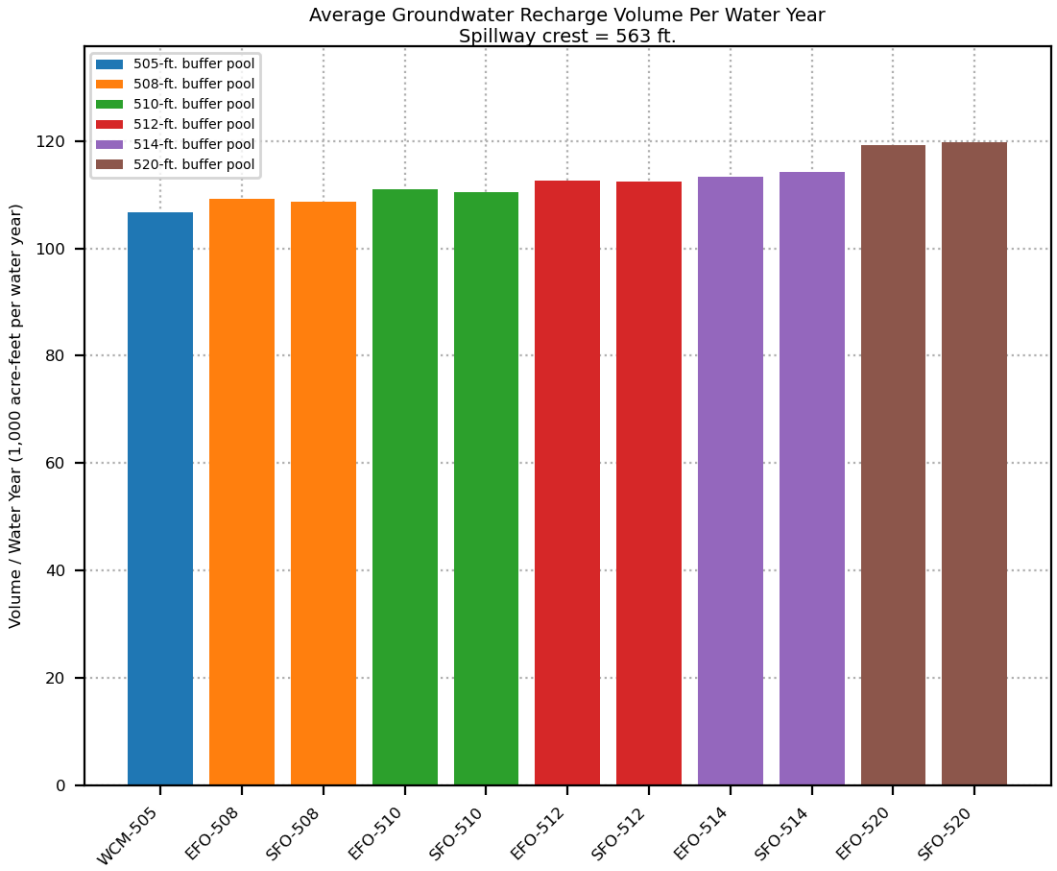
- Average days/yr > 5,000, 10,000, 15,000 cfs
- Change in days/yr > 5,000, 10,000, 15,000 cfs relative to WCM (baseline)

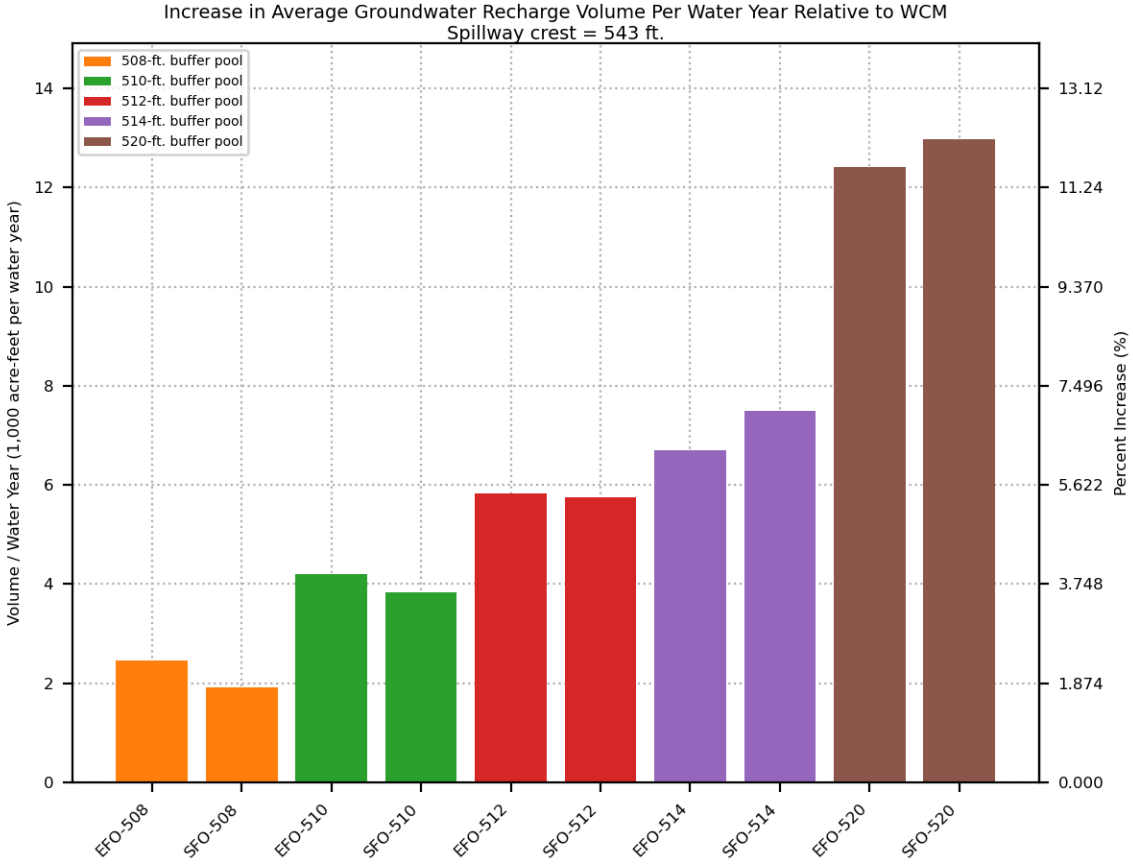
- Average days/yr > 1 meter pool rise during vireo nesting season (3/21-5/1)
- Change in days/yr > 1 meter pool rise during vireo nesting season (3/21–5/1) relative to WCM (baseline)

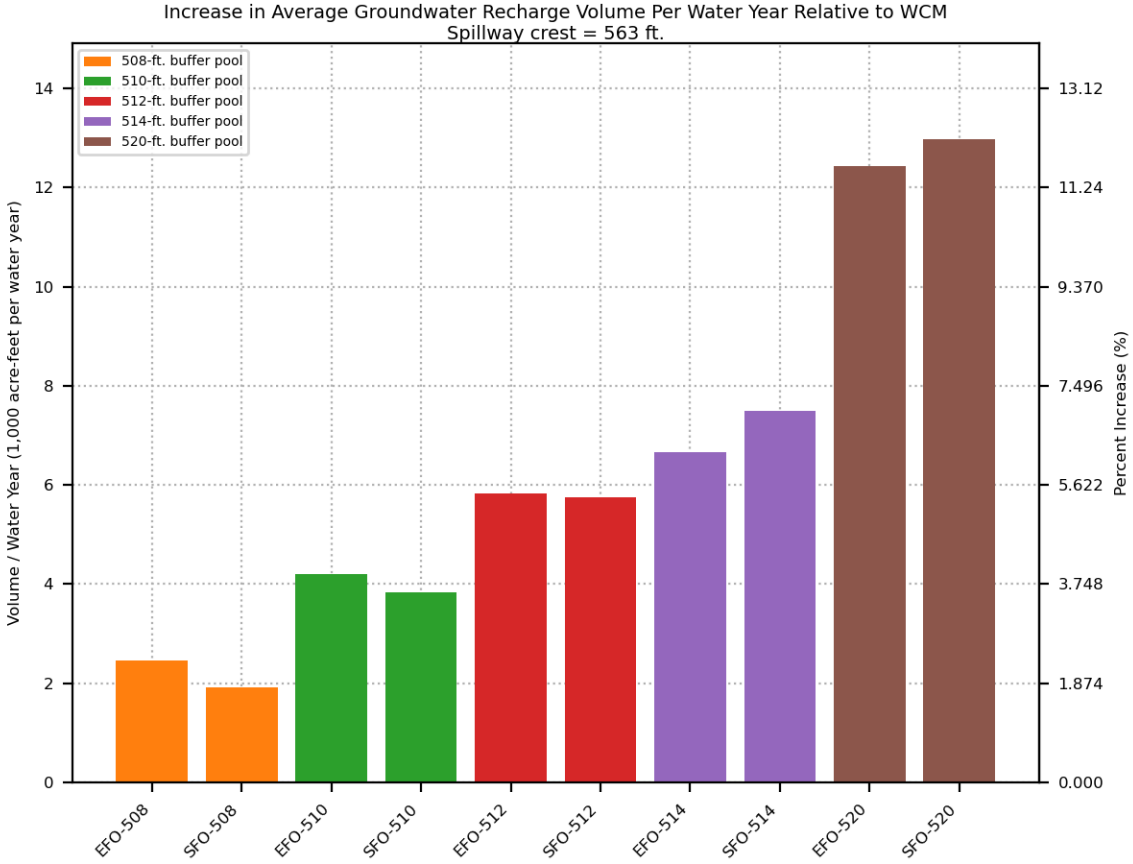
HEMP Metrics – Bar Charts (No PF No NF)

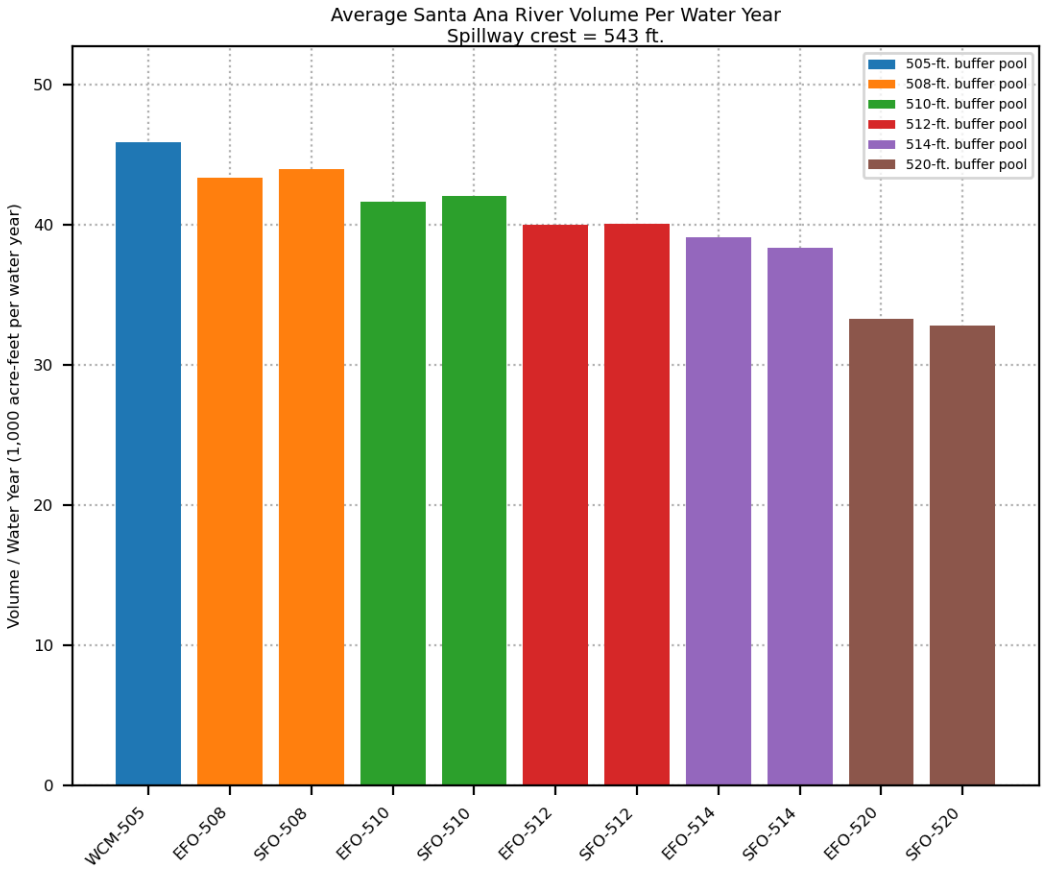
- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’, 510’, 512’, 514’, 520’
- WCP alternatives across X Axis
  - Perfect and No Forecast alternatives omitted

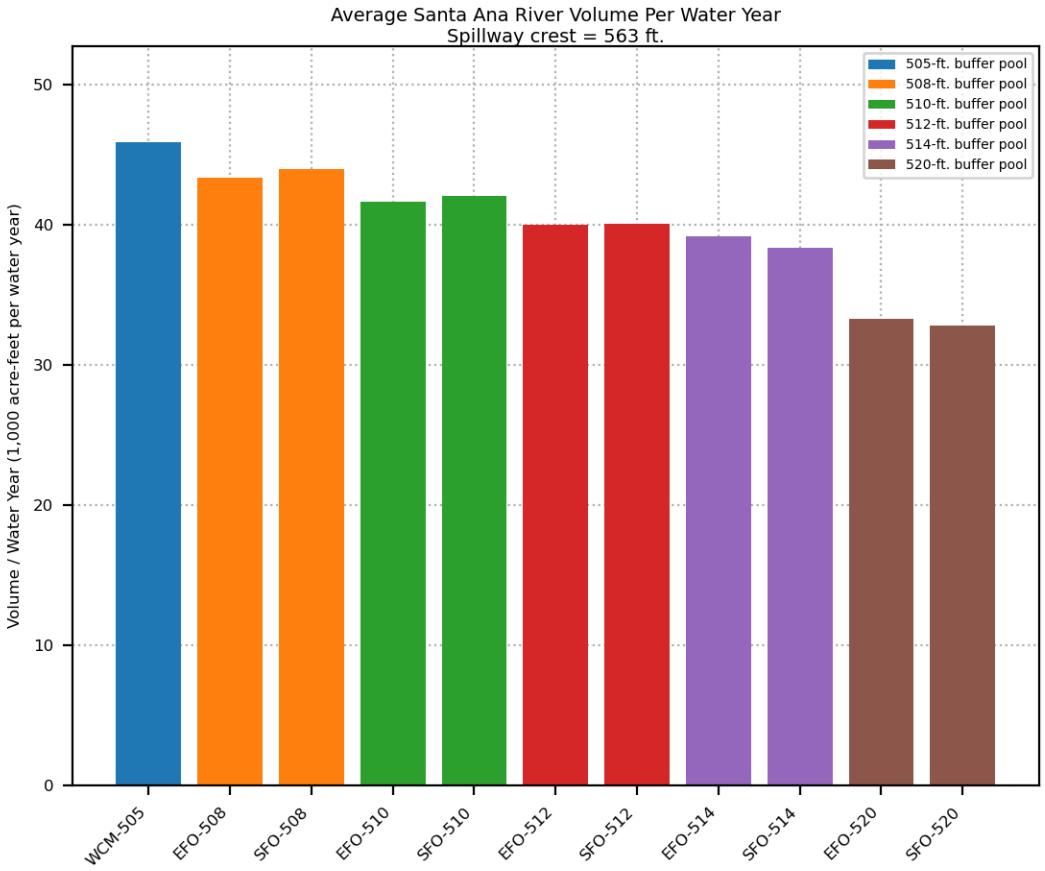

Average Groundwater Recharge Volume Per Water Year
Spillway crest = 543 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Volume / Water Year (1,000 acre-feet per water year)
0
20
40
60
80
100
120
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

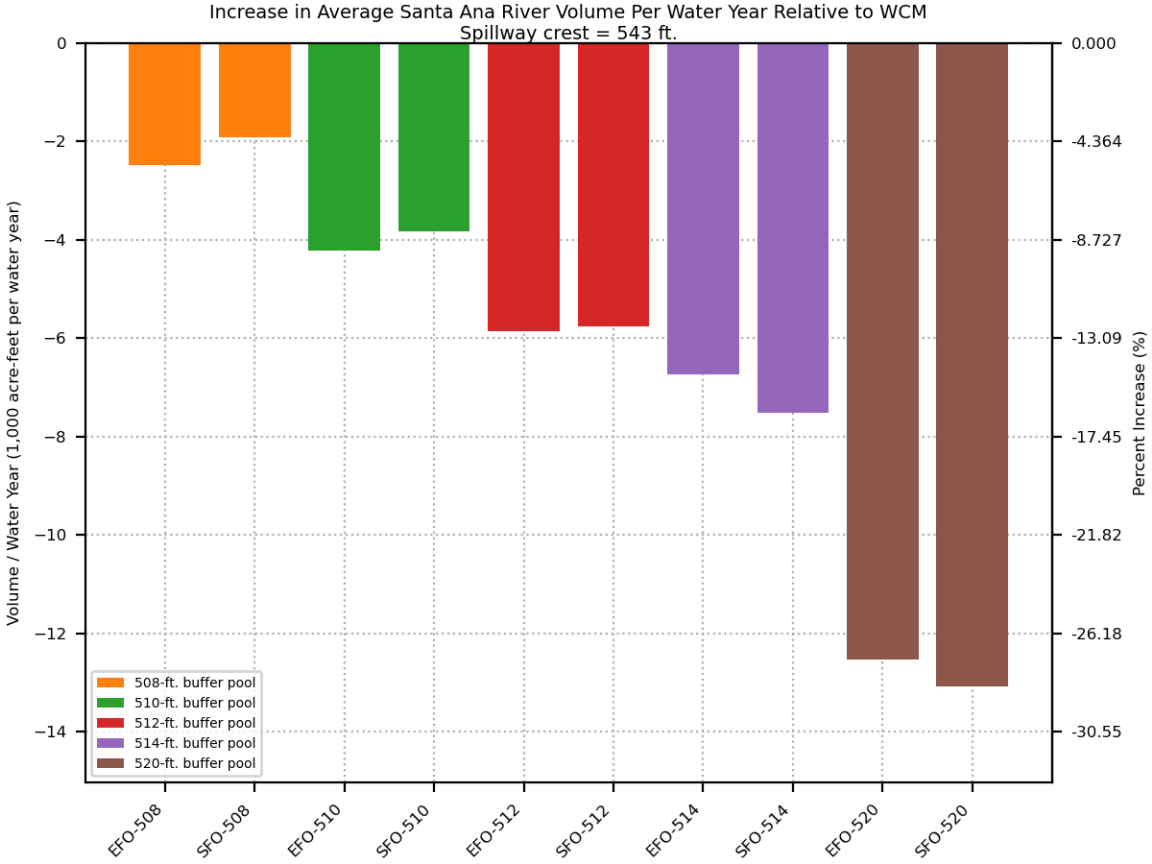

Average Groundwater Recharge Volume Per Water Year
Spillway crest = 563 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Volume / Water Year (1,000 acre-feet per water year)
0
20
40
60
80
100
120
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

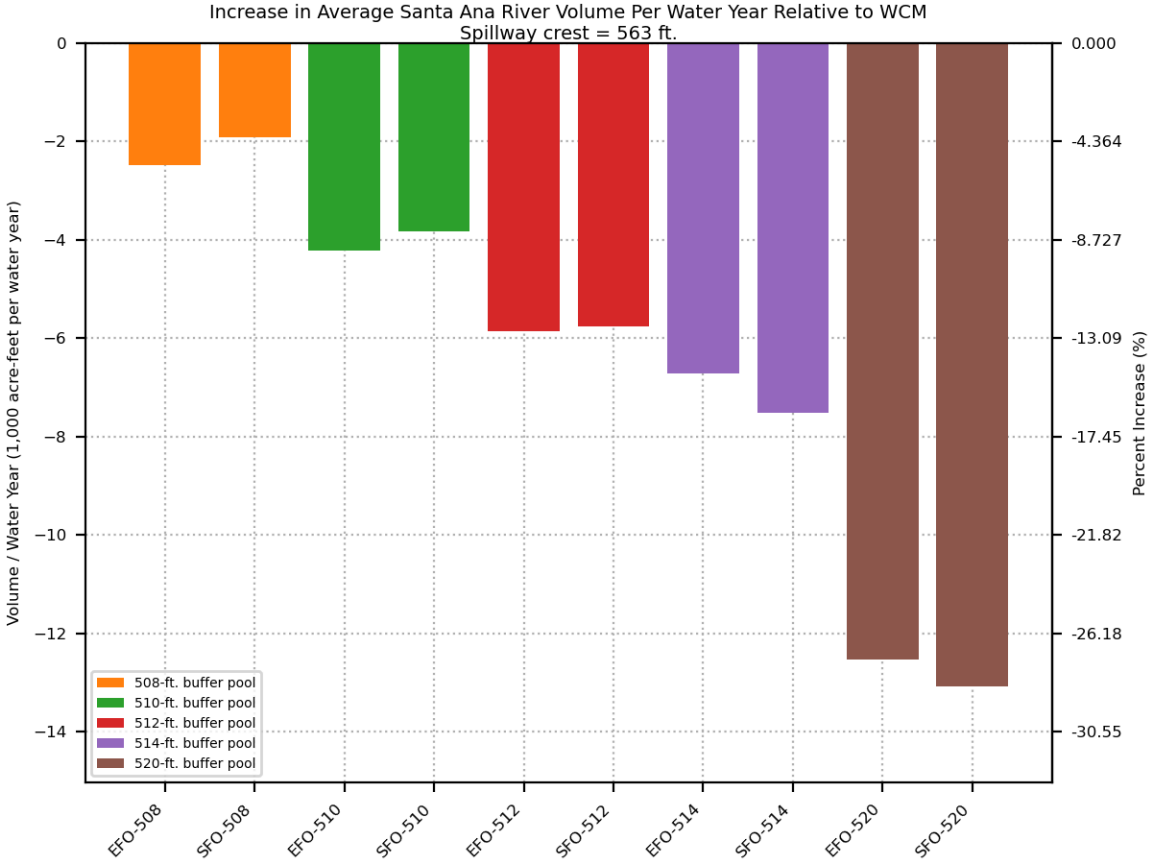

Increase in Average Groundwater Recharge Volume Per Water Year Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Volume / Water Year (1,000 acre-feet per water year)
Percent Increase (%)
0
2
4
6
8
10
12
14
0.000
1.874
3.748
5.622
7.496
9.370
11.24
13.12
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

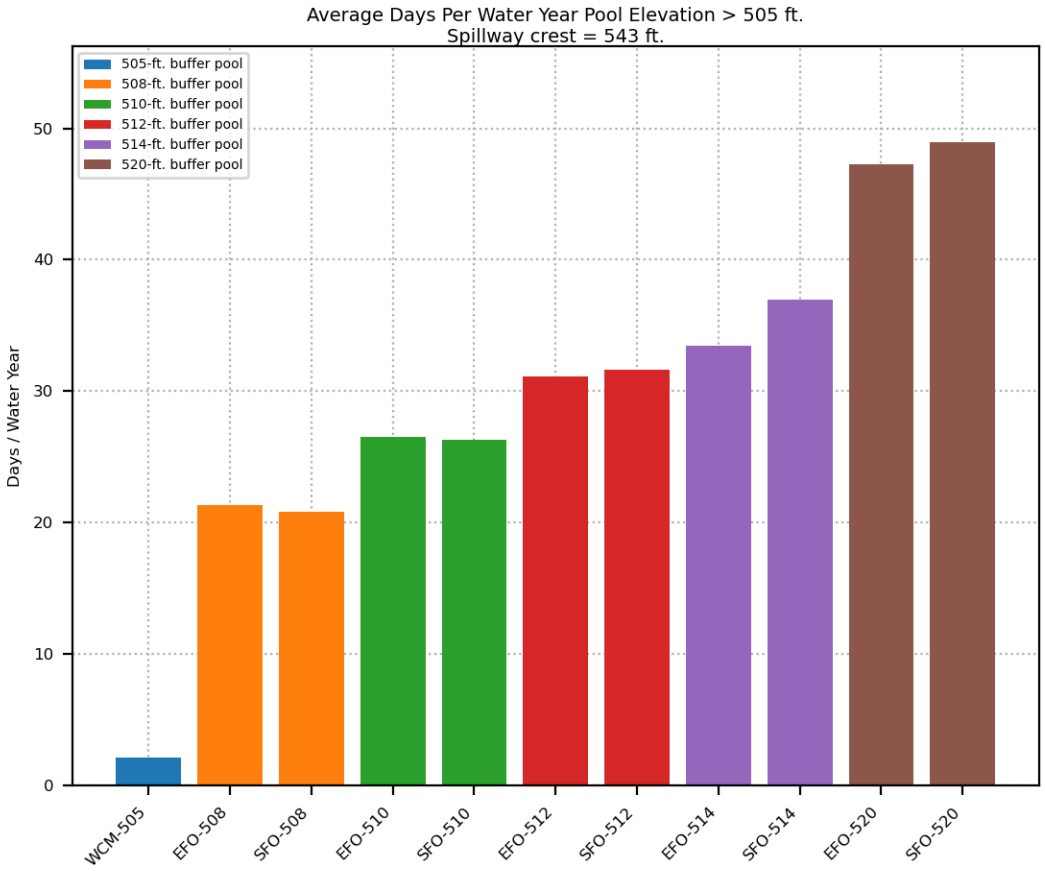

Increase in Average Groundwater Recharge Volume Per Water Year Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Volume / Water Year (1,000 acre-feet per water year)
Percent Increase (%)
0
2
4
6
8
10
12
14
0.000
1.874
3.748
5.622
7.496
9.370
11.24
13.12
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

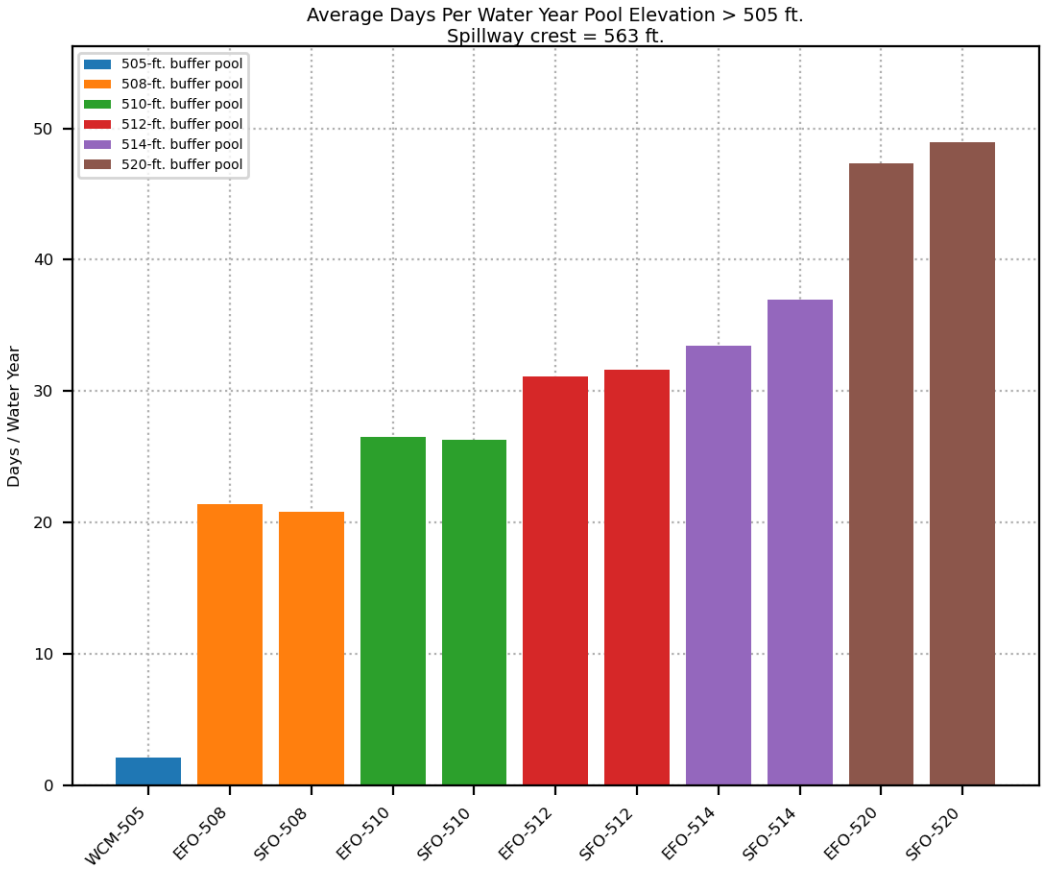

Average Santa Ana River Volume Per Water Year
Spillway crest = 543 ft.
Volume / Water Year (1,000 acre-feet per water year)
0
10
20
30
40
50
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

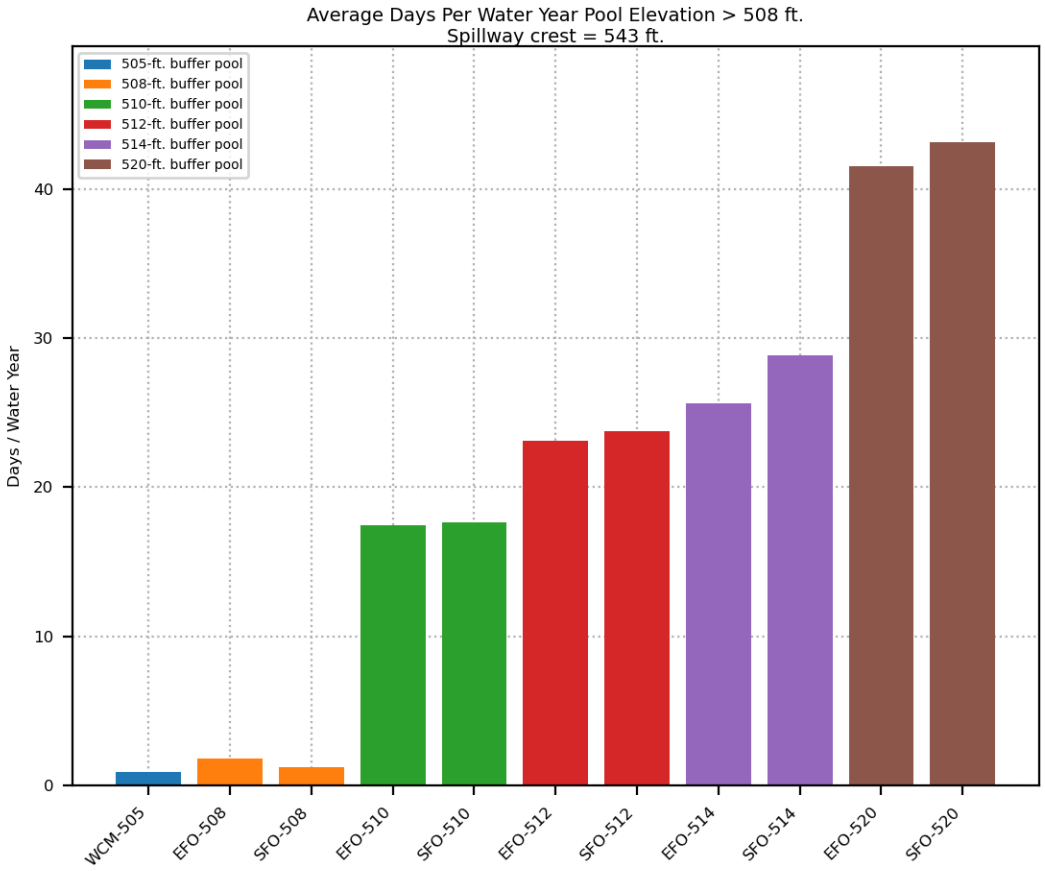

Average Santa Ana River Volume Per Water Year
Spillway crest = 563 ft.
Volume / Water Year (1,000 acre-feet per water year)
0
10
20
30
40
50
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

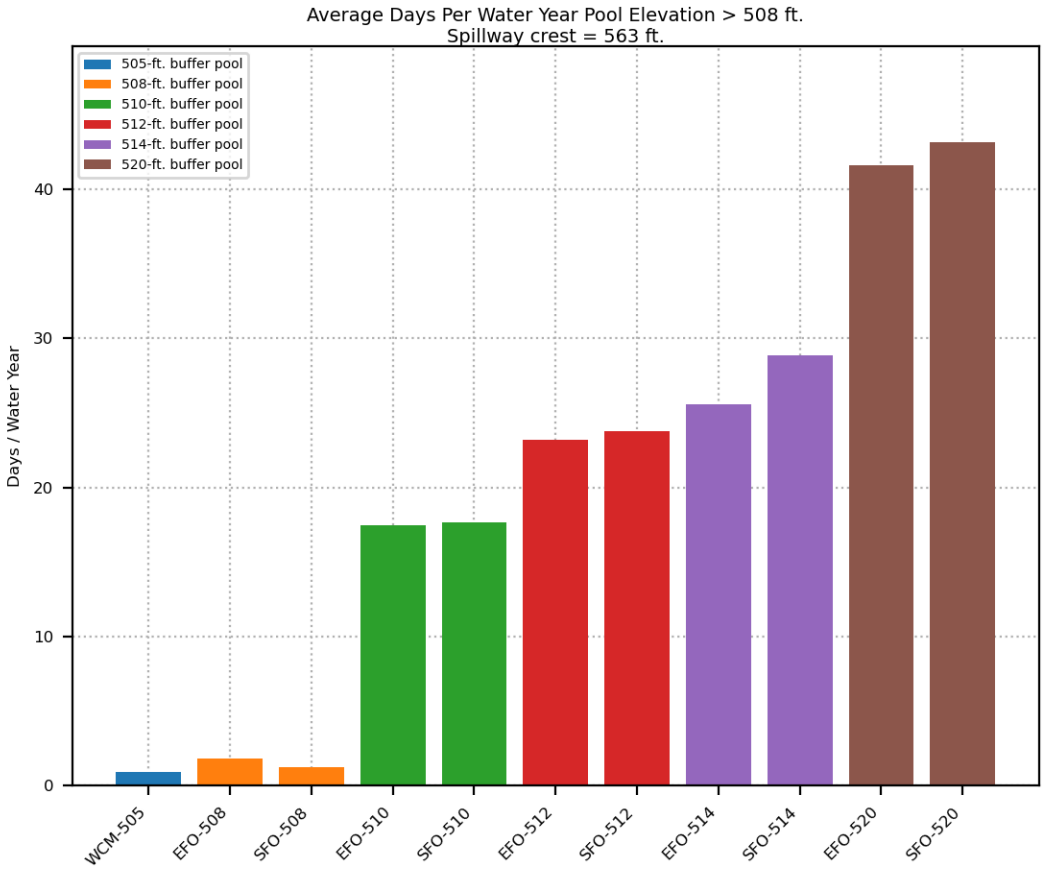

Increase in Average Santa Ana River Volume Per Water Year Relative to WCM
Spillway crest = 543 ft.
Volume / Water Year (1,000 acre-feet per water year)
Percent Increase (%)
0
−2
−4
−6
−8
−10
−12
−14
0.000
-4.364
-8.727
-13.09
-17.45
-21.82
-26.18
-30.55
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

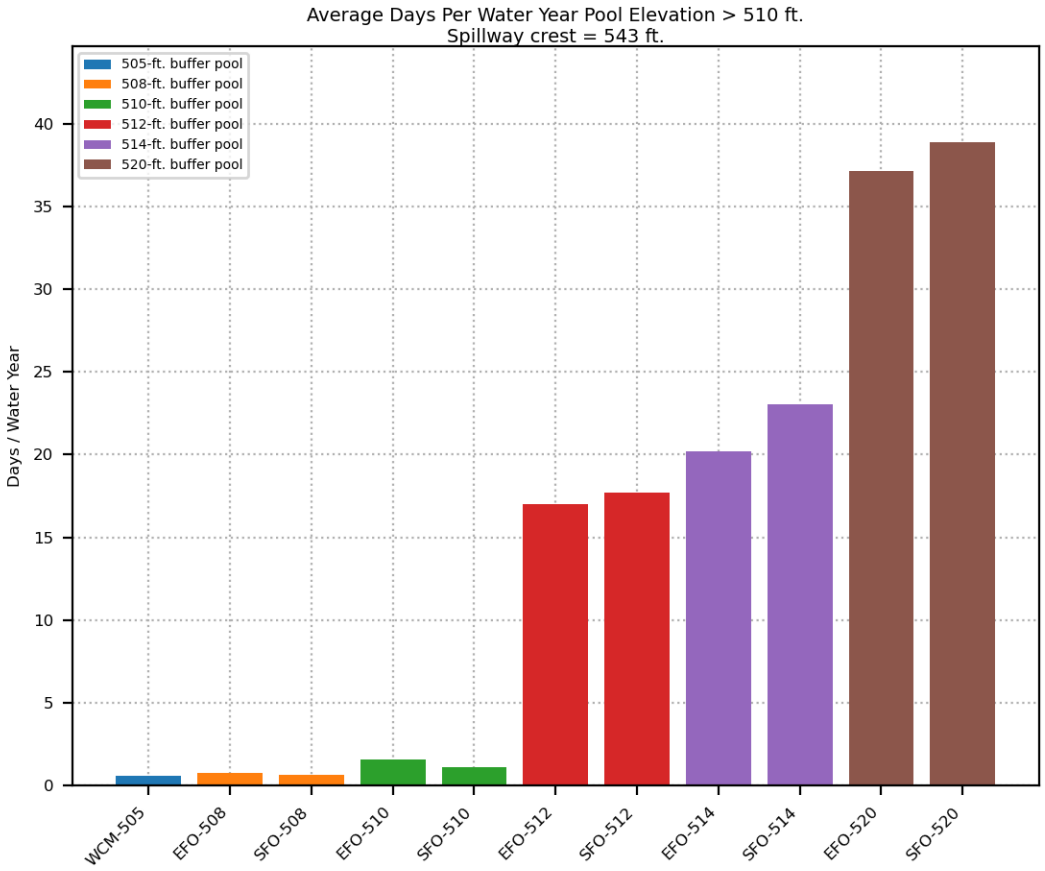

Increase in Average Santa Ana River Volume Per Water Year Relative to WCM
Spillway crest = 563 ft.
Volume / Water Year (1,000 acre-feet per water year)
Percent Increase (%)
0
−2
−4
−6
−8
−10
−12
−14
0.000
-4.364
-8.727
-13.09
-17.45
-21.82
-26.18
-30.55
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

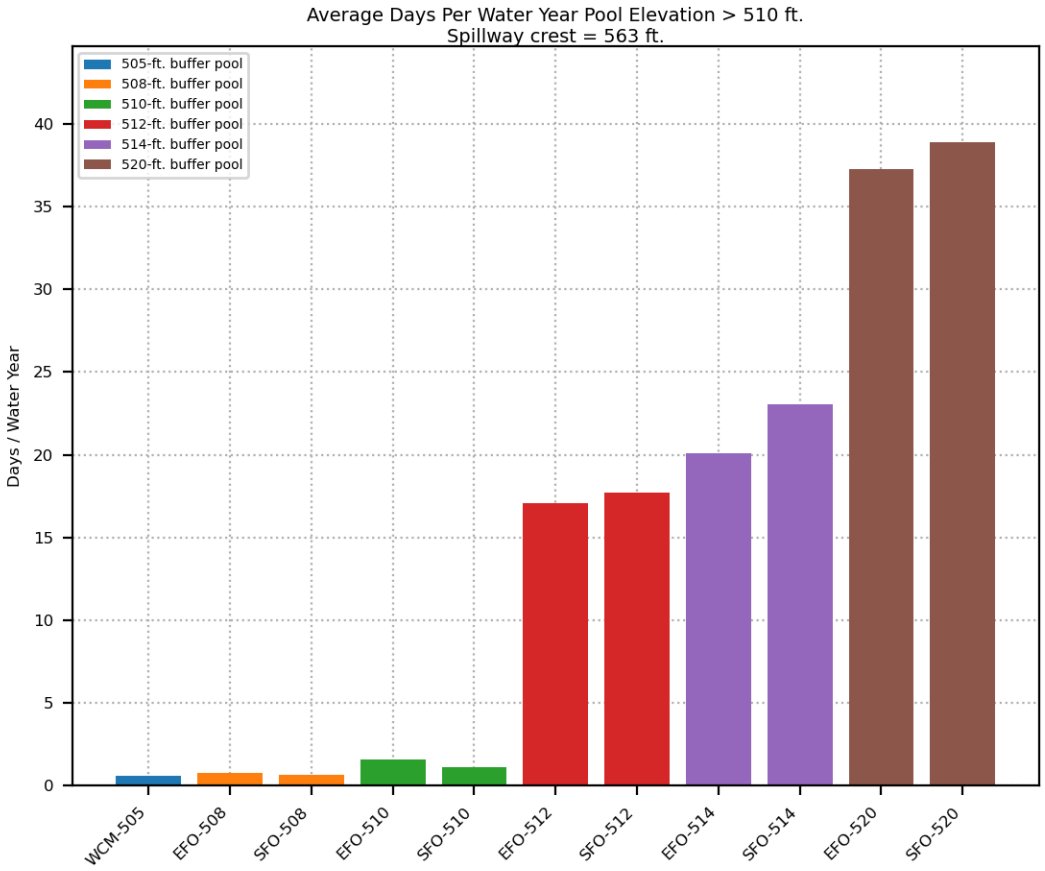

Average Days Per Water Year Pool Elevation > 505 ft.
Spillway crest = 543 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0
10
20
30
40
50
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

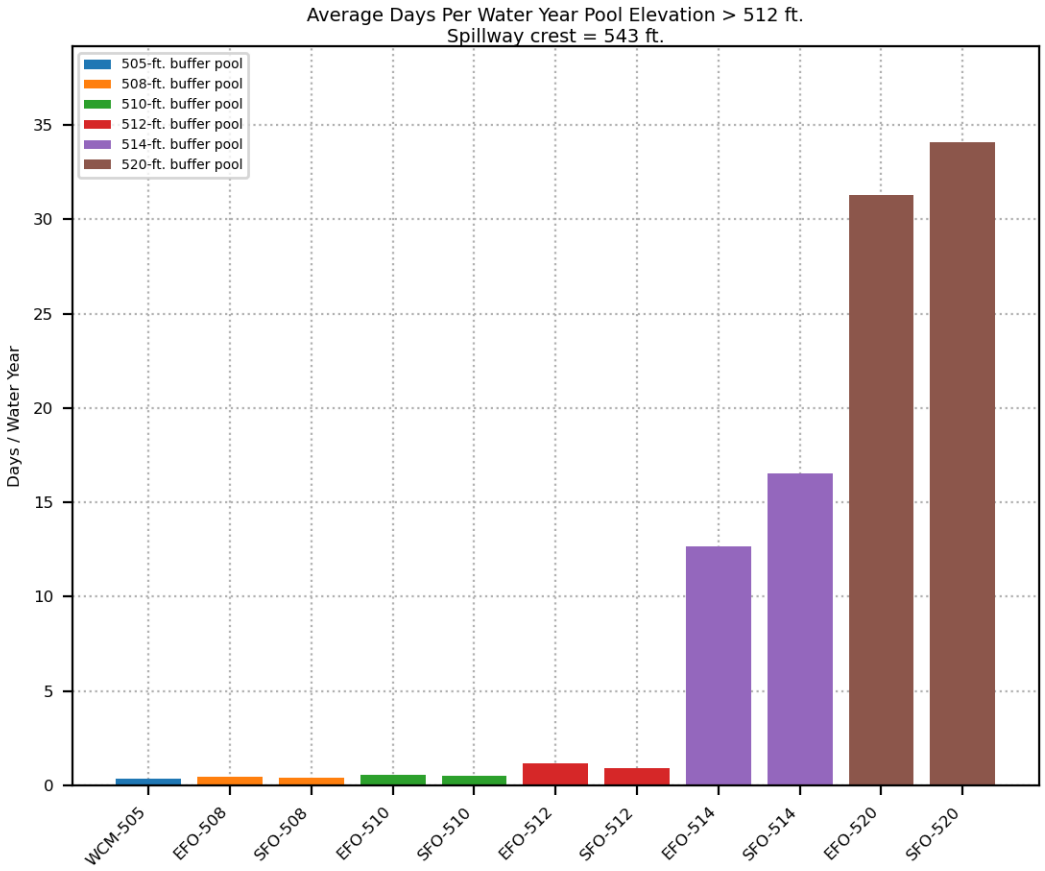

Average Days Per Water Year Pool Elevation > 505 ft.
Spillway crest = 563 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0
10
20
30
40
50
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

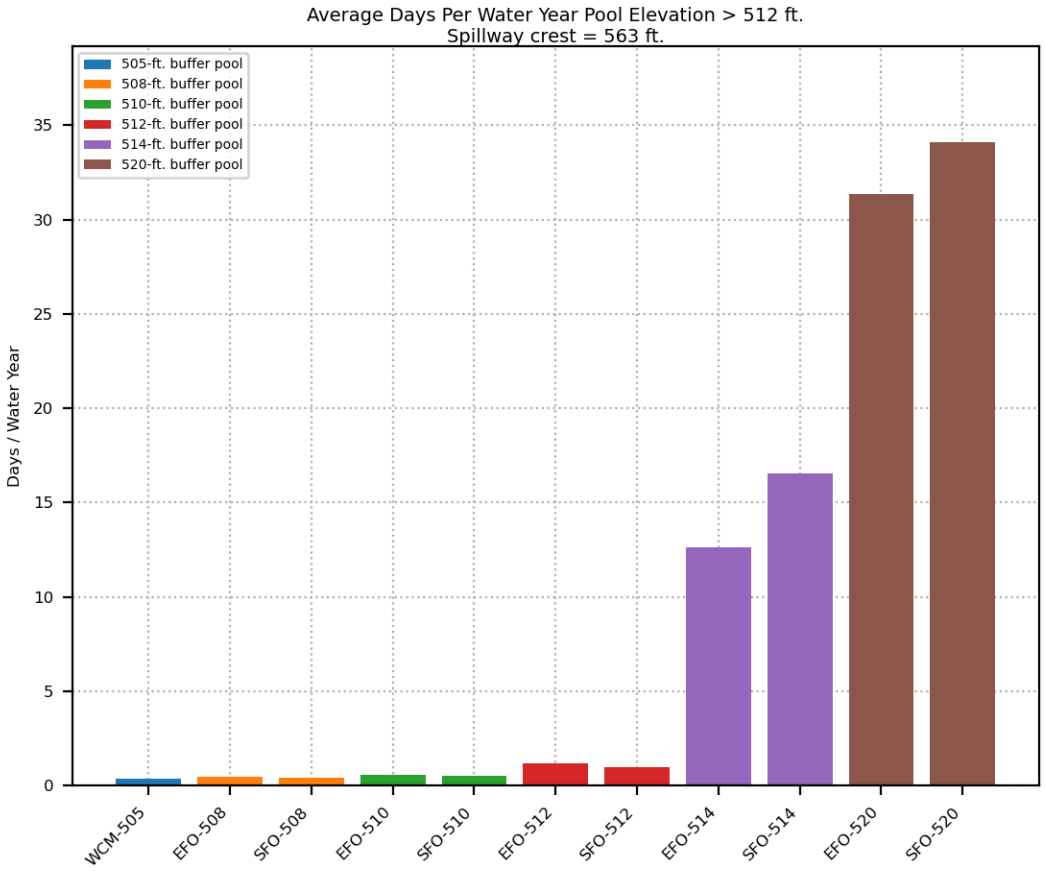

Average Days Per Water Year Pool Elevation > 508 ft.
Spillway crest = 543 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0
10
20
30
40
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

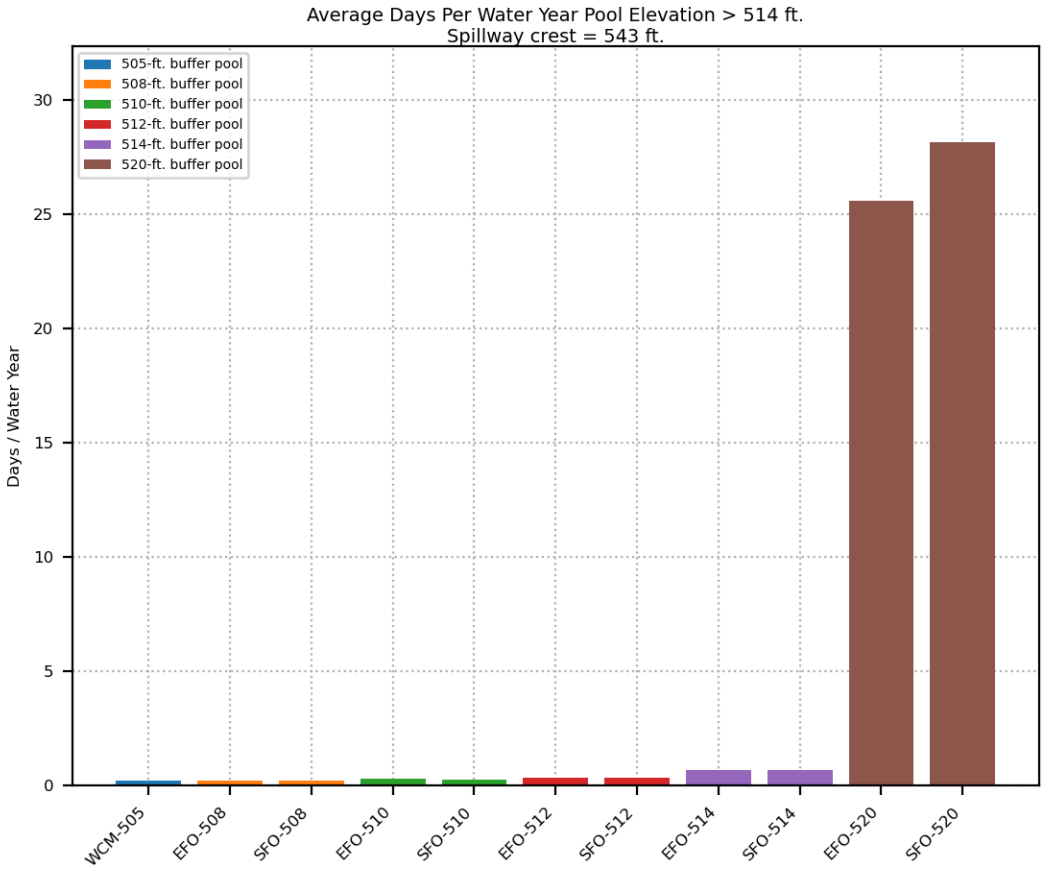

Average Days Per Water Year Pool Elevation > 508 ft.
Spillway crest = 563 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0
10
20
30
40
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

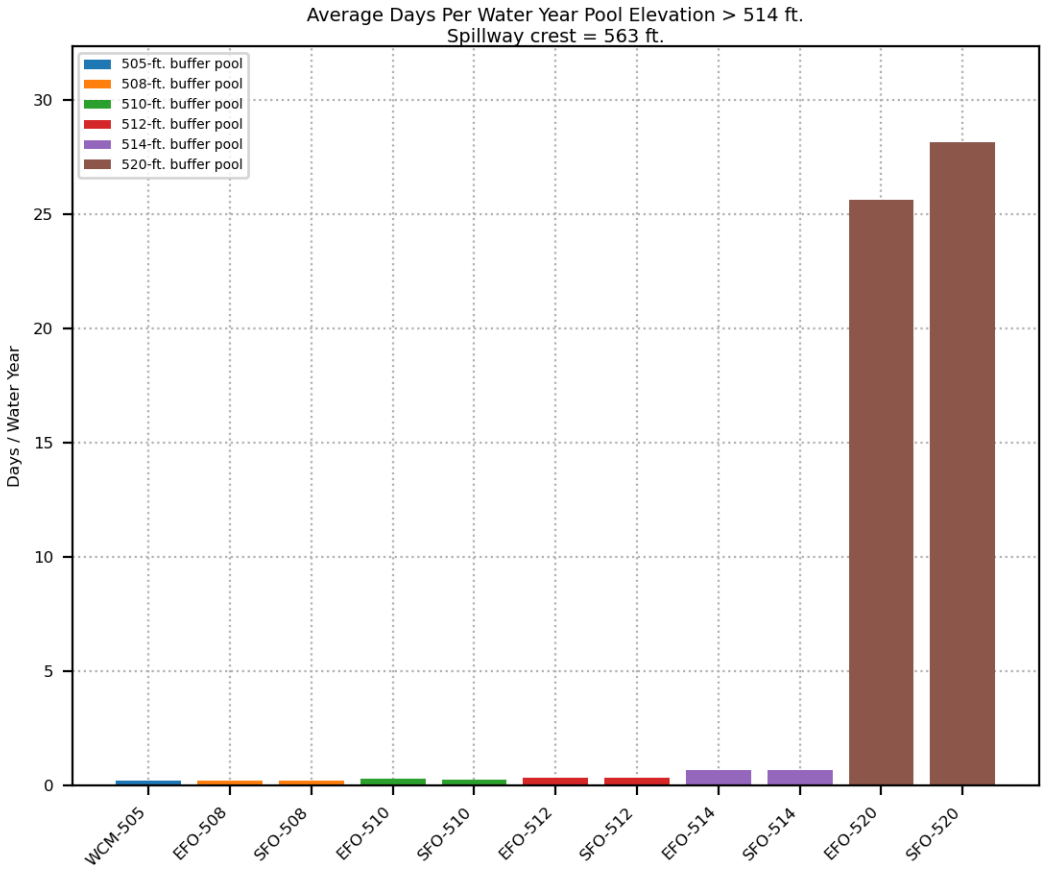

Average Days Per Water Year Pool Elevation > 510 ft.
Spillway crest = 543 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0
5
10
15
20
25
30
35
40
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

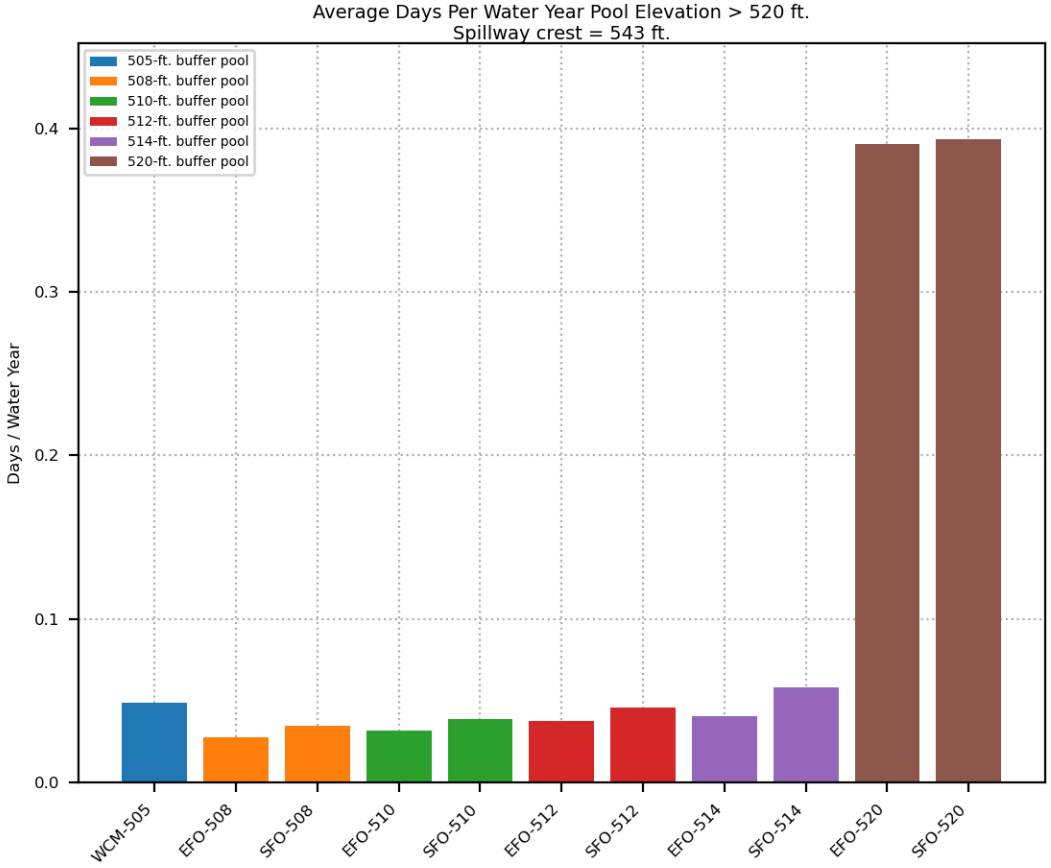

Average Days Per Water Year Pool Elevation > 510 ft.
Spillway crest = 563 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0
5
10
15
20
25
30
35
40
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

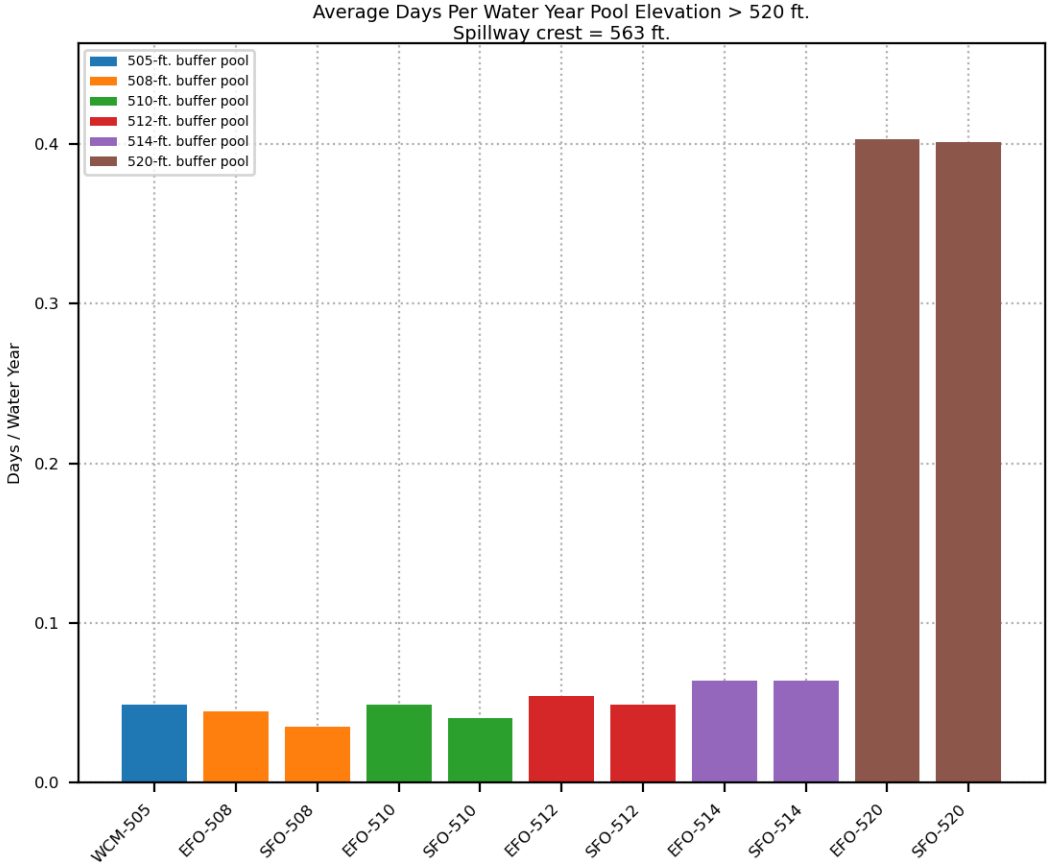

Average Days Per Water Year Pool Elevation > 512 ft.
Spillway crest = 543 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0
5
10
15
20
25
30
35
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

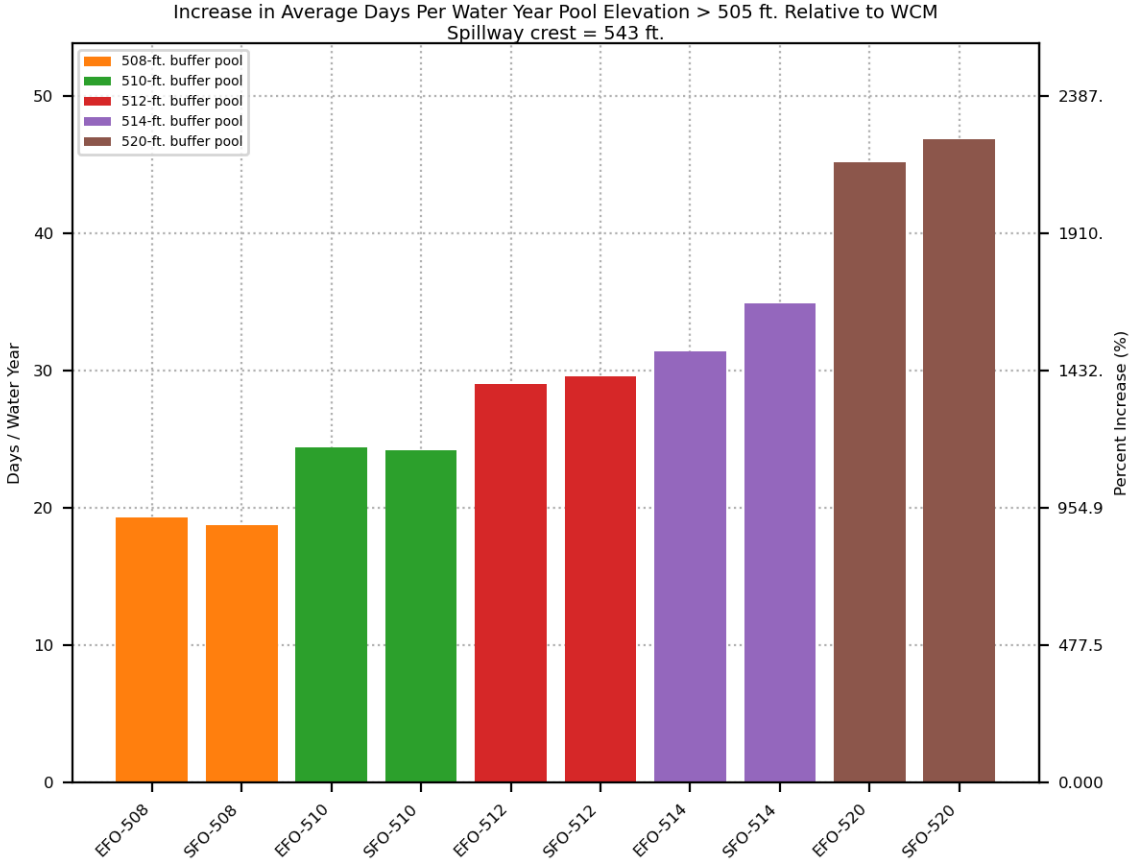

Average Days Per Water Year Pool Elevation > 512 ft.
Spillway crest = 563 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0
5
10
15
20
25
30
35
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

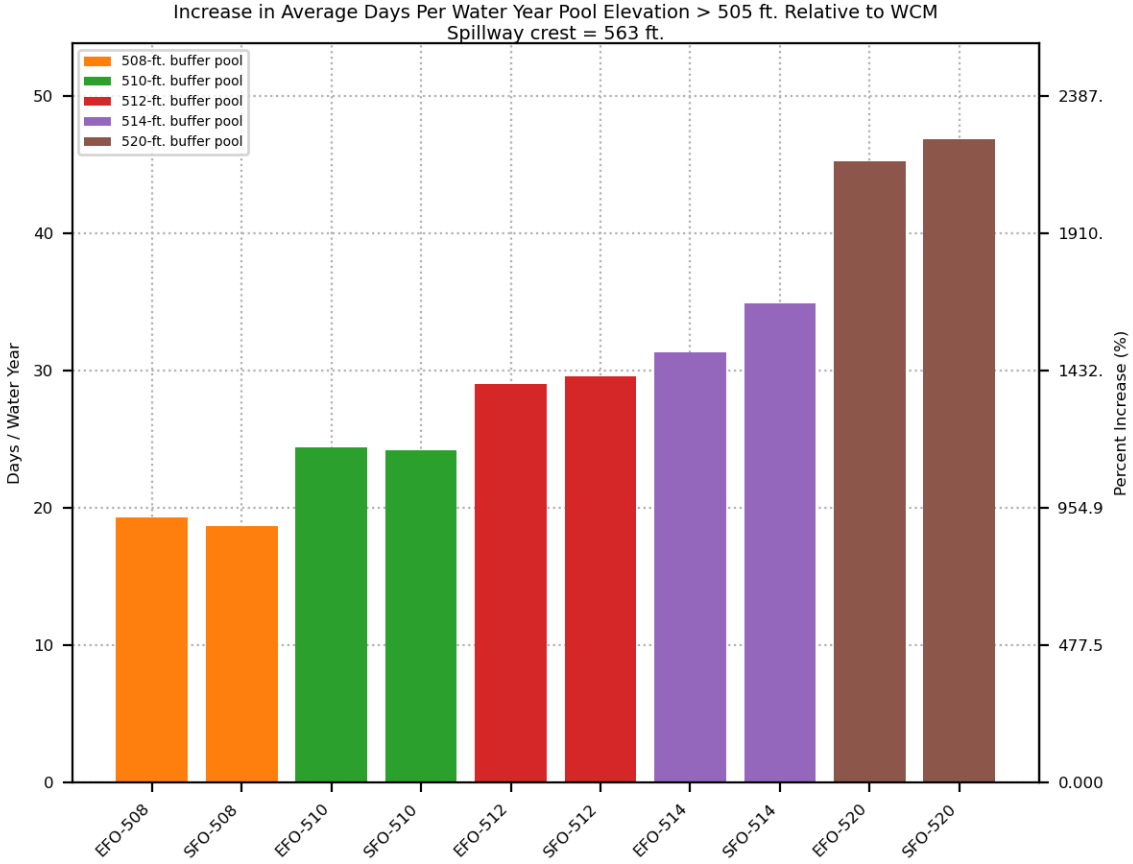

Average Days Per Water Year Pool Elevation > 514 ft.
Spillway crest = 543 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0
5
10
15
20
25
30
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

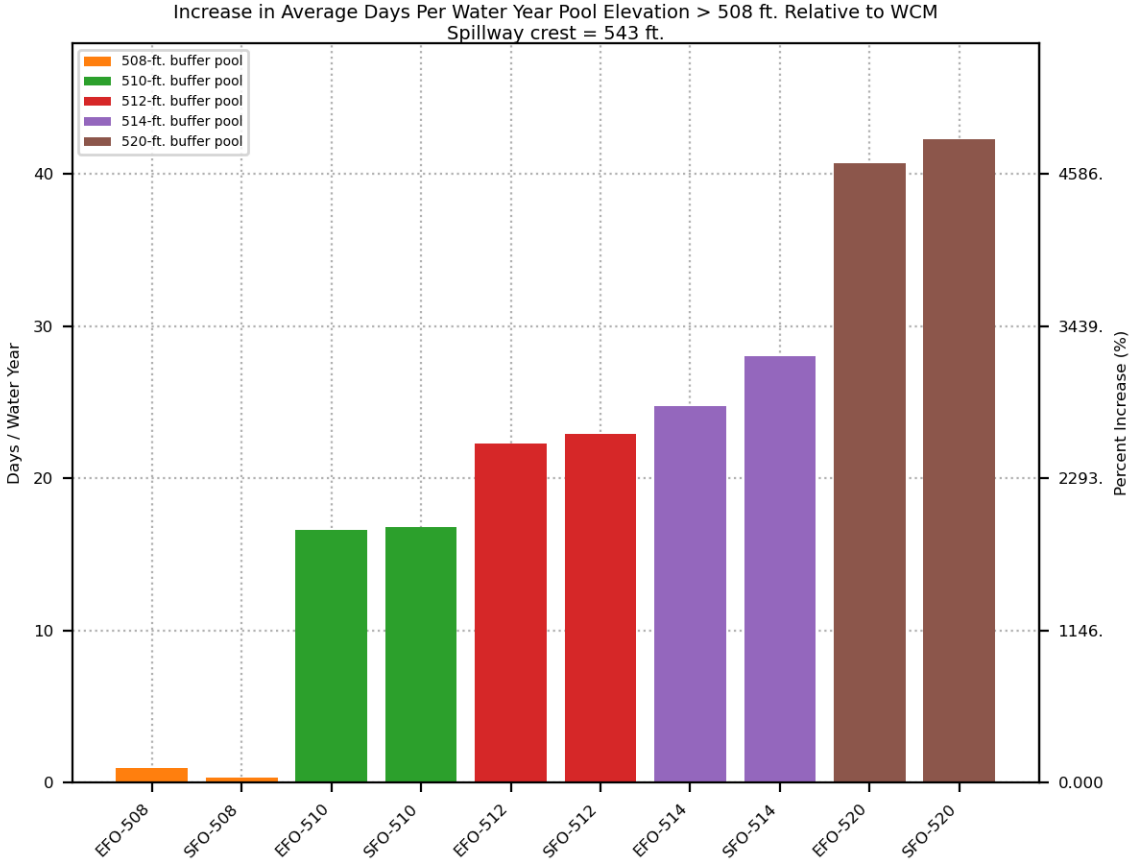

Average Days Per Water Year Pool Elevation > 514 ft.
Spillway crest = 563 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0
5
10
15
20
25
30
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

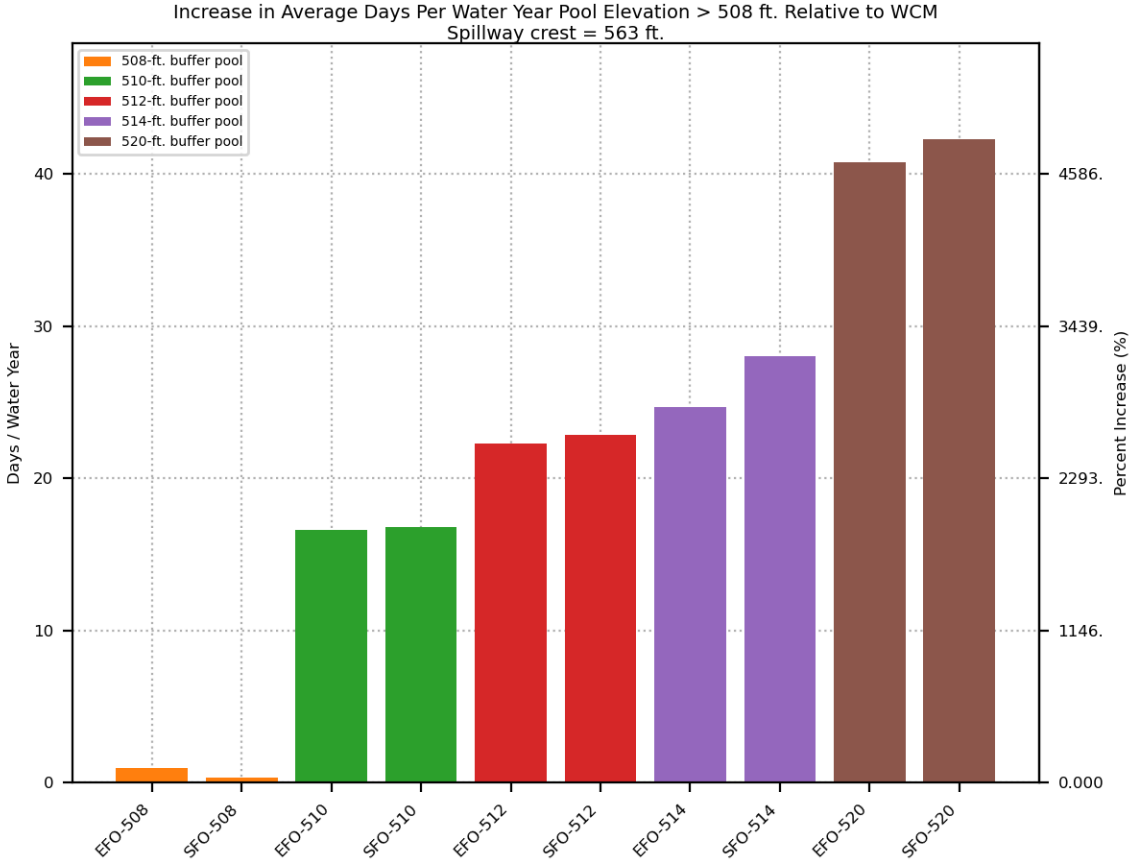

Average Days Per Water Year Pool Elevation > 520 ft.
Spillway crest = 543 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0.0
0.1
0.2
0.3
0.4
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

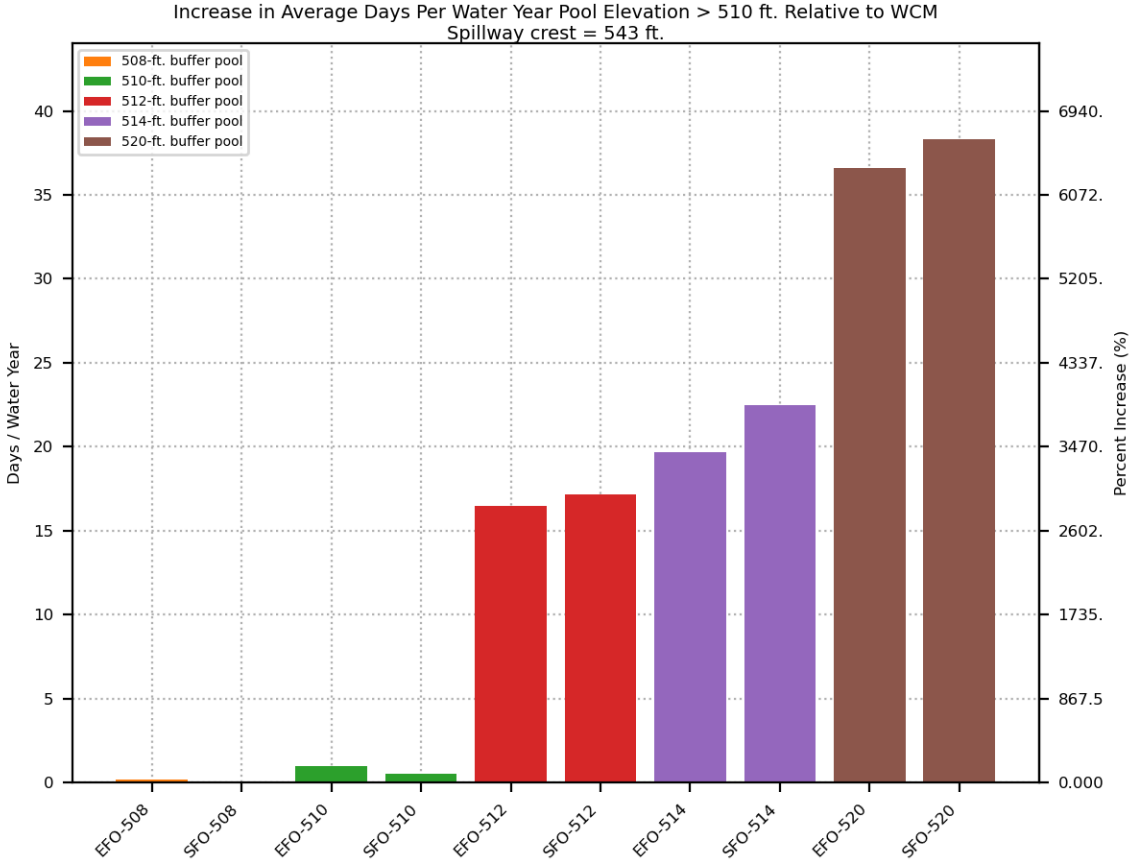

Average Days Per Water Year Pool Elevation > 520 ft.
Spillway crest = 563 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0.0
0.1
0.2
0.3
0.4
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

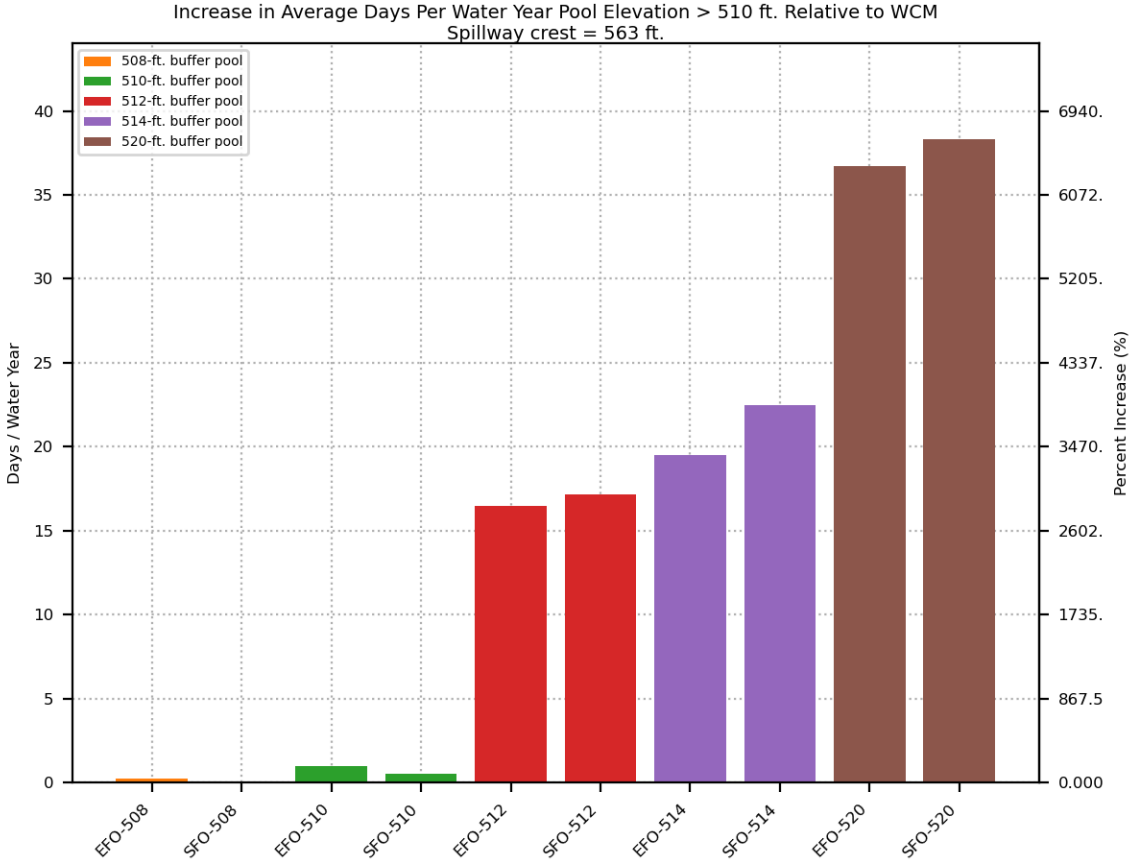

Increase in Average Days Per Water Year Pool Elevation > 505 ft. Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
10
20
30
40
50
0.000
477.5
954.9
1432.
1910.
2387.
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

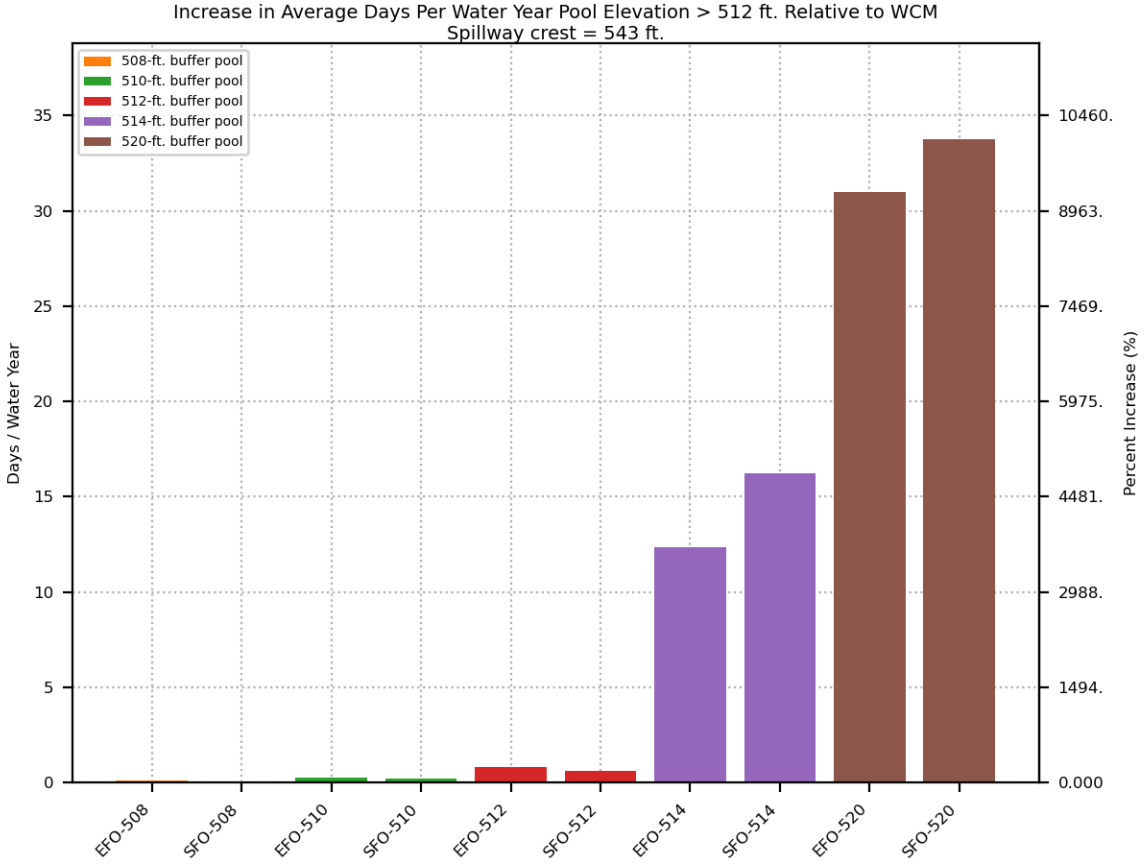

Increase in Average Days Per Water Year Pool Elevation > 505 ft. Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
10
20
30
40
50
0.000
477.5
954.9
1432.
1910.
2387.
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

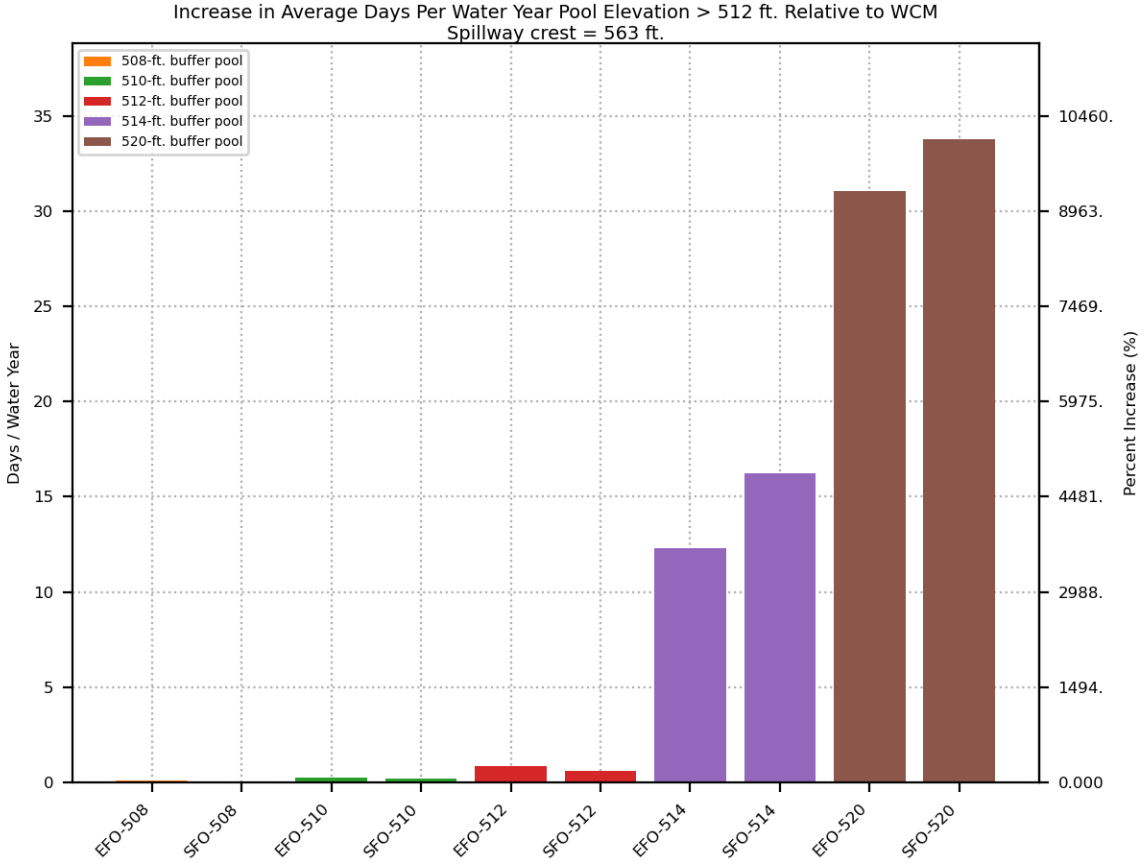

Increase in Average Days Per Water Year Pool Elevation > 508 ft. Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
10
20
30
40
0.000
1146.
2293.
3439.
4586.
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

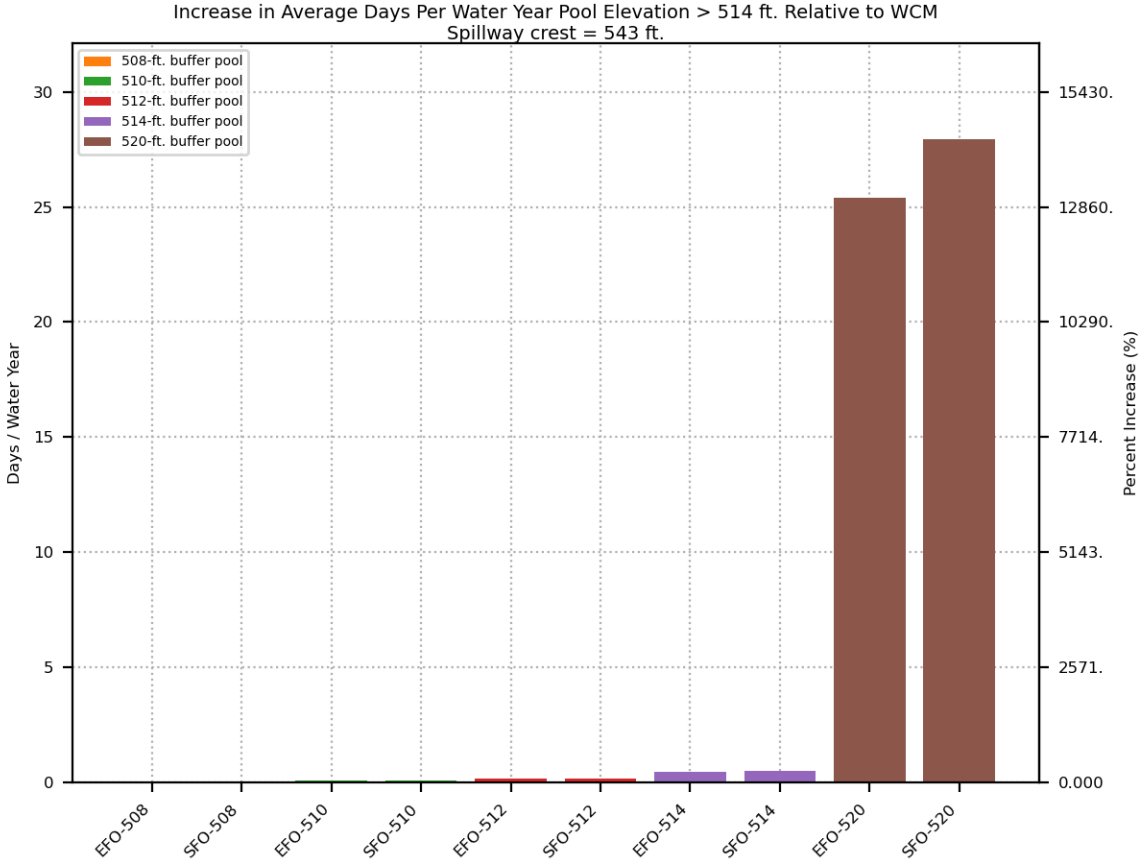

Increase in Average Days Per Water Year Pool Elevation > 508 ft. Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
10
20
30
40
0.000
1146.
2293.
3439.
4586.
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

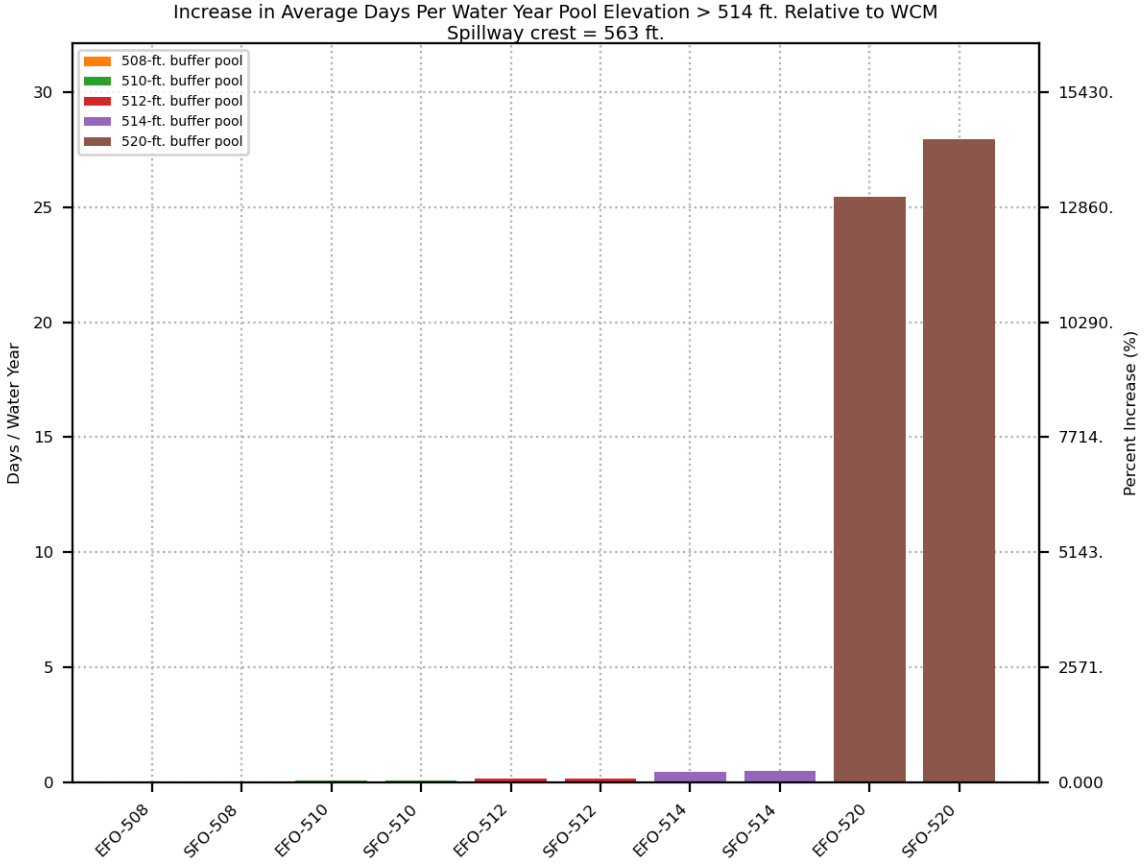

Increase in Average Days Per Water Year Pool Elevation > 510 ft. Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
5
10
15
20
25
30
35
40
0.000
867.5
1735.
2602.
3470.
4337.
5205.
6072.
6940.
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

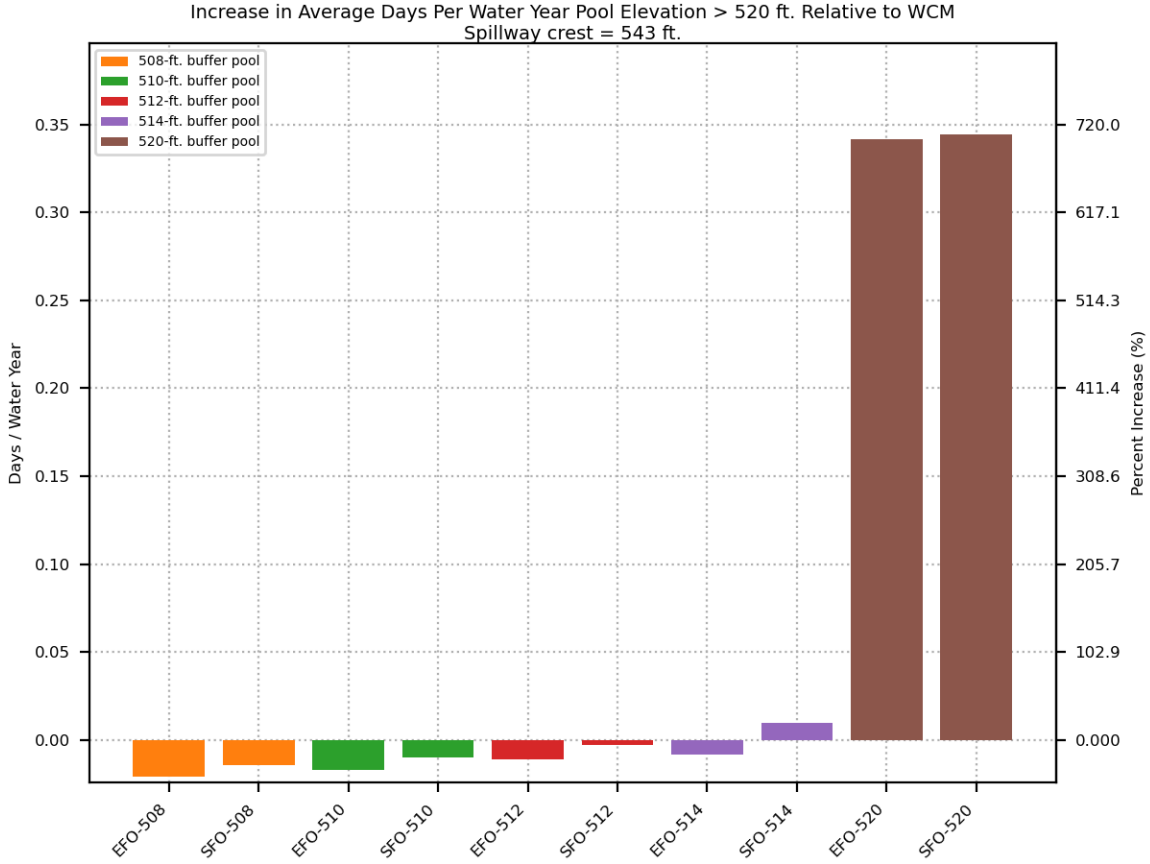

Increase in Average Days Per Water Year Pool Elevation > 510 ft. Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
5
10
15
20
25
30
35
40
0.000
867.5
1735.
2602.
3470.
4337.
5205.
6072.
6940.
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

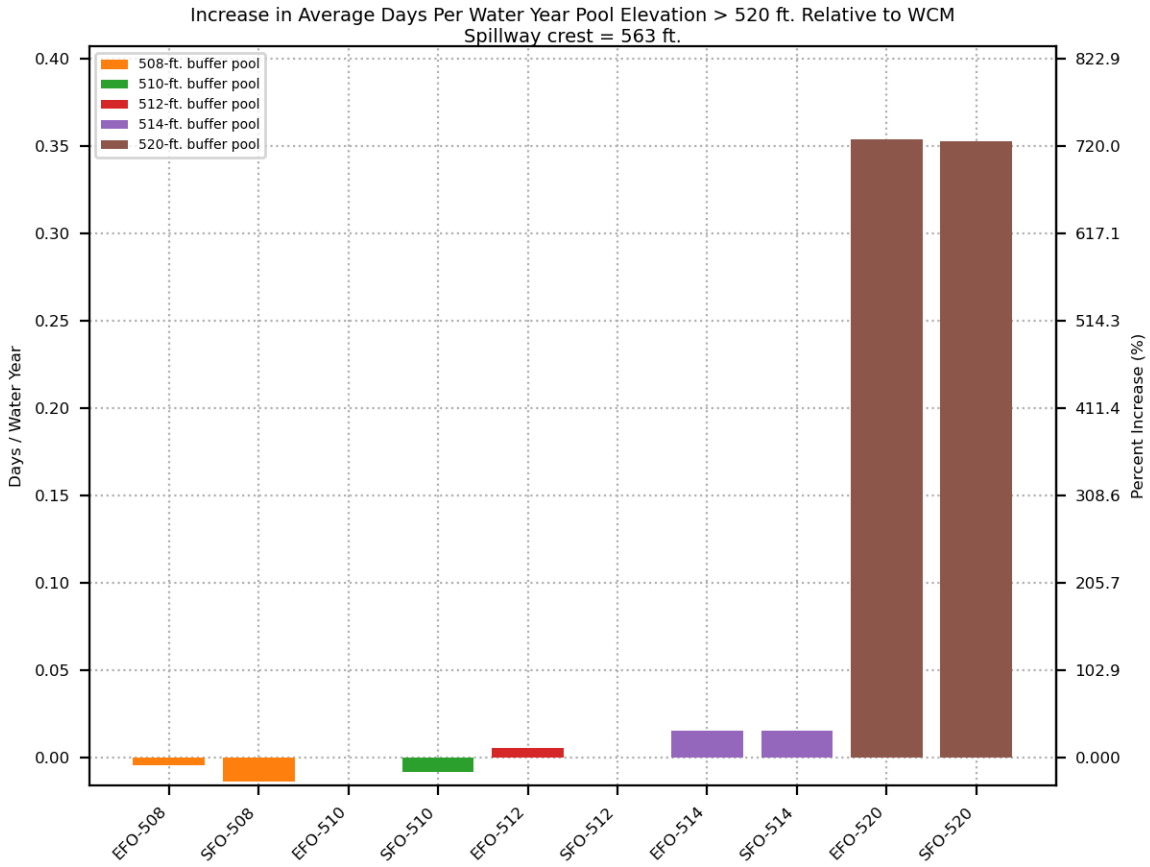

Increase in Average Days Per Water Year Pool Elevation > 512 ft. Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
5
10
15
20
25
30
35
0.000
1494.
2988.
4481.
5975.
7469.
8963.
10460.
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

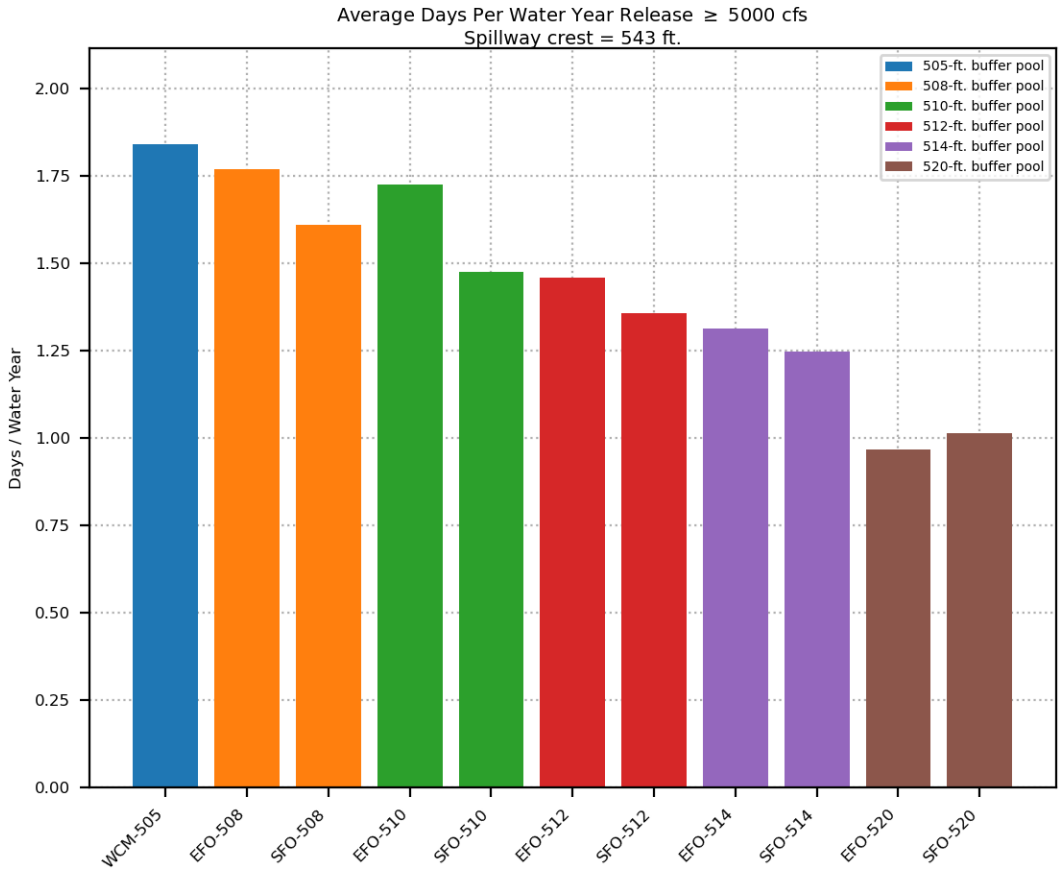

Increase in Average Days Per Water Year Pool Elevation > 512 ft. Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
5
10
15
20
25
30
35
0.000
1494.
2988.
4481.
5975.
7469.
8963.
10460.
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

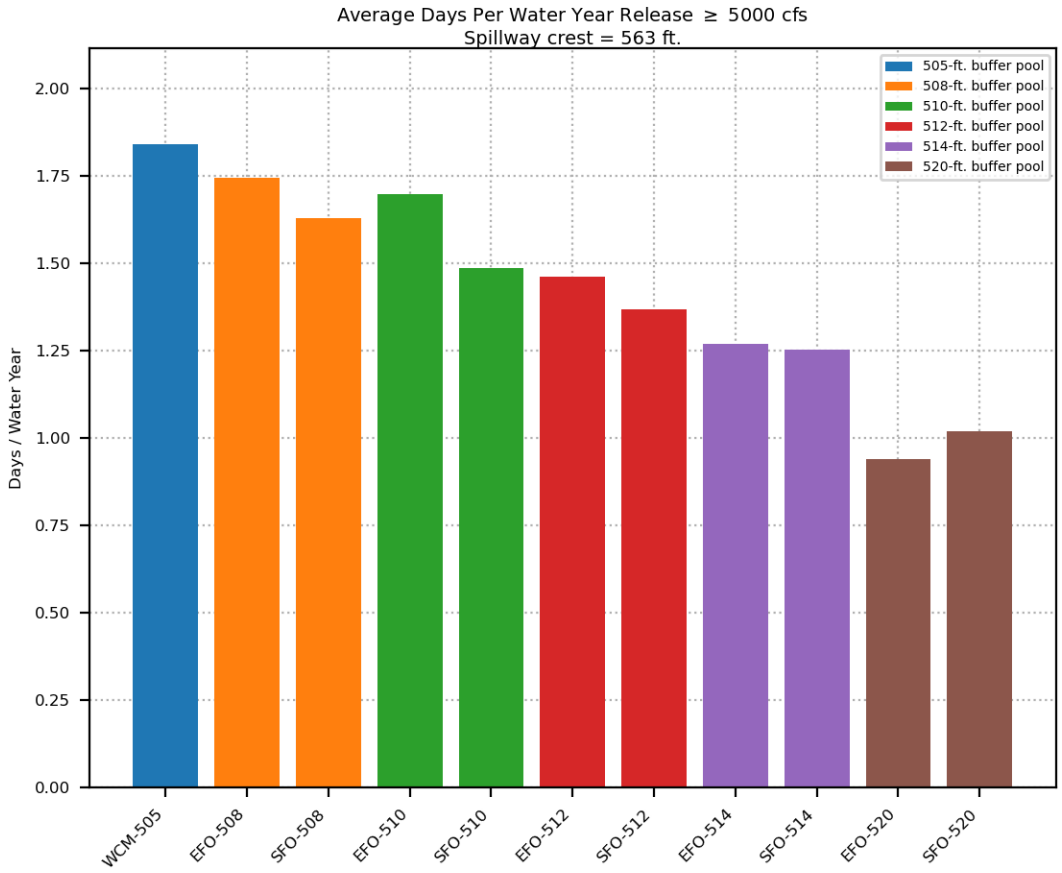

Increase in Average Days Per Water Year Pool Elevation > 514 ft. Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
5
10
15
20
25
30
0.000
2571.
5143.
7714.
10290.
12860.
15430.
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

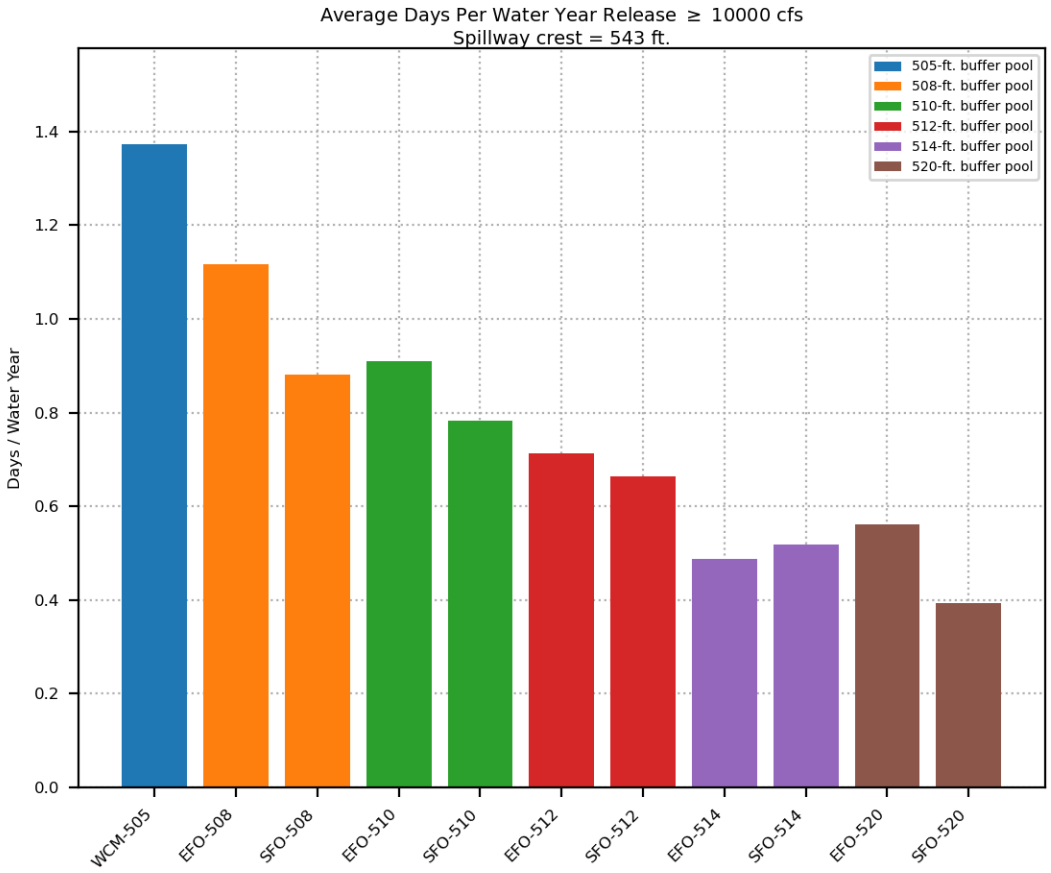

Increase in Average Days Per Water Year Pool Elevation > 514 ft. Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0
5
10
15
20
25
30
0.000
2571.
5143.
7714.
10290.
12860.
15430.
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

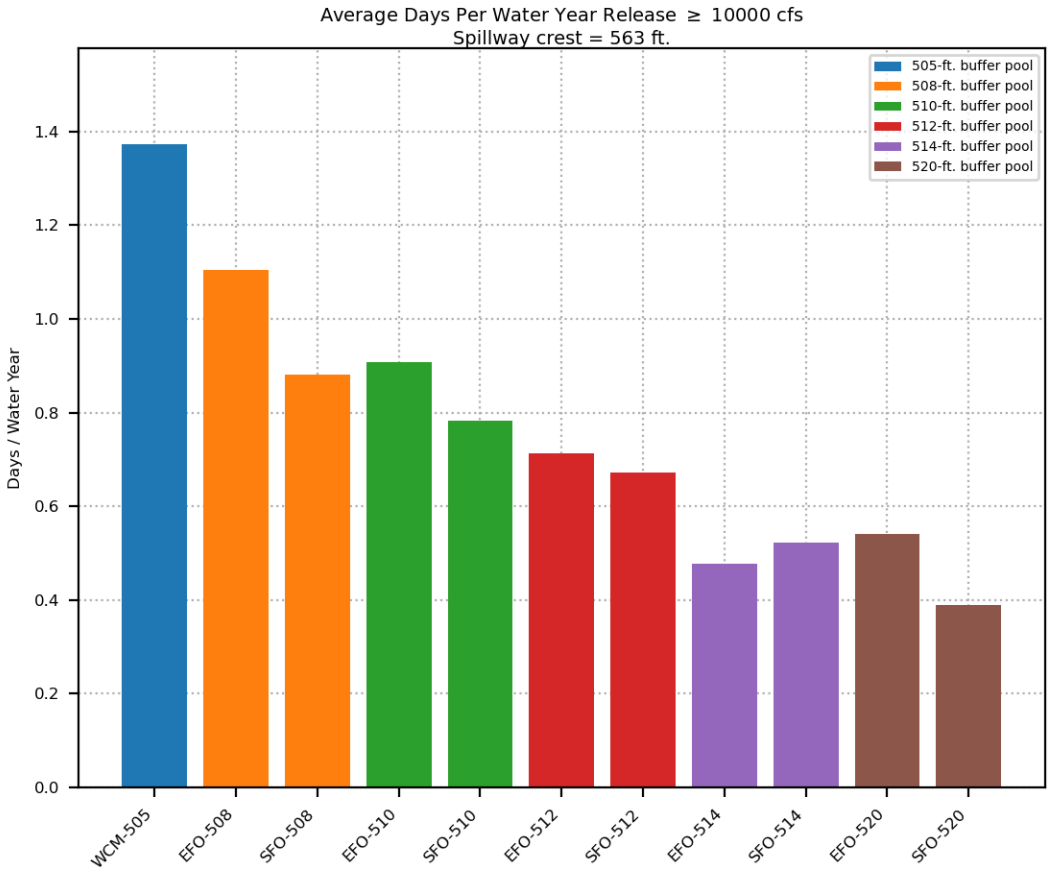

Increase in Average Days Per Water Year Pool Elevation > 520 ft. Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Percent Increase (%)
720.0
617.1
514.3
411.4
308.6
205.7
102.9
0.000
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

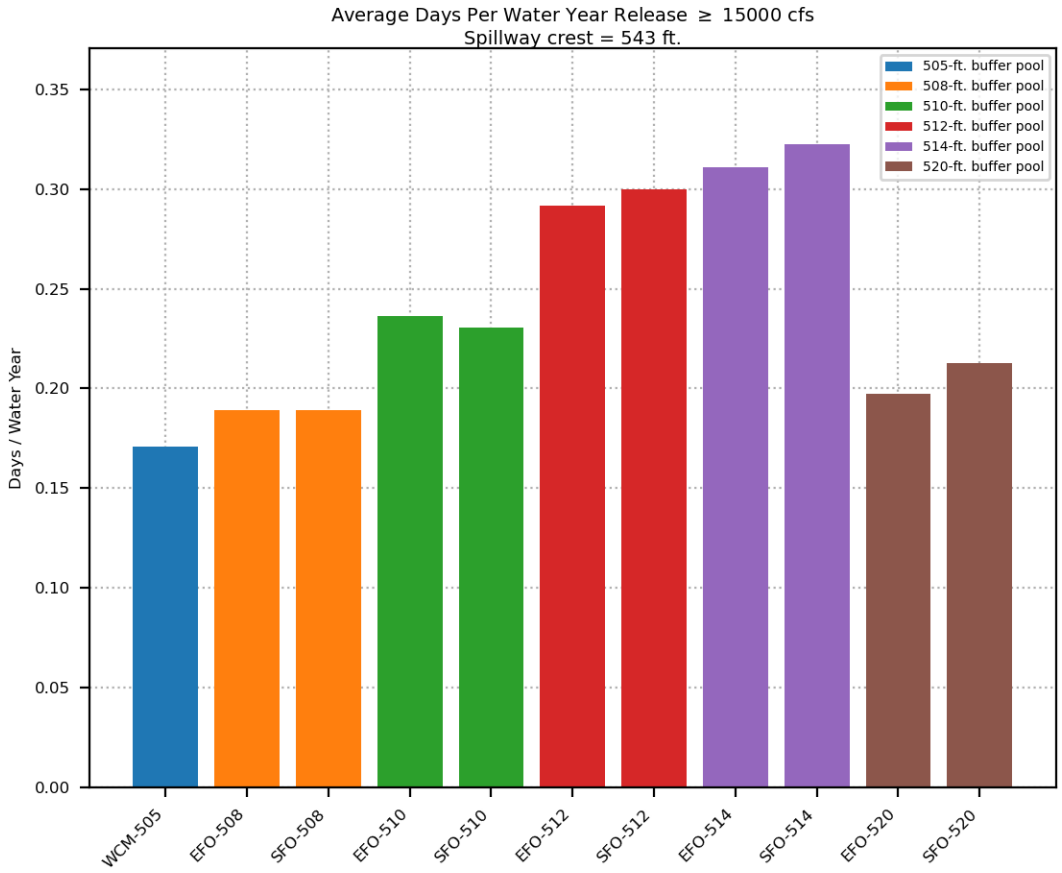

Increase in Average Days Per Water Year Pool Elevation > 520 ft. Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
822.9
720.0
617.1
514.3
411.4
308.6
205.7
102.9
0.000
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

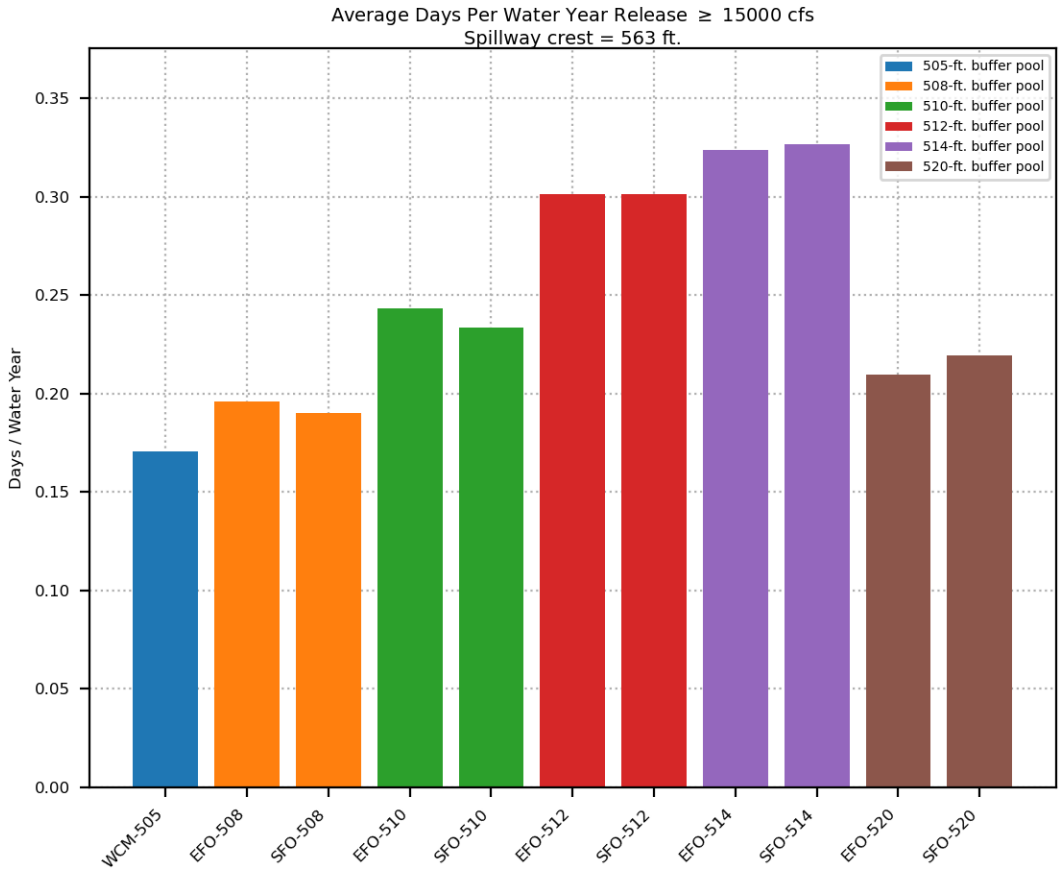

Average Days Per Water Year Release ≥ 5000 cfs
Spillway crest = 543 ft.
Days / Water Year
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

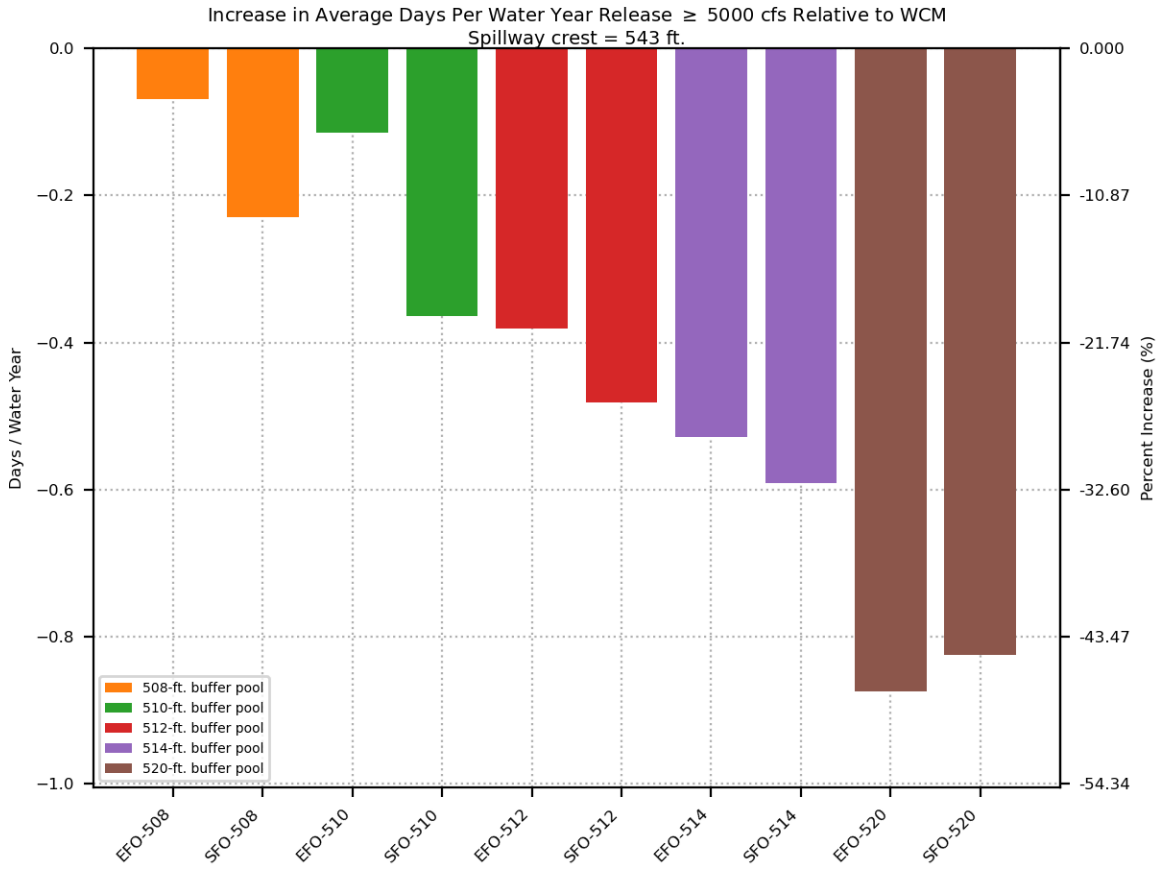

Average Days Per Water Year Release ≥ 5000 cfs
Spillway crest = 563 ft.
Days / Water Year
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

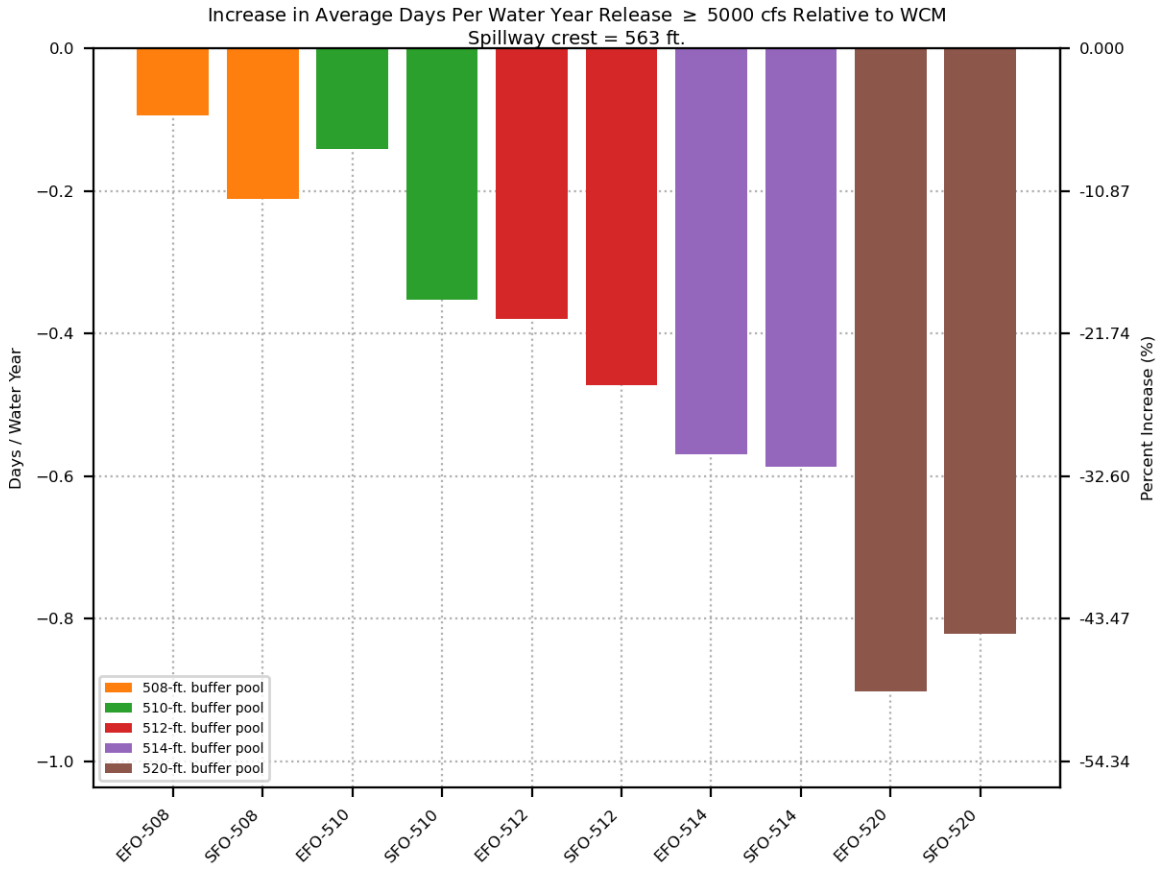

Average Days Per Water Year Release ≥ 10000 cfs
Spillway crest = 543 ft.
Days / Water Year
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

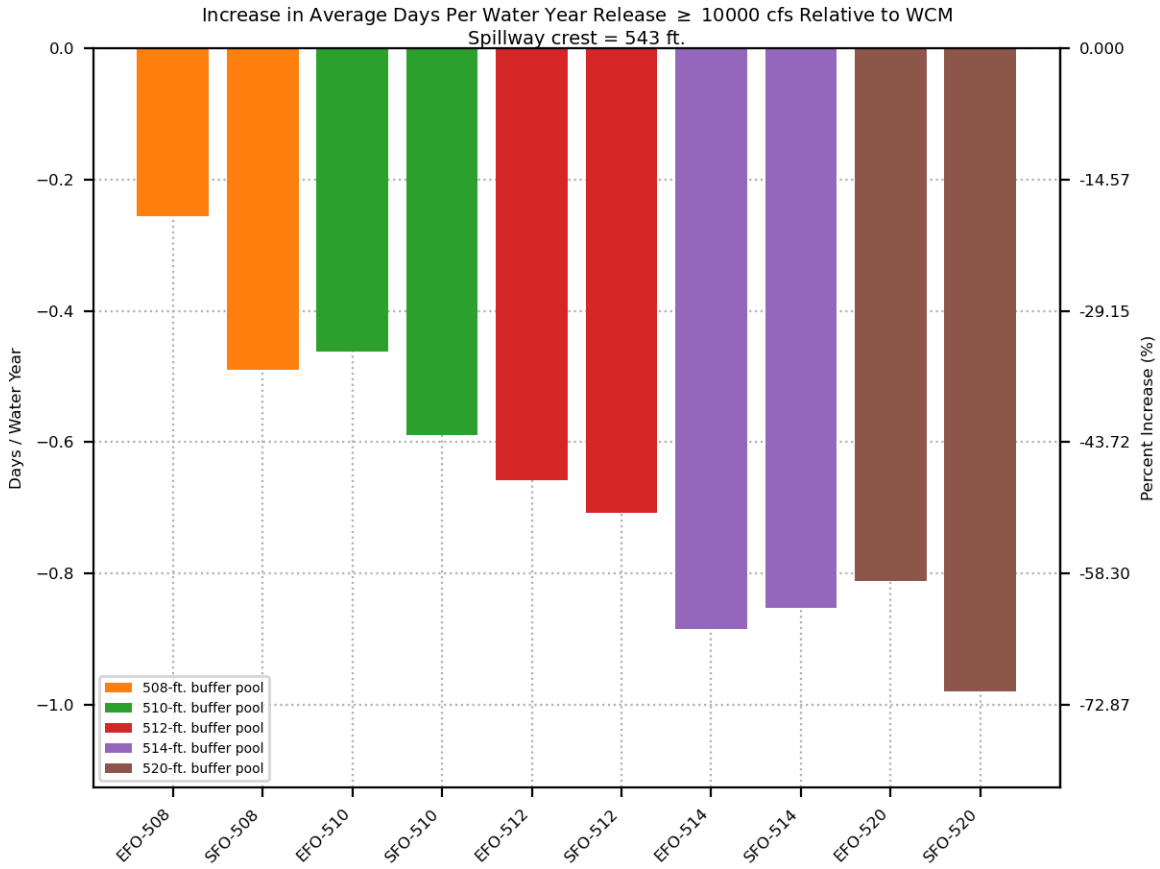

Average Days Per Water Year Release ≥ 10000 cfs
Spillway crest = 563 ft.
Days / Water Year
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

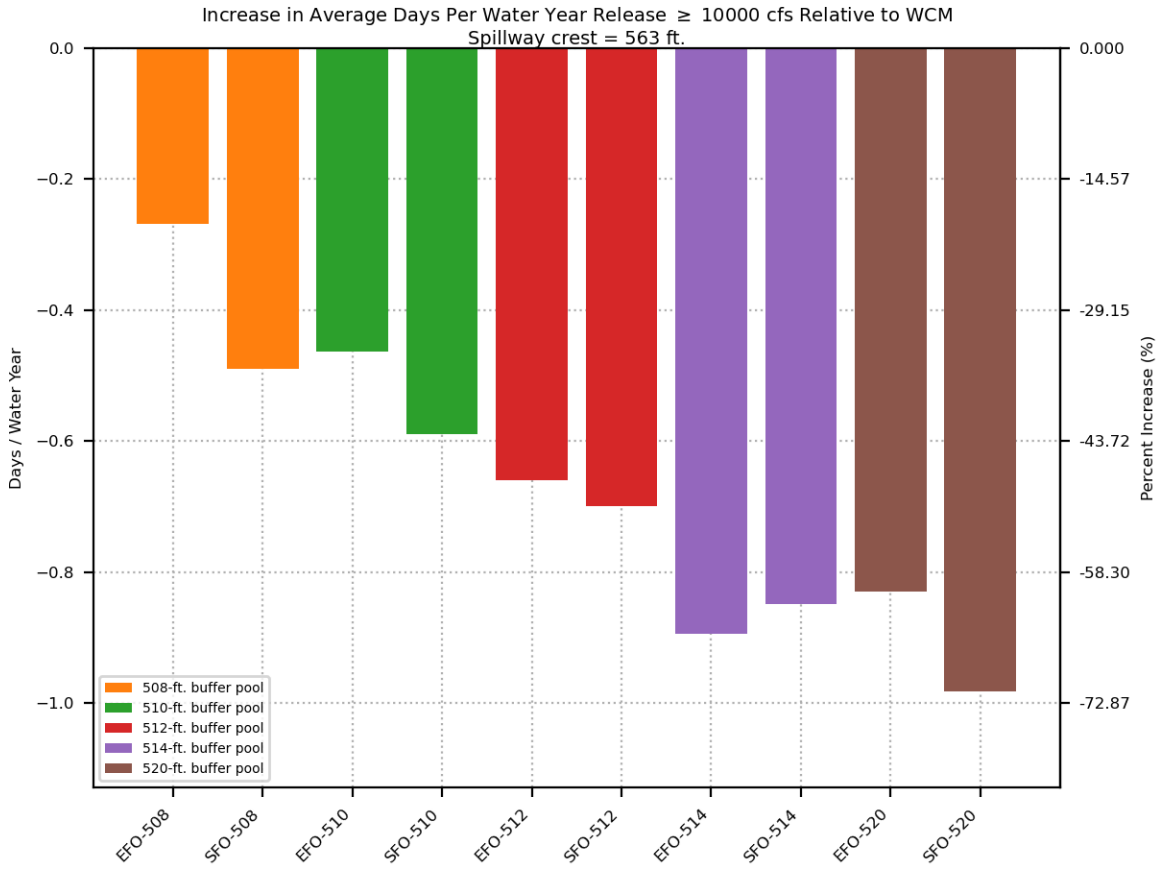

Average Days Per Water Year Release ≥ 15000 cfs
Spillway crest = 543 ft.
Days / Water Year
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

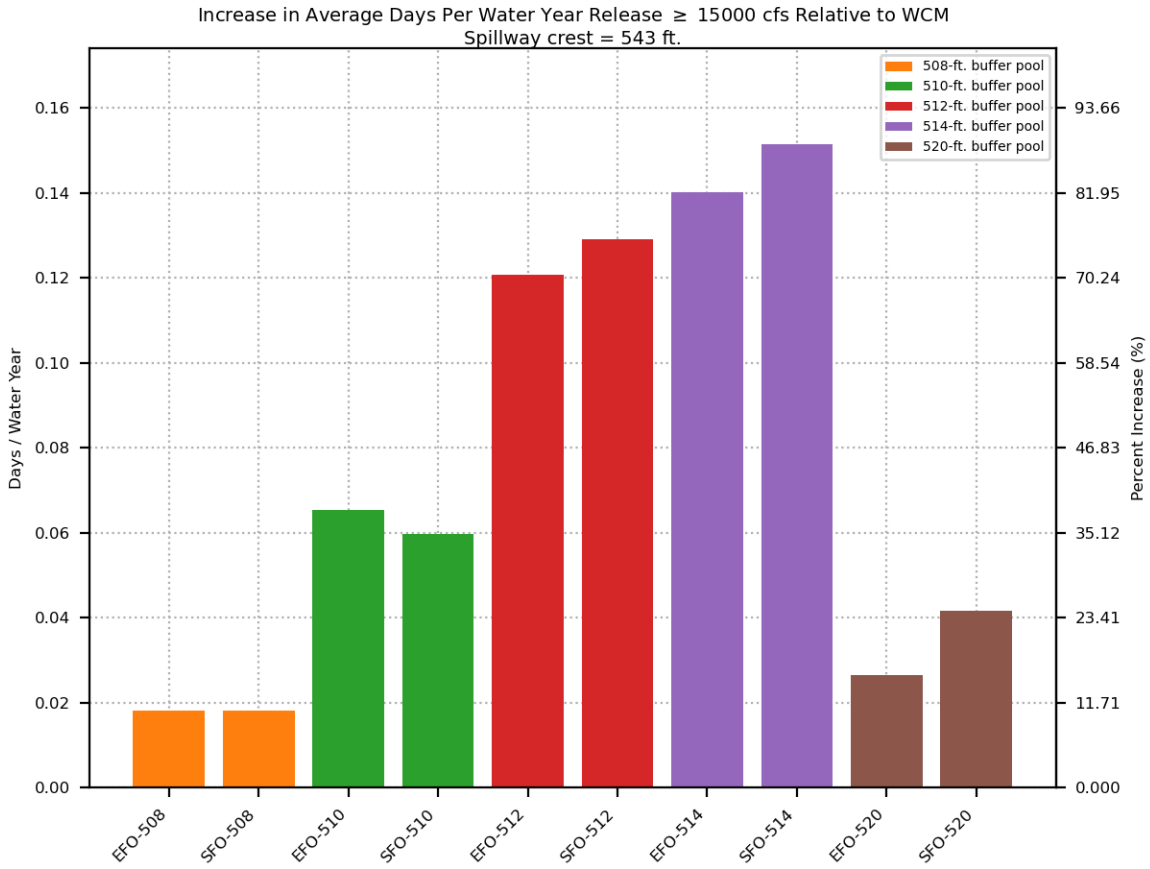

Average Days Per Water Year Release ≥ 15000 cfs
Spillway crest = 563 ft.
Days / Water Year
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

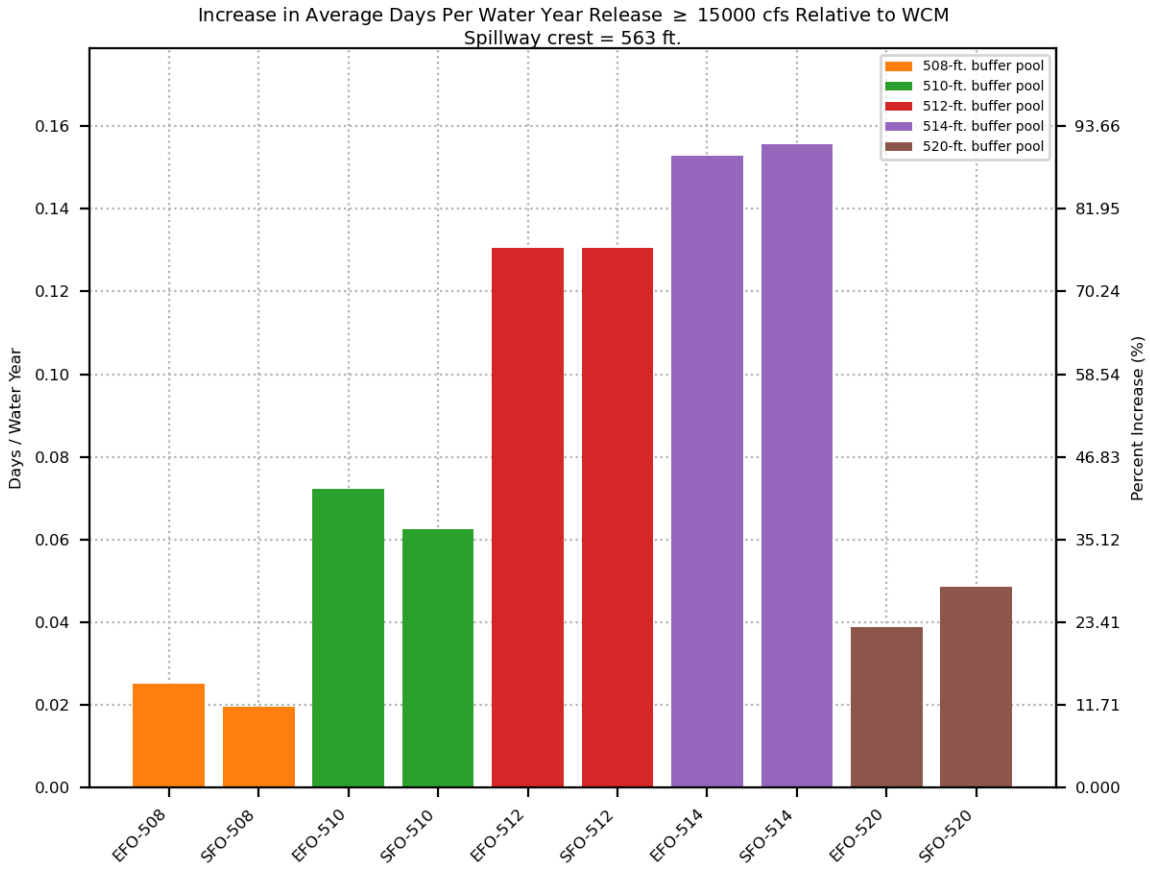

Increase in Average Days Per Water Year Release ≥ 5000 cfs Relative to WCM
Spillway crest = 543 ft.
Days / Water Year
Percent Increase (%)
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
0.000
-10.87
-21.74
-32.60
-43.47
-54.34
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

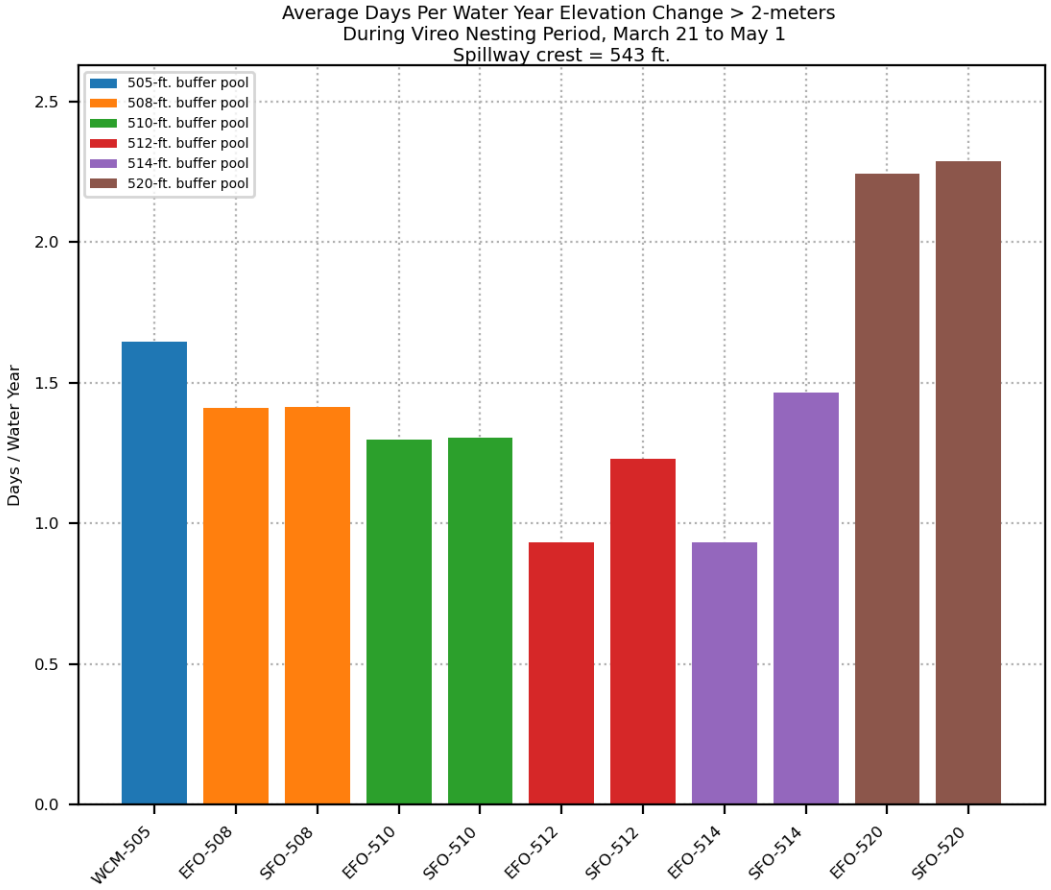

Increase in Average Days Per Water Year Release ≥ 5000 cfs Relative to WCM
Spillway crest = 563 ft.
Days / Water Year
Percent Increase (%)
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
0.000
-10.87
-21.74
-32.60
-43.47
-54.34
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

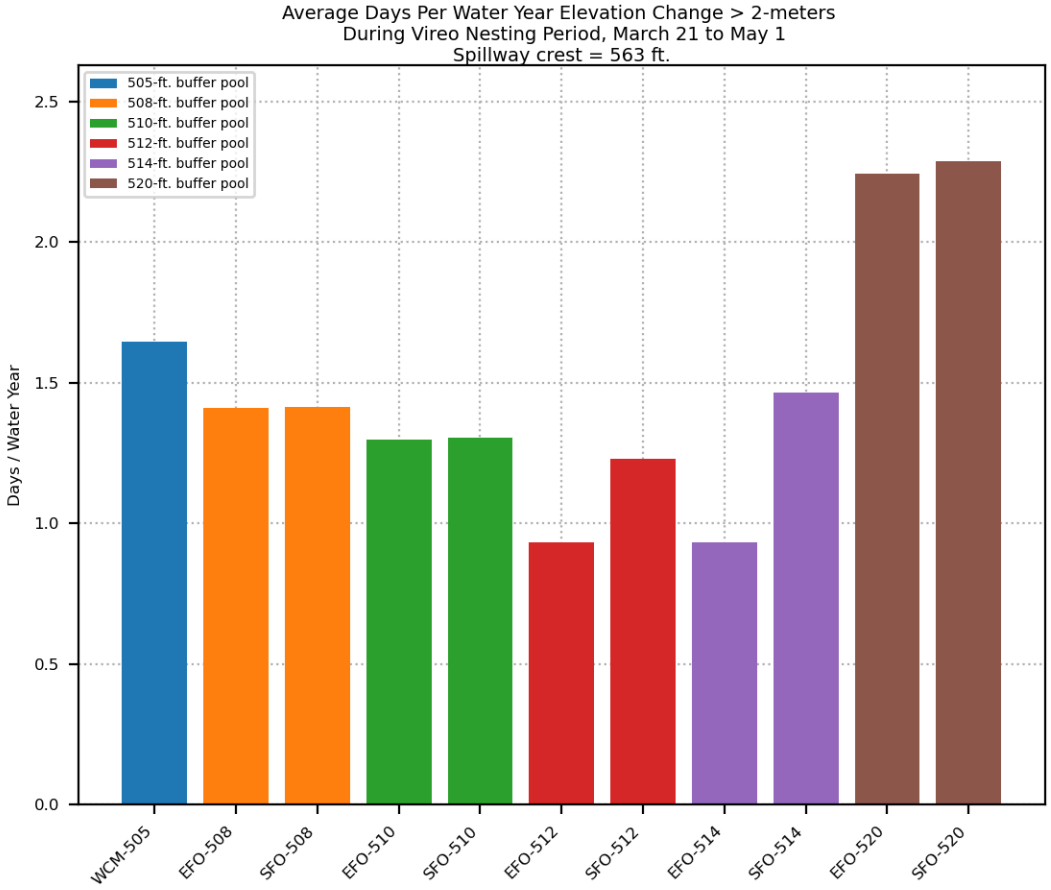

Increase in Average Days Per Water Year Release ≥ 10000 cfs Relative to WCM
Spillway crest = 543 ft.
Days / Water Year
Percent Increase (%)
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
0.000
-14.57
-29.15
-43.72
-58.30
-72.87
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

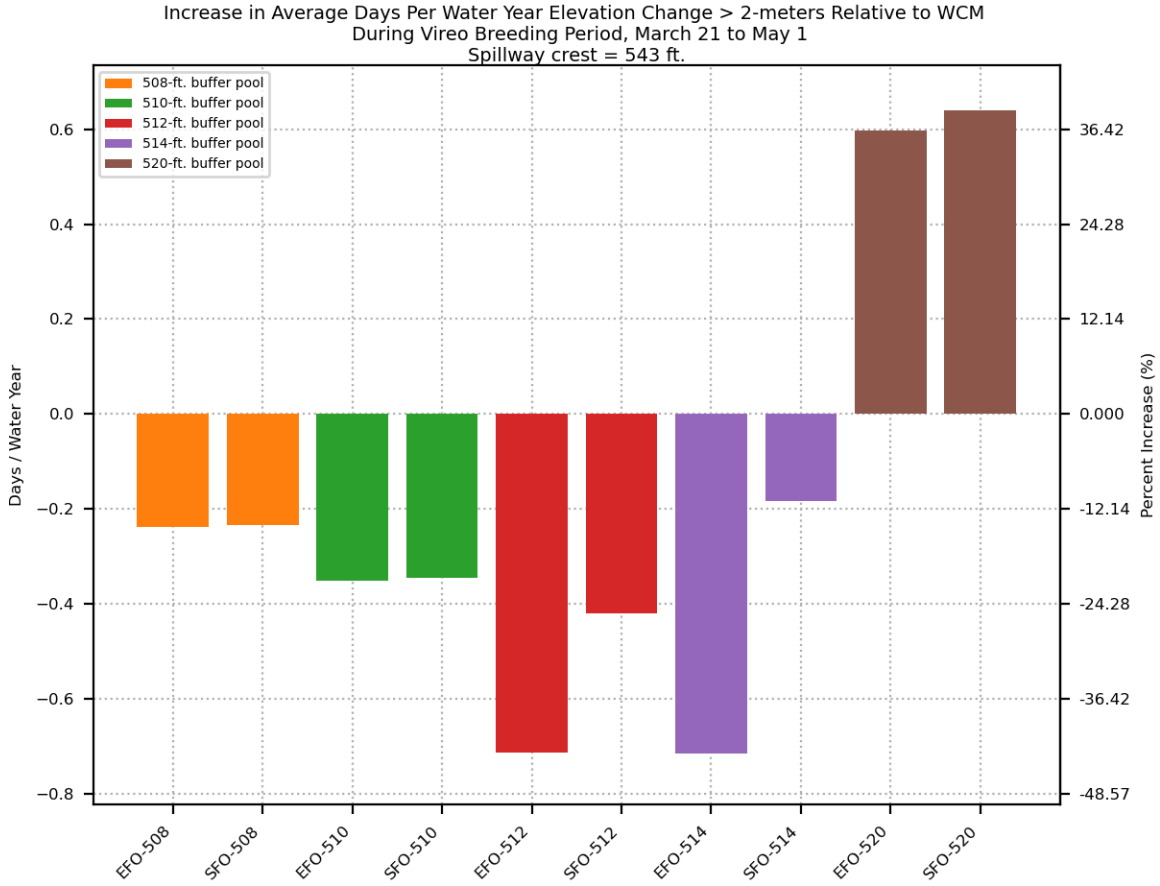

Increase in Average Days Per Water Year Release ≥ 10000 cfs Relative to WCM
Spillway crest = 563 ft.
Days / Water Year
Percent Increase (%)
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
0.000
-14.57
-29.15
-43.72
-58.30
-72.87
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

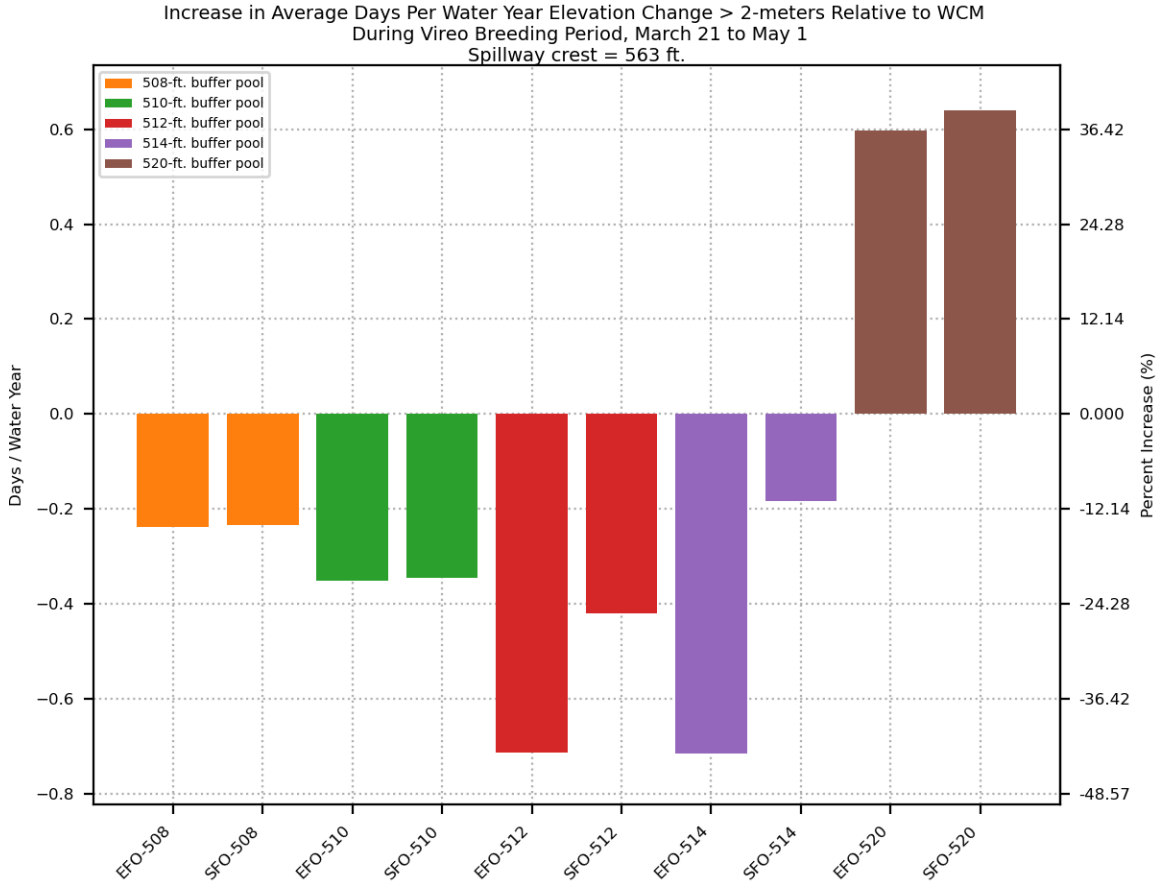

Increase in Average Days Per Water Year Release ≥ 15000 cfs Relative to WCM
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.000
11.71
23.41
35.12
46.83
58.54
70.24
81.95
93.66
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520


Increase in Average Days Per Water Year Release ≥ 15000 cfs Relative to WCM
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.000
11.71
23.41
35.12
46.83
58.54
70.24
81.95
93.66
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520


Average Days Per Water Year Elevation Change > 2-meters
During Vireo Nesting Period, March 21 to May 1
Spillway crest = 543 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0.0
0.5
1.0
1.5
2.0
2.5
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520


Average Days Per Water Year Elevation Change > 2-meters
During Vireo Nesting Period, March 21 to May 1
Spillway crest = 563 ft.
505-ft. buffer pool
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
0.0
0.5
1.0
1.5
2.0
2.5
WCM-505
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520


Increase in Average Days Per Water Year Elevation Change > 2-meters Relative to WCM
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 543 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
36.42
24.28
12.14
0.000
-12.14
-24.28
-36.42
-48.57
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520


Increase in Average Days Per Water Year Elevation Change > 2-meters Relative to WCM
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 563 ft.
508-ft. buffer pool
510-ft. buffer pool
512-ft. buffer pool
514-ft. buffer pool
520-ft. buffer pool
Days / Water Year
Percent Increase (%)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
36.42
24.28
12.14
0.000
-12.14
-24.28
-36.42
-48.57
EFO-508
SFO-508
EFO-510
SFO-510
EFO-512
SFO-512
EFO-514
SFO-514
EFO-520
SFO-520

APPENDIX B-6

HEMP Metrics – Box/Whisker Plots

- Groundwater Recharge
- Santa Anna River discharge to Pacific Ocean
- Peak Reservoir Release
- Peak Reservoir Elevation
- Pool elevation > 505’, 508’, 510’, 512’, 514’, 520’
- Reservoir release > 5,000, 10,000, 15,000 cfs
- >1 meter rise between 3/21 and 5/1

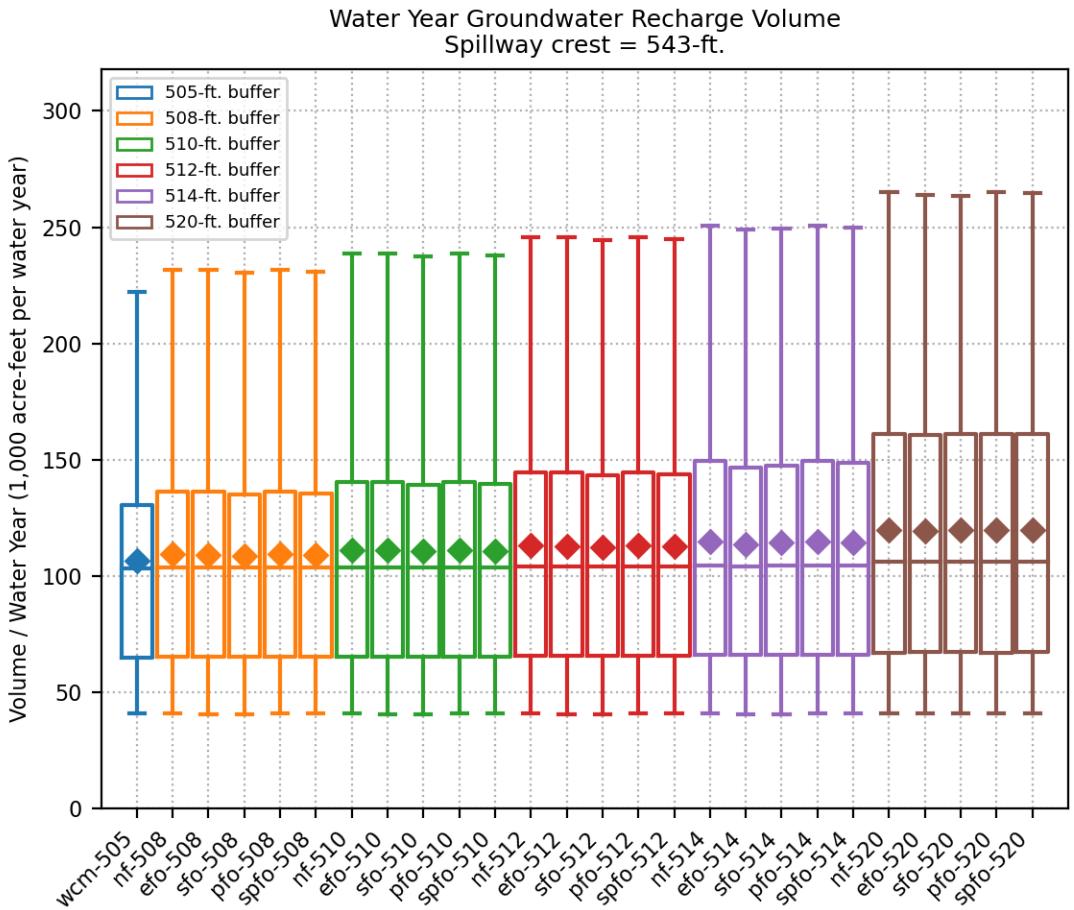
HEMP Metrics – Box/Whisker Plots

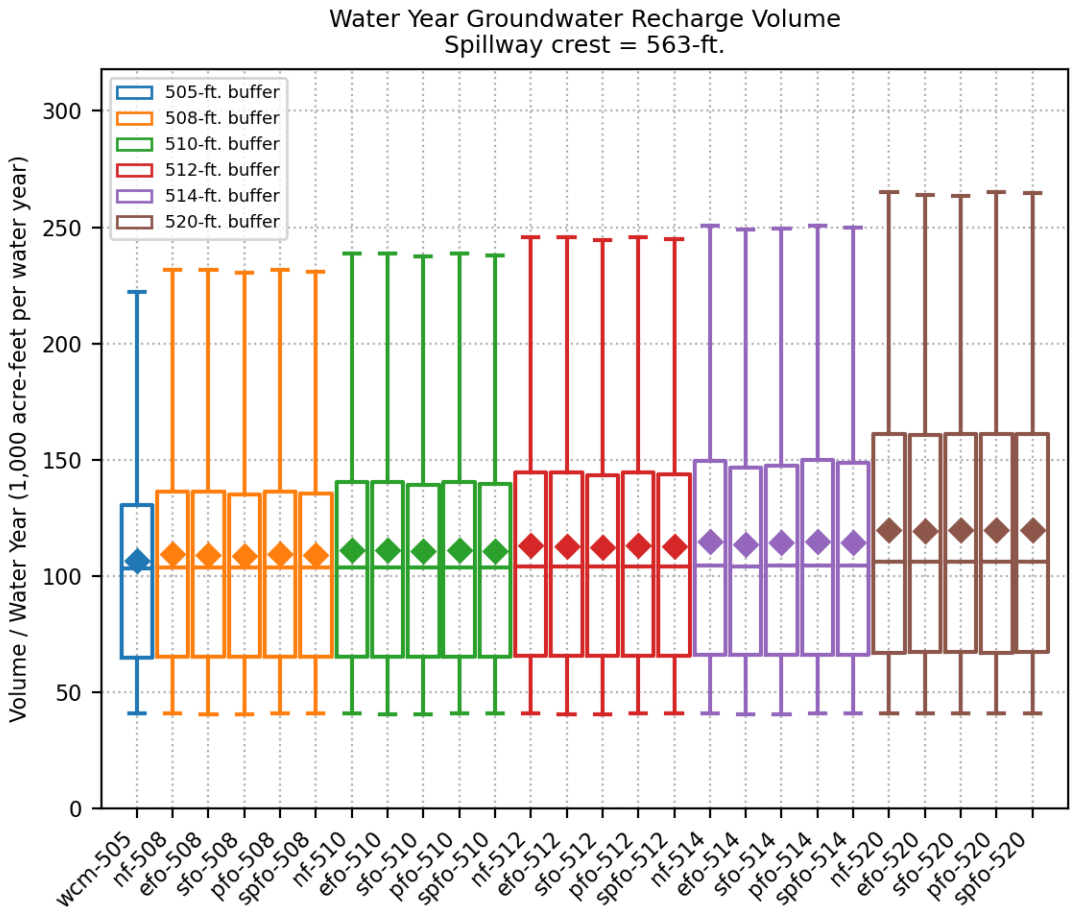
- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’, 510’, 512’, 514’, 520’
- WCP alternatives across X Axis

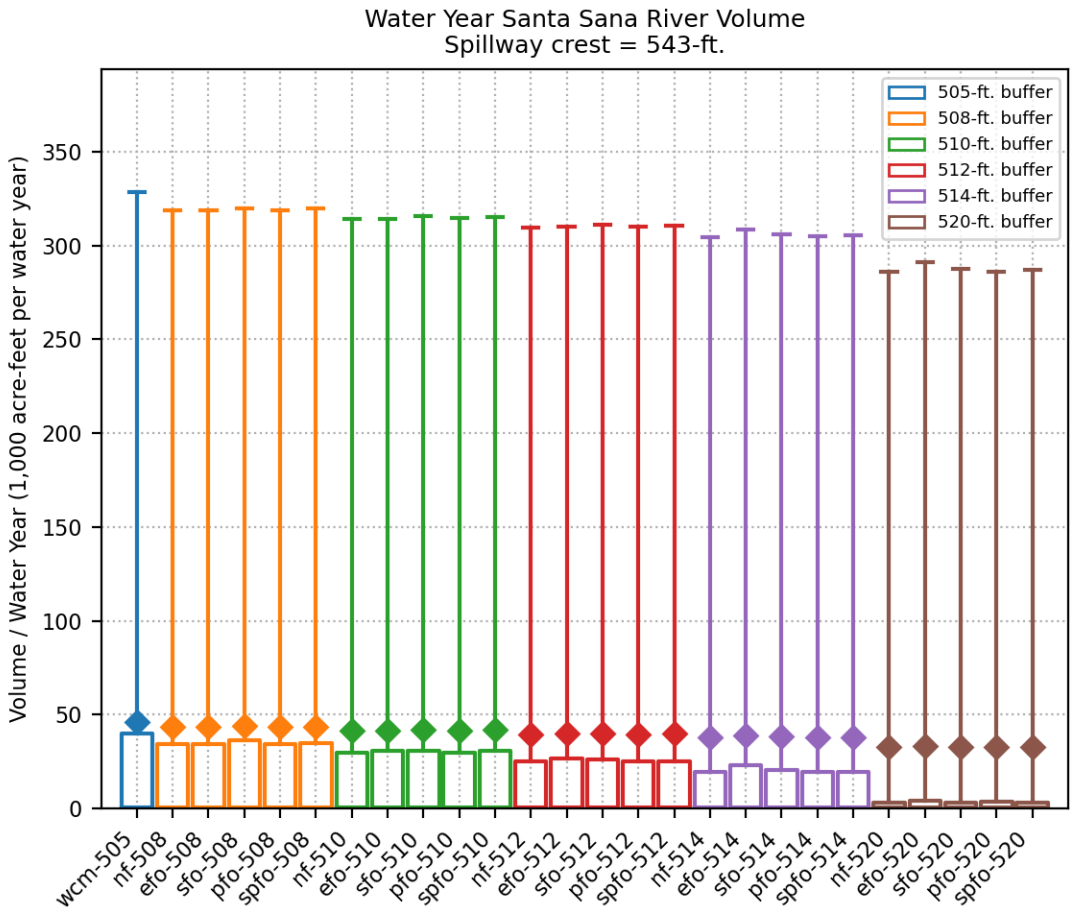
- Whiskers 5% - 95%
- Boxes 25% - 75%
- Diamonds @ median

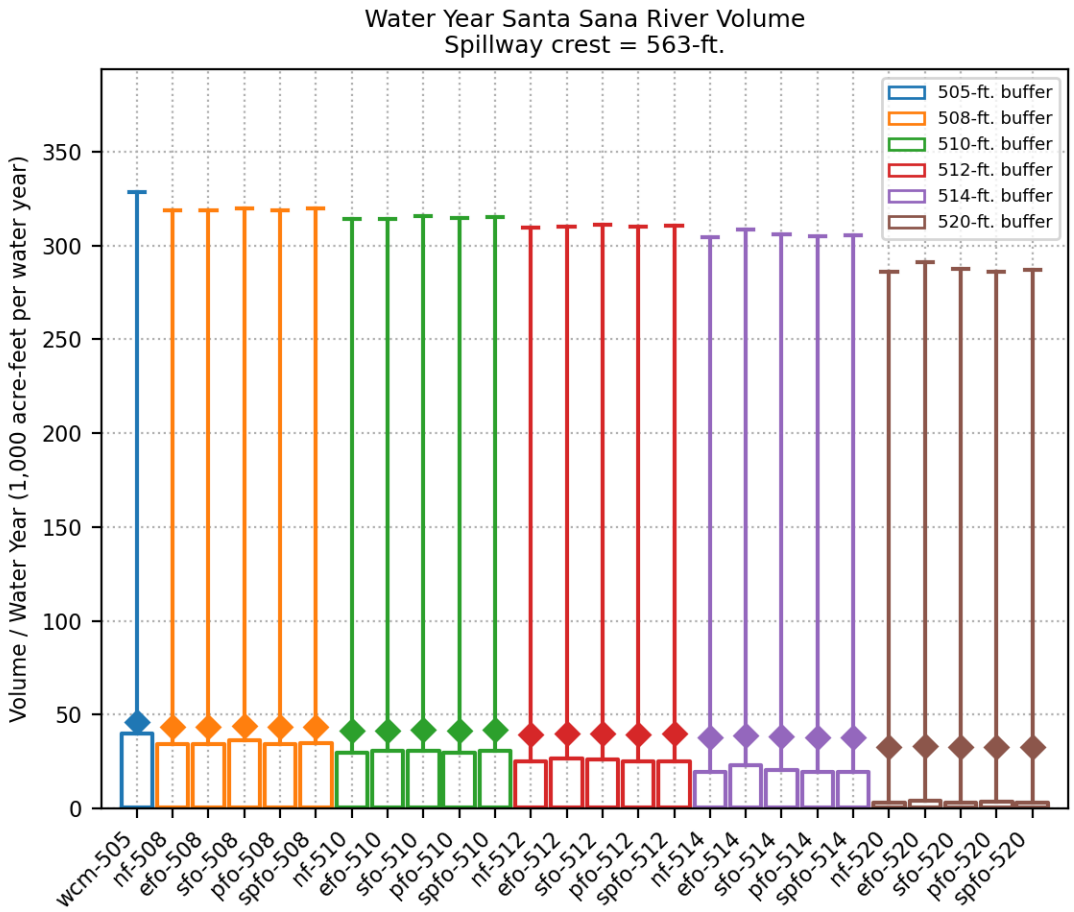
HEMP Metrics – Box Plots

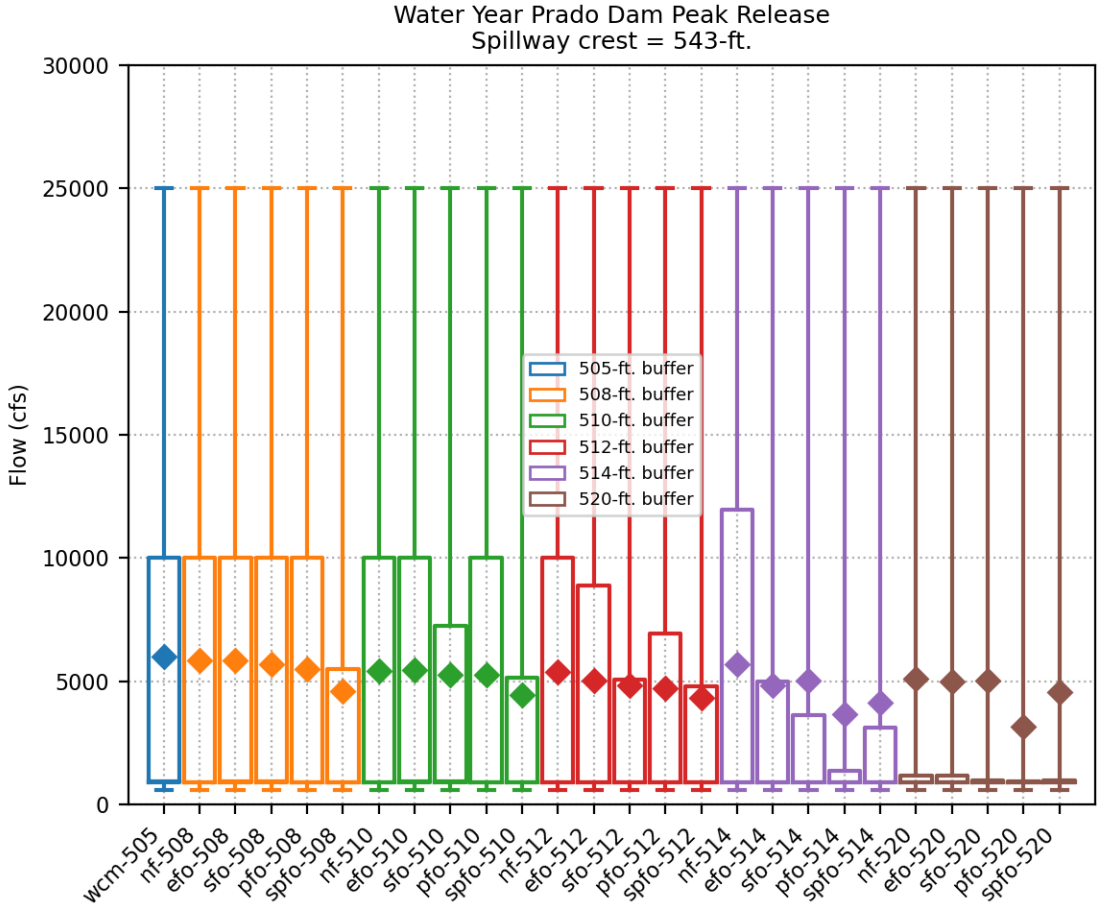
- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’, 510’, 512’, 514’, 520’
- WCP alternatives in legend

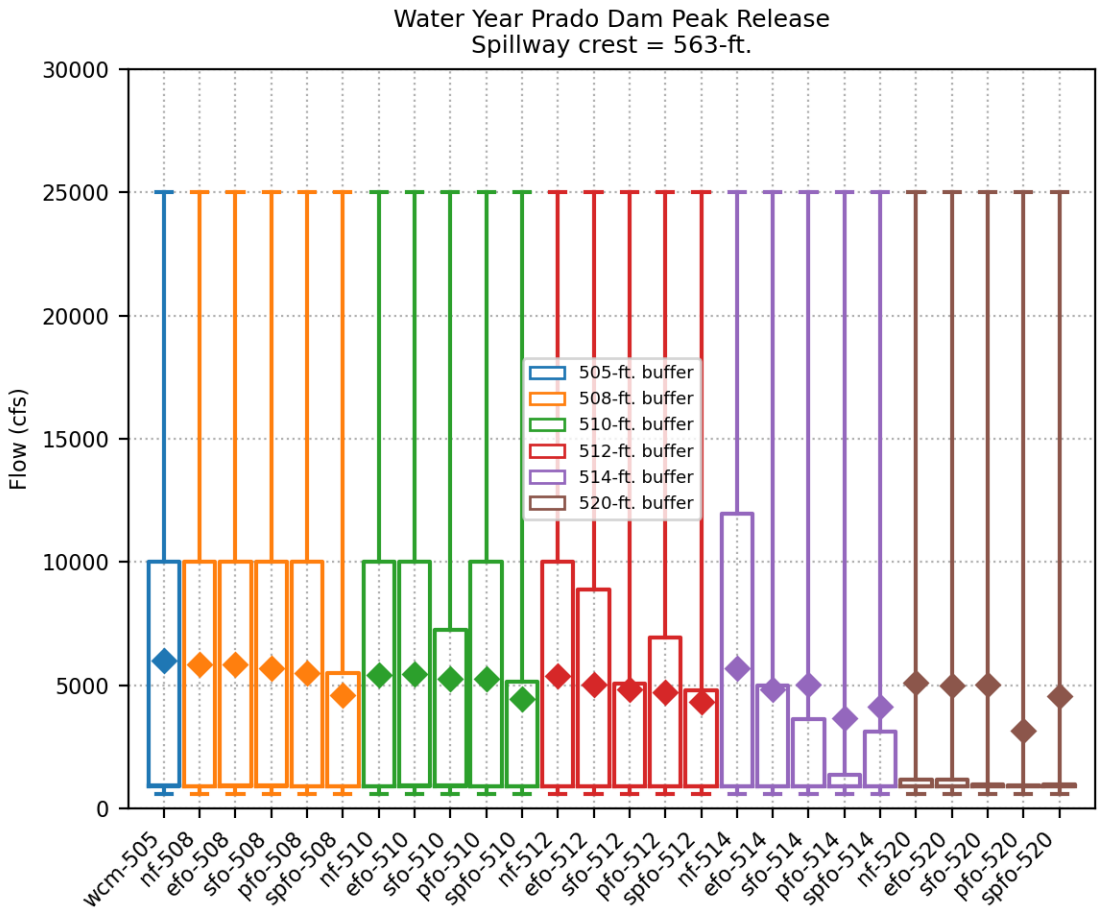

Water Year Groundwater Recharge Volume
Spillway crest = 543-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Volume / Water Year (1,000 acre-feet per water year)
0
50
100
150
200
250
300
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

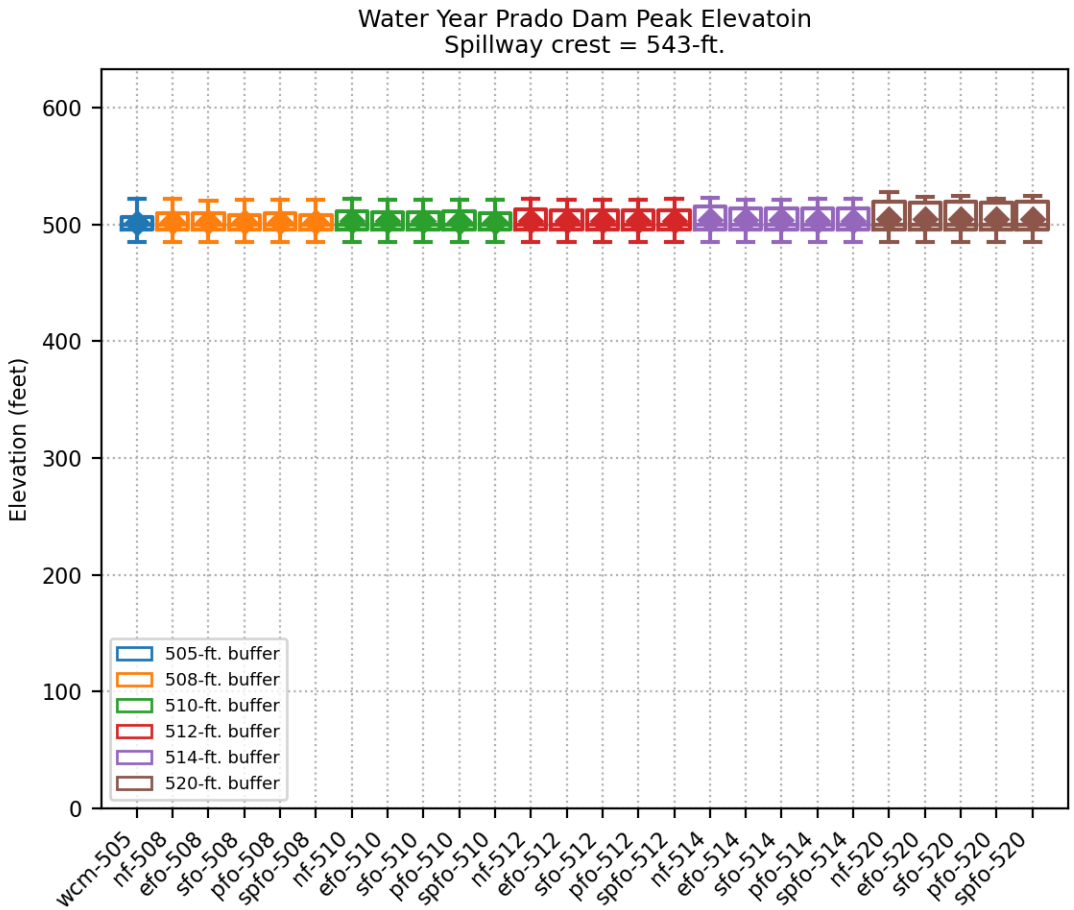

Water Year Groundwater Recharge Volume
Spillway crest = 563-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Volume / Water Year (1,000 acre-feet per water year)
0
50
100
150
200
250
300
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

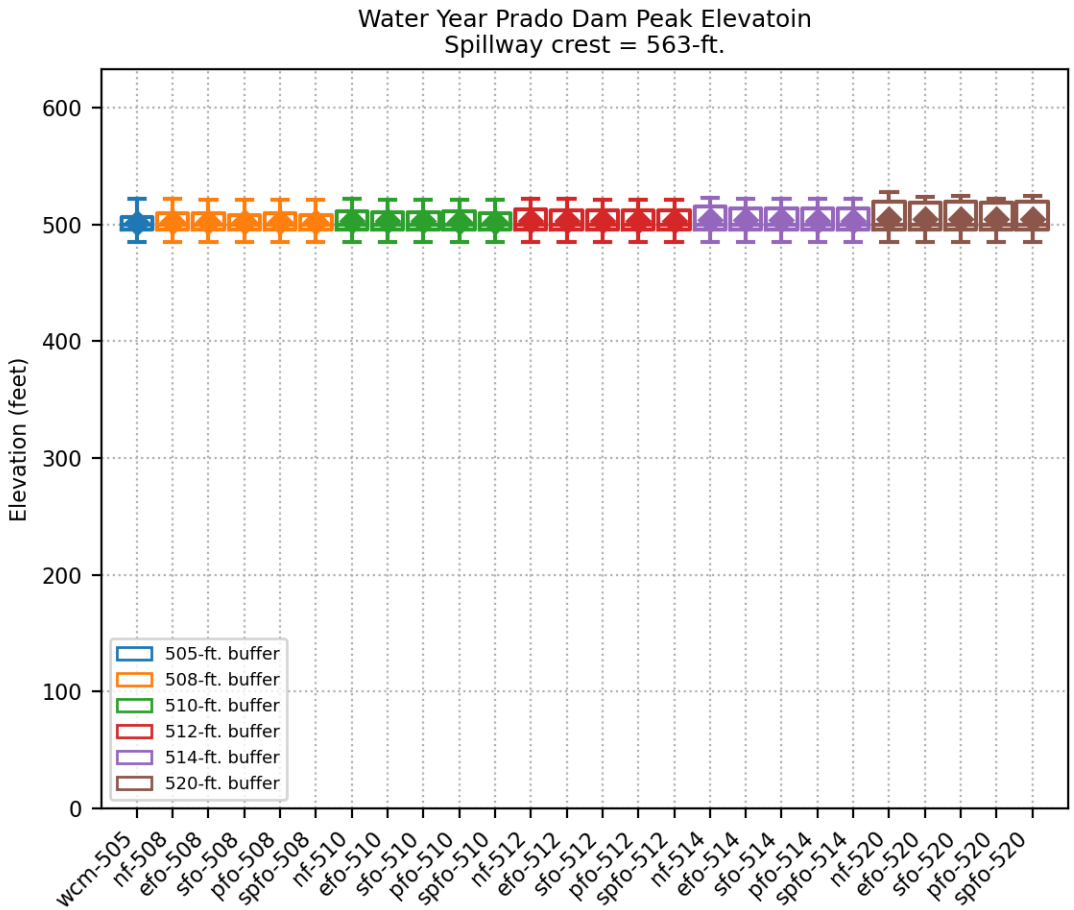

Water Year Santa Sana River Volume
Spillway crest = 543-ft.
Volume / Water Year (1,000 acre-feet per water year)
0
50
100
150
200
250
300
350
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

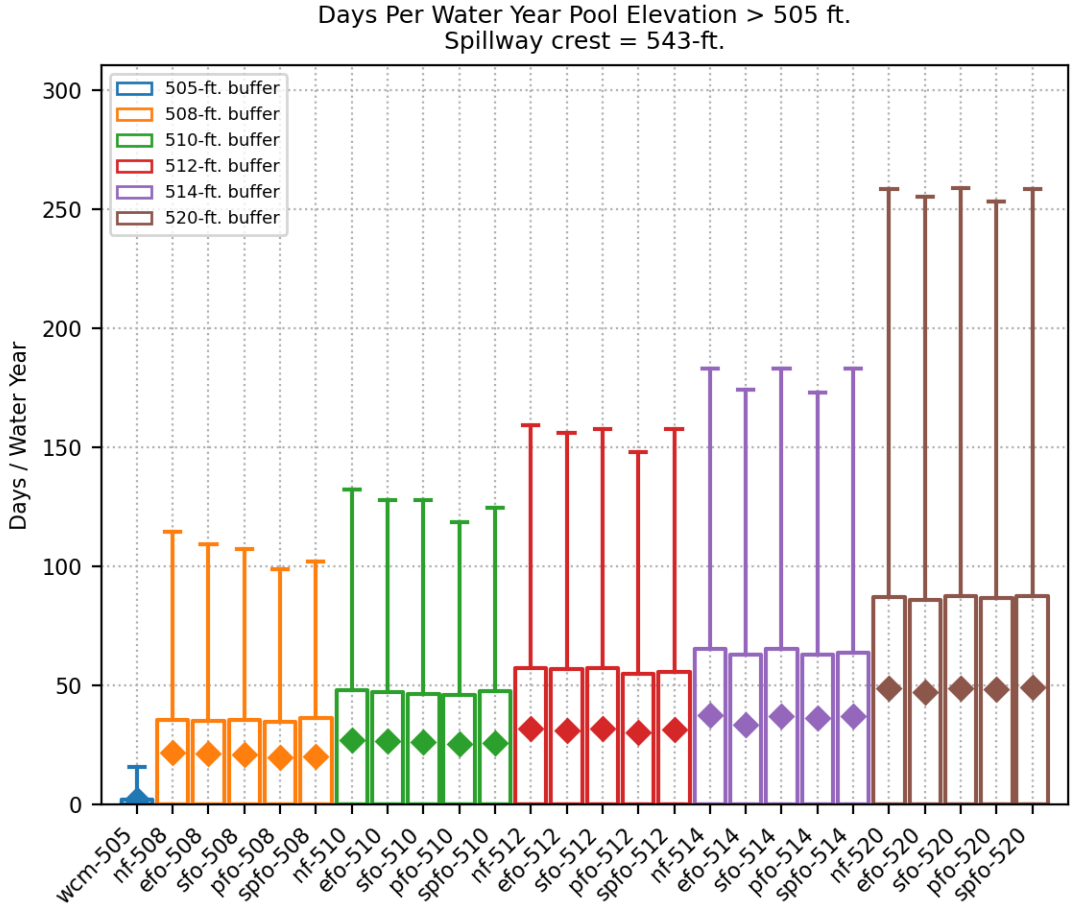

Water Year Santa Sana River Volume
Spillway crest = 563-ft.
Volume / Water Year (1,000 acre-feet per water year)
0
50
100
150
200
250
300
350
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

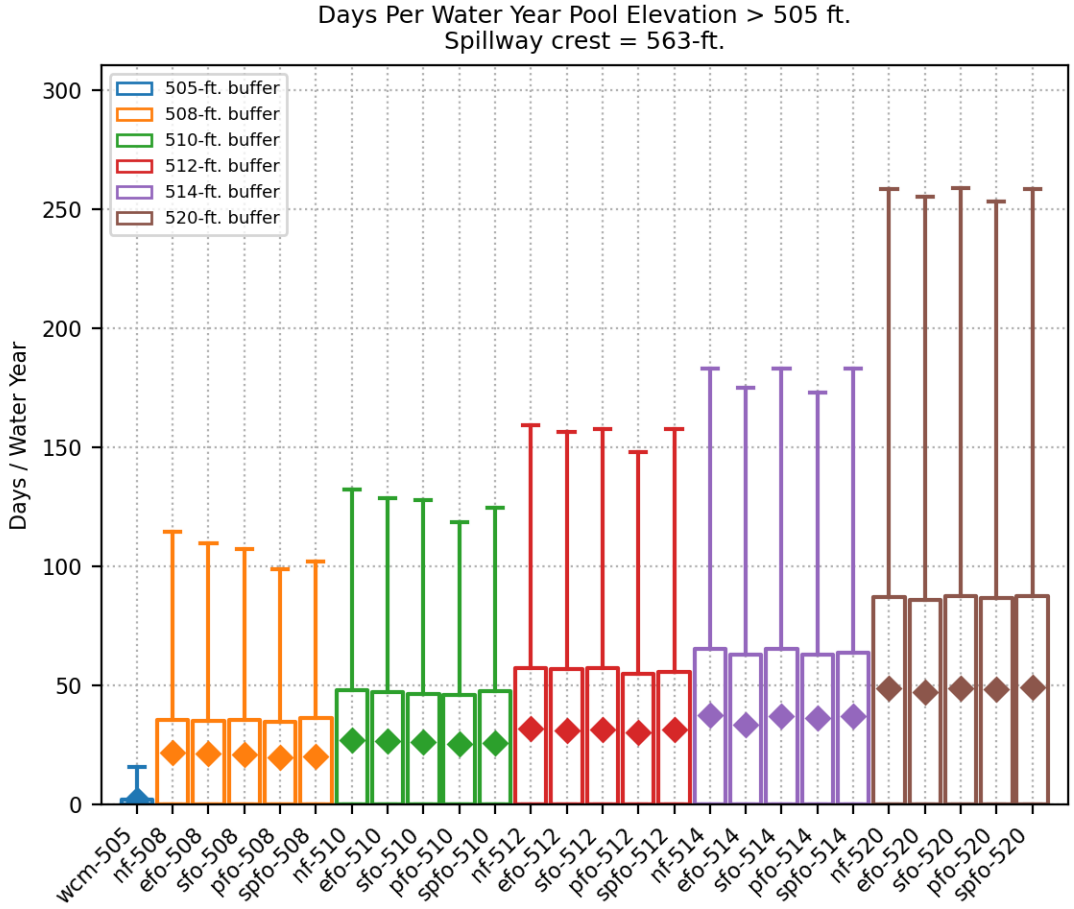

Water Year Prado Dam Peak Release
Spillway crest = 543-ft.
Flow (cfs)
30000
25000
20000
15000
10000
5000
0
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

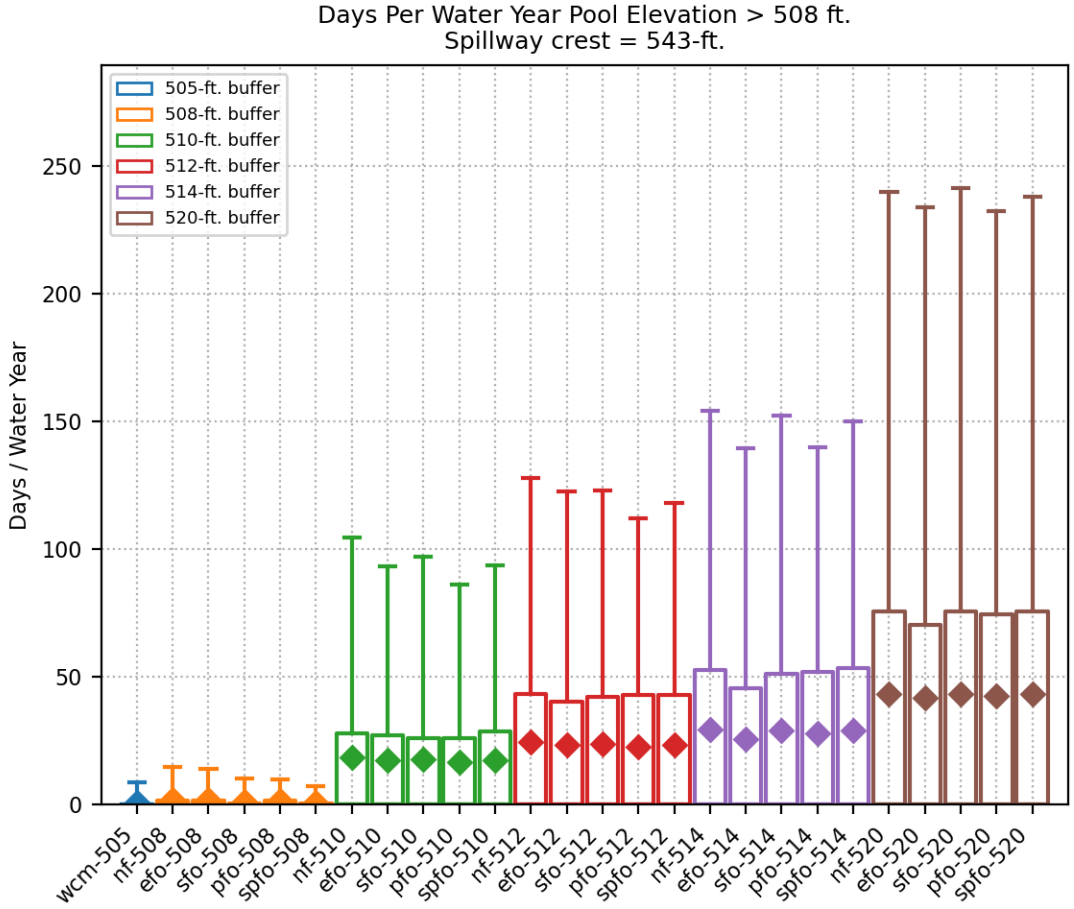

Water Year Prado Dam Peak Release
Spillway crest = 563-ft.
Flow (cfs)
30000
25000
20000
15000
10000
5000
0
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

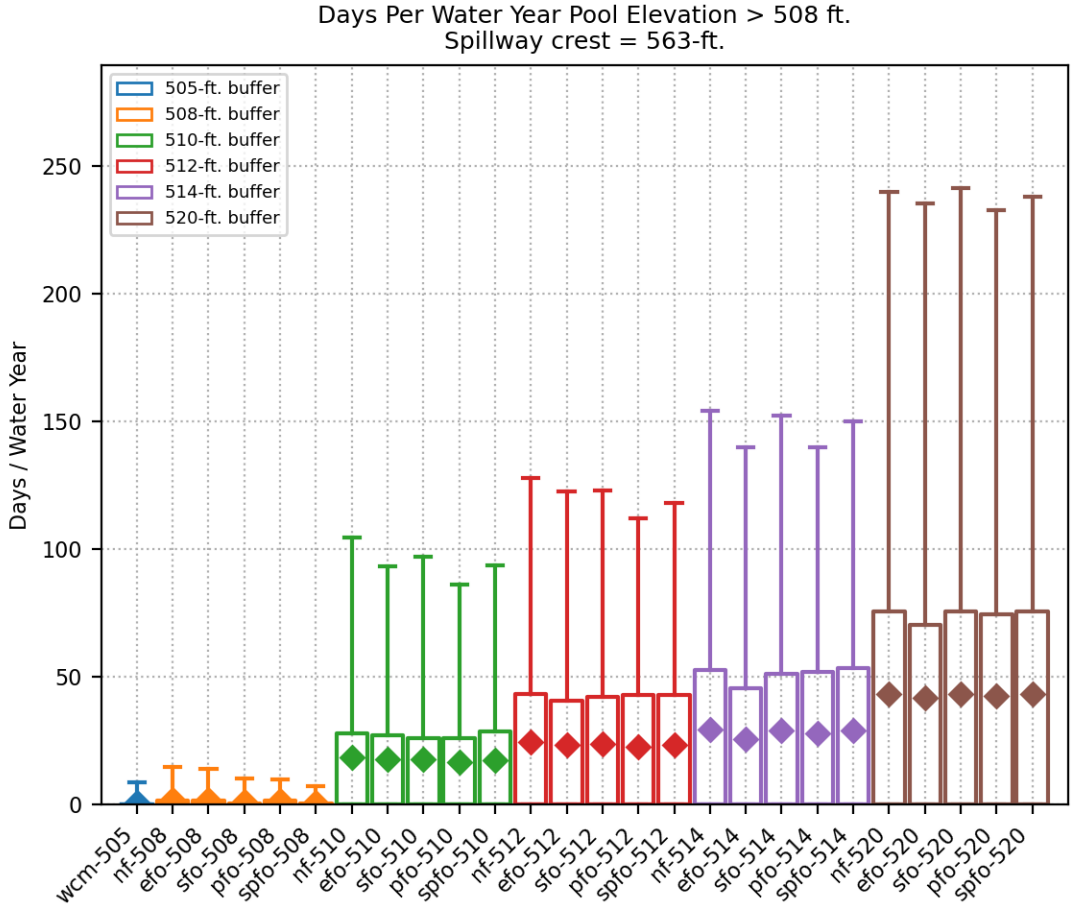

Water Year Prado Dam Peak Elevatoin
Spillway crest = 543-ft.
Elevation (feet)
0
100
200
300
400
500
600
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

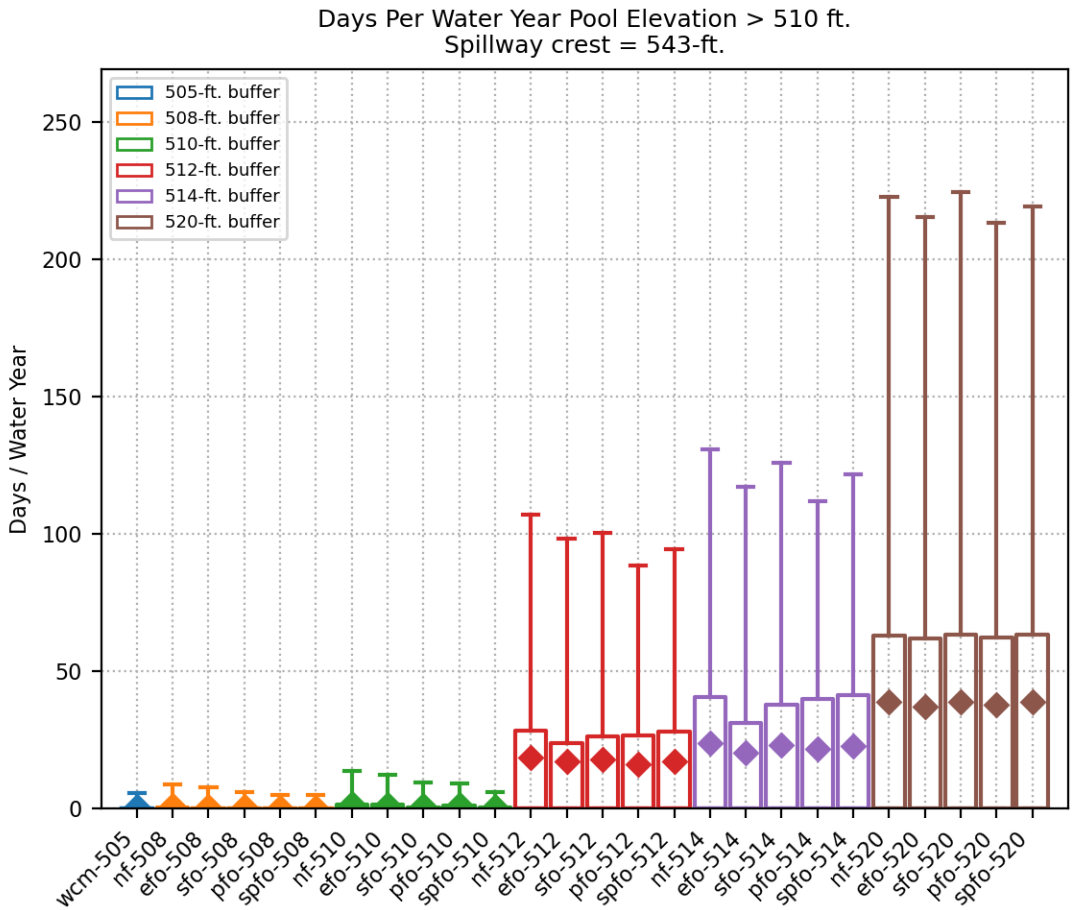

Water Year Prado Dam Peak Elevatoin
Spillway crest = 563-ft.
Elevation (feet)
0
100
200
300
400
500
600
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

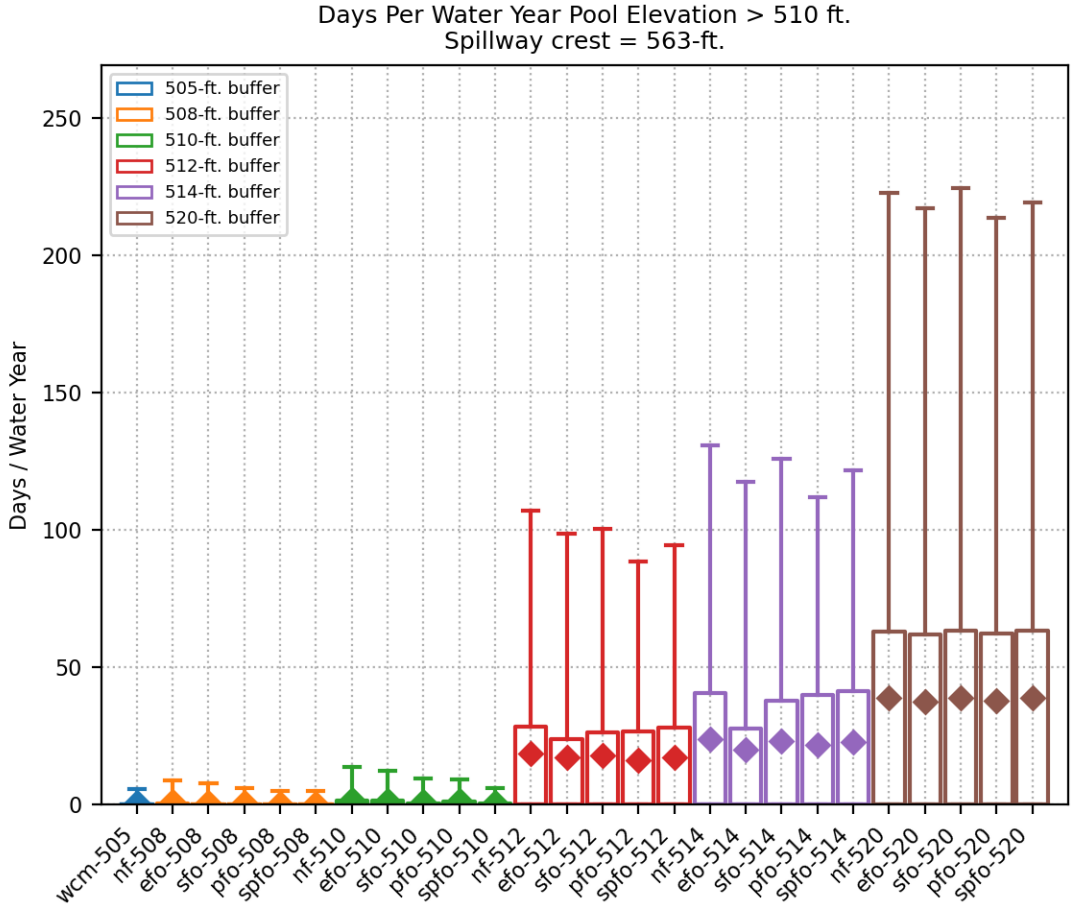

Days Per Water Year Pool Elevation > 505 ft.
Spillway crest = 543-ft.
Days / Water Year
0
50
100
150
200
250
300
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

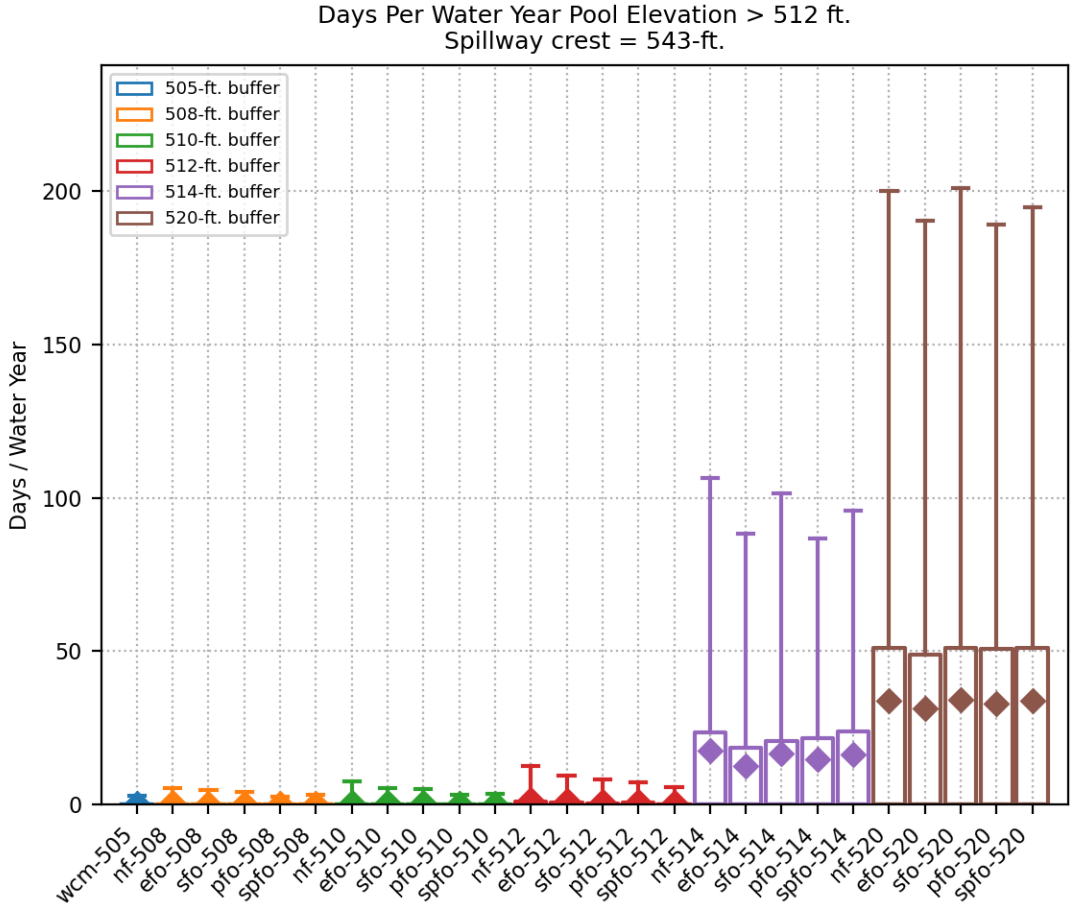

Days Per Water Year Pool Elevation > 505 ft.
Spillway crest = 563-ft.
Days / Water Year
0
50
100
150
200
250
300
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

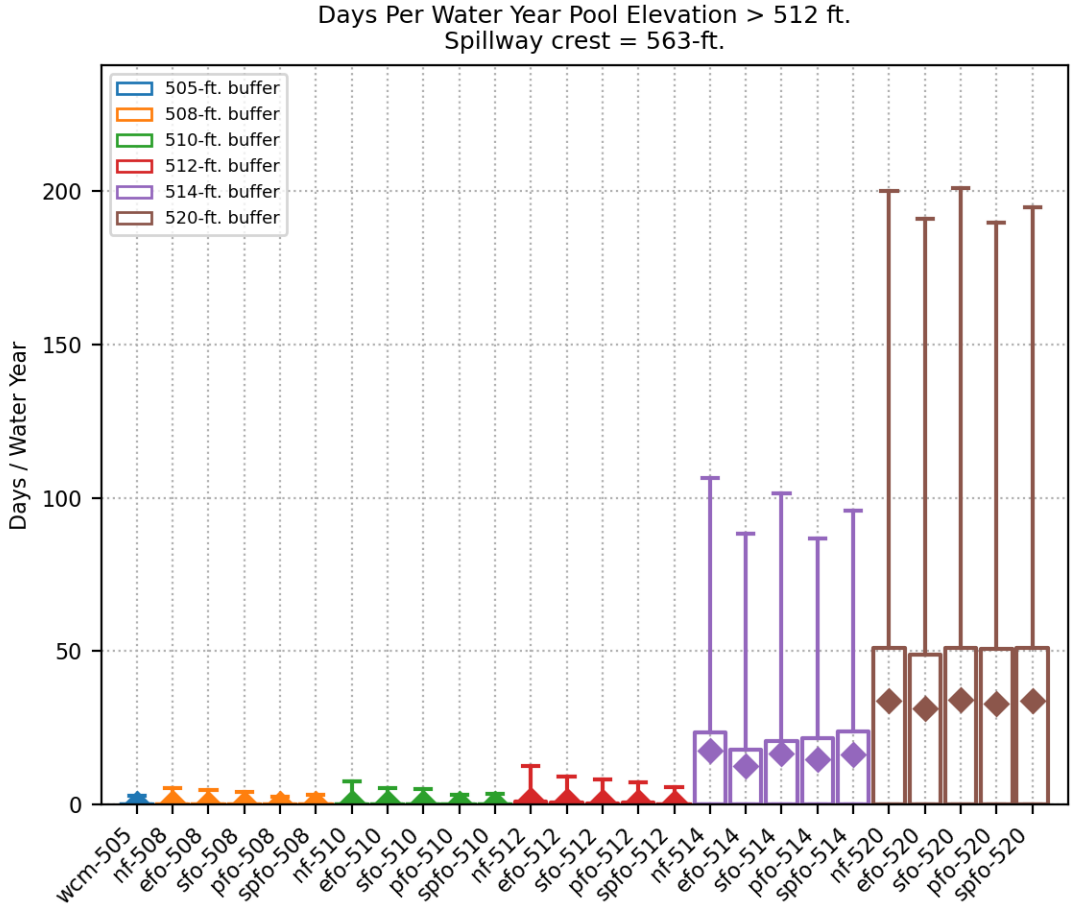

Days Per Water Year Pool Elevation > 508 ft.
Spillway crest = 543-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Days / Water Year
0
50
100
150
200
250
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

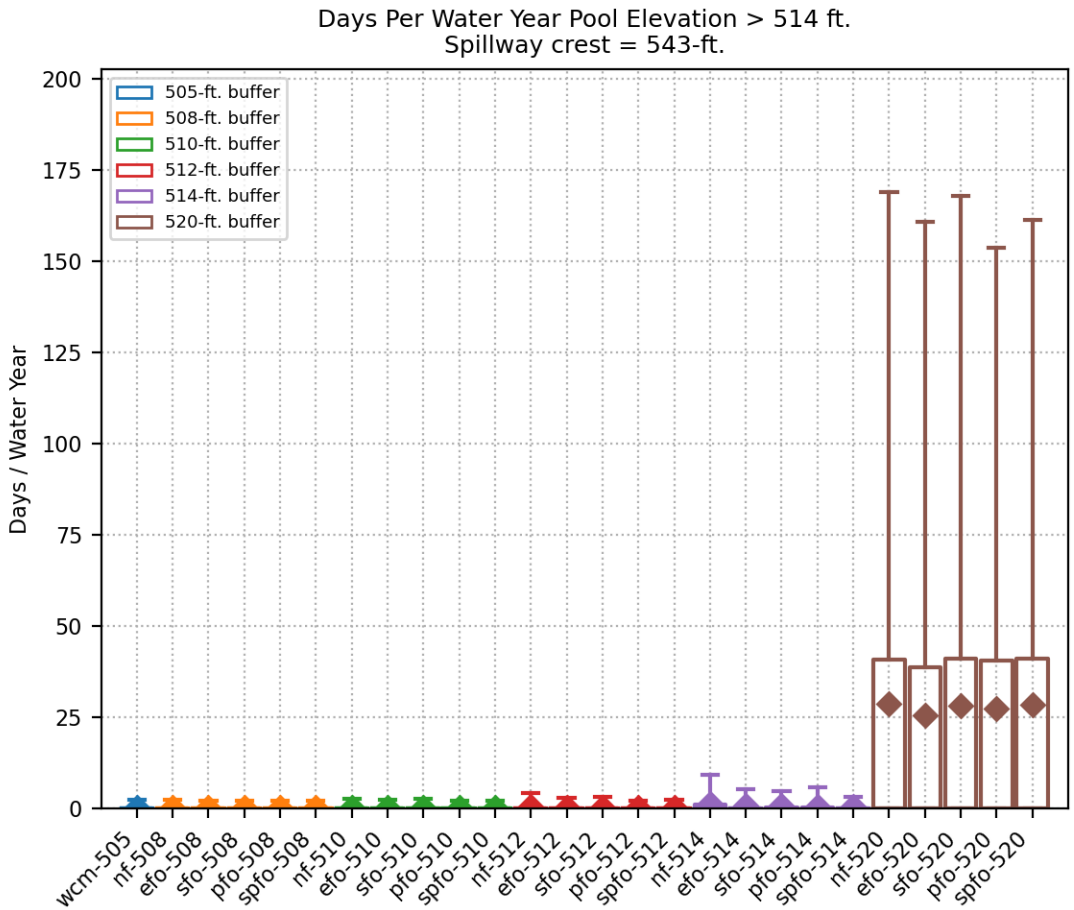

Days Per Water Year Pool Elevation > 508 ft.
Spillway crest = 563-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Days / Water Year
0
50
100
150
200
250
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

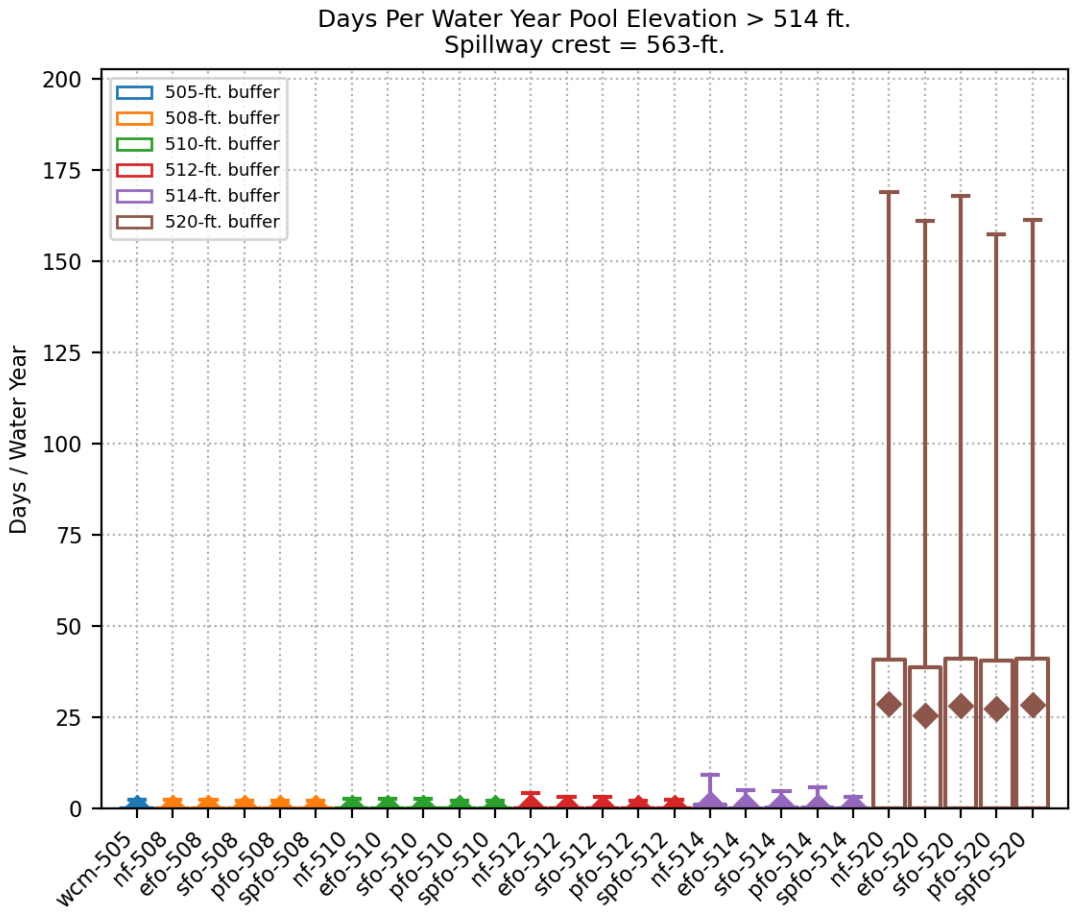

Days Per Water Year Pool Elevation > 510 ft.
Spillway crest = 543-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Days / Water Year
0
50
100
150
200
250
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

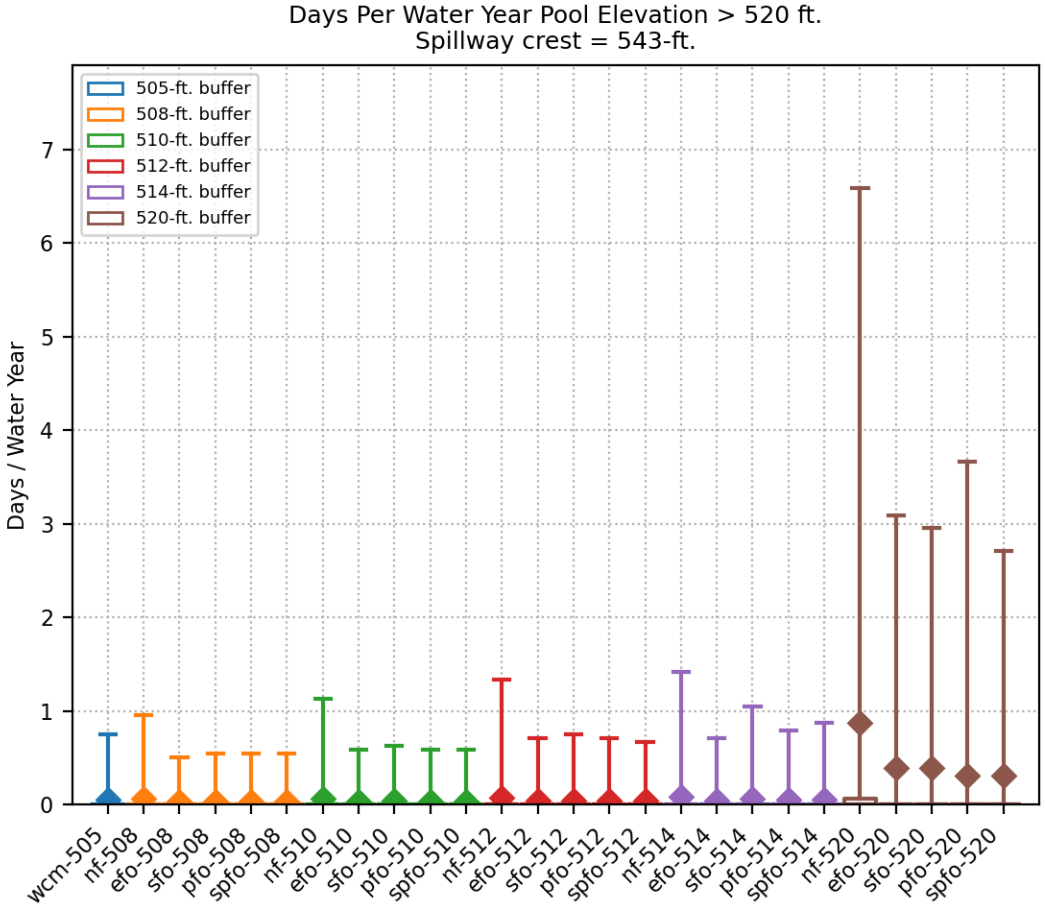

Days Per Water Year Pool Elevation > 510 ft.
Spillway crest = 563-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Days / Water Year
0
50
100
150
200
250
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

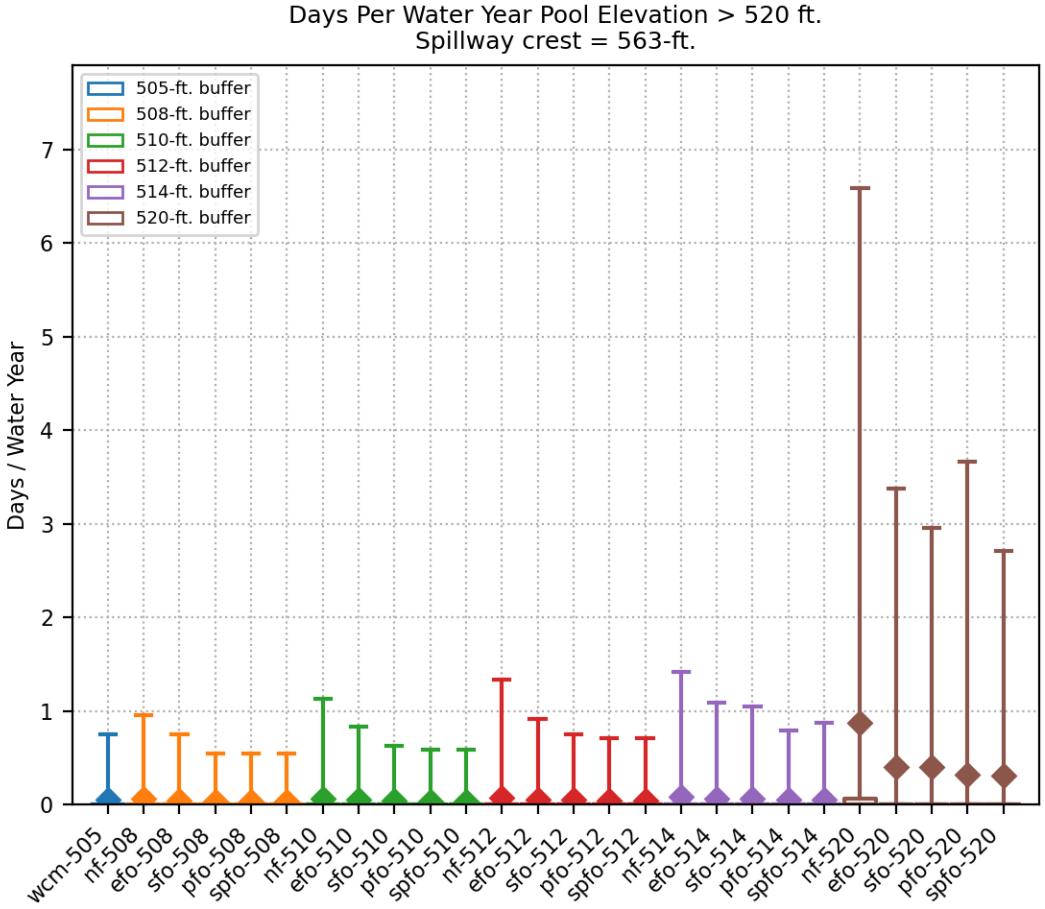

Days Per Water Year Pool Elevation > 512 ft.
Spillway crest = 543-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Days / Water Year
0
50
100
150
200
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

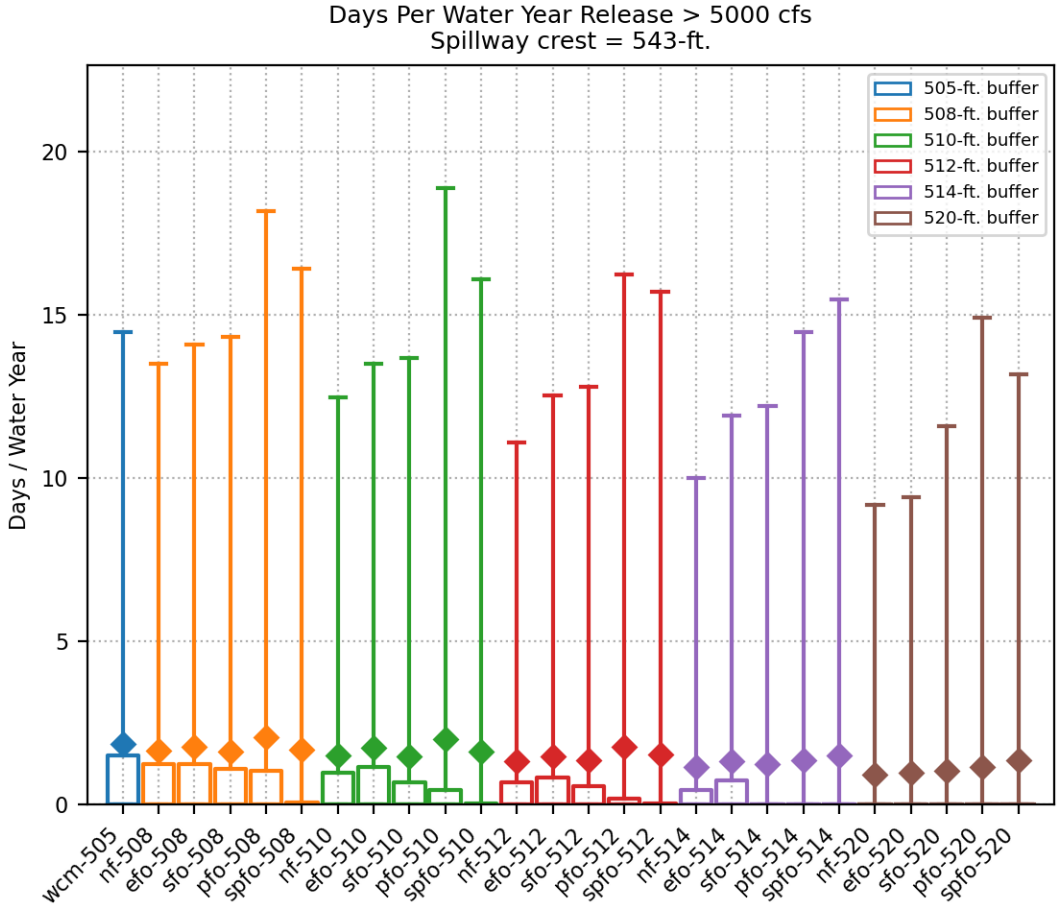

Days Per Water Year Pool Elevation > 512 ft.
Spillway crest = 563-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Days / Water Year
0
50
100
150
200
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

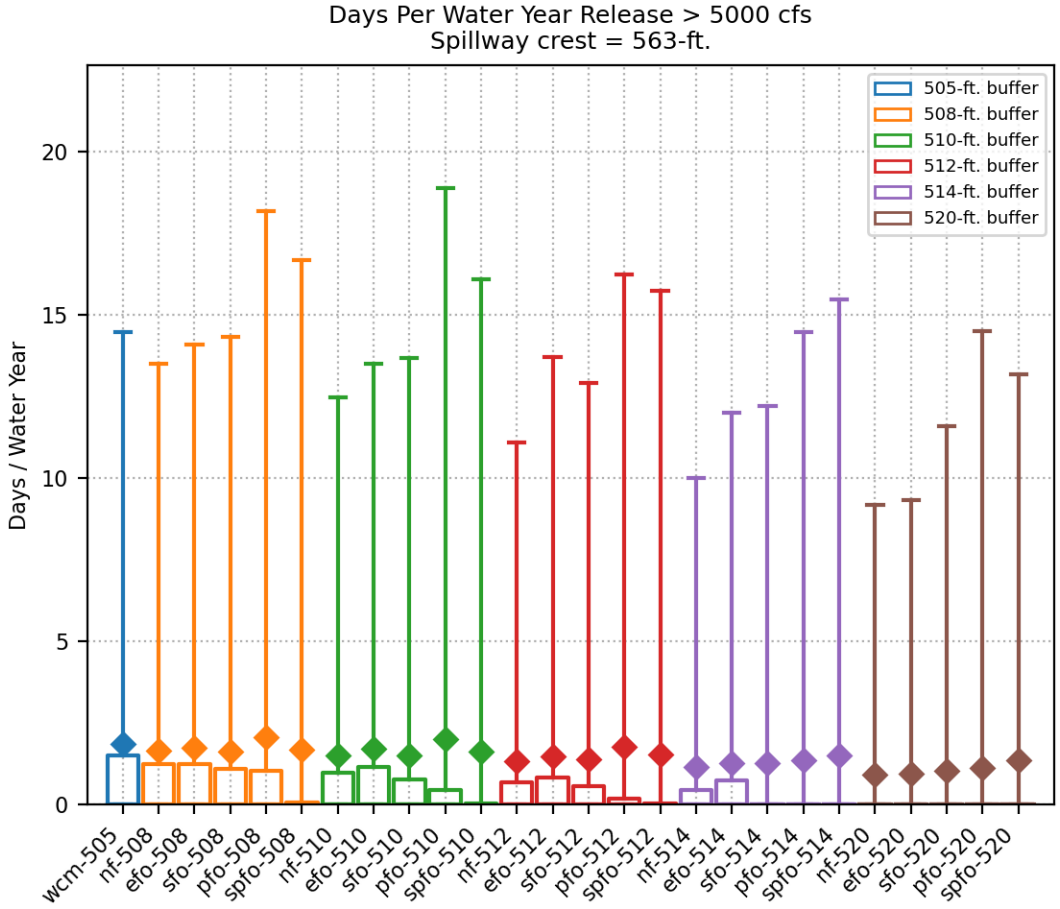

Days Per Water Year Pool Elevation > 514 ft.
Spillway crest = 543-ft.
Days / Water Year
0
25
50
75
100
125
150
175
200
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

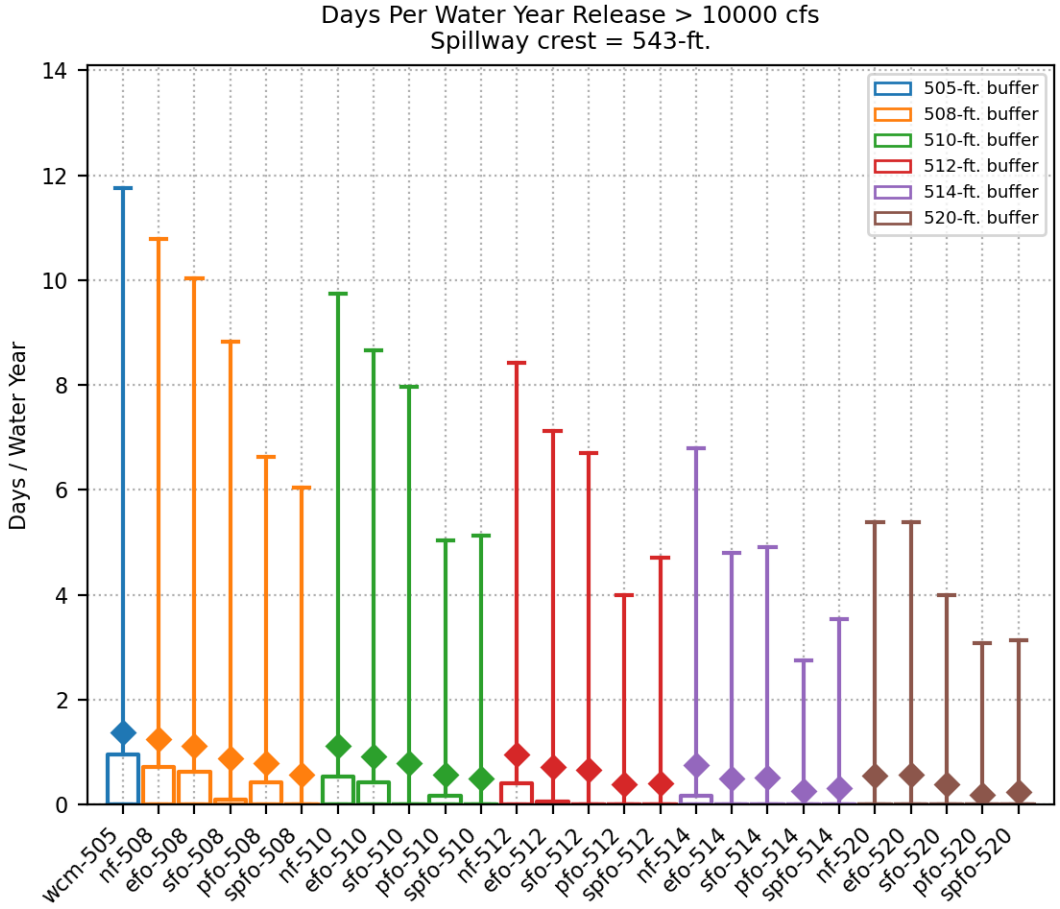

Days Per Water Year Pool Elevation > 514 ft.
Spillway crest = 563-ft.
Days / Water Year
0
25
50
75
100
125
150
175
200
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

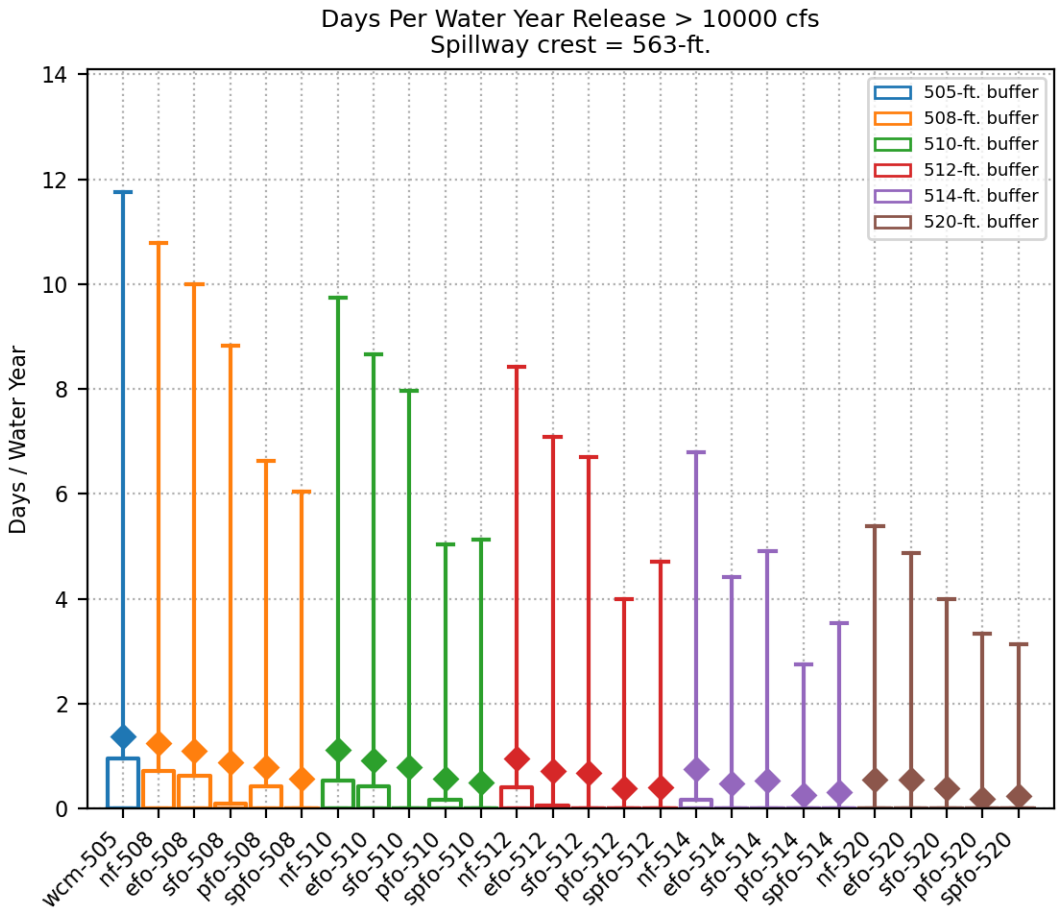

Days Per Water Year Pool Elevation > 520 ft.
Spillway crest = 543-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Days / Water Year
0
1
2
3
4
5
6
7
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

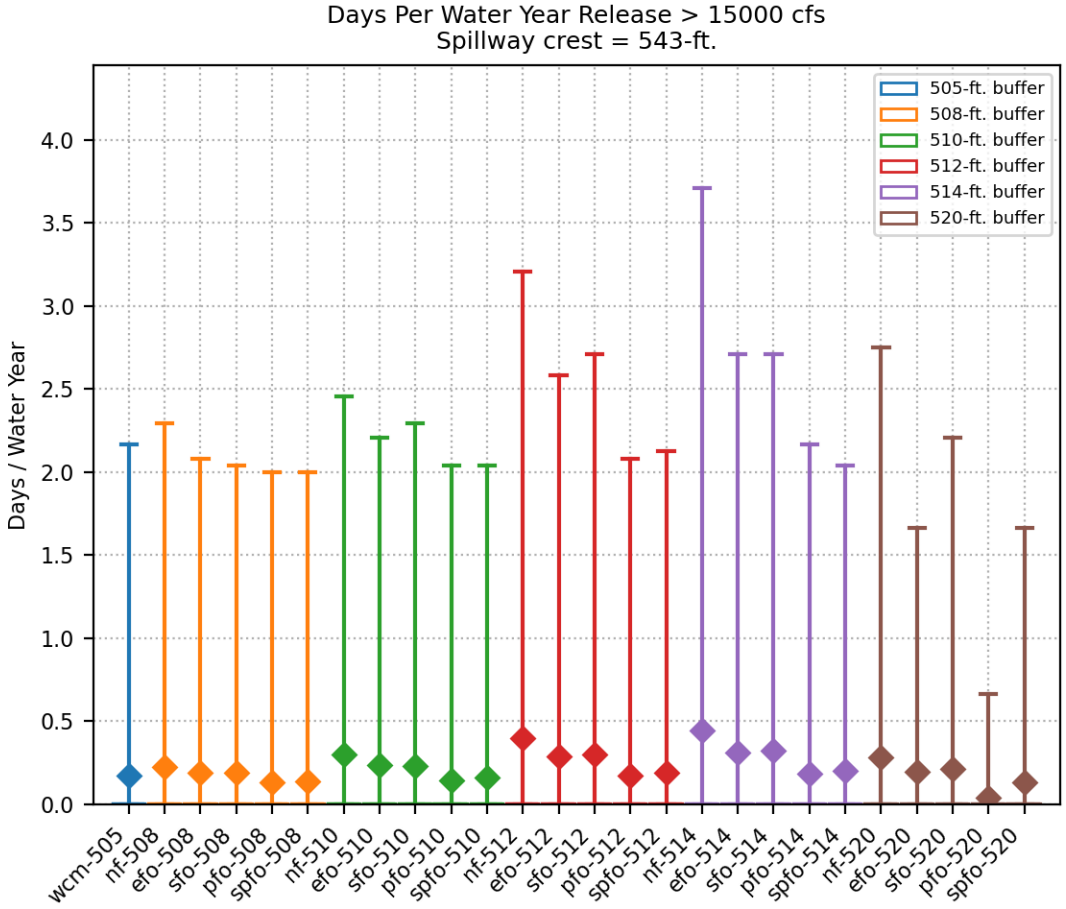

Days Per Water Year Pool Elevation > 520 ft.
Spillway crest = 563-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Days / Water Year
0
1
2
3
4
5
6
7
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

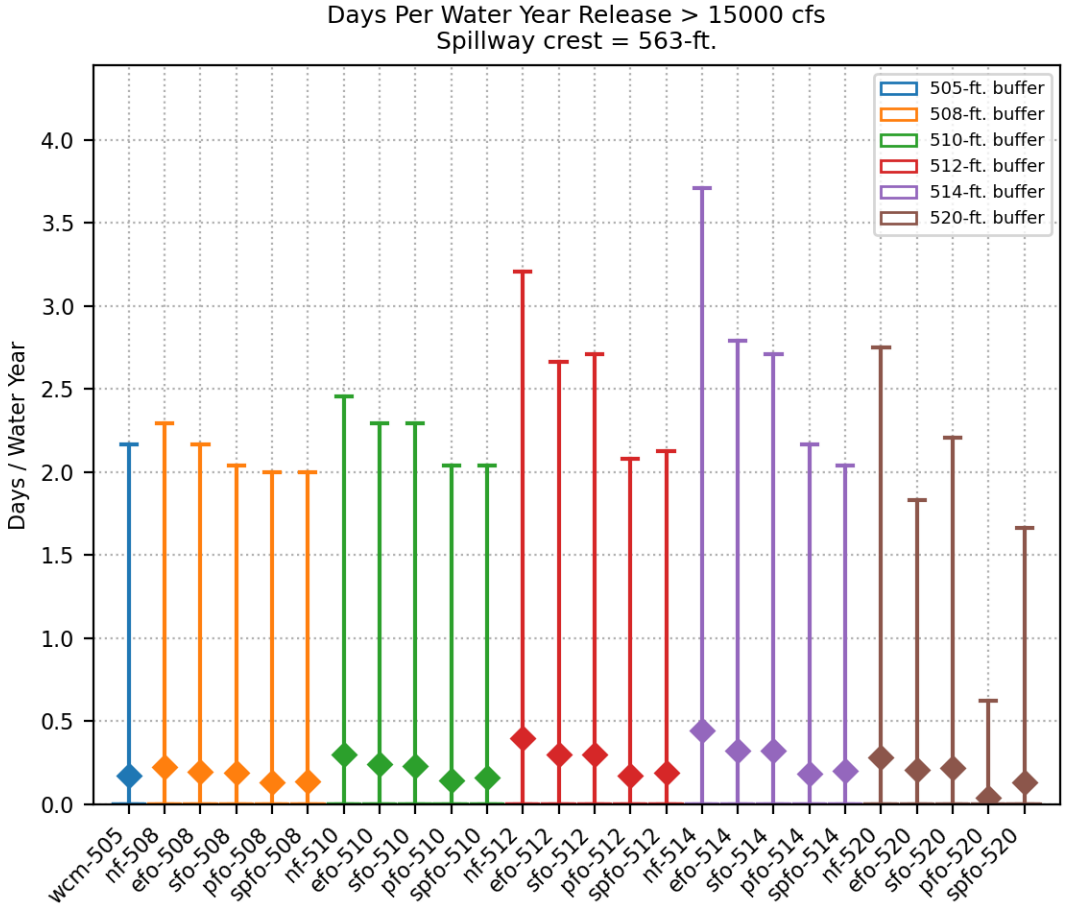

Days Per Water Year Release > 5000 cfs
Spillway crest = 543-ft.
Days / Water Year
0
5
10
15
20
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

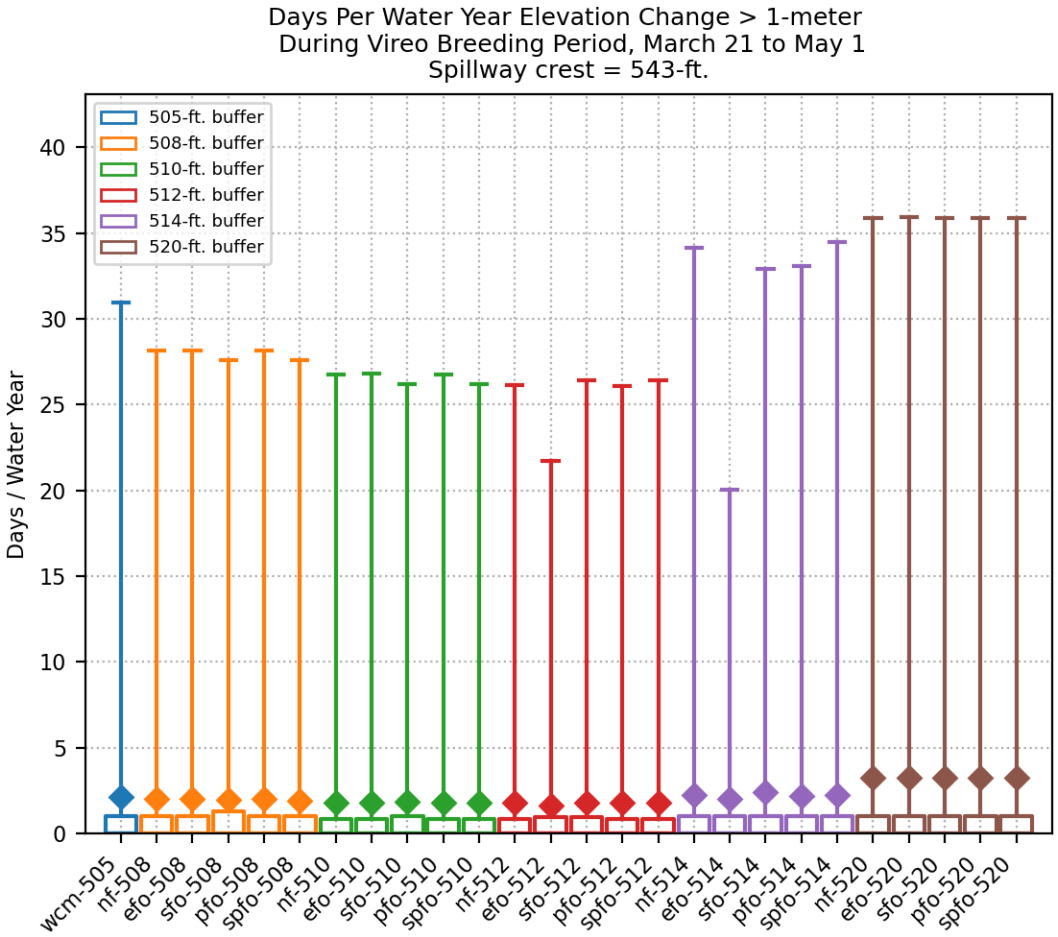

Days Per Water Year Release > 5000 cfs
Spillway crest = 563-ft.
Days / Water Year
0
5
10
15
20
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

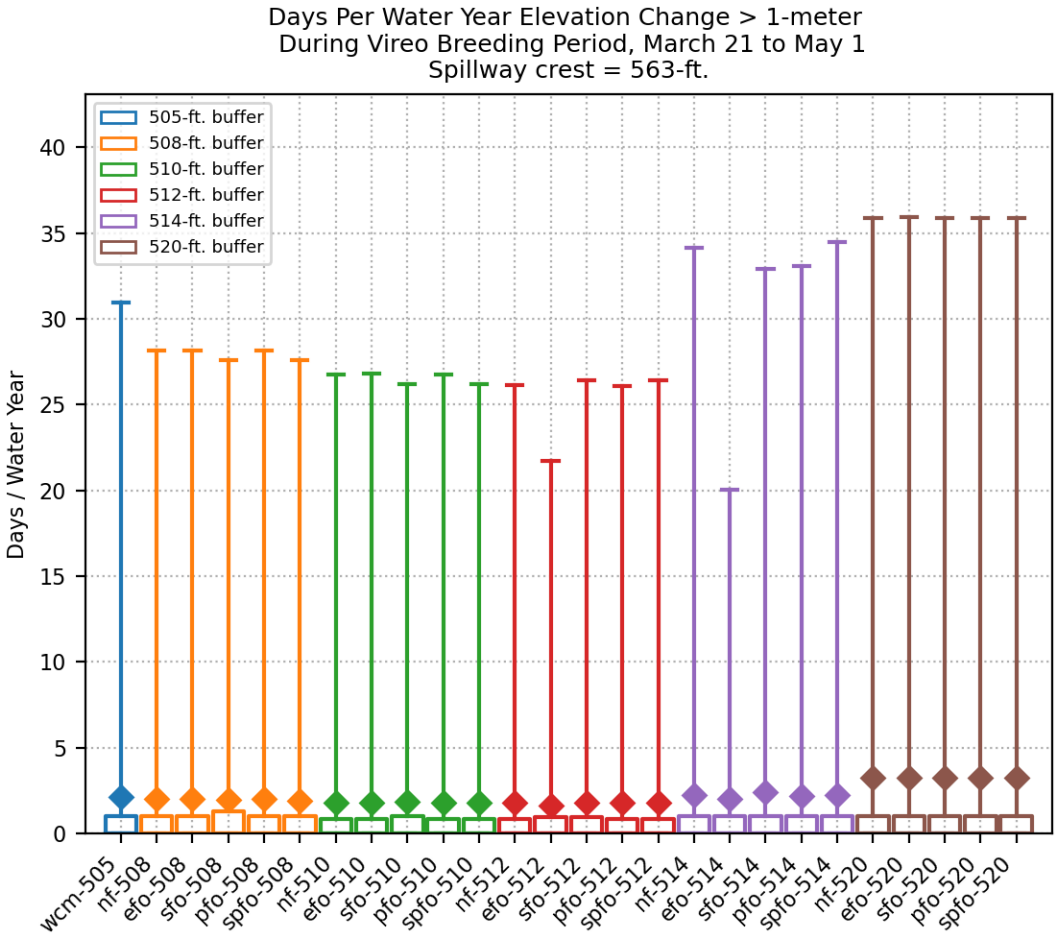

Days Per Water Year Release > 10000 cfs
Spillway crest = 543-ft.
Days / Water Year
0
2
4
6
8
10
12
14
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520


Days Per Water Year Release > 10000 cfs
Spillway crest = 563-ft.
Days / Water Year
0
2
4
6
8
10
12
14
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520


Days Per Water Year Release > 15000 cfs
Spillway crest = 543-ft.
Days / Water Year
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520


Days Per Water Year Release > 15000 cfs
Spillway crest = 563-ft.
Days / Water Year
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520


Days Per Water Year Elevation Change > 1-meter
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 543-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Days / Water Year
0
5
10
15
20
25
30
35
40
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520


Days Per Water Year Elevation Change > 1-meter
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 563-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Days / Water Year
0
5
10
15
20
25
30
35
40
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514
nf-520
efo-520
sfo-520
pfo-520
spfo-520

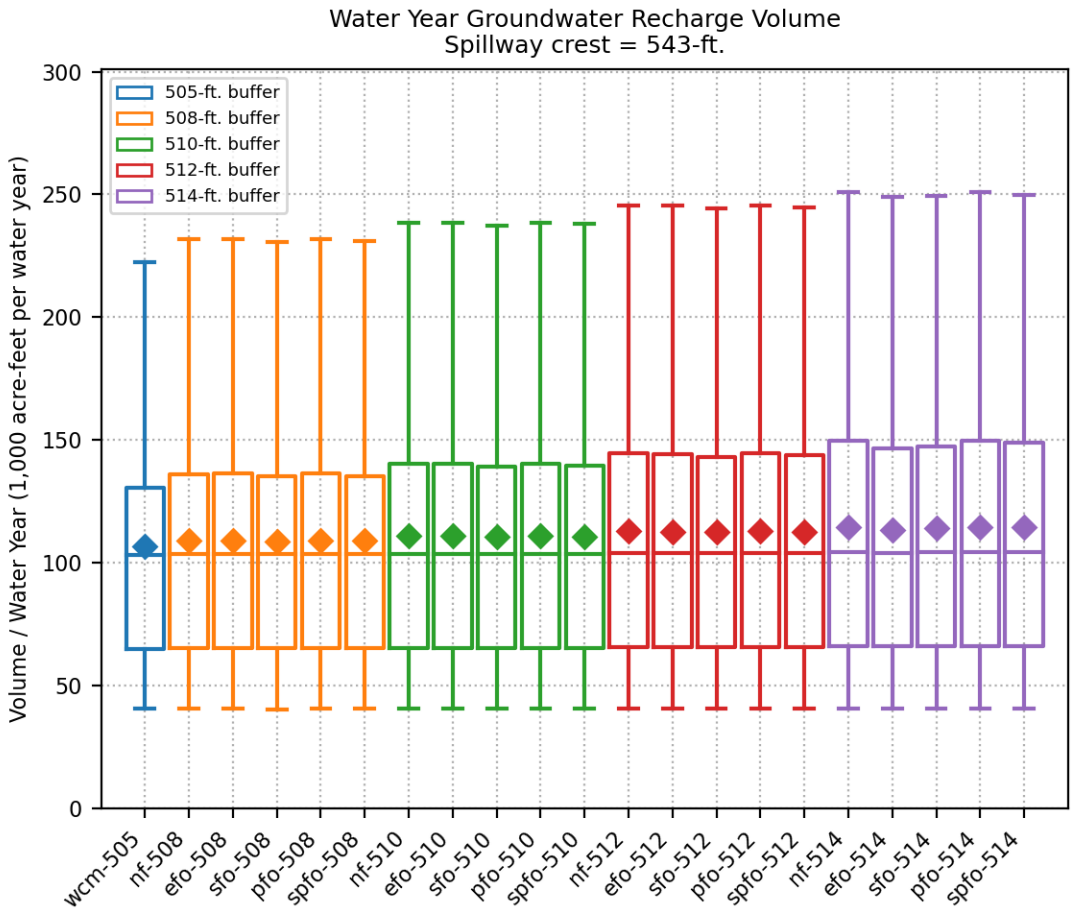
HEMP Metrics – Box/Whisker Plots (No 520)

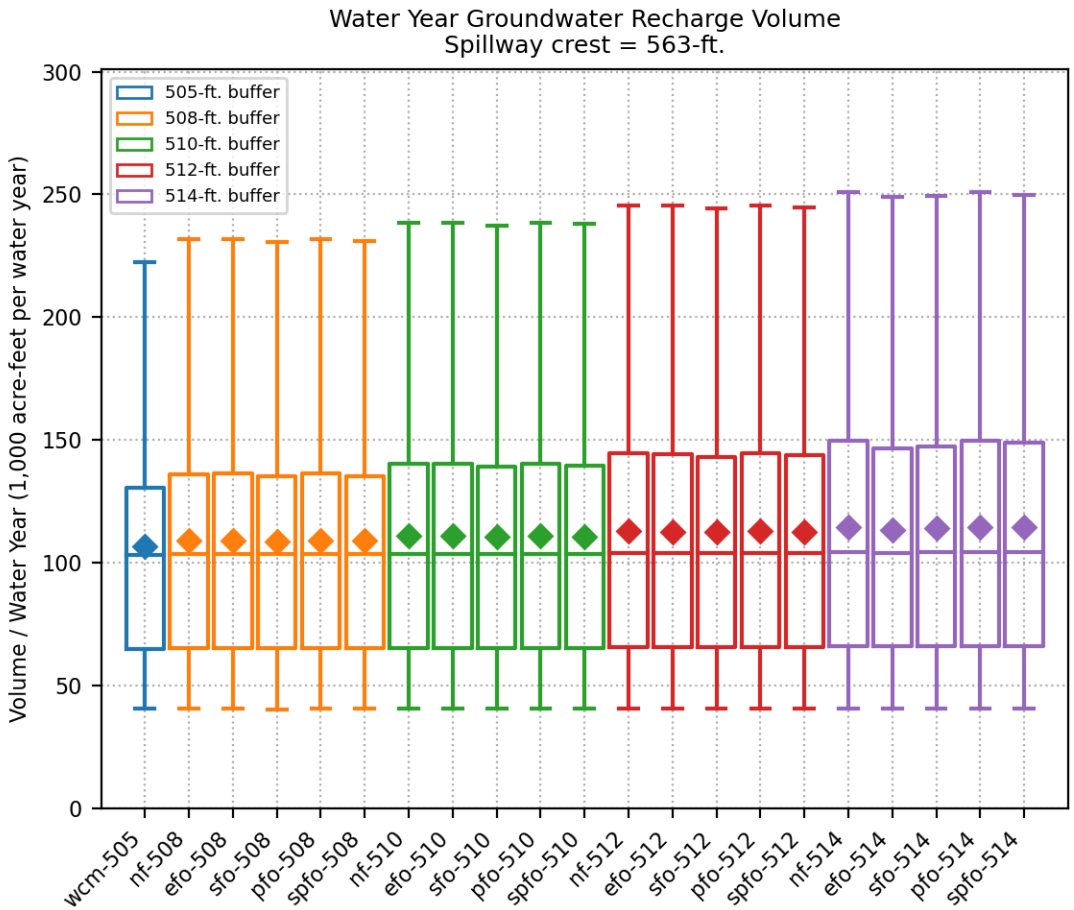
- Groundwater Recharge
- Santa Anna River discharge to Pacific Ocean
- Peak Reservoir Release
- Peak Reservoir Elevation
- Pool elevation > 505’, 508’, 510’, 512’, 514’
- Reservoir release > 5,000, 10,000, 15,000 cfs
- >1 meter rise between 3/21 and 5/1

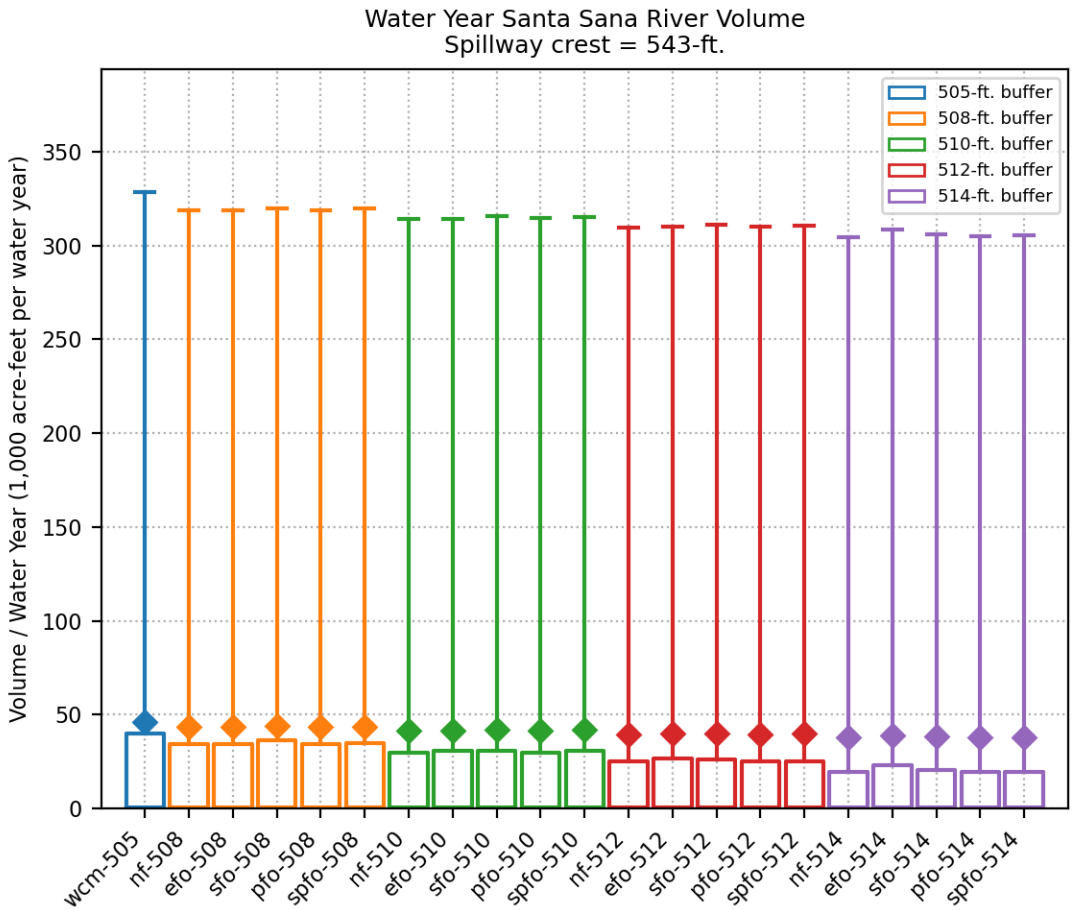
HEMP Metrics – Box/Whisker Plots (No 520)

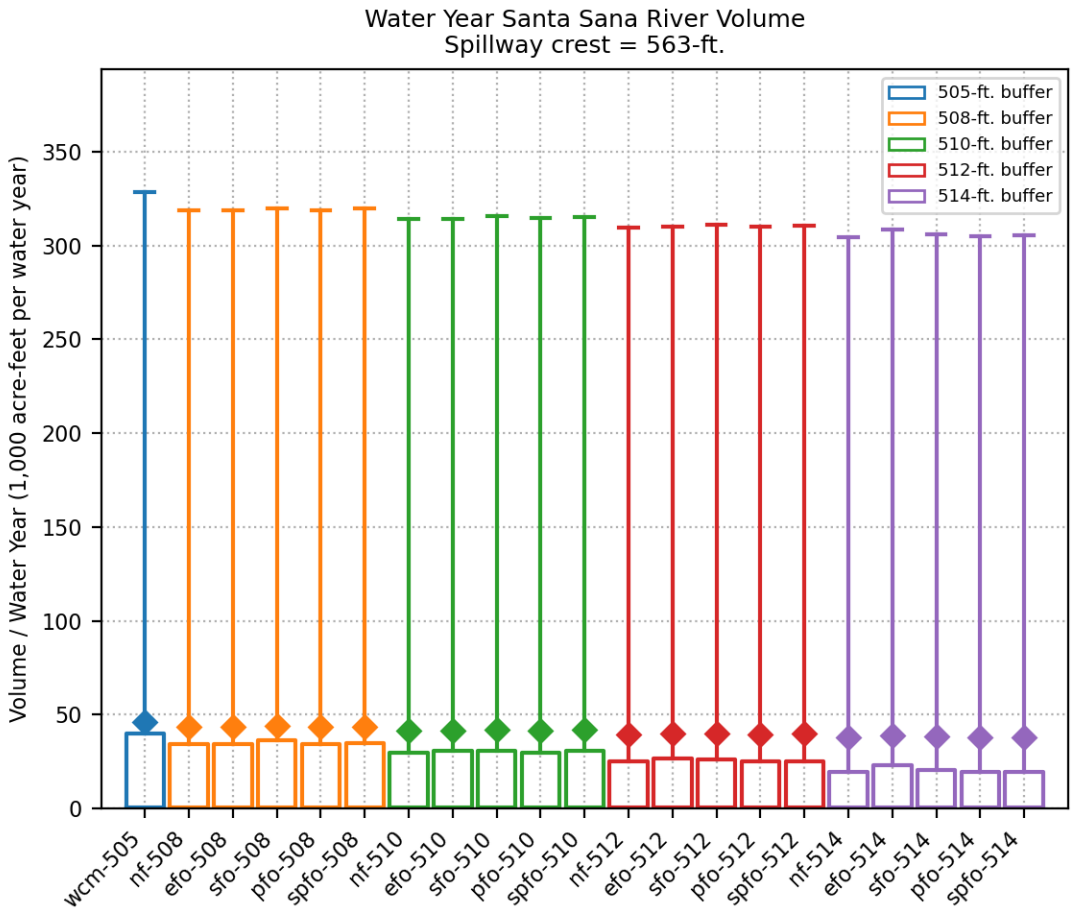
- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’, 510’, 512’, 514’, 520’
- WCP alternatives across X Axis

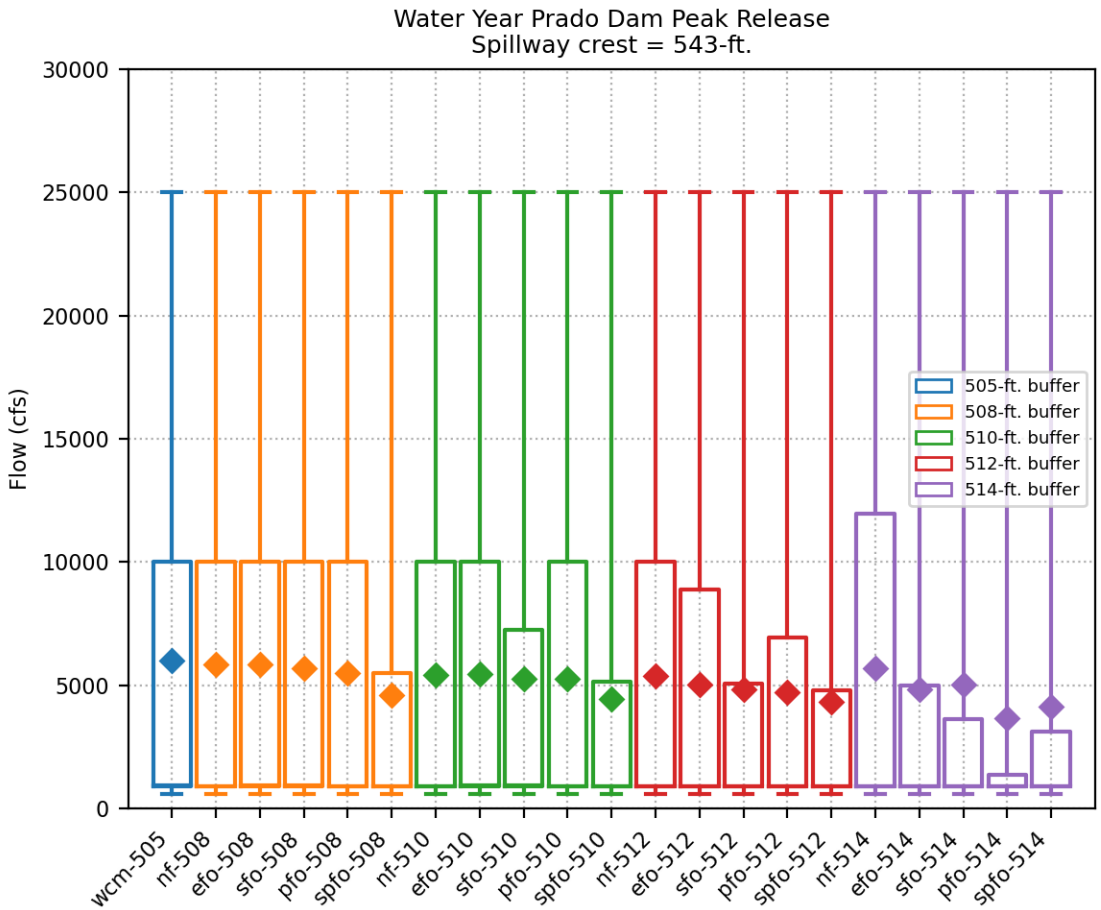
- Whiskers 5% - 95%
- Boxes 25% - 75%
- Diamonds @ median

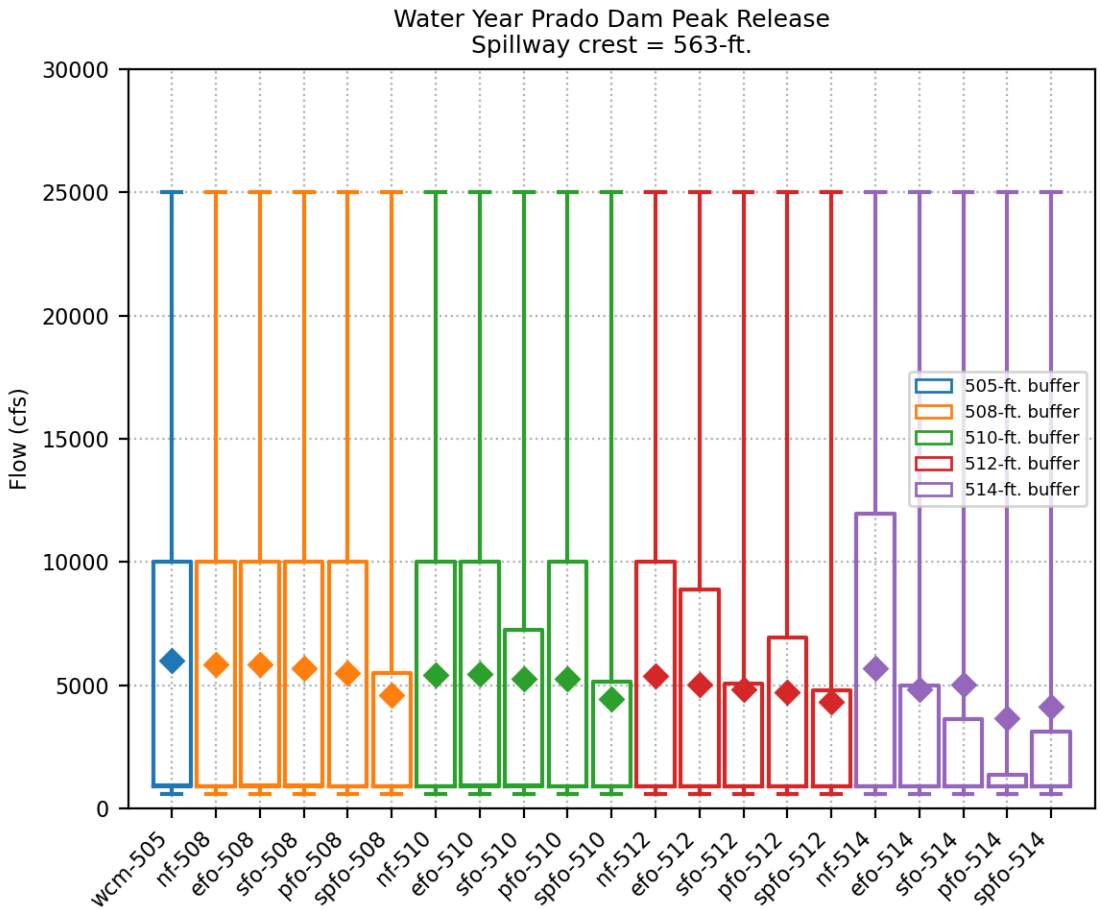

Water Year Groundwater Recharge Volume
Spillway crest = 543-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
Volume / Water Year (1,000 acre-feet per water year)
0
50
100
150
200
250
300
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514

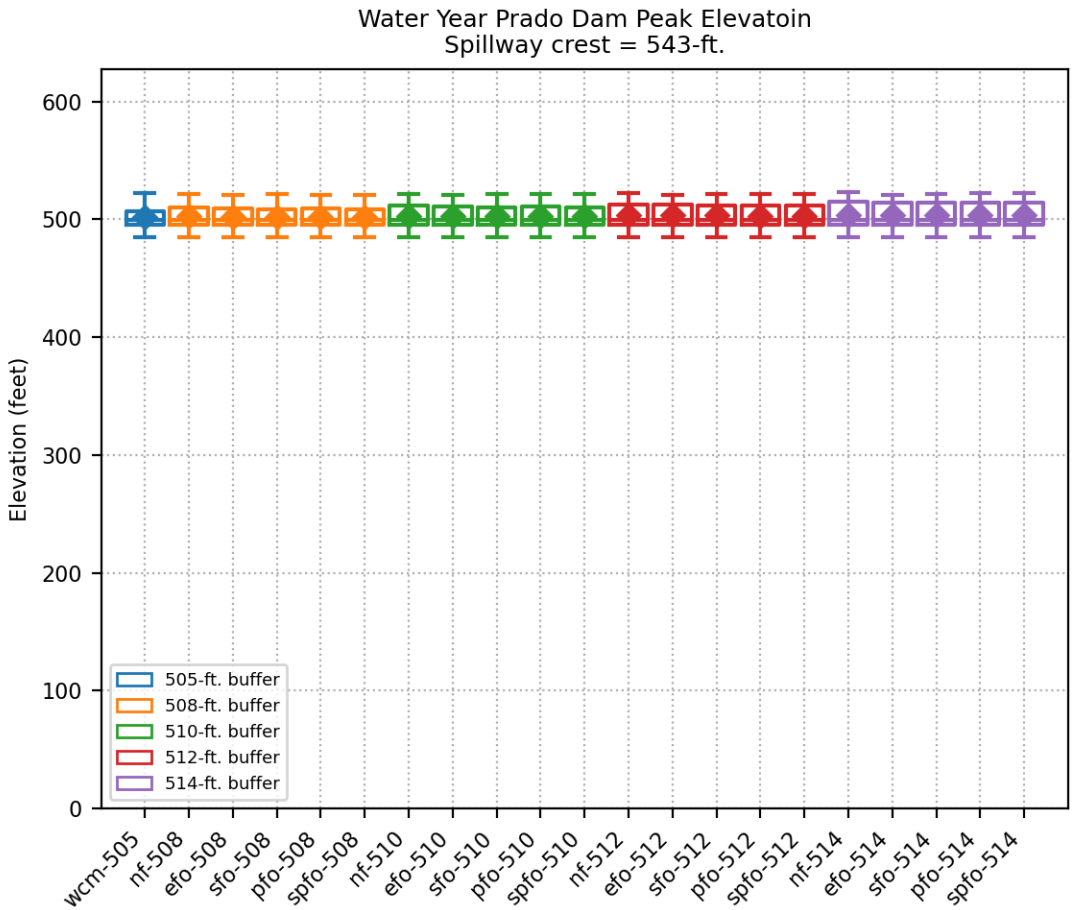

Water Year Groundwater Recharge Volume
Spillway crest = 563-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
Volume / Water Year (1,000 acre-feet per water year)
0
50
100
150
200
250
300
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514

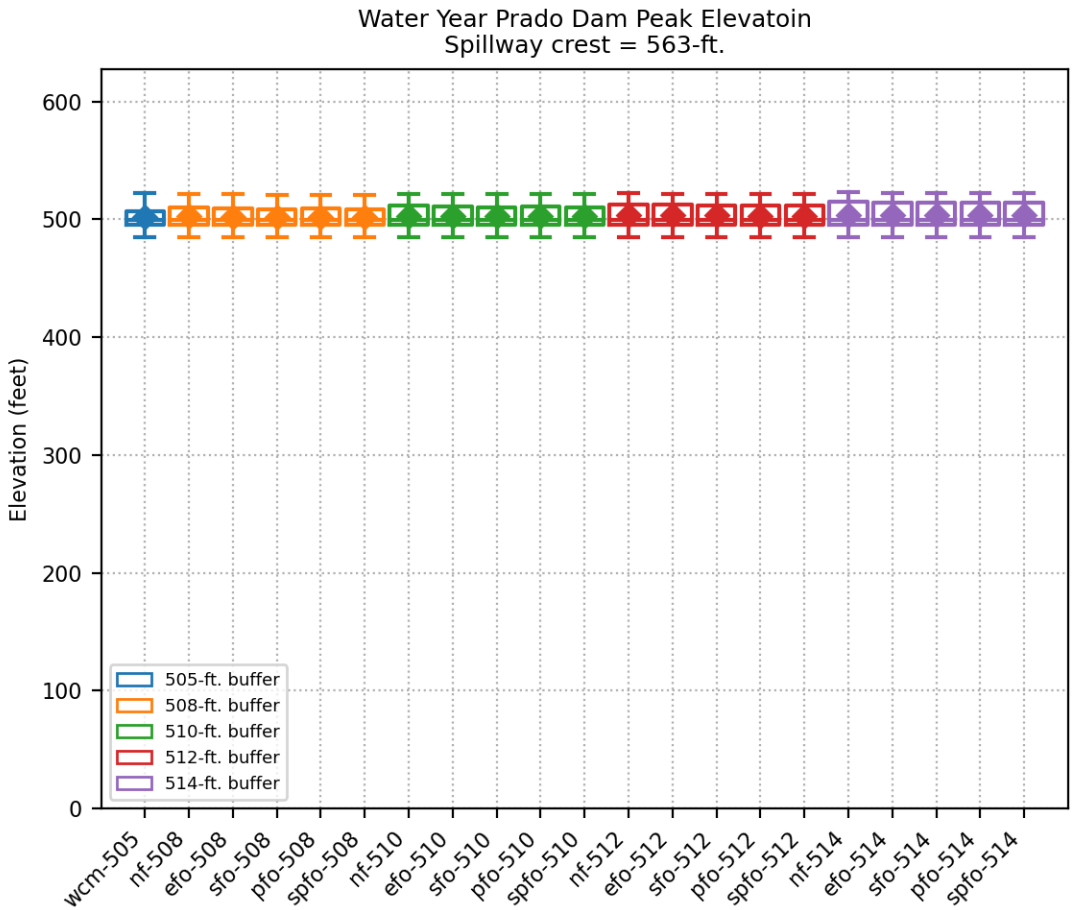

Water Year Santa Sana River Volume
Spillway crest = 543-ft.
Volume / Water Year (1,000 acre-feet per water year)
0
50
100
150
200
250
300
350
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514

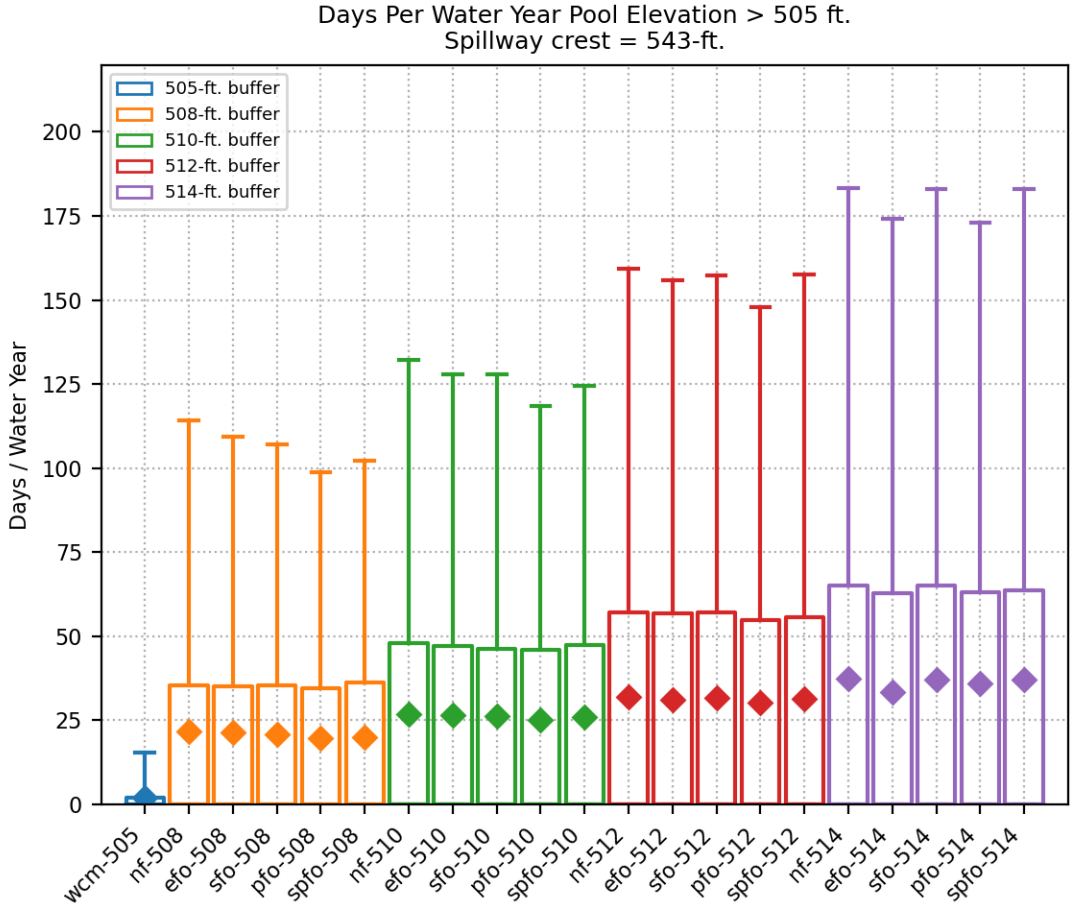

Water Year Santa Sana River Volume
Spillway crest = 563-ft.
Volume / Water Year (1,000 acre-feet per water year)
0
50
100
150
200
250
300
350
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514

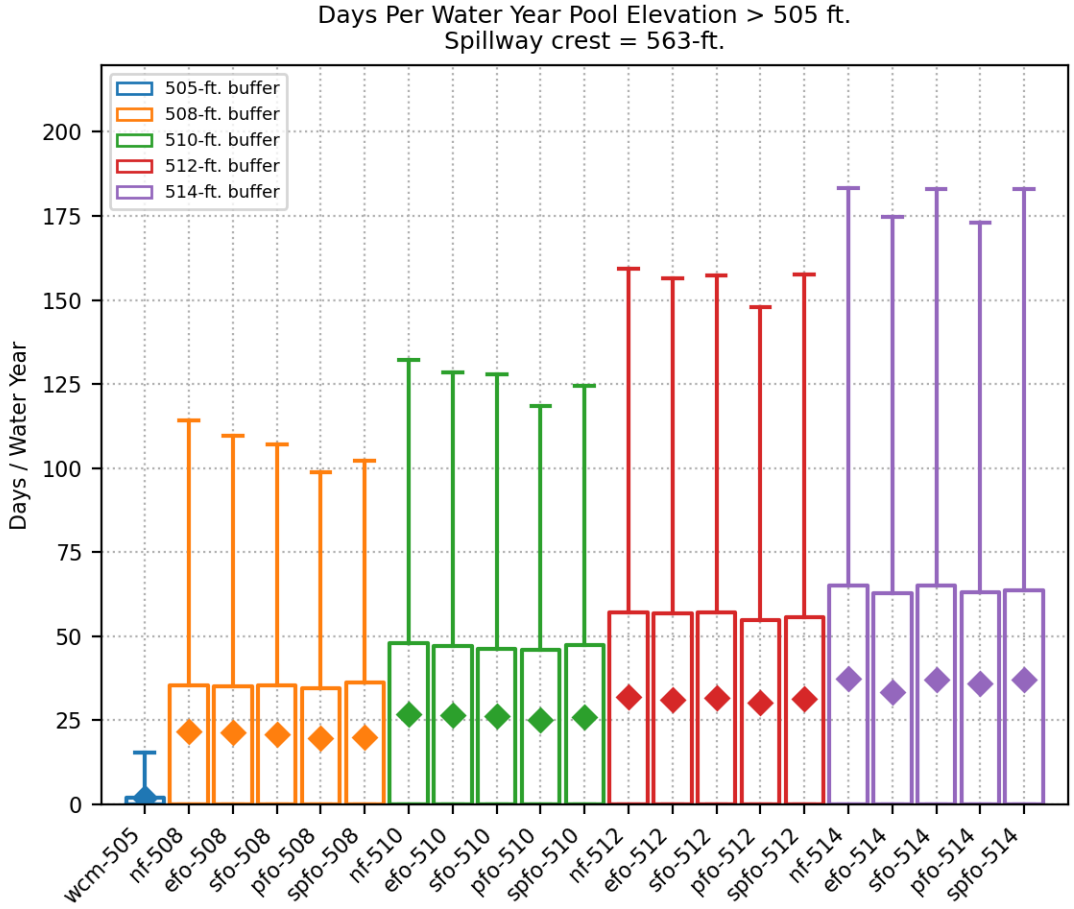

Water Year Prado Dam Peak Release
Spillway crest = 543-ft.
Flow (cfs)
30000
25000
20000
15000
10000
5000
0
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514


Water Year Prado Dam Peak Release
Spillway crest = 563-ft.
Flow (cfs)
30000
25000
20000
15000
10000
5000
0
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514


Water Year Prado Dam Peak Elevatoin
Spillway crest = 543-ft.
Elevation (feet)
0
100
200
300
400
500
600
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514


Water Year Prado Dam Peak Elevatoin
Spillway crest = 563-ft.
Elevation (feet)
600
500
400
300
200
100
0
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514


Days Per Water Year Pool Elevation > 505 ft.
Spillway crest = 543-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
Days / Water Year
0
25
50
75
100
125
150
175
200
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514


Days Per Water Year Pool Elevation > 505 ft.
Spillway crest = 563-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
Days / Water Year
0
25
50
75
100
125
150
175
200
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
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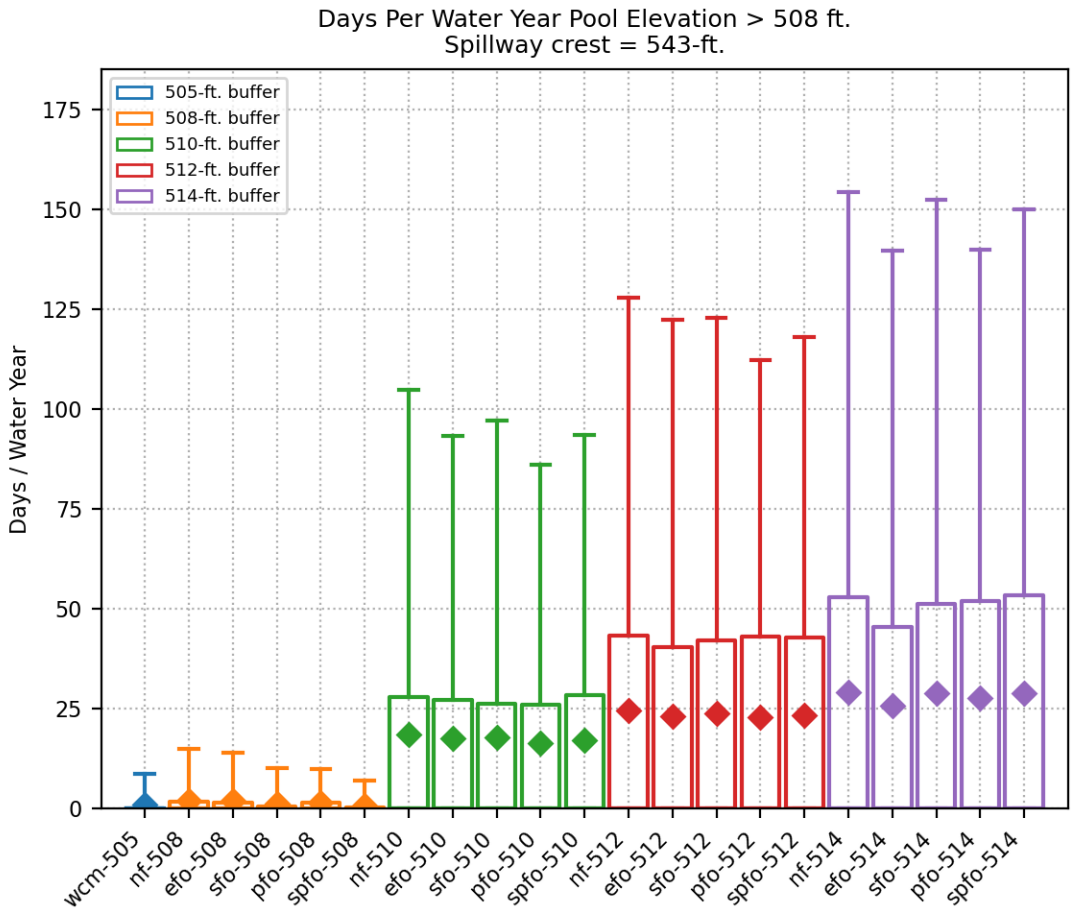
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514


Days Per Water Year Pool Elevation > 508 ft.
Spillway crest = 543-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
Days / Water Year
0
25
50
75
100
125
150
175
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
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sfo-512
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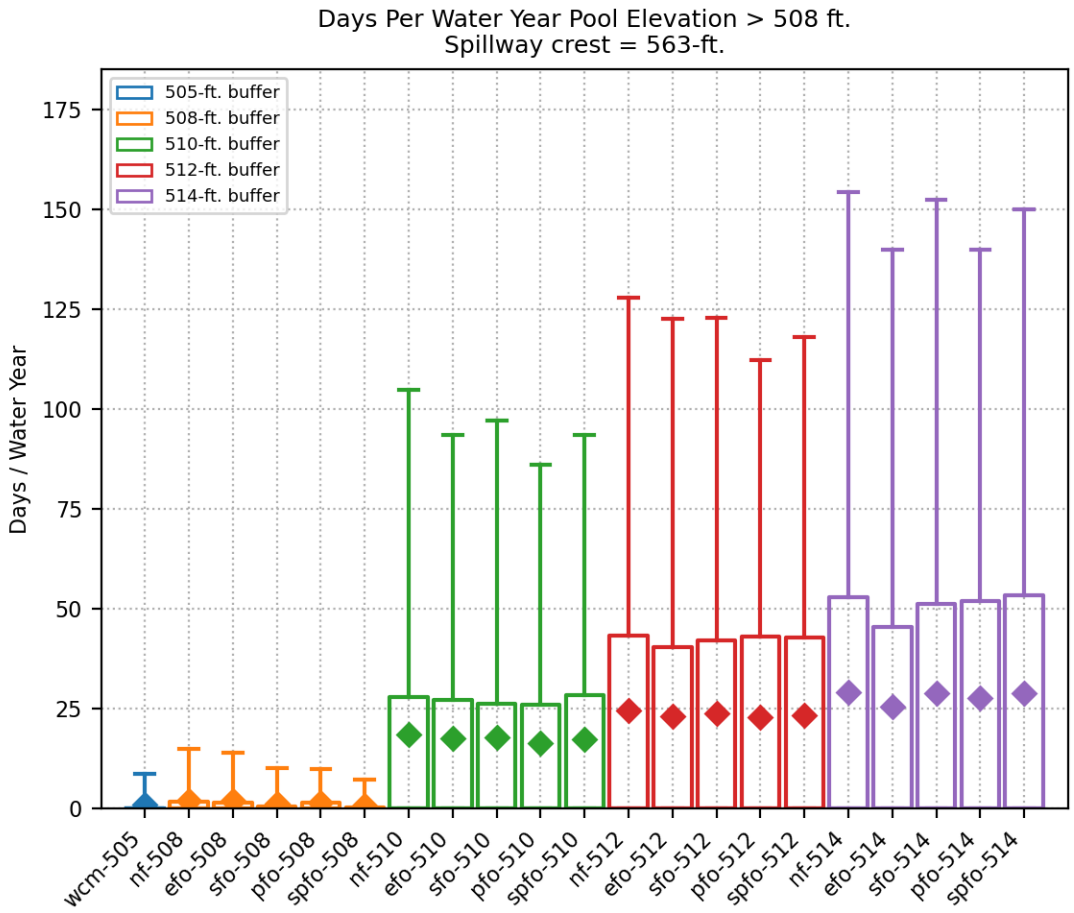
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514


Days Per Water Year Pool Elevation > 508 ft.
Spillway crest = 563-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
Days / Water Year
0
25
50
75
100
125
150
175
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
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sfo-512
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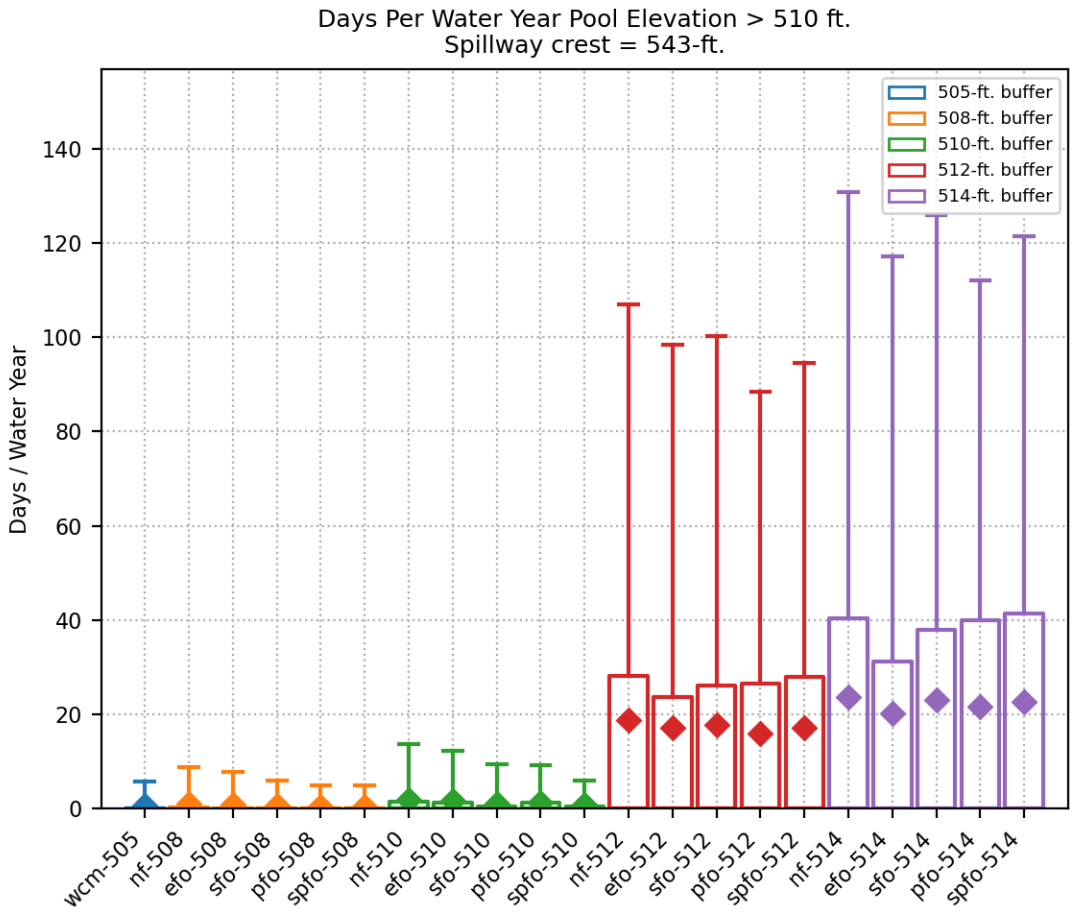
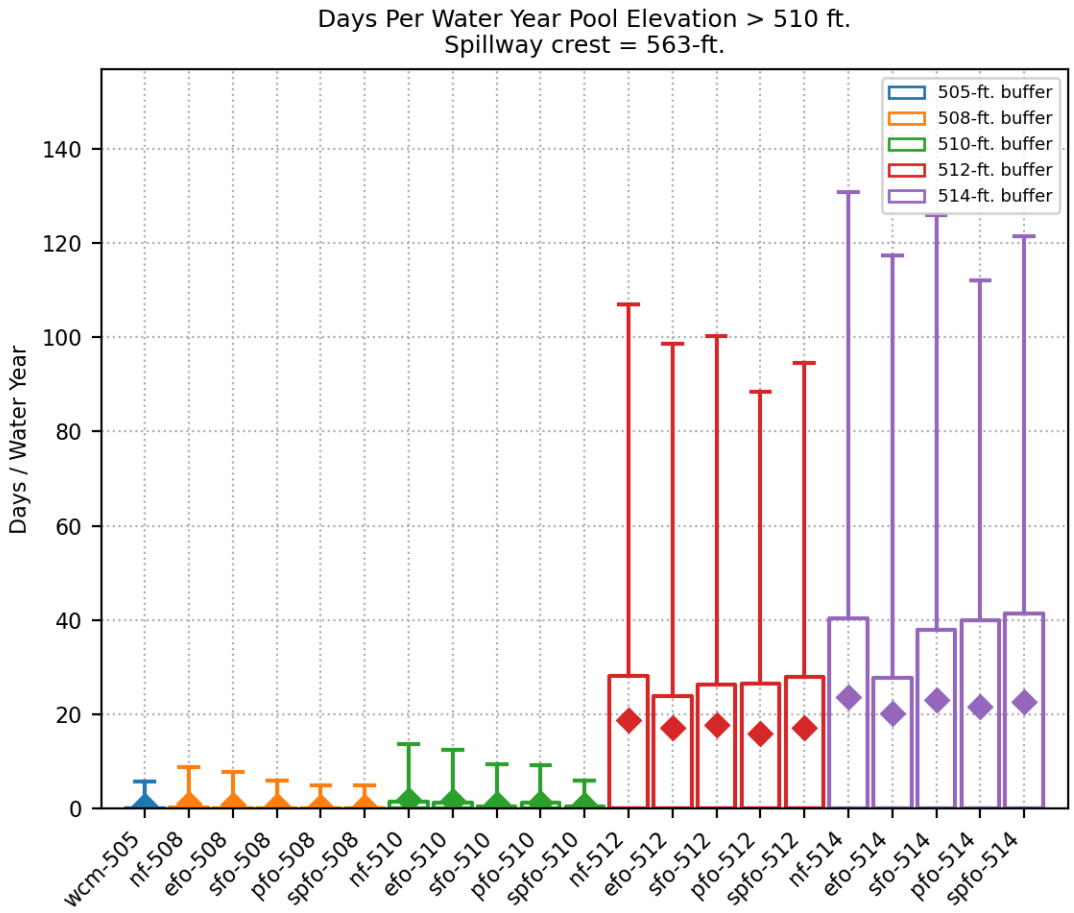
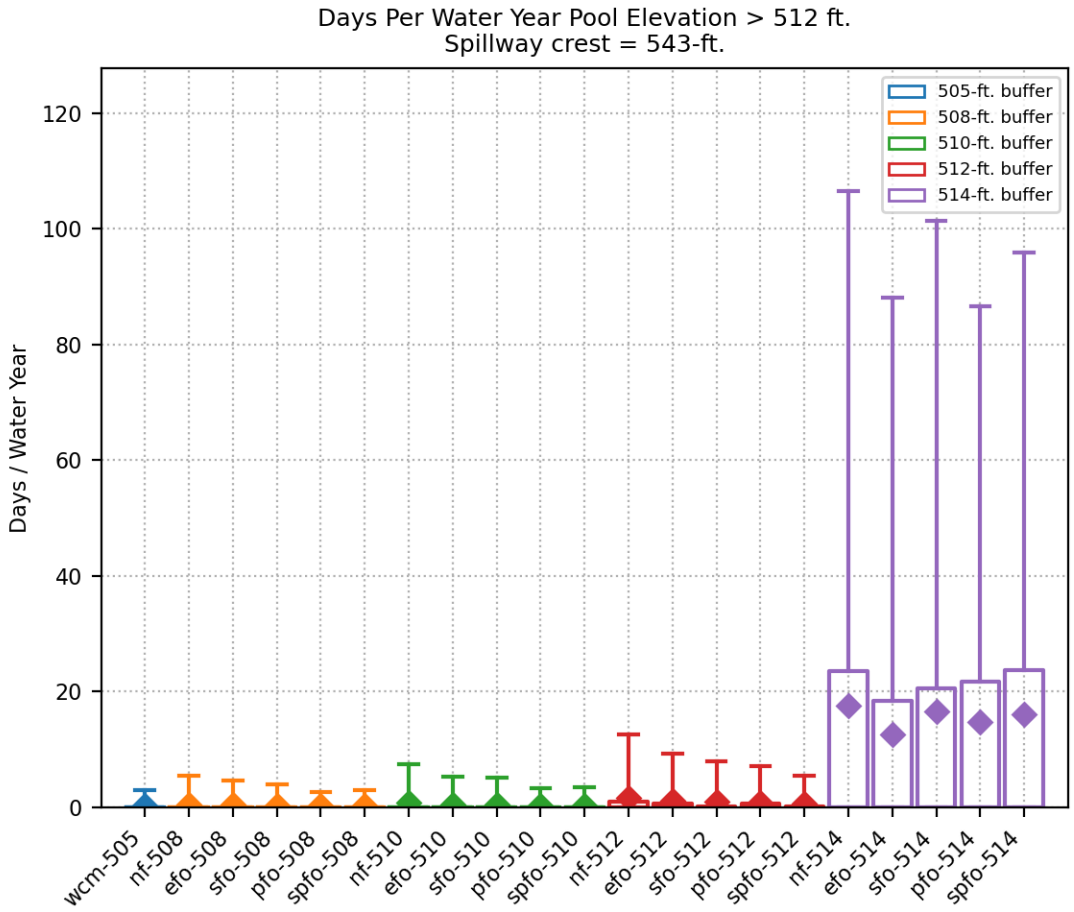
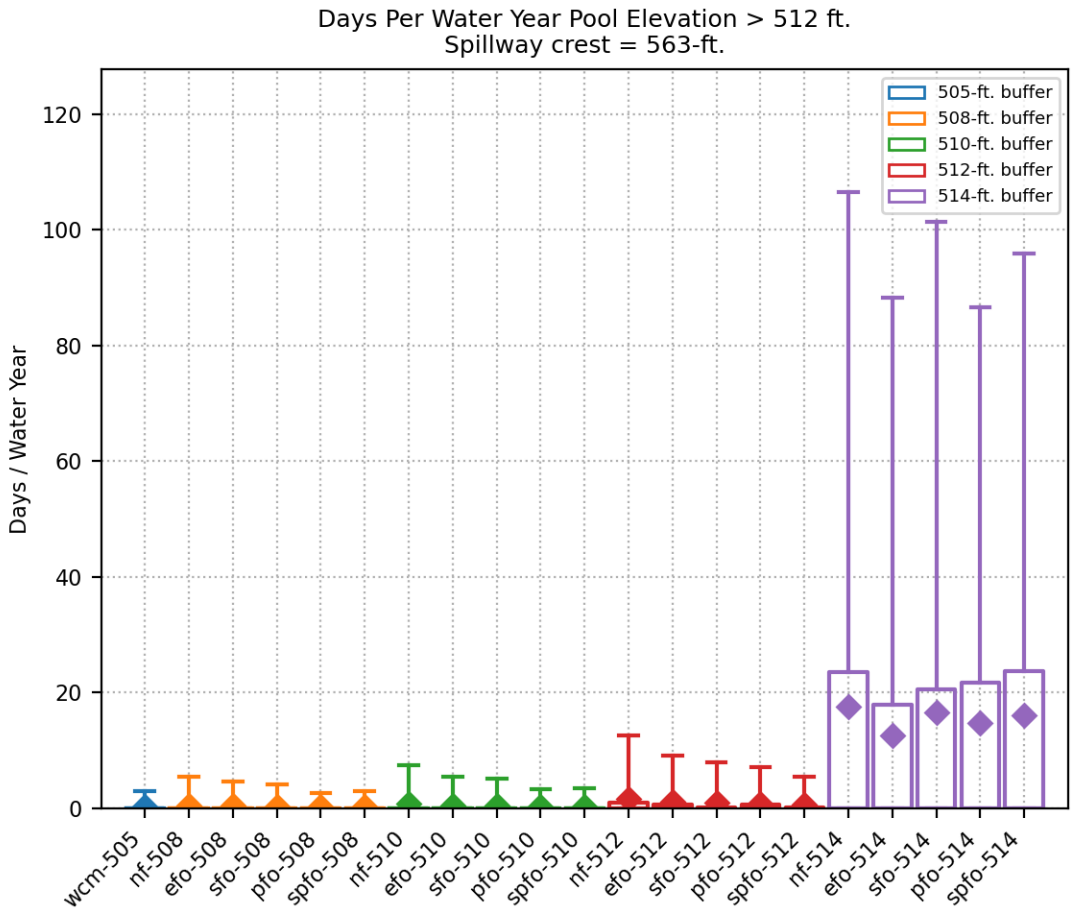
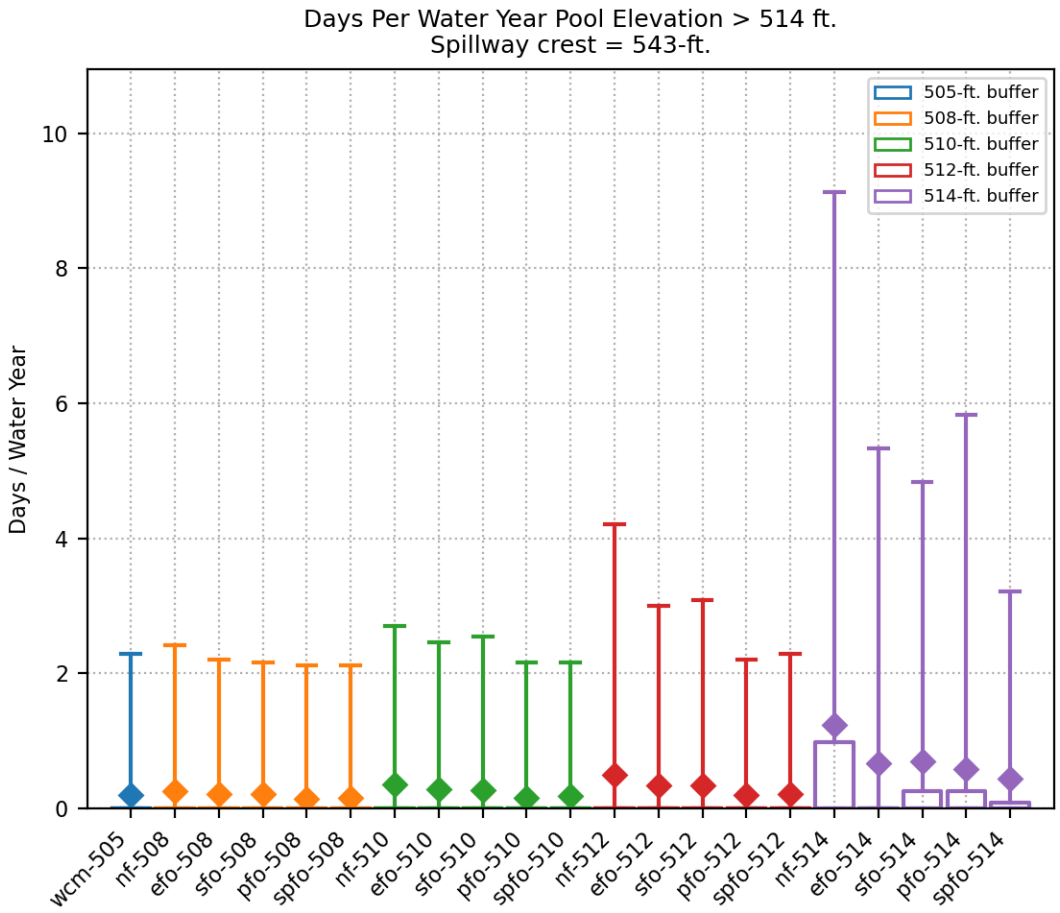
nf-514
efo-514
sfo-514
pfo-514
spfo-514

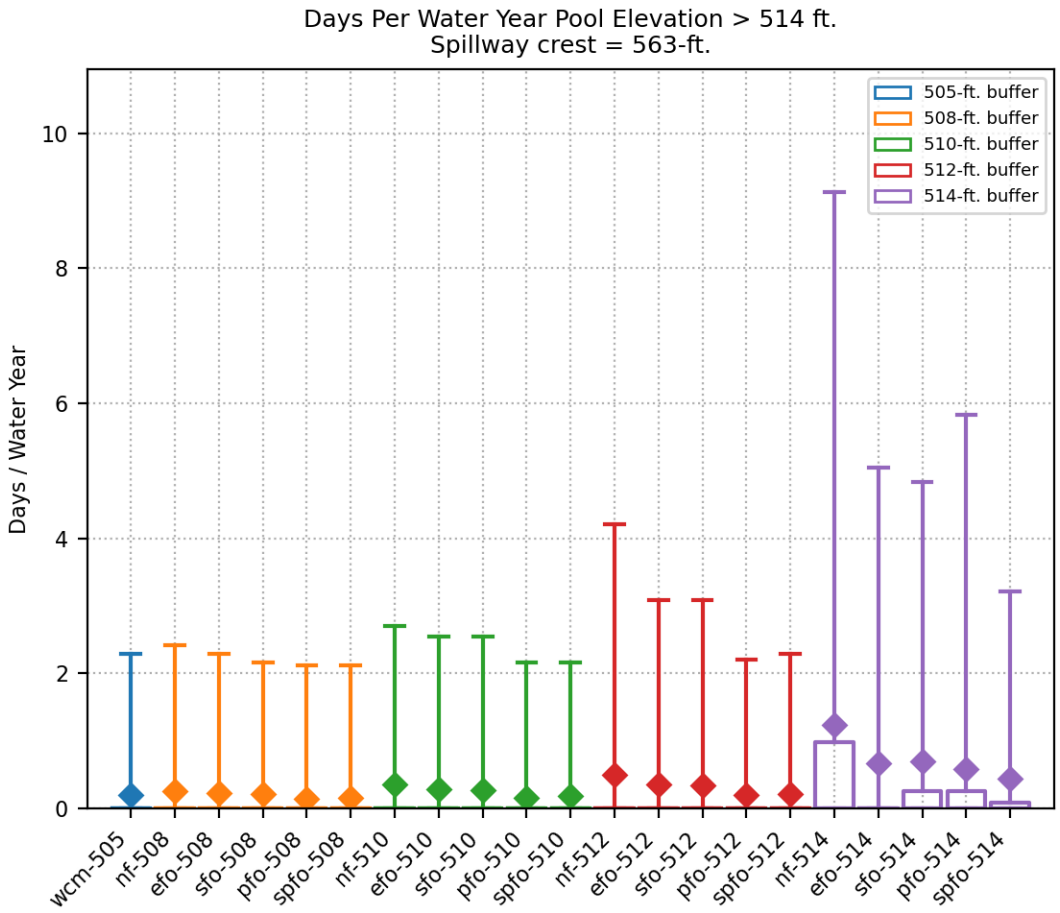

Days Per Water Year Pool Elevation > 510 ft.
Spillway crest = 543-ft.
Days / Water Year
0
20
40
60
80
100
120
140
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514


Days Per Water Year Pool Elevation > 510 ft.
Spillway crest = 563-ft.
Days / Water Year
0
20
40
60
80
100
120
140
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514


Days Per Water Year Pool Elevation > 512 ft.
Spillway crest = 543-ft.
Days / Water Year
0
20
40
60
80
100
120
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514


Days Per Water Year Pool Elevation > 512 ft.
Spillway crest = 563-ft.
Days / Water Year
0
20
40
60
80
100
120
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514


Days Per Water Year Pool Elevation > 514 ft.
Spillway crest = 543-ft.
Days / Water Year
0
2
4
6
8
10
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514


Days Per Water Year Pool Elevation > 514 ft.
Spillway crest = 563-ft.
Days / Water Year
0
2
4
6
8
10
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
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sfo-512
pfo-512
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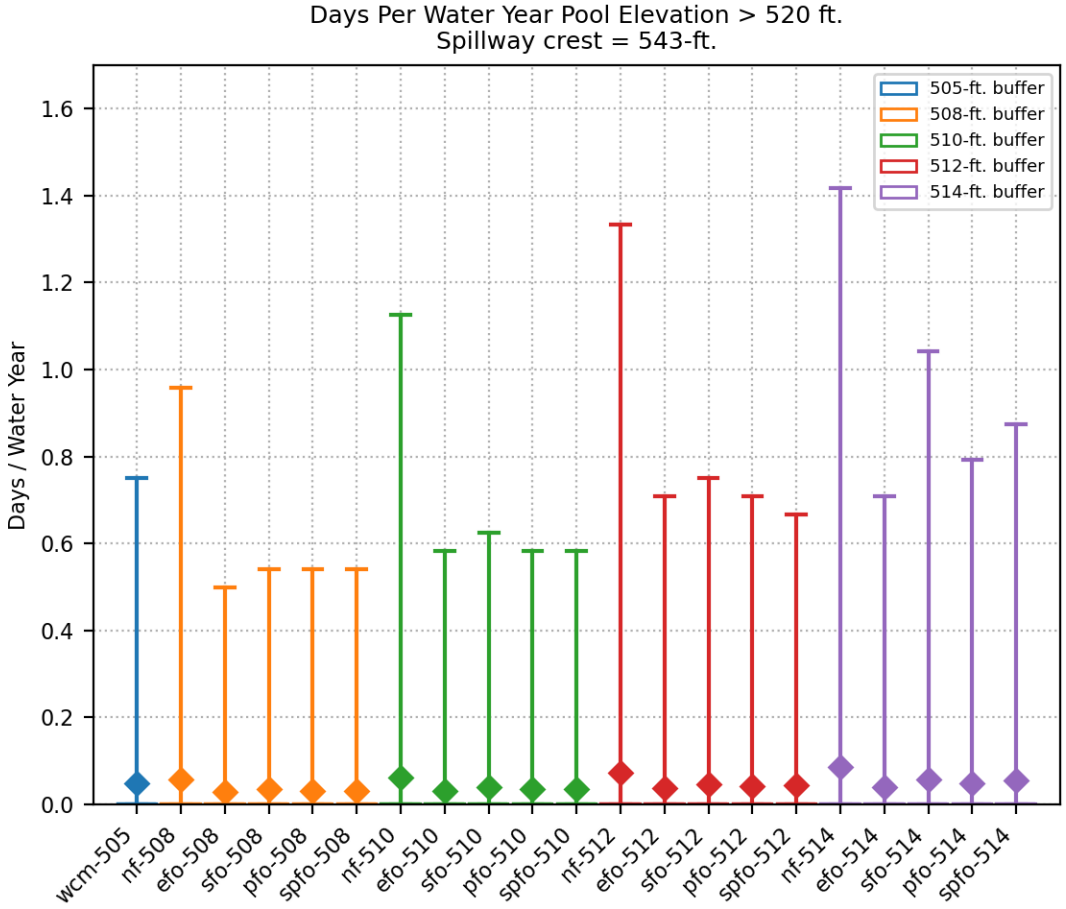
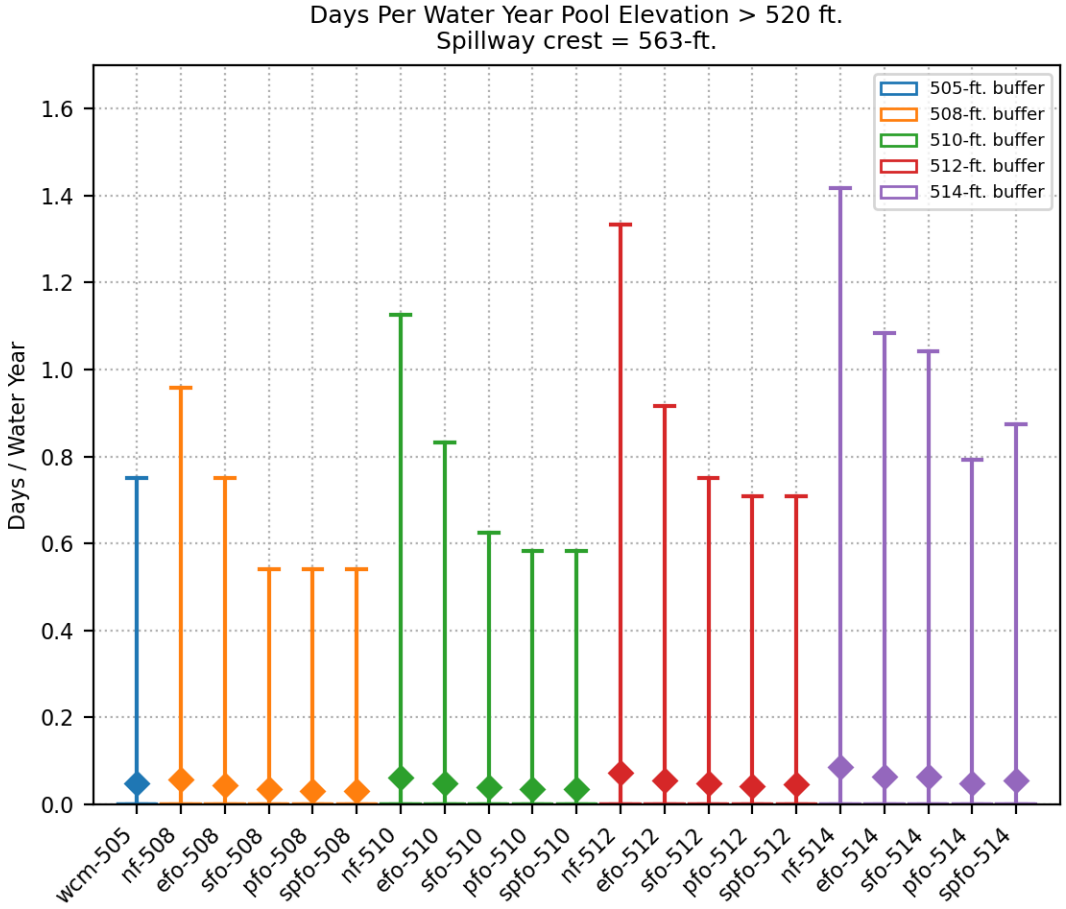
nf-514
efo-514
sfo-514
pfo-514
spfo-514


Days Per Water Year Pool Elevation > 520 ft.
Spillway crest = 543-ft.
Days / Water Year
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514


Days Per Water Year Pool Elevation > 520 ft.
Spillway crest = 563-ft.
Days / Water Year
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
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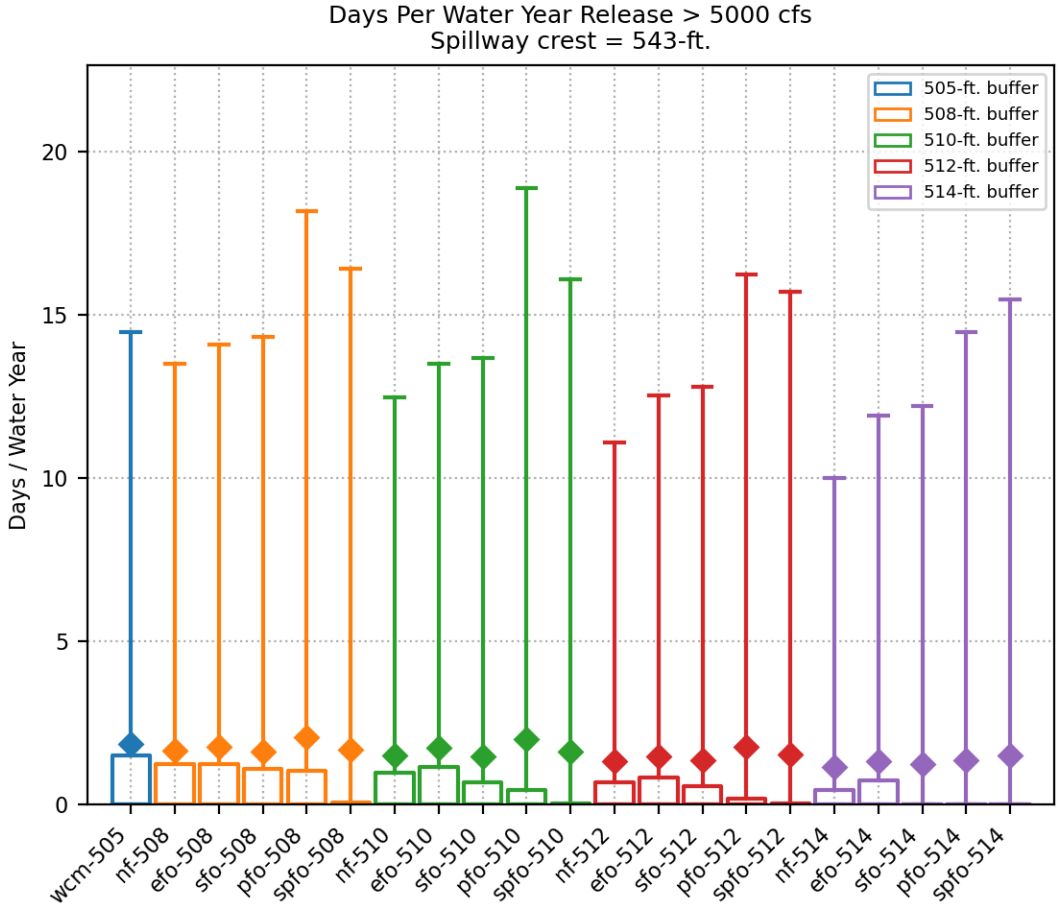
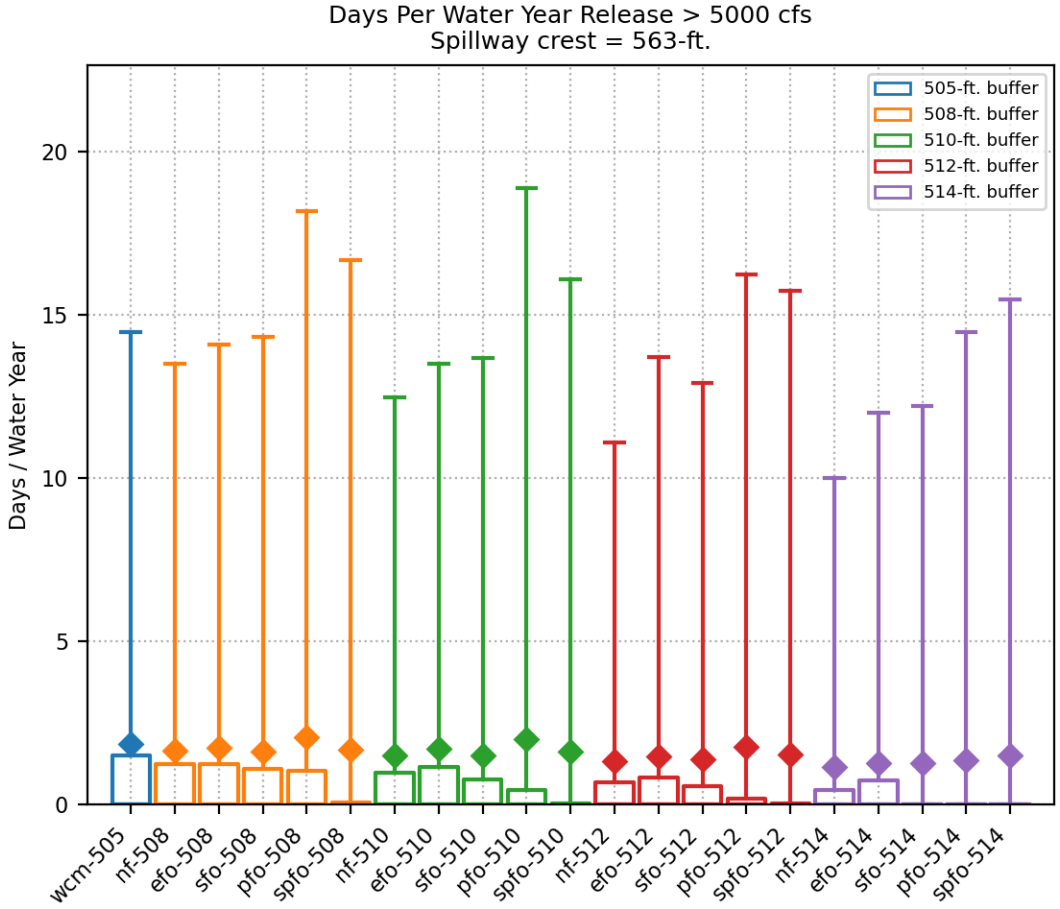
nf-514
efo-514
sfo-514
pfo-514
spfo-514


Days Per Water Year Release > 5000 cfs
Spillway crest = 543-ft.
Days / Water Year
0
5
10
15
20
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514


Days Per Water Year Release > 5000 cfs
Spillway crest = 563-ft.
Days / Water Year
0
5
10
15
20
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
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sfo-512
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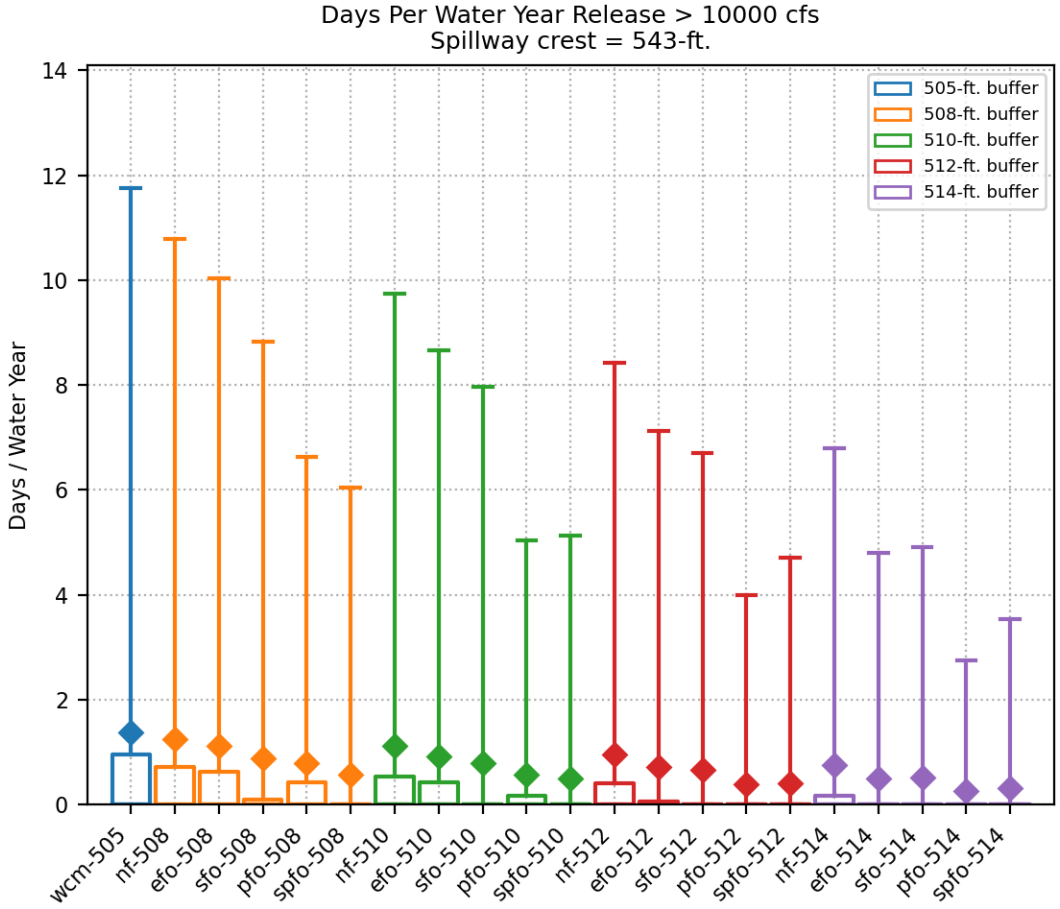
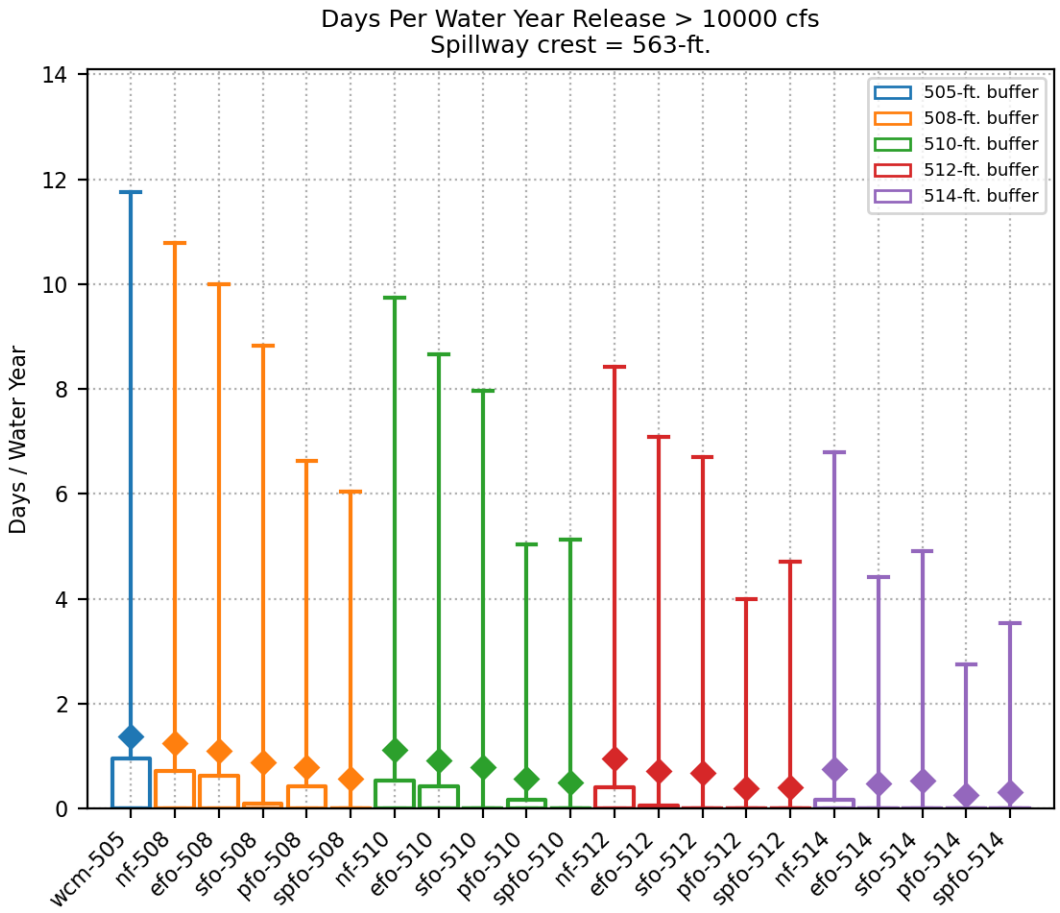
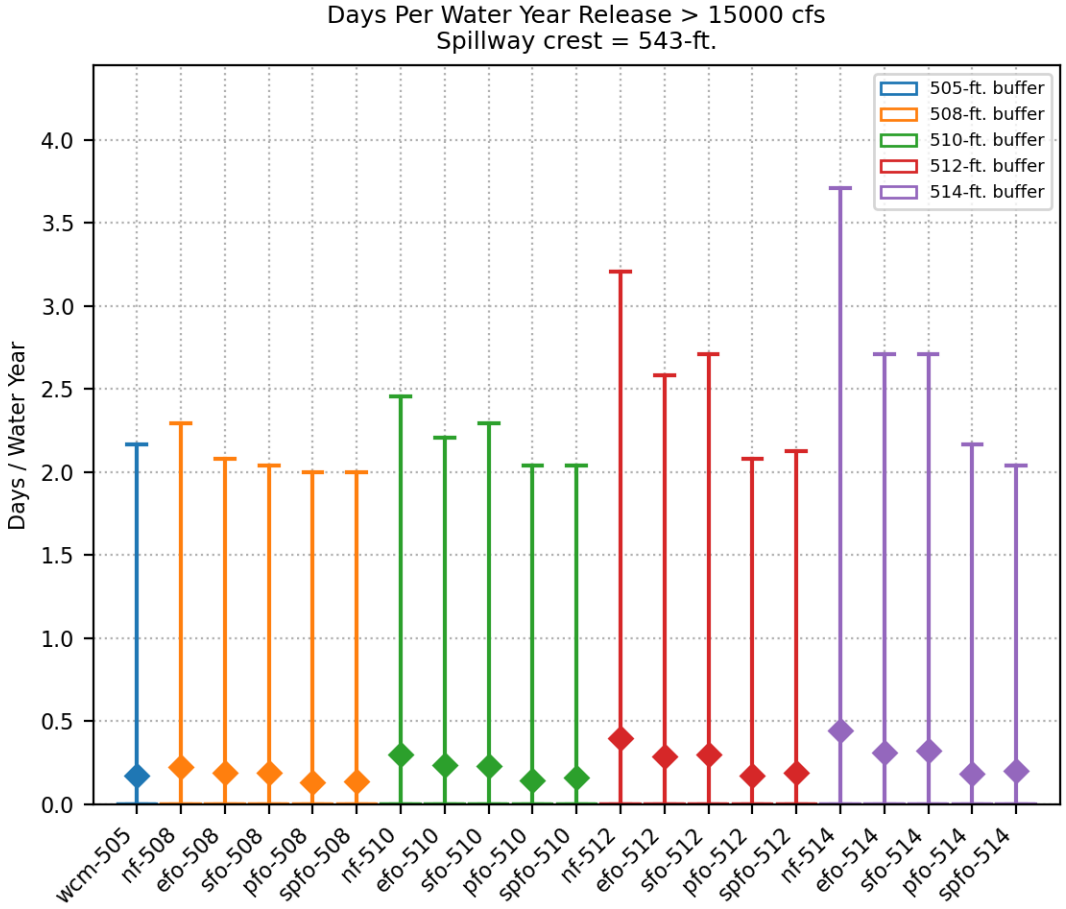
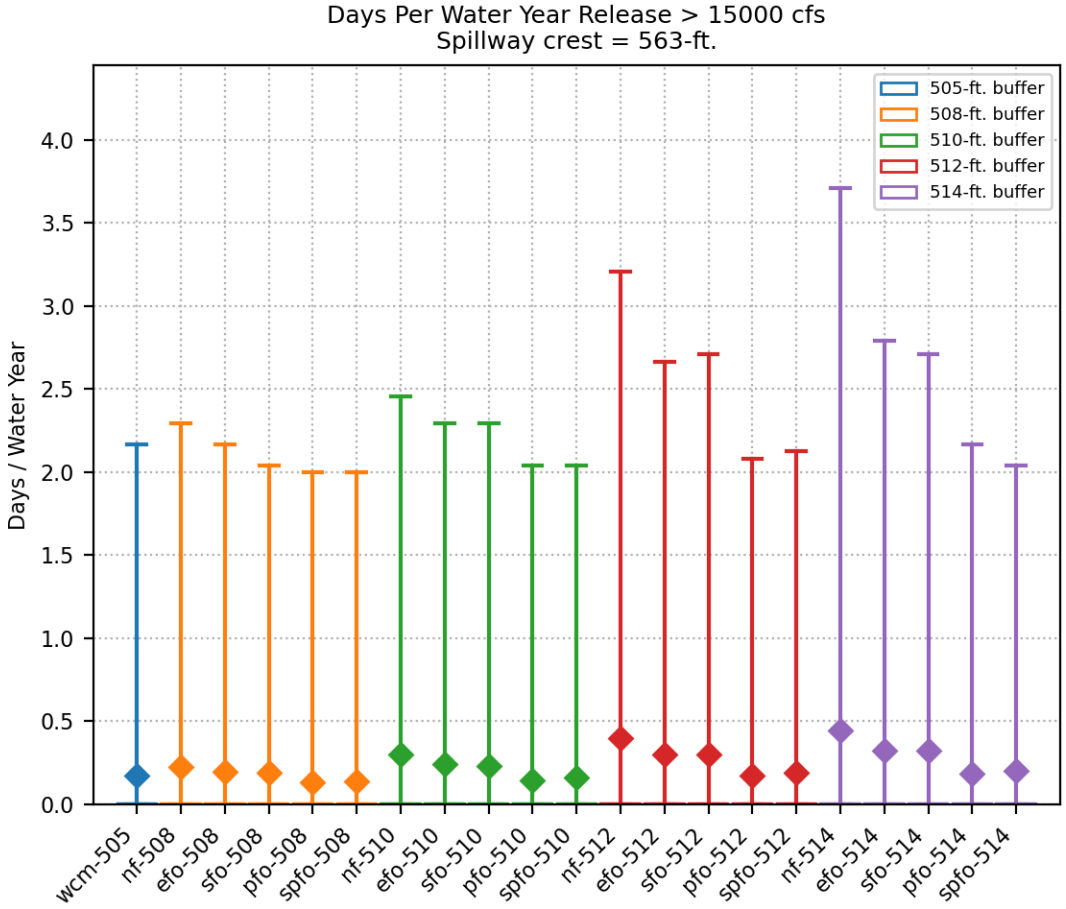
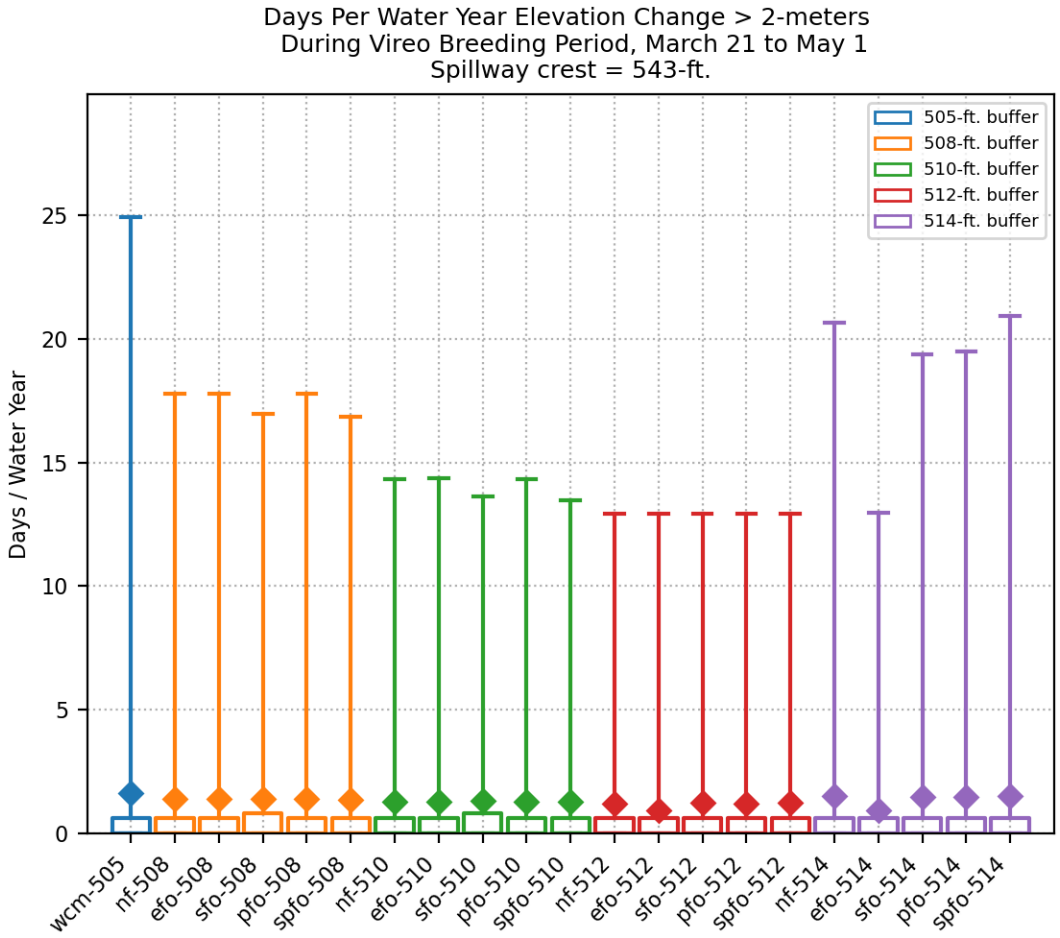
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514

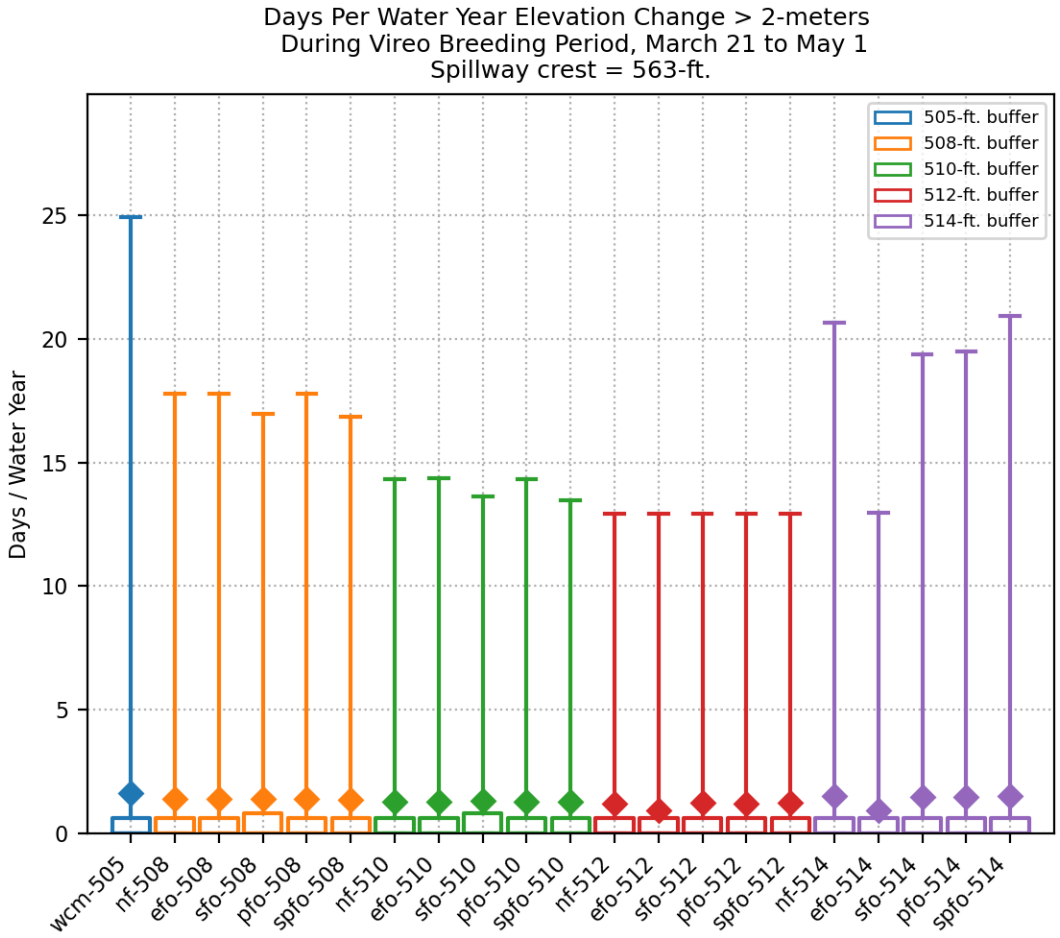

Days Per Water Year Release > 10000 cfs
Spillway crest = 543-ft.
Days / Water Year
0
2
4
6
8
10
12
14
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514


Days Per Water Year Release > 10000 cfs
Spillway crest = 563-ft.
Days / Water Year
0
2
4
6
8
10
12
14
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514


Days Per Water Year Release > 15000 cfs
Spillway crest = 543-ft.
Days / Water Year
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514


Days Per Water Year Release > 15000 cfs
Spillway crest = 563-ft.
Days / Water Year
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514


Days Per Water Year Elevation Change > 2-meters
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 543-ft.
Days / Water Year
0
5
10
15
20
25
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514


Days Per Water Year Elevation Change > 2-meters
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 563-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
Days / Water Year
0
5
10
15
20
25
wcm-505
nf-508
efo-508
sfo-508
pfo-508
spfo-508
nf-510
efo-510
sfo-510
pfo-510
spfo-510
nf-512
efo-512
sfo-512
pfo-512
spfo-512
nf-514
efo-514
sfo-514
pfo-514
spfo-514

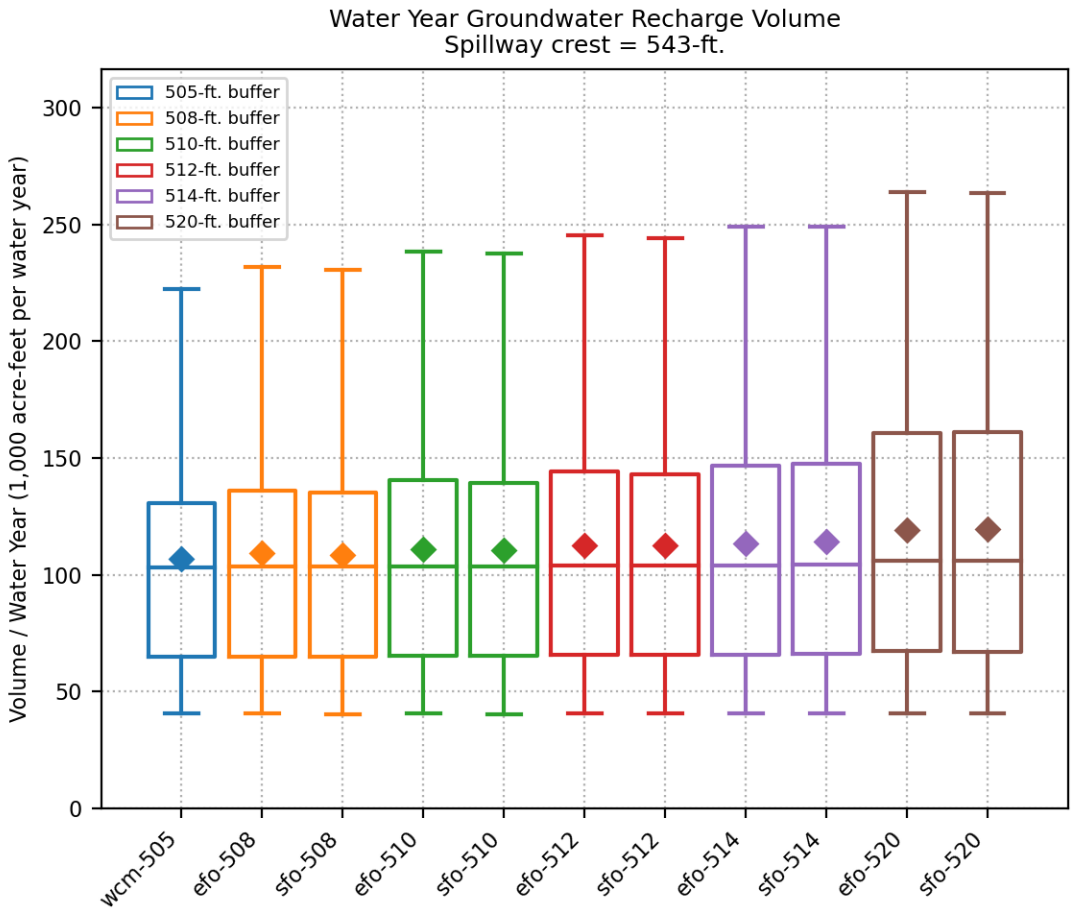
HEMP Metrics – Box/Whisker Plots (No PF No NF)

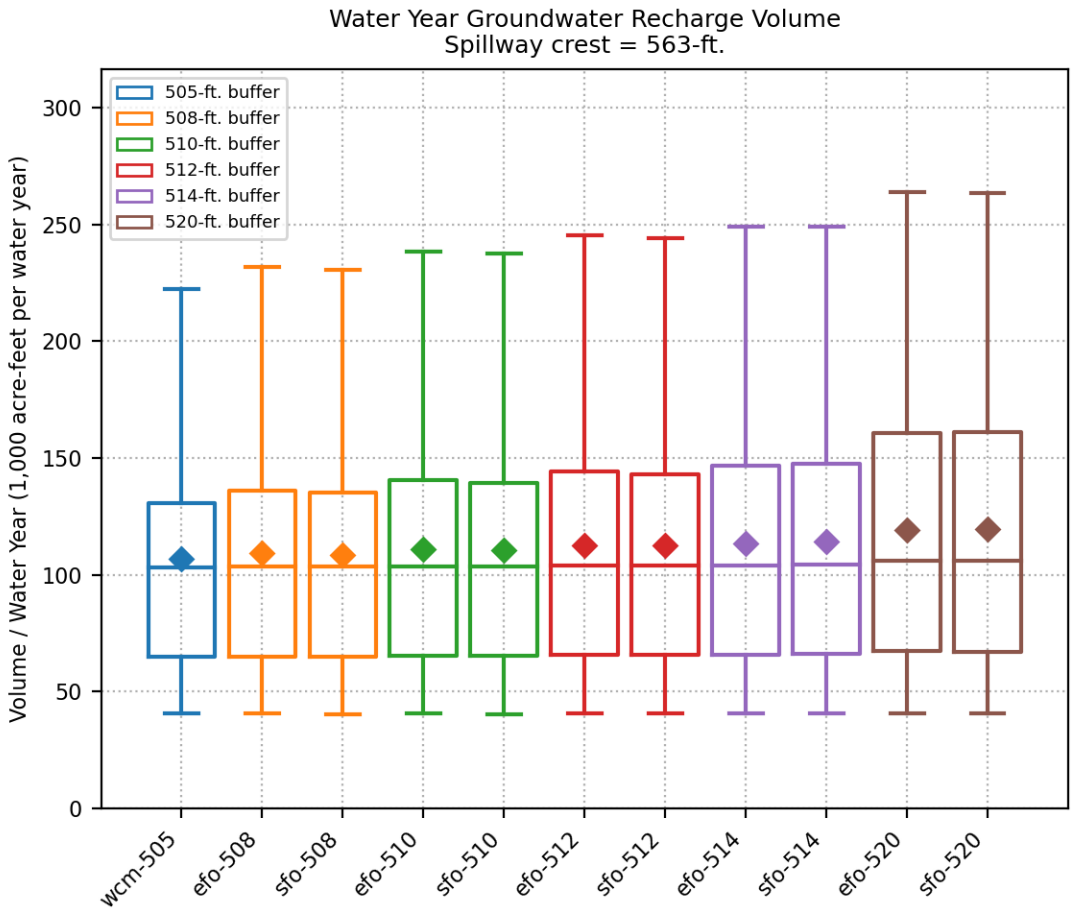
- Groundwater Recharge
- Santa Anna River discharge to Pacific Ocean
- Peak Reservoir Release
- Peak Reservoir Elevation
- Pool elevation > 505’, 508’, 510’, 512’, 514’, 520’
- Reservoir release > 5,000, 10,000, 15,000 cfs
- >1 meter rise between 3/21 and 5/1

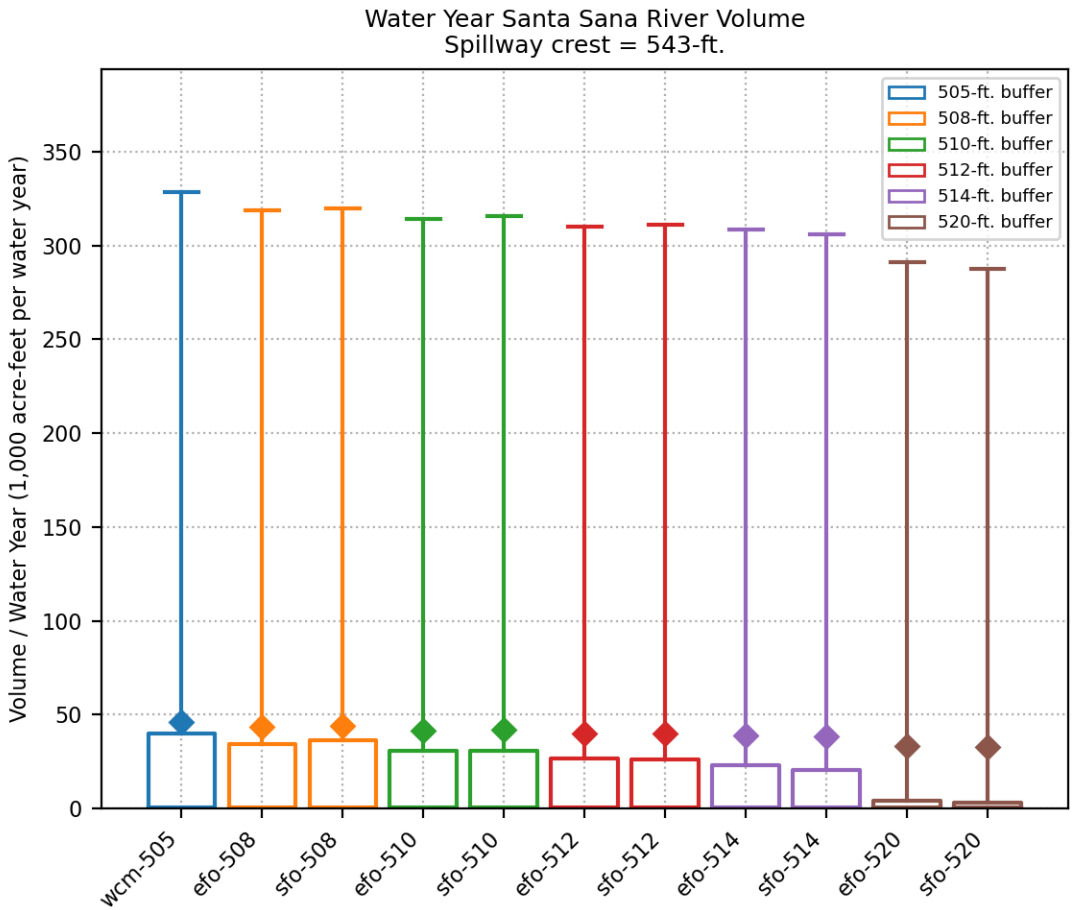
HEMP Metrics – Box/Whisker Plots (No PF No NF)

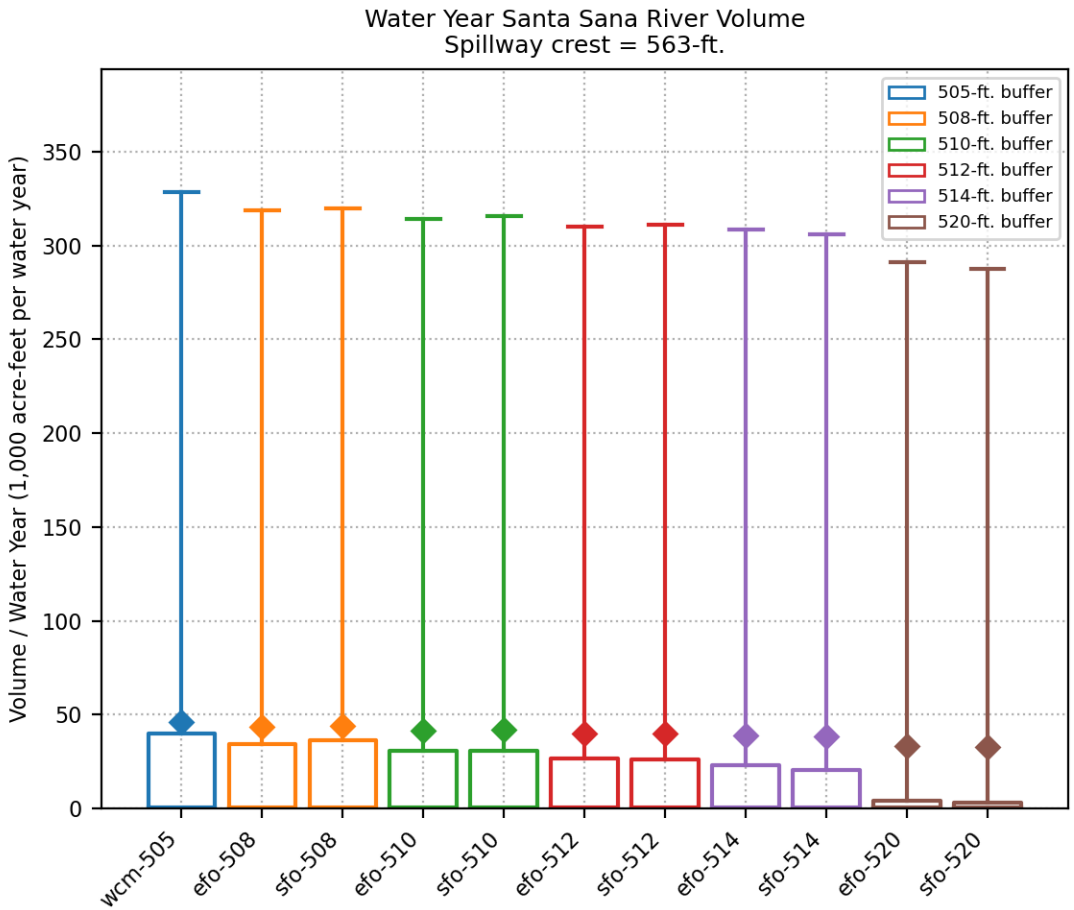
- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’, 510’, 512’, 514’, 520’
- WCP alternatives across X Axis
  - No Perfect Forecast or No Forecast Alternatives

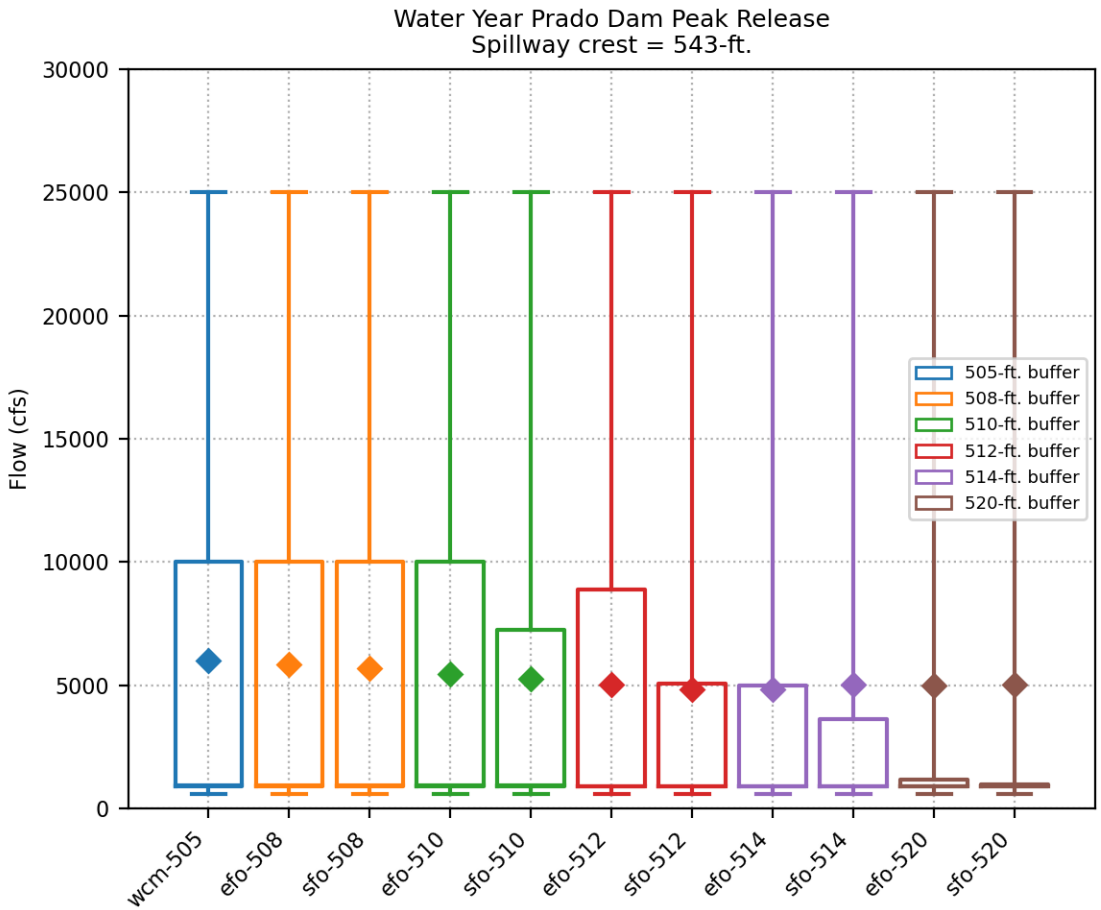
- Whiskers 5% - 95%
- Boxes 25% - 75%
- Diamonds @ median

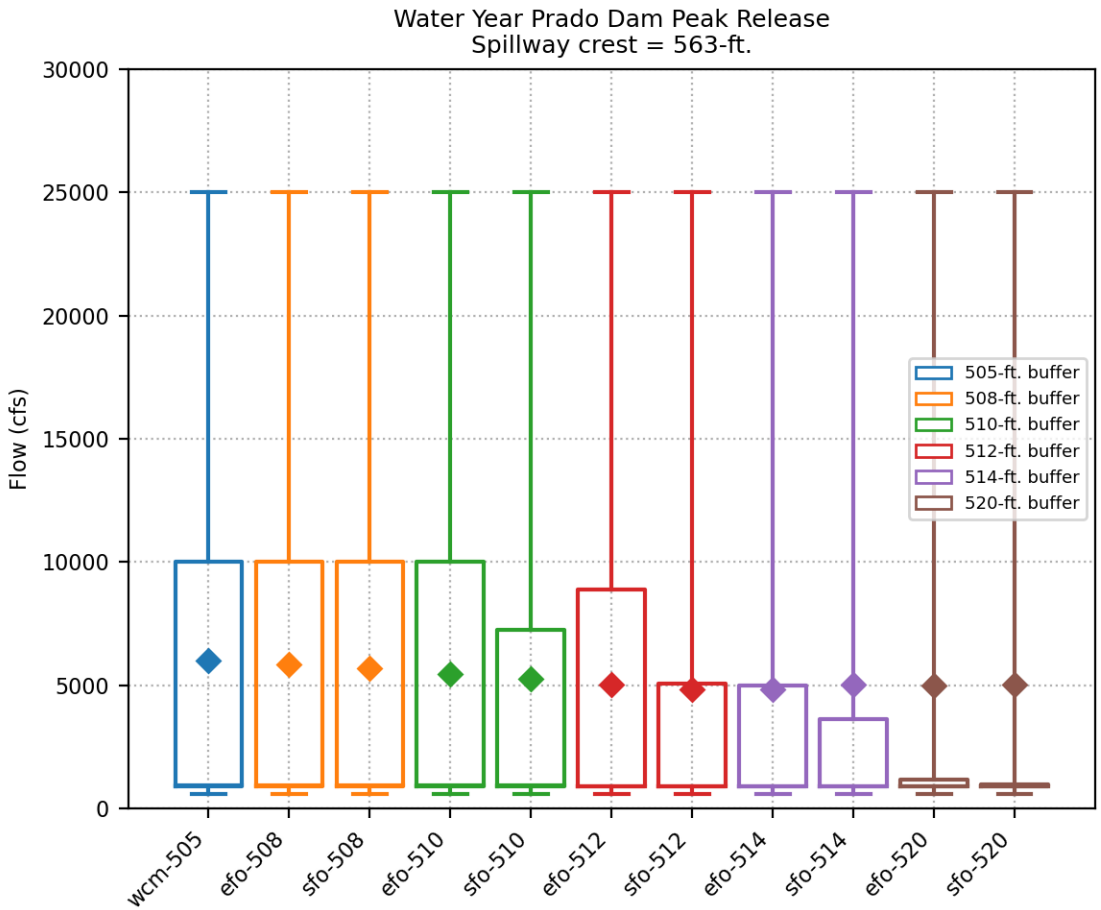

Water Year Groundwater Recharge Volume
Spillway crest = 543-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Volume / Water Year (1,000 acre-feet per water year)
0
50
100
150
200
250
300
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520

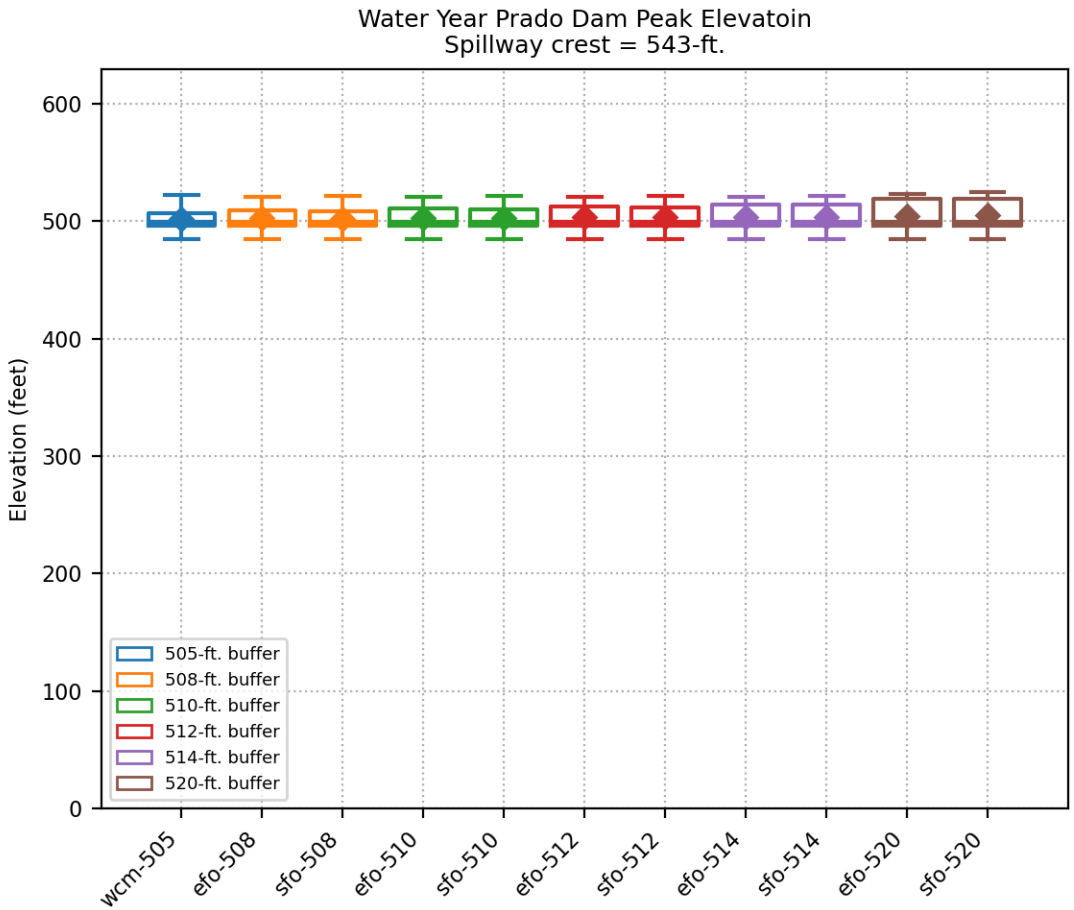

Water Year Groundwater Recharge Volume
Spillway crest = 563-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Volume / Water Year (1,000 acre-feet per water year)
0
50
100
150
200
250
300
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520

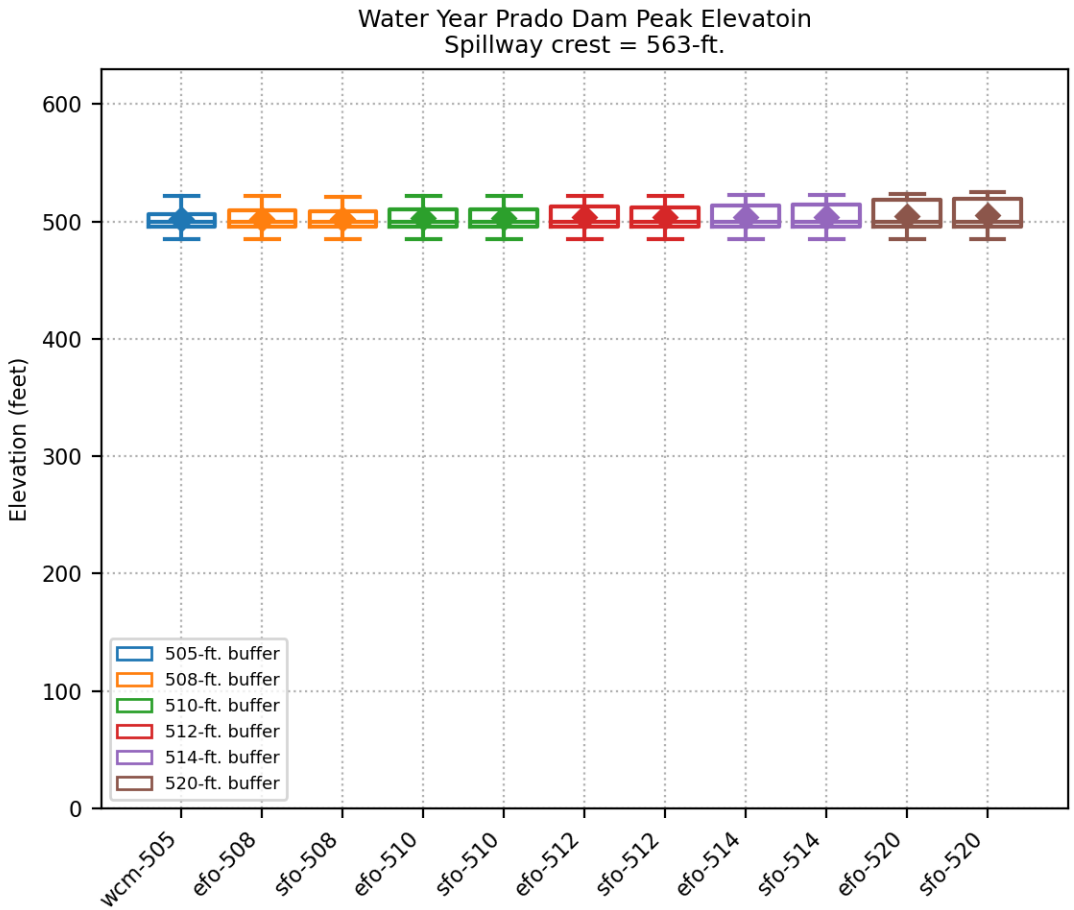

Water Year Santa Sana River Volume
Spillway crest = 543-ft.
Volume / Water Year (1,000 acre-feet per water year)
0
50
100
150
200
250
300
350
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520

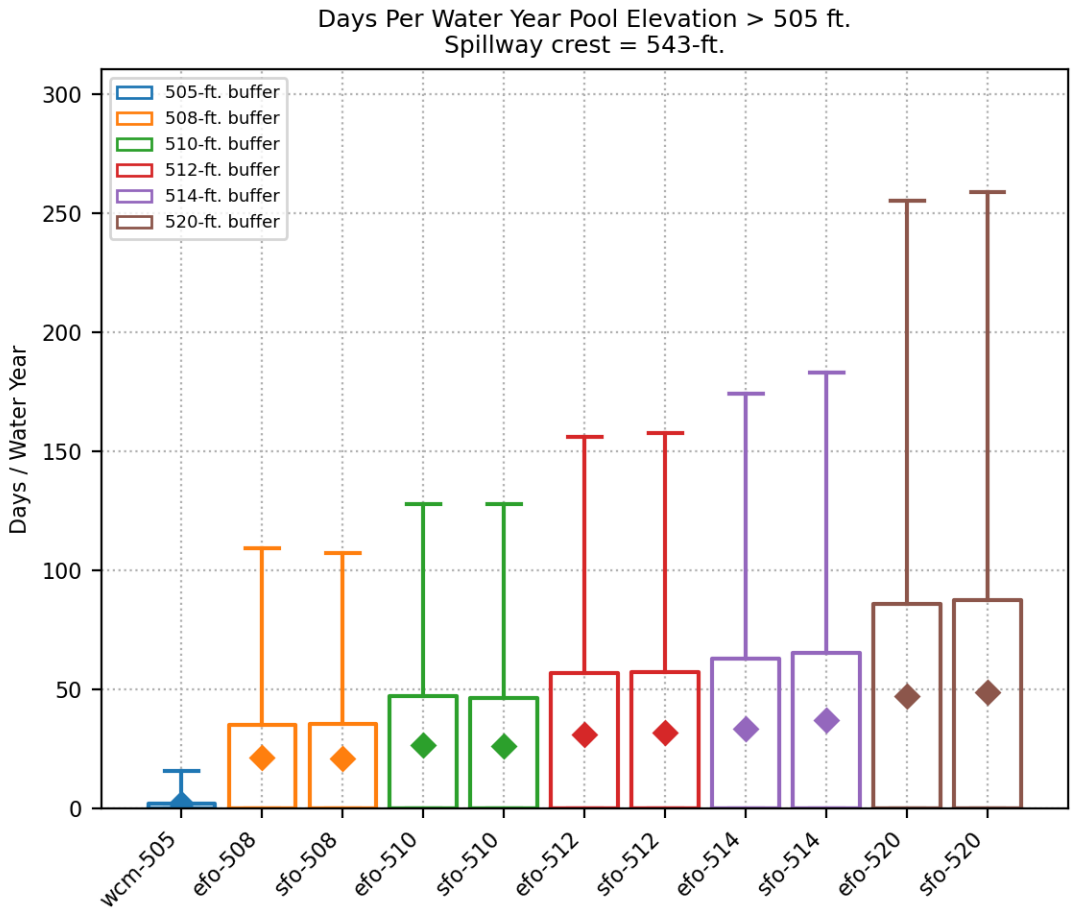

Water Year Santa Sana River Volume
Spillway crest = 563-ft.
Volume / Water Year (1,000 acre-feet per water year)
0
50
100
150
200
250
300
350
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520

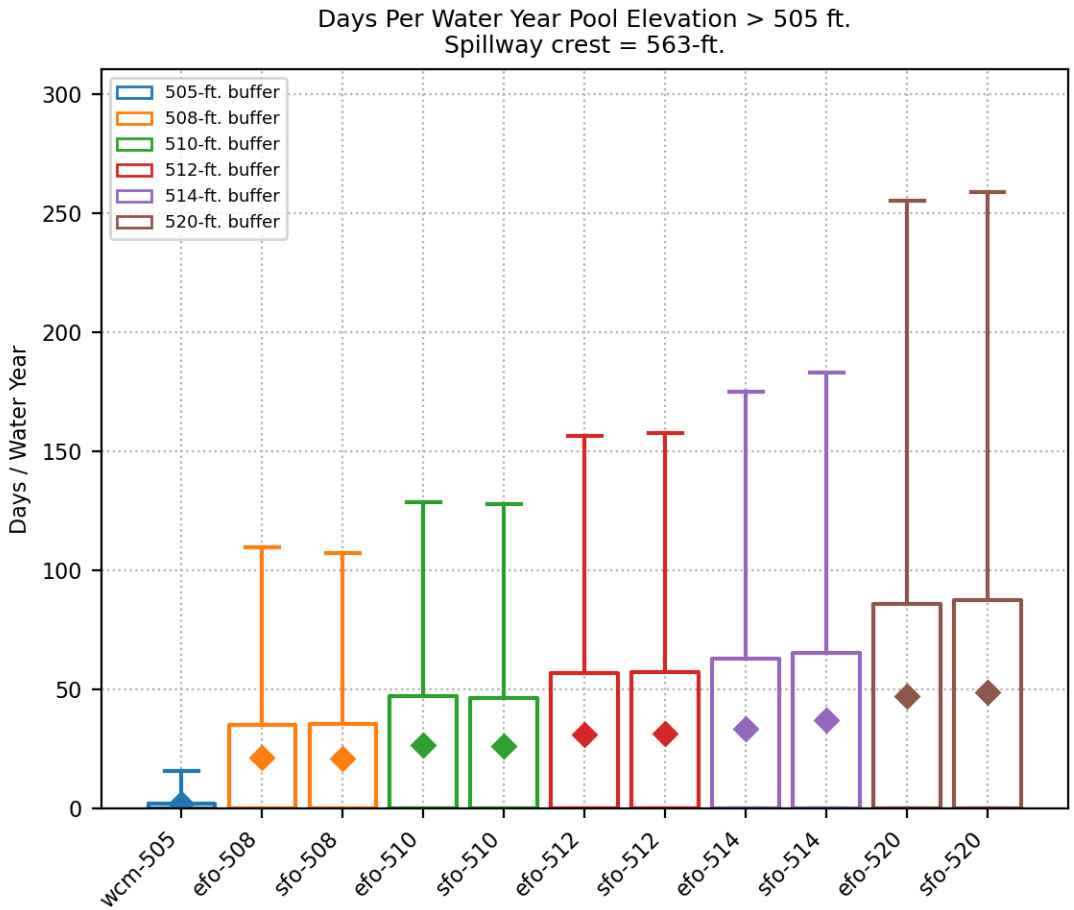

Water Year Prado Dam Peak Release
Spillway crest = 543-ft.
Flow (cfs)
30000
25000
20000
15000
10000
5000
0
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer

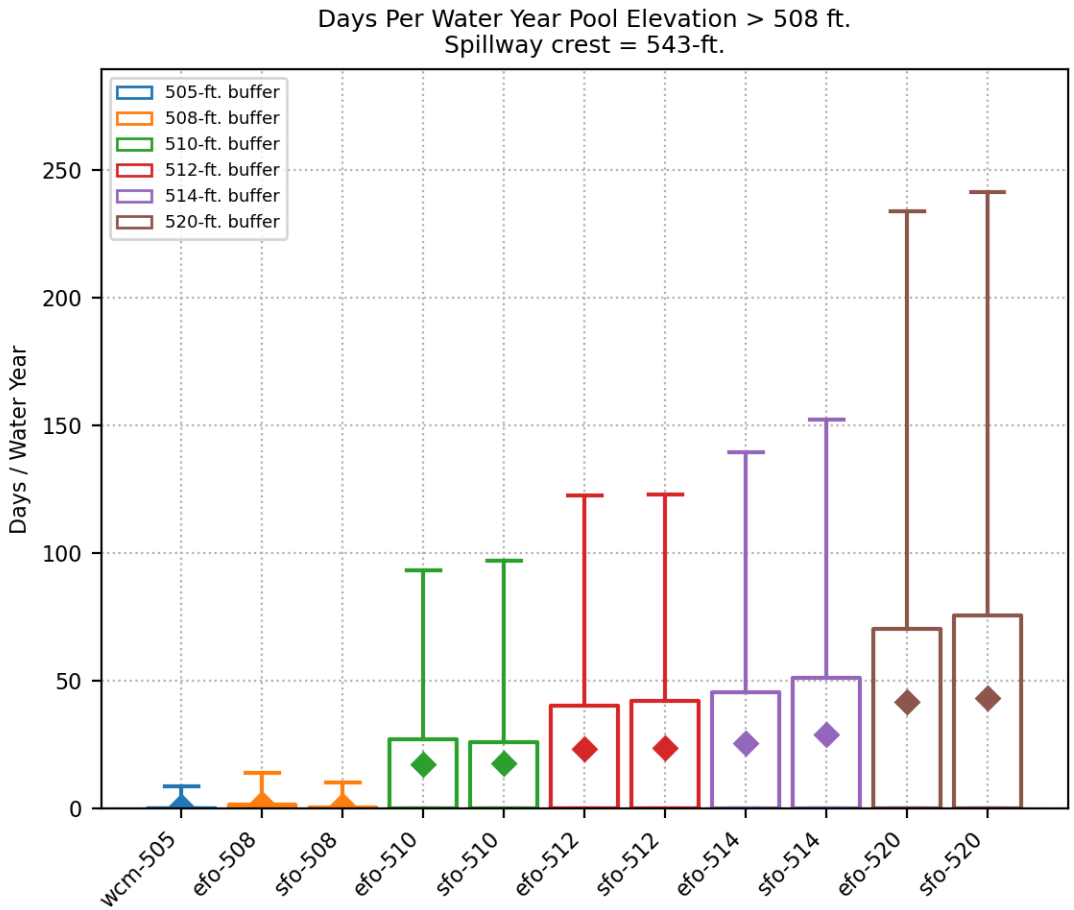

Water Year Prado Dam Peak Release
Spillway crest = 563-ft.
Flow (cfs)
30000
25000
20000
15000
10000
5000
0
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer

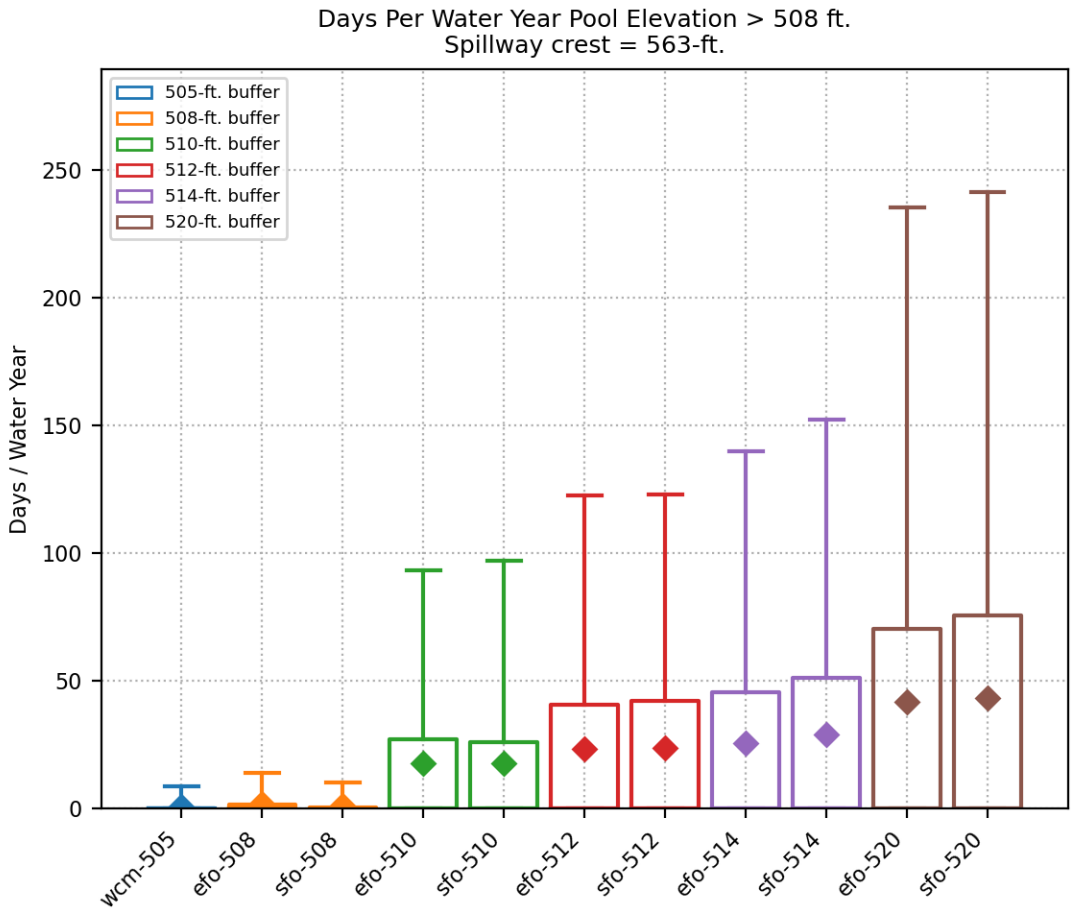

Water Year Prado Dam Peak Elevatoin
Spillway crest = 543-ft.
Elevation (feet)
0
100
200
300
400
500
600
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520

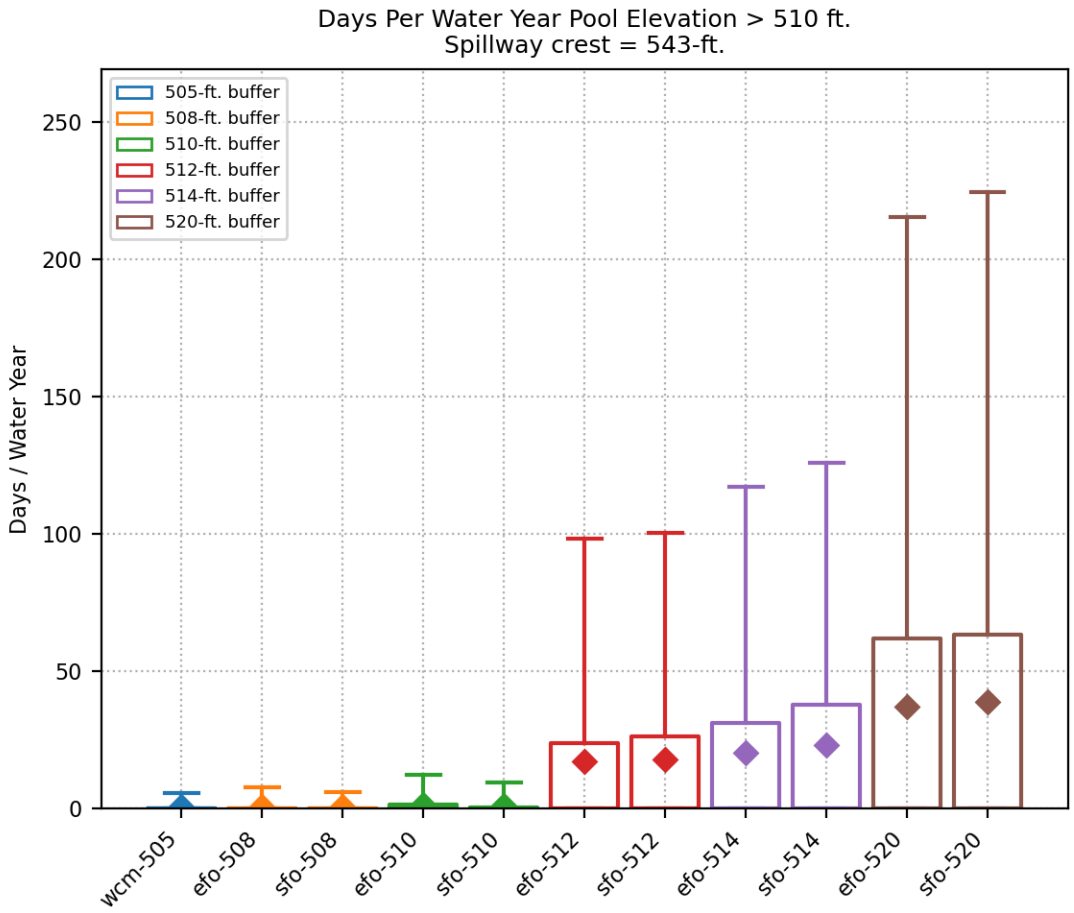

Water Year Prado Dam Peak Elevatoin
Spillway crest = 563-ft.
Elevation (feet)
600
500
400
300
200
100
0
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520

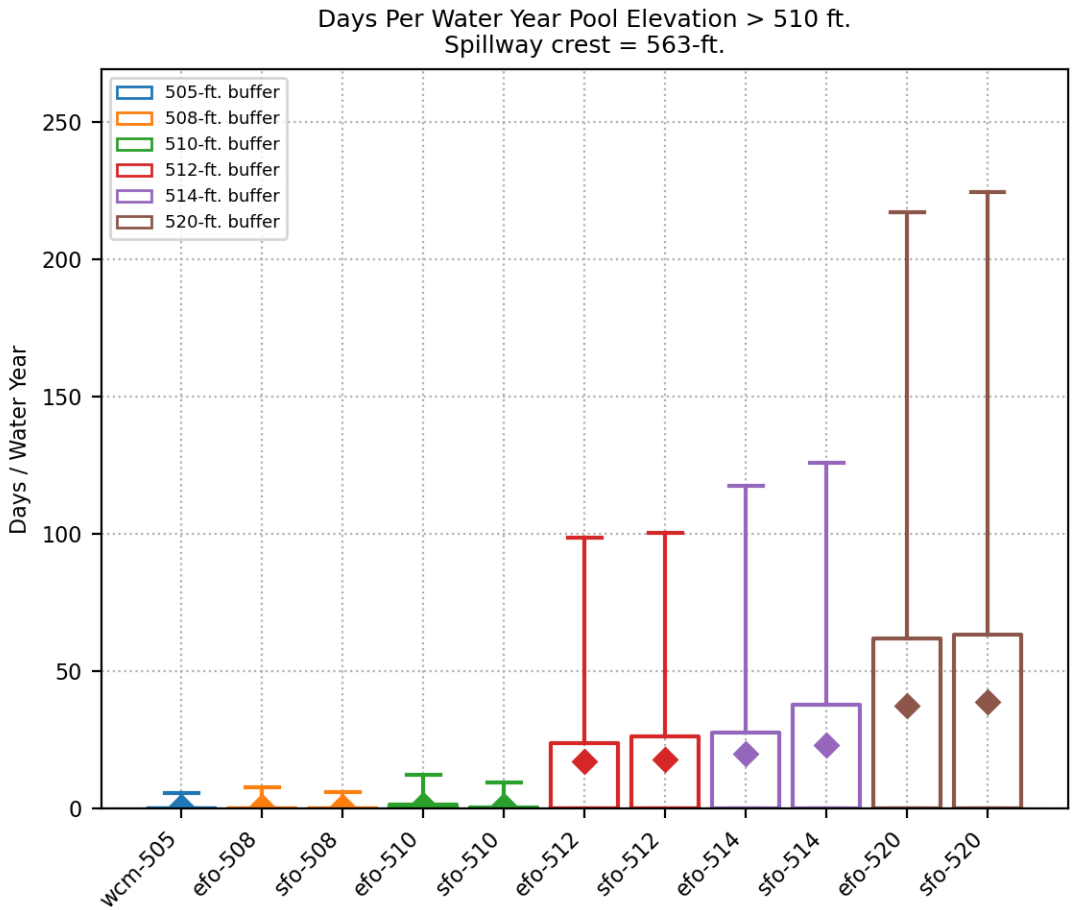

Days Per Water Year Pool Elevation > 505 ft.
Spillway crest = 543-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Days / Water Year
0
50
100
150
200
250
300
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520

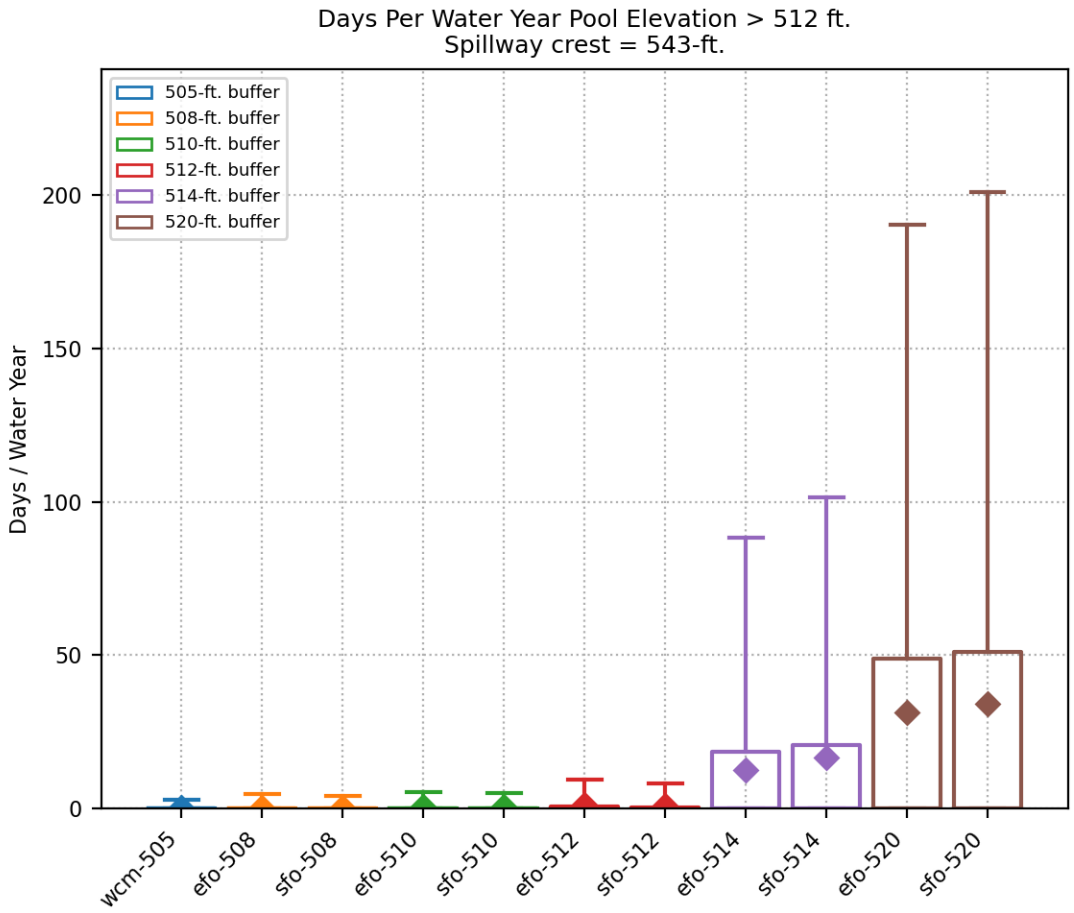

Days Per Water Year Pool Elevation > 505 ft.
Spillway crest = 563-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Days / Water Year
0
50
100
150
200
250
300
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520

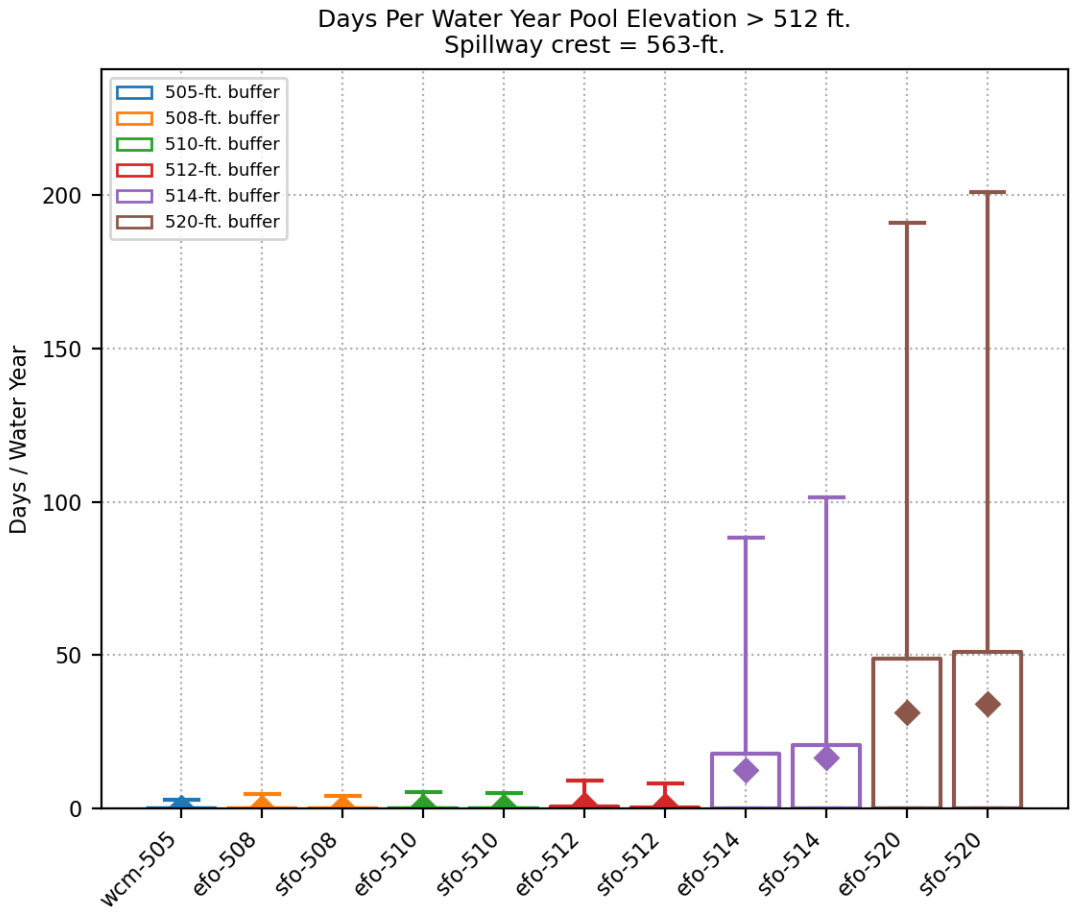

Days Per Water Year Pool Elevation > 508 ft.
Spillway crest = 543-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Days / Water Year
0
50
100
150
200
250
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520

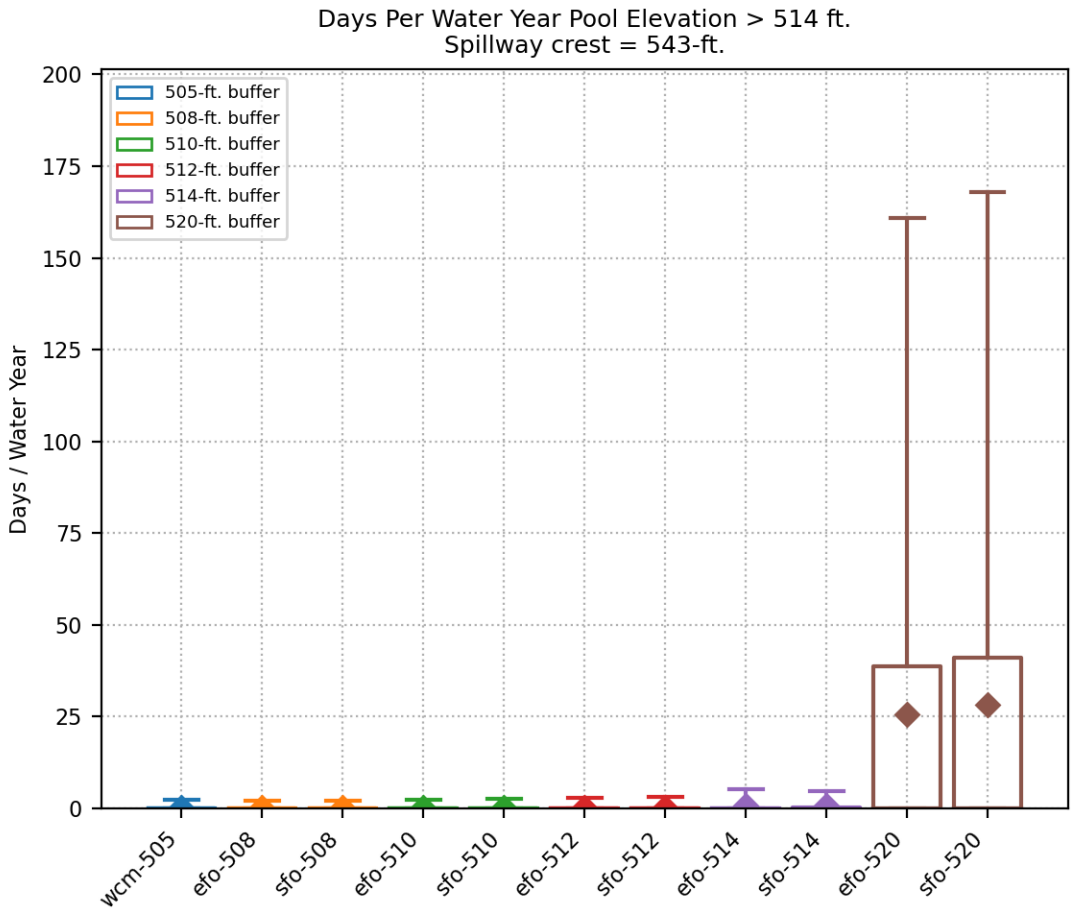

Days Per Water Year Pool Elevation > 508 ft.
Spillway crest = 563-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Days / Water Year
0
50
100
150
200
250
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520

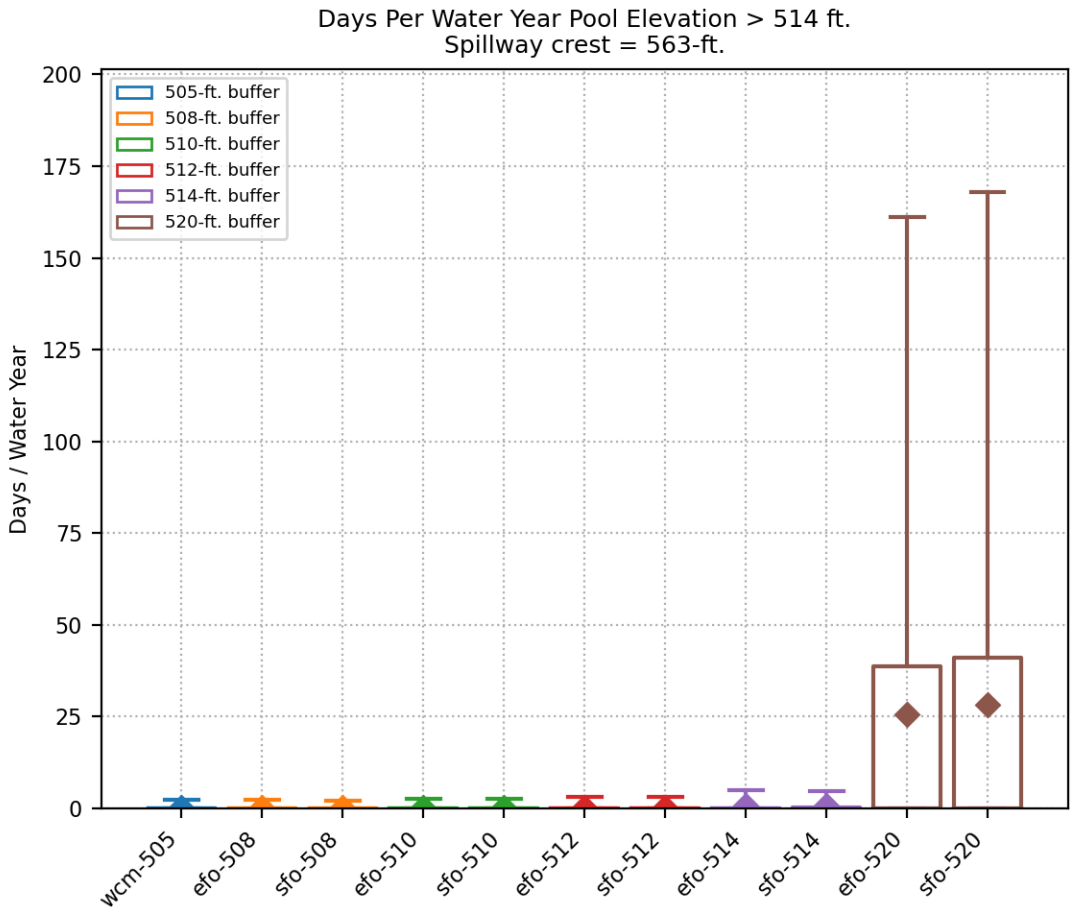

Days Per Water Year Pool Elevation > 510 ft.
Spillway crest = 543-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Days / Water Year
0
50
100
150
200
250
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520

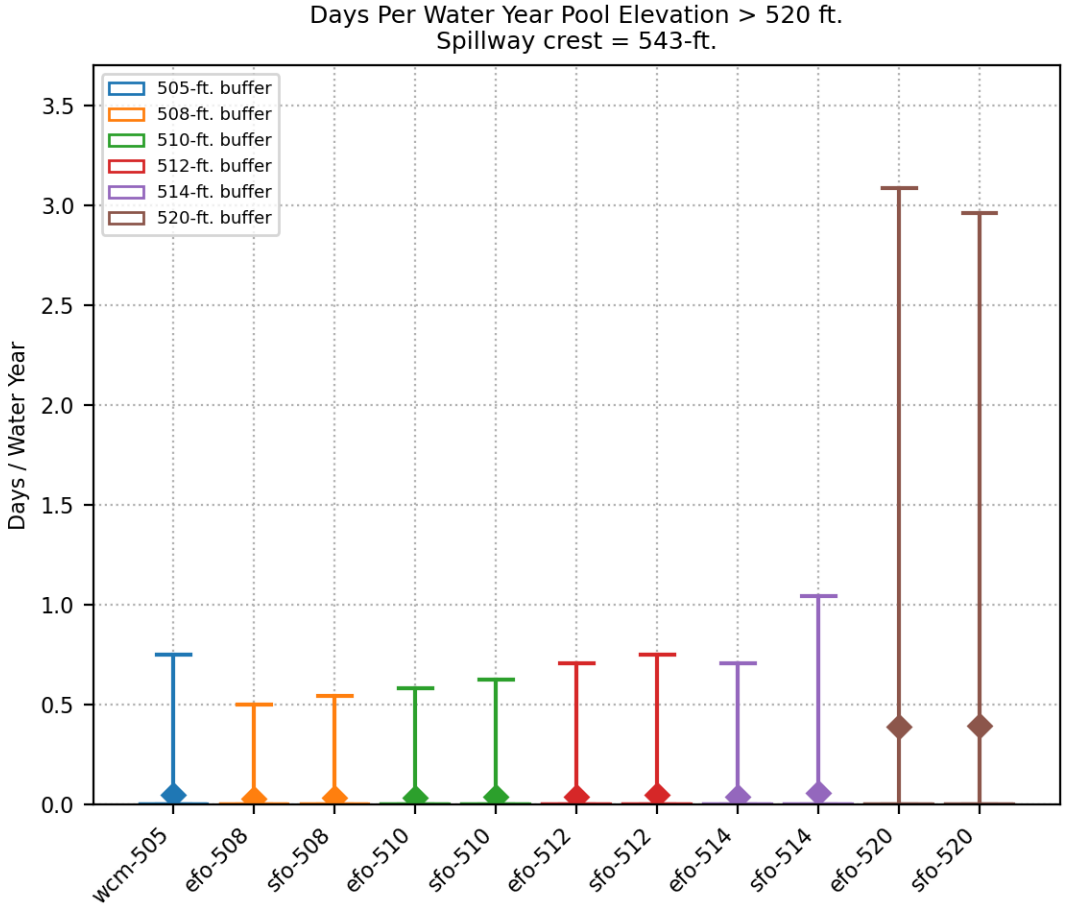

Days Per Water Year Pool Elevation > 510 ft.
Spillway crest = 563-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Days / Water Year
0
50
100
150
200
250
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520

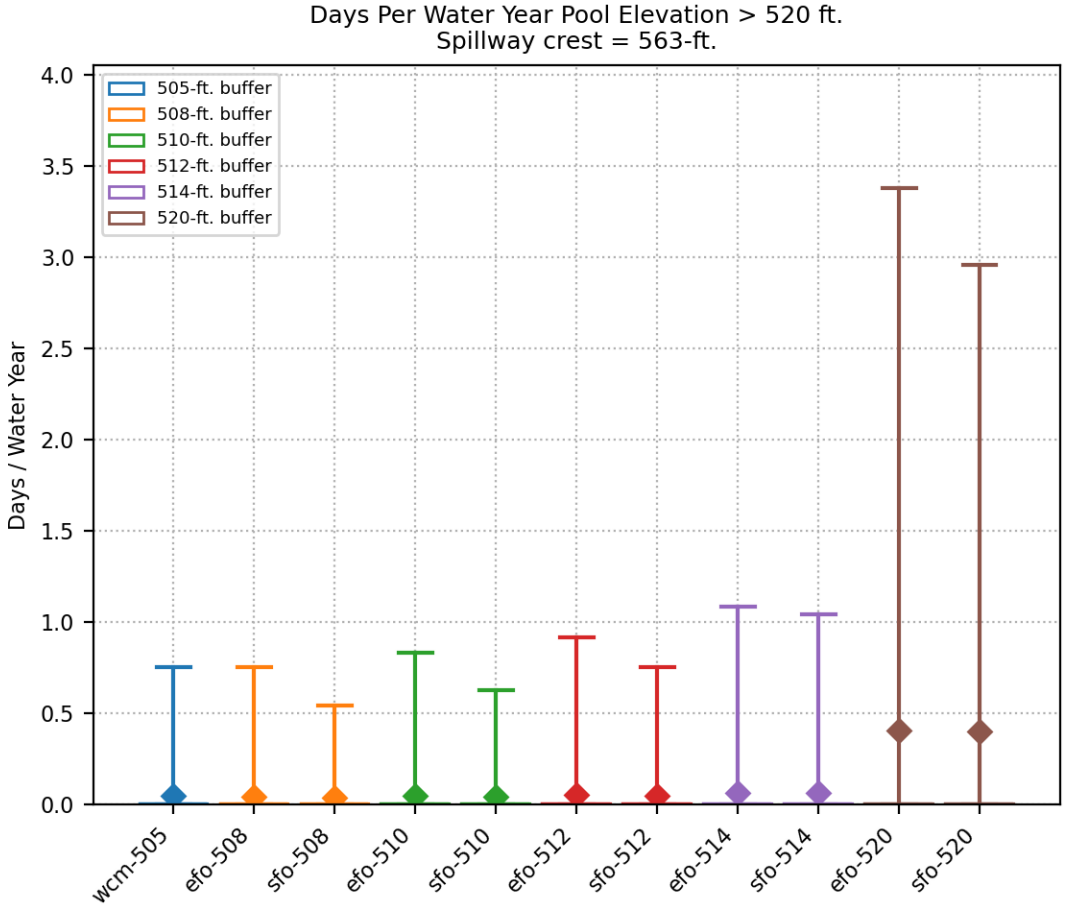

Days Per Water Year Pool Elevation > 512 ft.
Spillway crest = 543-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Days / Water Year
0
50
100
150
200
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520

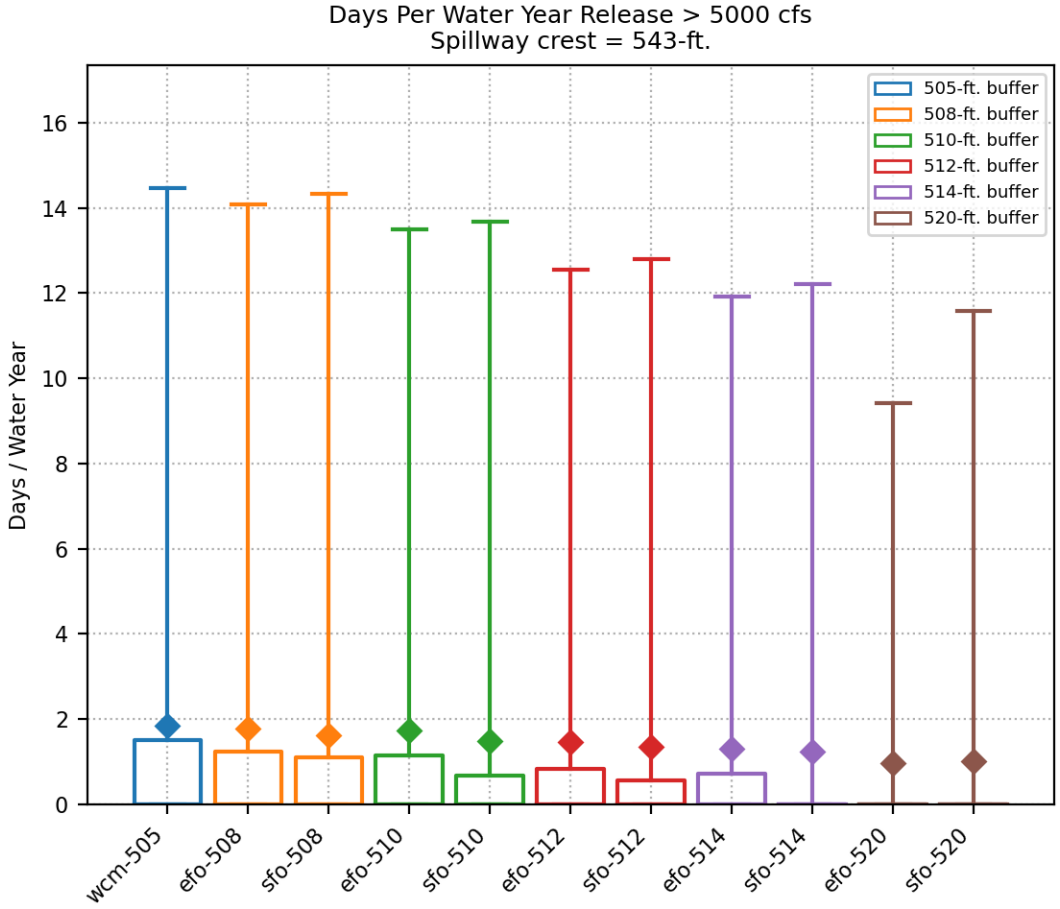

Days Per Water Year Pool Elevation > 512 ft.
Spillway crest = 563-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Days / Water Year
0
50
100
150
200
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520

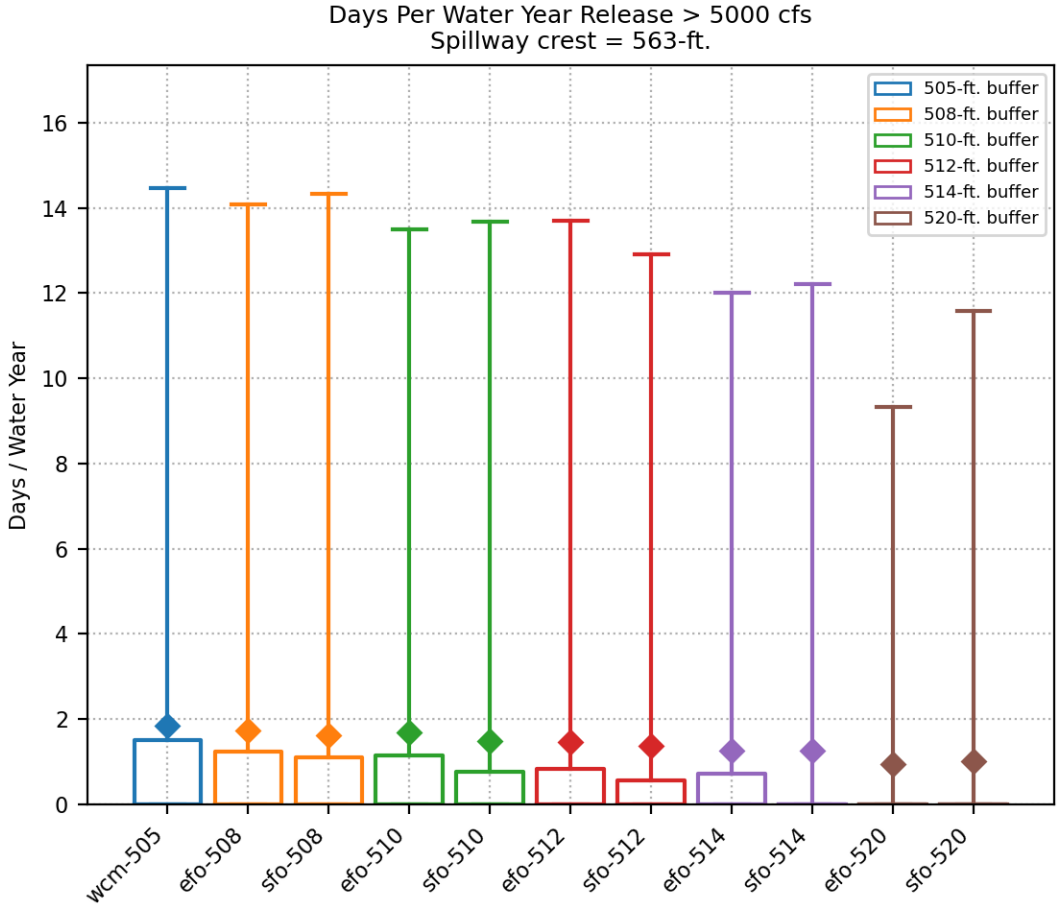

Days Per Water Year Pool Elevation > 514 ft.
Spillway crest = 543-ft.
Days / Water Year
0
25
50
75
100
125
150
175
200
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520

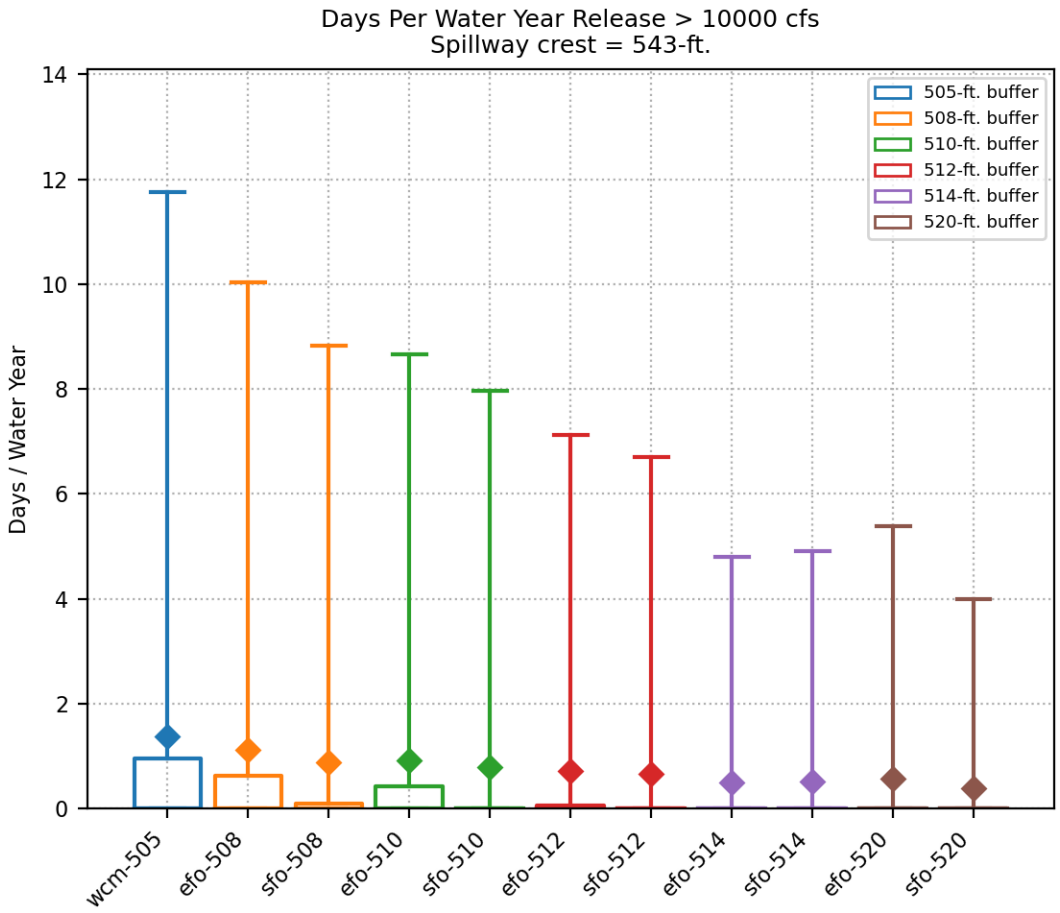

Days Per Water Year Pool Elevation > 514 ft.
Spillway crest = 563-ft.
Days / Water Year
0
25
50
75
100
125
150
175
200
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520

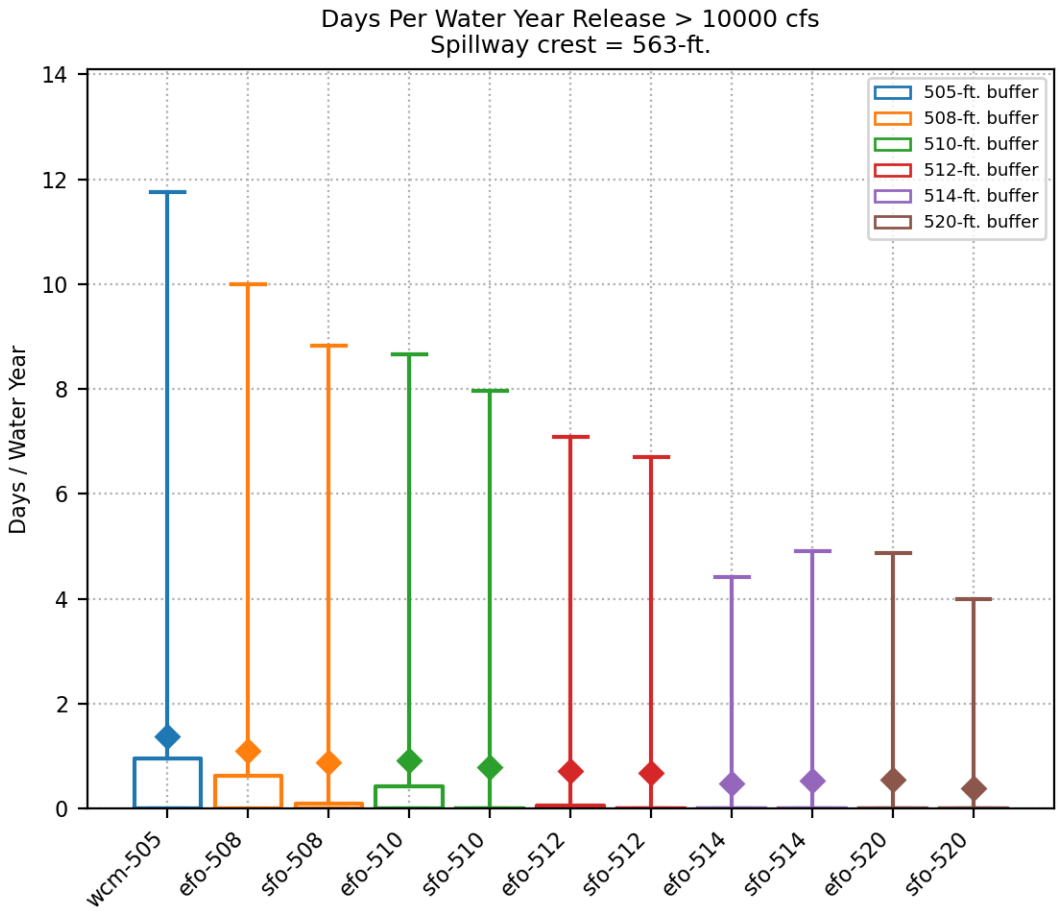

Days Per Water Year Pool Elevation > 520 ft.
Spillway crest = 543-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Days / Water Year
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520

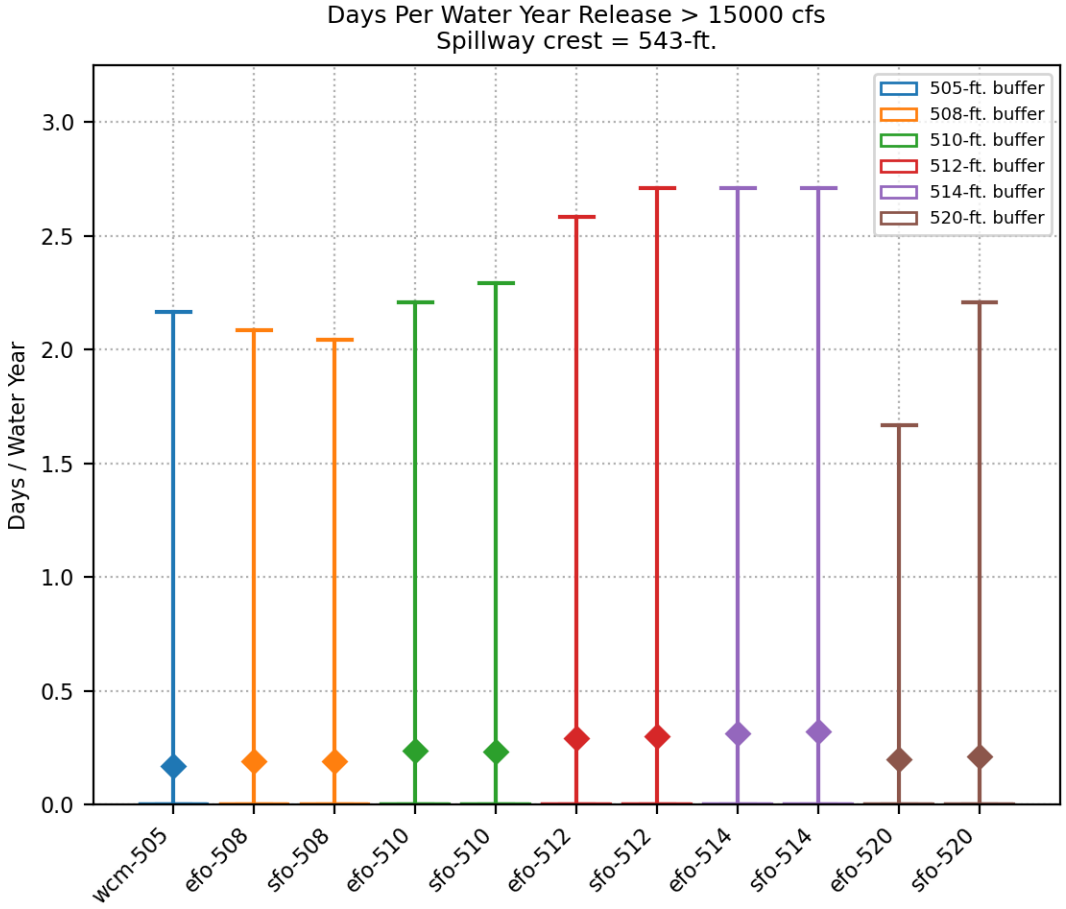

Days Per Water Year Pool Elevation > 520 ft.
Spillway crest = 563-ft.
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
Days / Water Year
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520

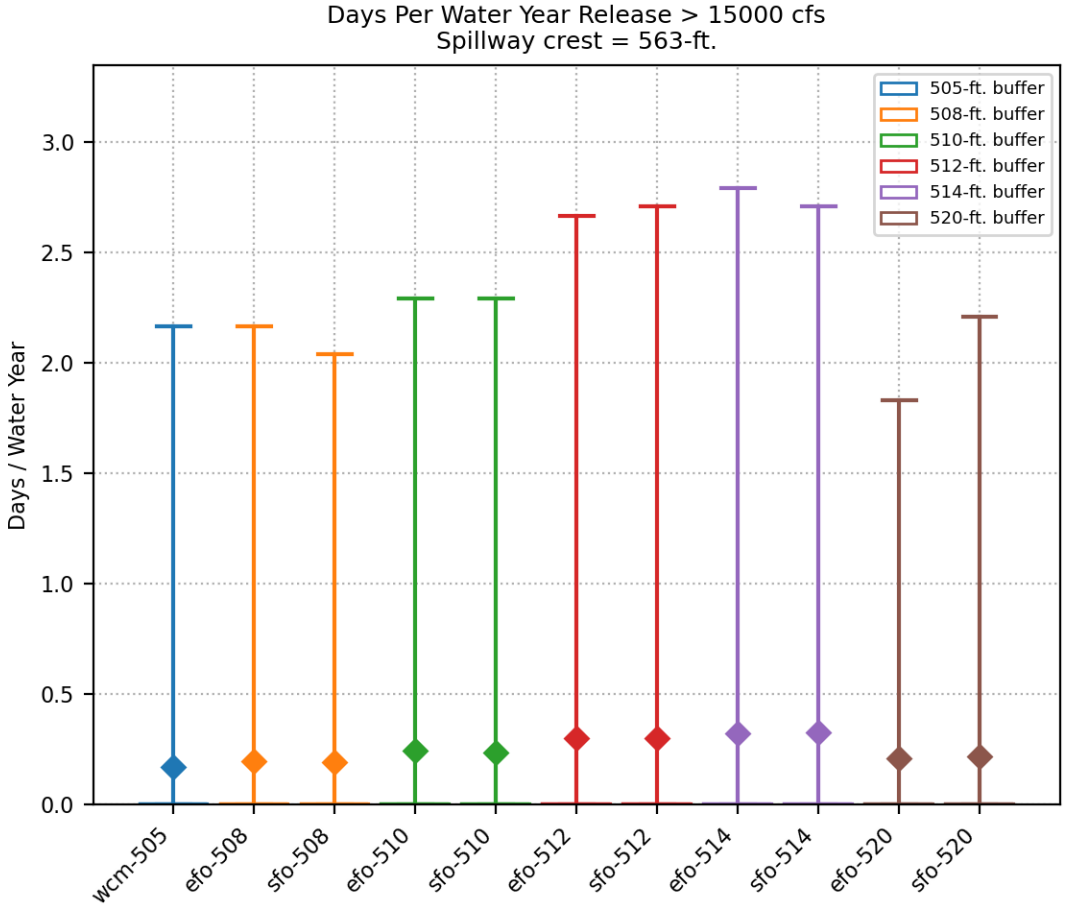

Days Per Water Year Release > 5000 cfs
Spillway crest = 543-ft.
Days / Water Year
0
2
4
6
8
10
12
14
16
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520

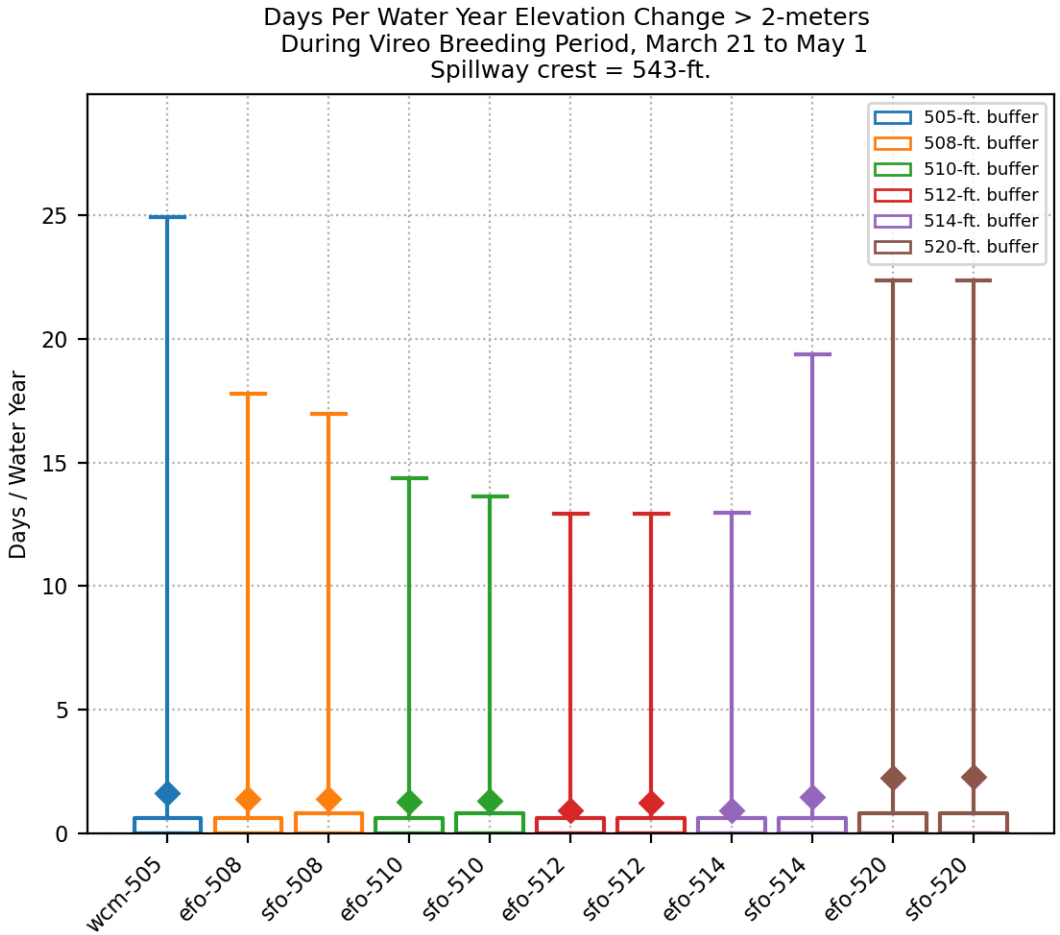

Days Per Water Year Release > 5000 cfs
Spillway crest = 563-ft.
Days / Water Year
0
2
4
6
8
10
12
14
16
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520

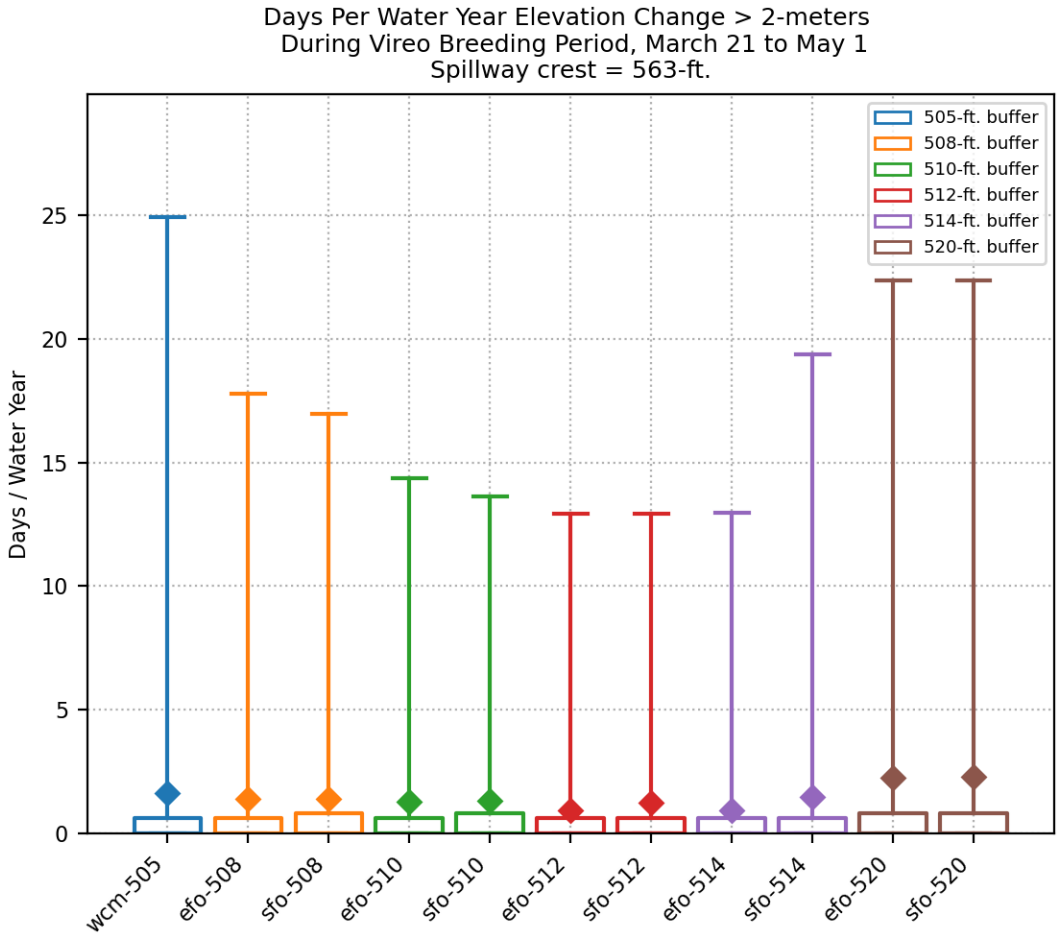

Days Per Water Year Release > 10000 cfs
Spillway crest = 543-ft.
Days / Water Year
0
2
4
6
8
10
12
14
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520


Days Per Water Year Release > 10000 cfs
Spillway crest = 563-ft.
Days / Water Year
0
2
4
6
8
10
12
14
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520


Days Per Water Year Release > 15000 cfs
Spillway crest = 543-ft.
Days / Water Year
0.0
0.5
1.0
1.5
2.0
2.5
3.0
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520


Days Per Water Year Release > 15000 cfs
Spillway crest = 563-ft.
Days / Water Year
0.0
0.5
1.0
1.5
2.0
2.5
3.0
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520


Days Per Water Year Elevation Change > 2-meters
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 543-ft.
Days / Water Year
0
5
10
15
20
25
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520


Days Per Water Year Elevation Change > 2-meters
During Vireo Breeding Period, March 21 to May 1
Spillway crest = 563-ft.
Days / Water Year
0
5
10
15
20
25
505-ft. buffer
508-ft. buffer
510-ft. buffer
512-ft. buffer
514-ft. buffer
520-ft. buffer
wcm-505
efo-508
sfo-508
efo-510
sfo-510
efo-512
sfo-512
efo-514
sfo-514
efo-520
sfo-520

APPENDIX B-7

Scaled Hindcast Events by Alternative

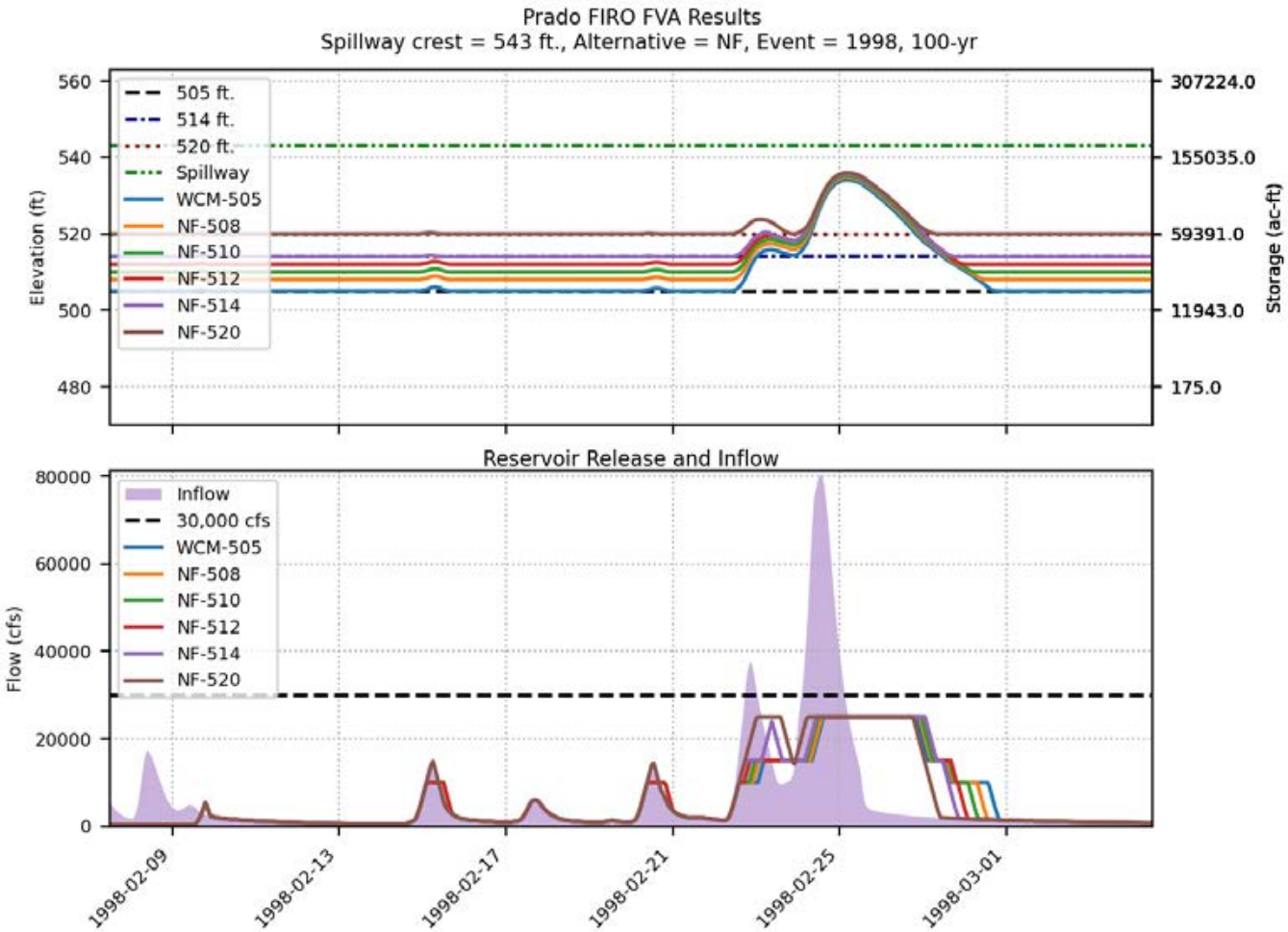
- Upper panel – Reservoir elevation/storage
- Lower panel – Reservoir inflow and release

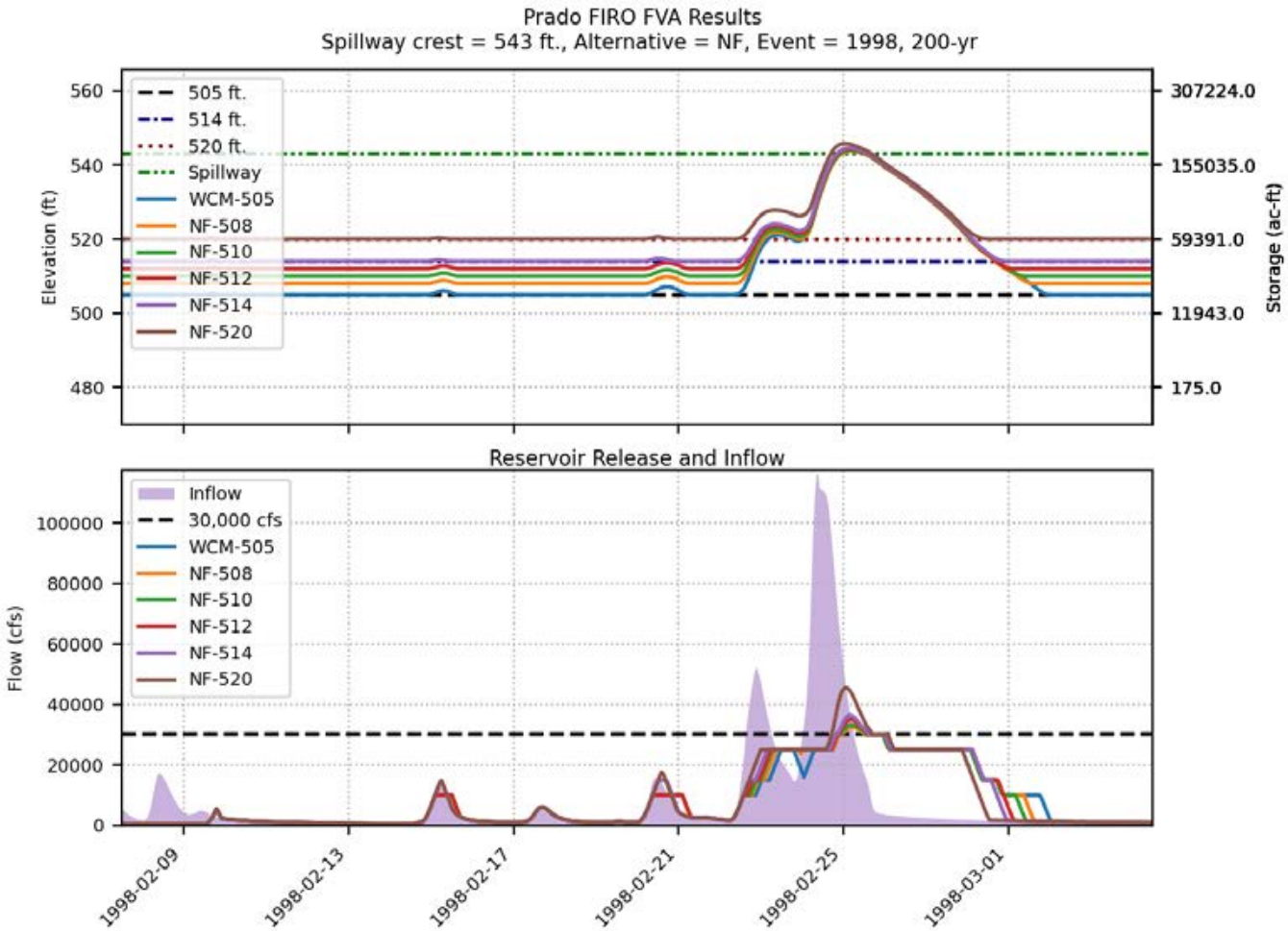
- February 1998
- January 2006
- December 2010

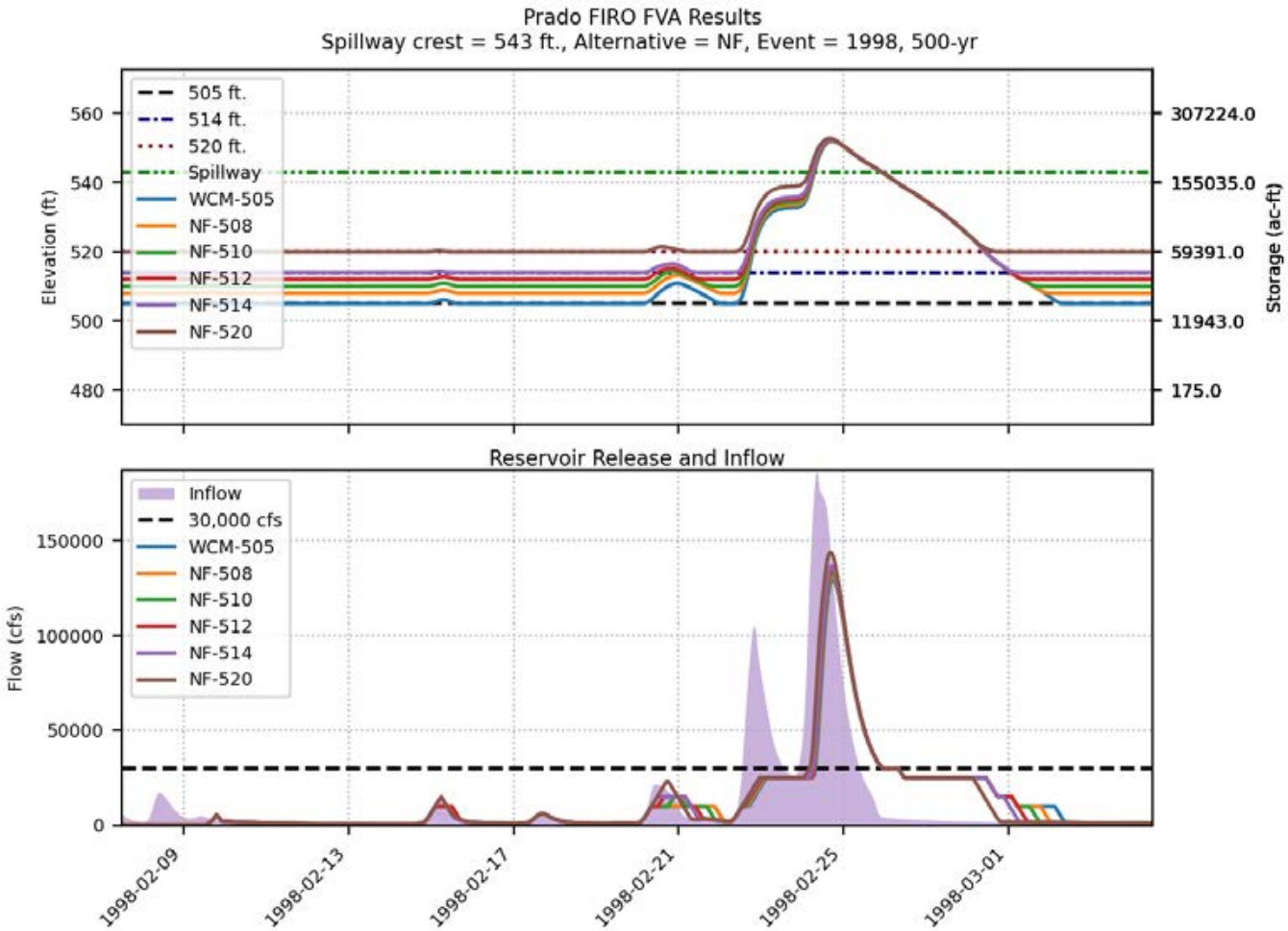
- Scaled to 100-y, 200-yr, 500-yr 3-day inflow volume

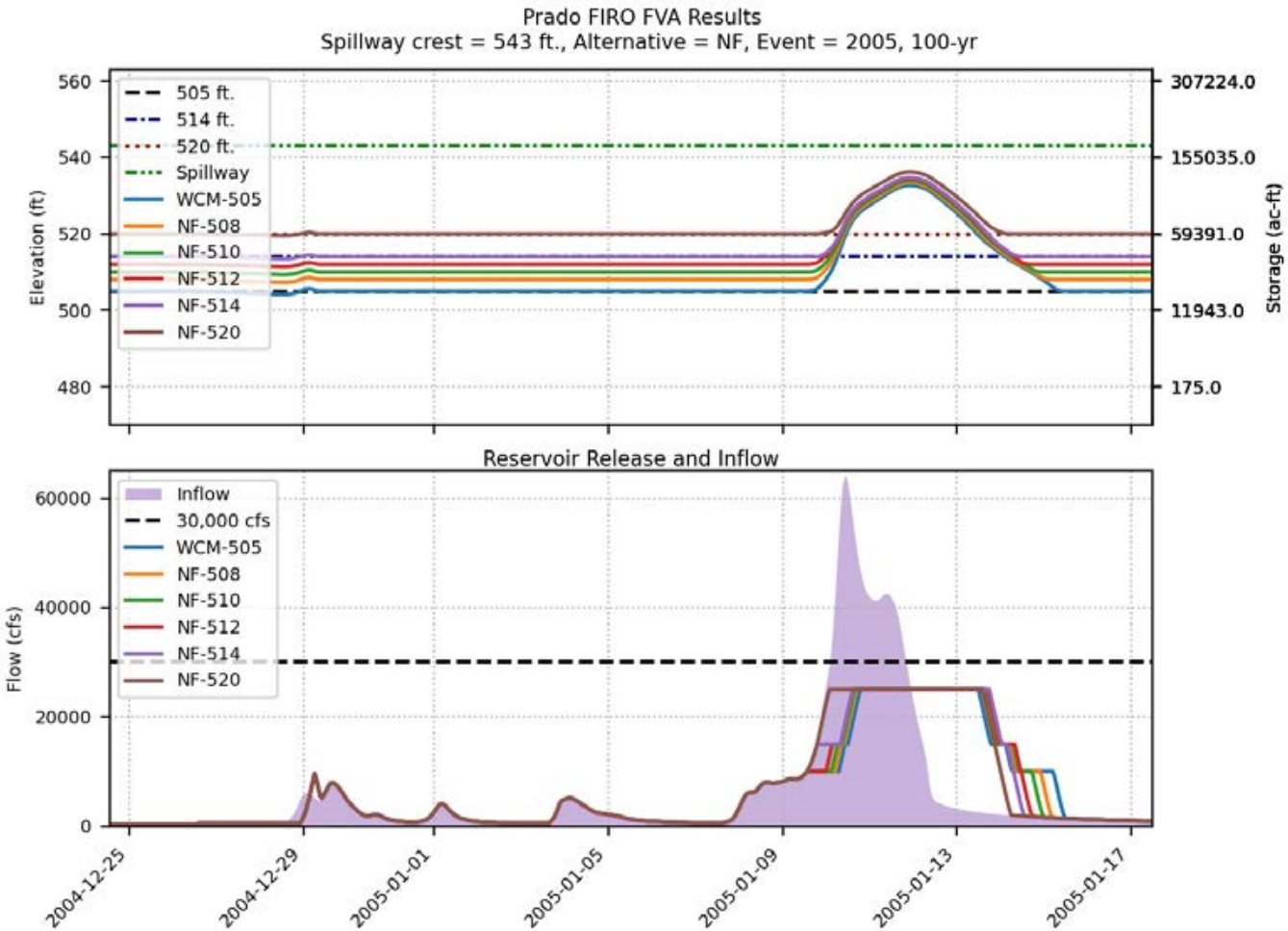
Scaled Hindcast Events by Alternative

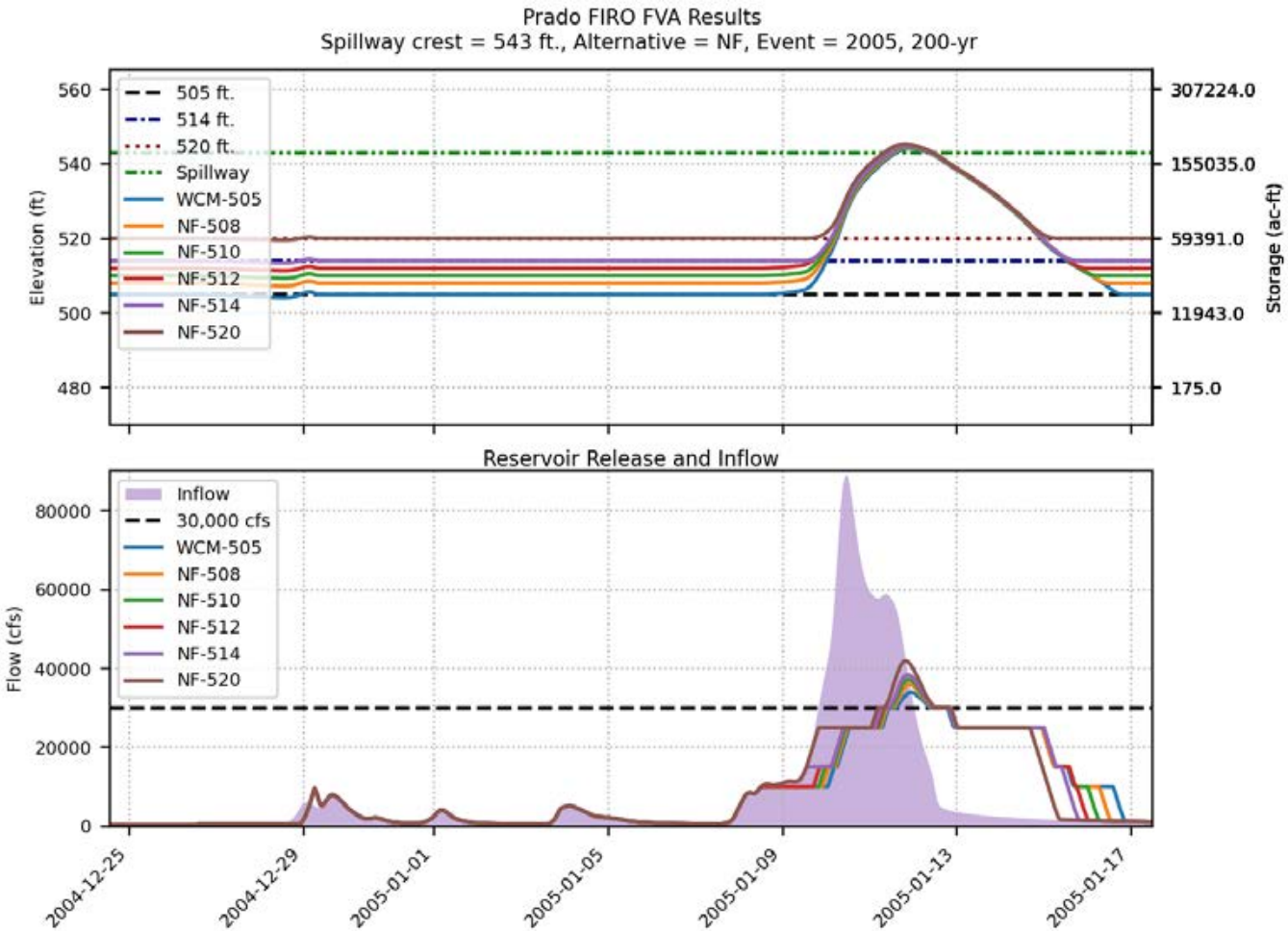
- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations in legend
  - 508’, 510’, 512’, 514’, 520’
- WCP alternatives
  - WCM is 505’ Buffer Pool in all plots
  - NF, EFO, SFO, PFO, SPFO

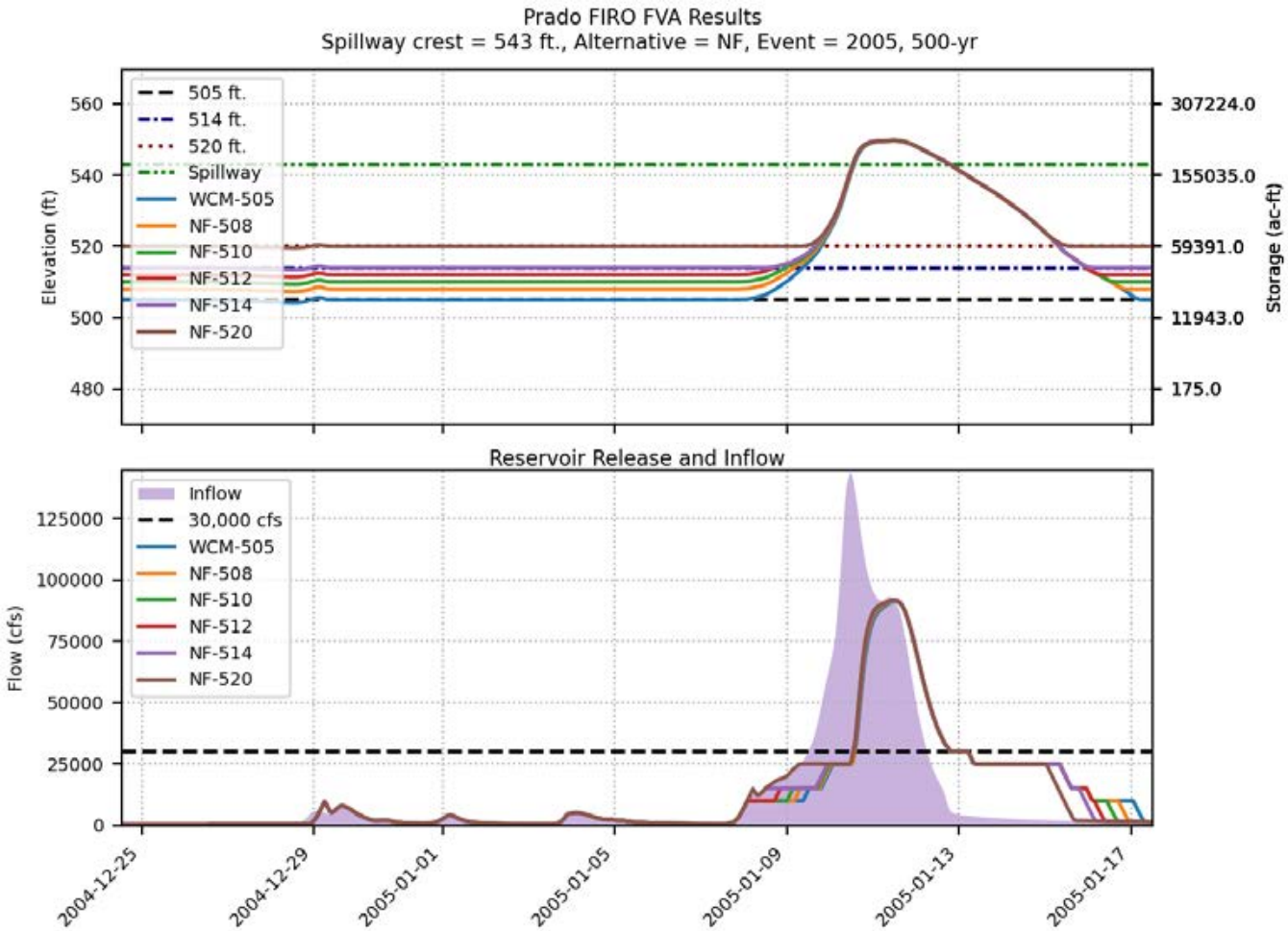

Prado FIRO FVA Results
Spillway crest = 543 ft., Alternative = NF, Event = 1998, 100-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Flow (cfs)
80000
60000
40000
20000
0
1998-02-09
1998-02-13
1998-02-17
1998-02-21
1998-02-25
1998-03-01

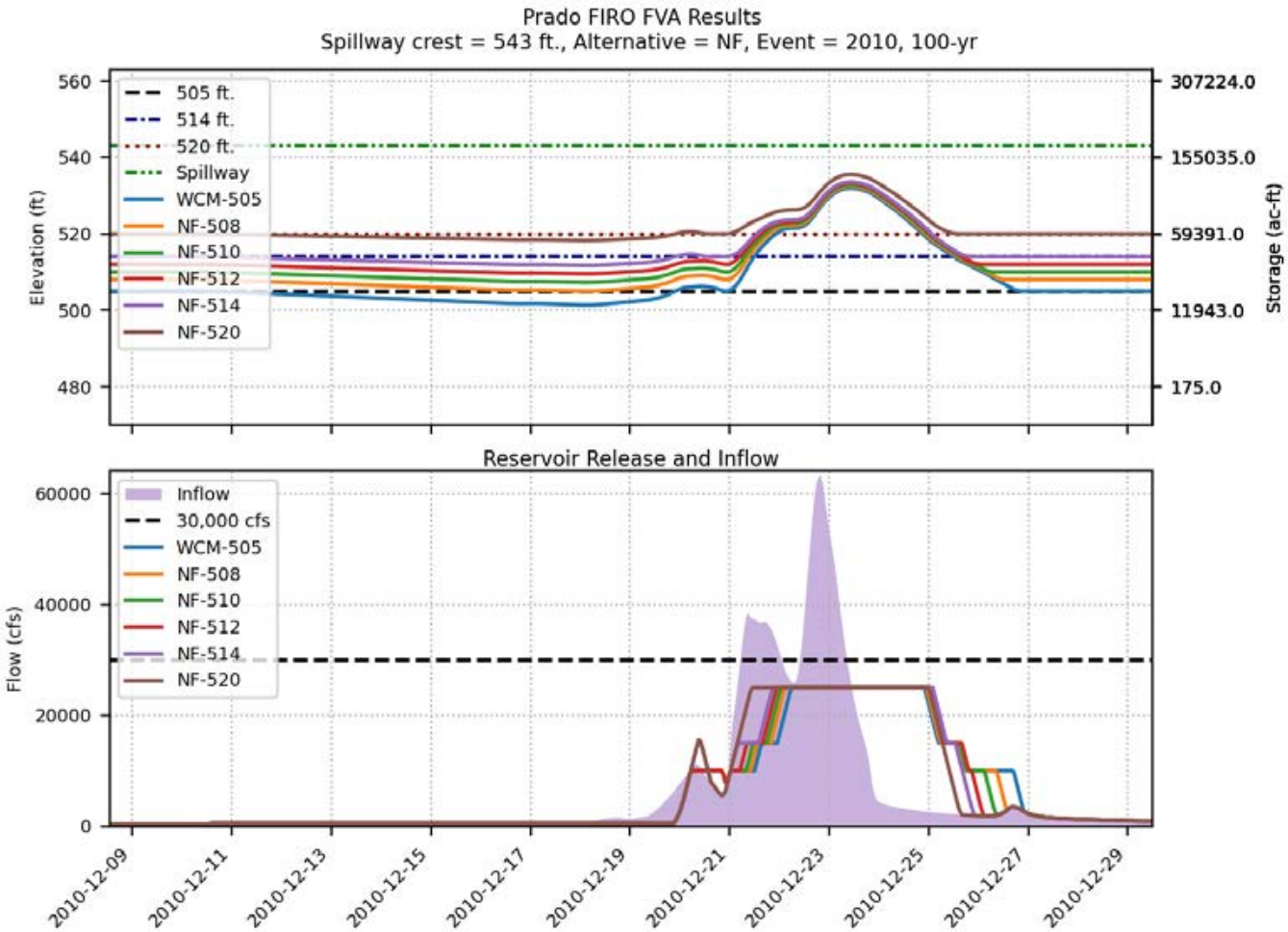

Prado FIRO FVA Results
Spillway crest = 543 ft., Alternative = NF, Event = 1998, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Flow (cfs)
100000
80000
60000
40000
20000
0
1998-02-09
1998-02-13
1998-02-17
1998-02-21
1998-02-25
1998-03-01


Prado FIRO FVA Results
Spillway crest = 543 ft., Alternative = NF, Event = 1998, 500-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Elevation (ft)
560
540
520
500
480
Storage (ac-ft)
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Flow (cfs)
150000
100000
50000
0
1998-02-09
1998-02-13
1998-02-17
1998-02-21
1998-02-25
1998-03-01


Prado FIRO FVA Results
Spillway crest = 543 ft., Alternative = NF, Event = 2005, 100-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Flow (cfs)
60000
40000
20000
0
2004-12-25
2004-12-29
2005-01-01
2005-01-05
2005-01-09
2005-01-13
2005-01-17


Prado FIRO FVA Results
Spillway crest = 543 ft., Alternative = NF, Event = 2005, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Flow (cfs)
80000
60000
40000
20000
0
2004-12-25
2004-12-29
2005-01-01
2005-01-05
2005-01-09
2005-01-13
2005-01-17


Prado FIRO FVA Results
Spillway crest = 543 ft., Alternative = NF, Event = 2005, 500-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Flow (cfs)
125000
100000
75000
50000
25000
0
2004-12-25
2004-12-29
2005-01-01
2005-01-05
2005-01-09
2005-01-13
2005-01-17


Prado FIRO FVA Results
Spillway crest = 543 ft., Alternative = NF, Event = 2010, 100-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Flow (cfs)
60000
40000
20000
0
2010-12-09
2010-12-11
2010-12-13
2010-12-15
2010-12-17
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2010-12-21
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2010-12-25
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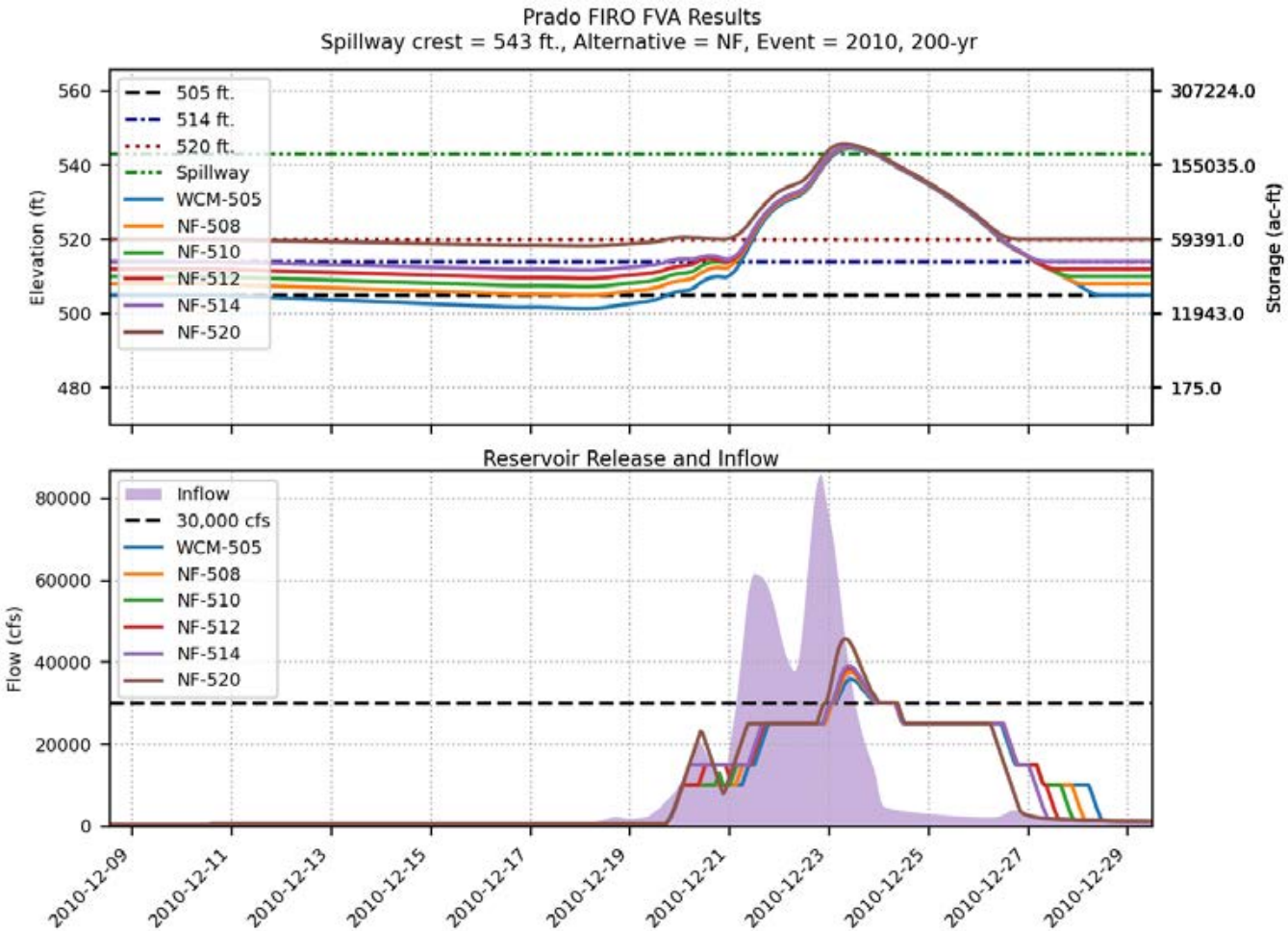
2010-12-29


Prado FIRO FVA Results
Spillway crest = 543 ft., Alternative = NF, Event = 2010, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Flow (cfs)
80000
60000
40000
20000
0
2010-12-09
2010-12-11
2010-12-13
2010-12-15
2010-12-17
2010-12-19
2010-12-21
2010-12-23
2010-12-25
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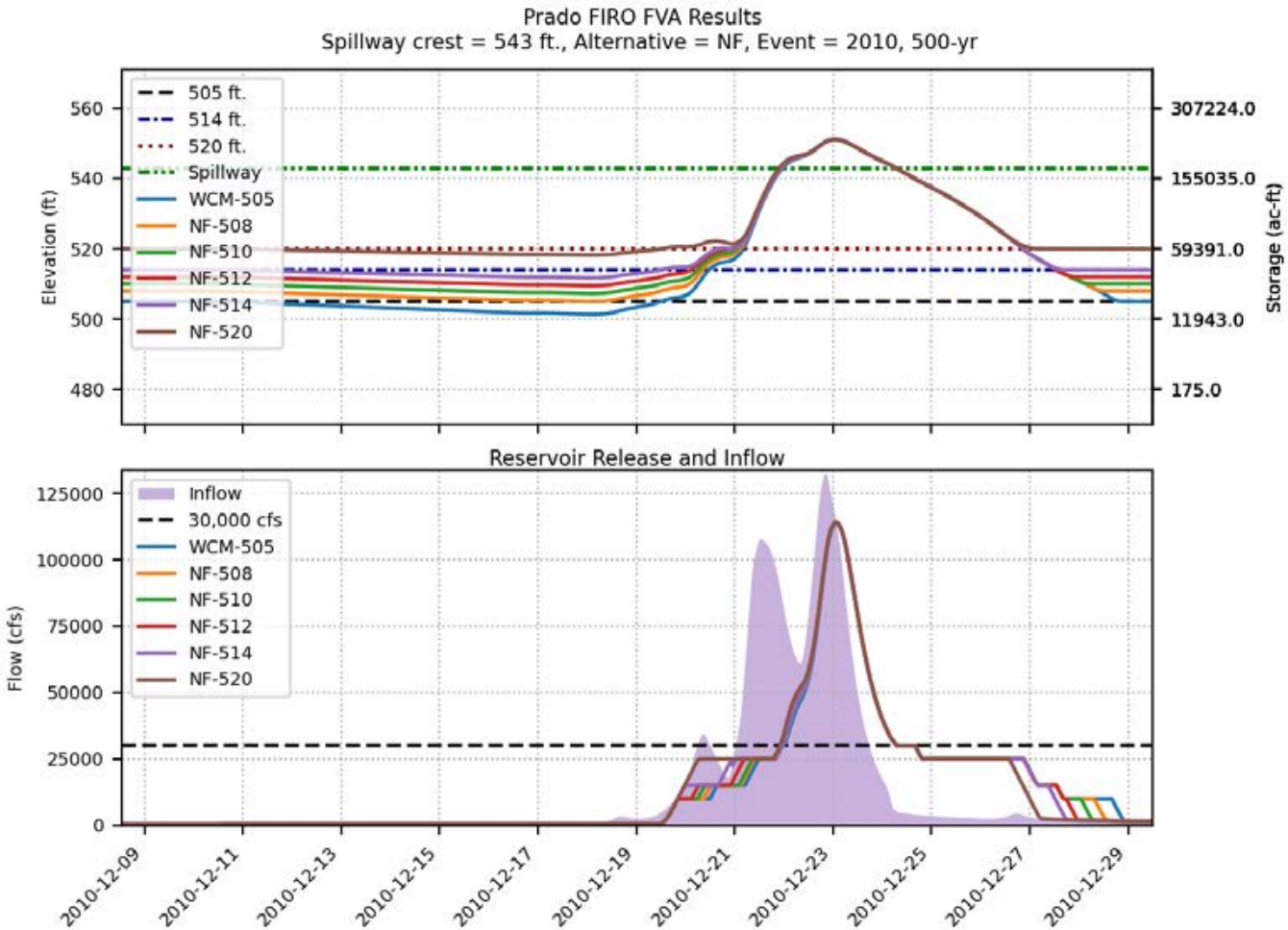
2010-12-29


Prado FIRO FVA Results
Spillway crest = 543 ft., Alternative = NF, Event = 2010, 500-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Flow (cfs)
125000
100000
75000
50000
25000
0
2010-12-09
2010-12-11
2010-12-13
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2010-12-25
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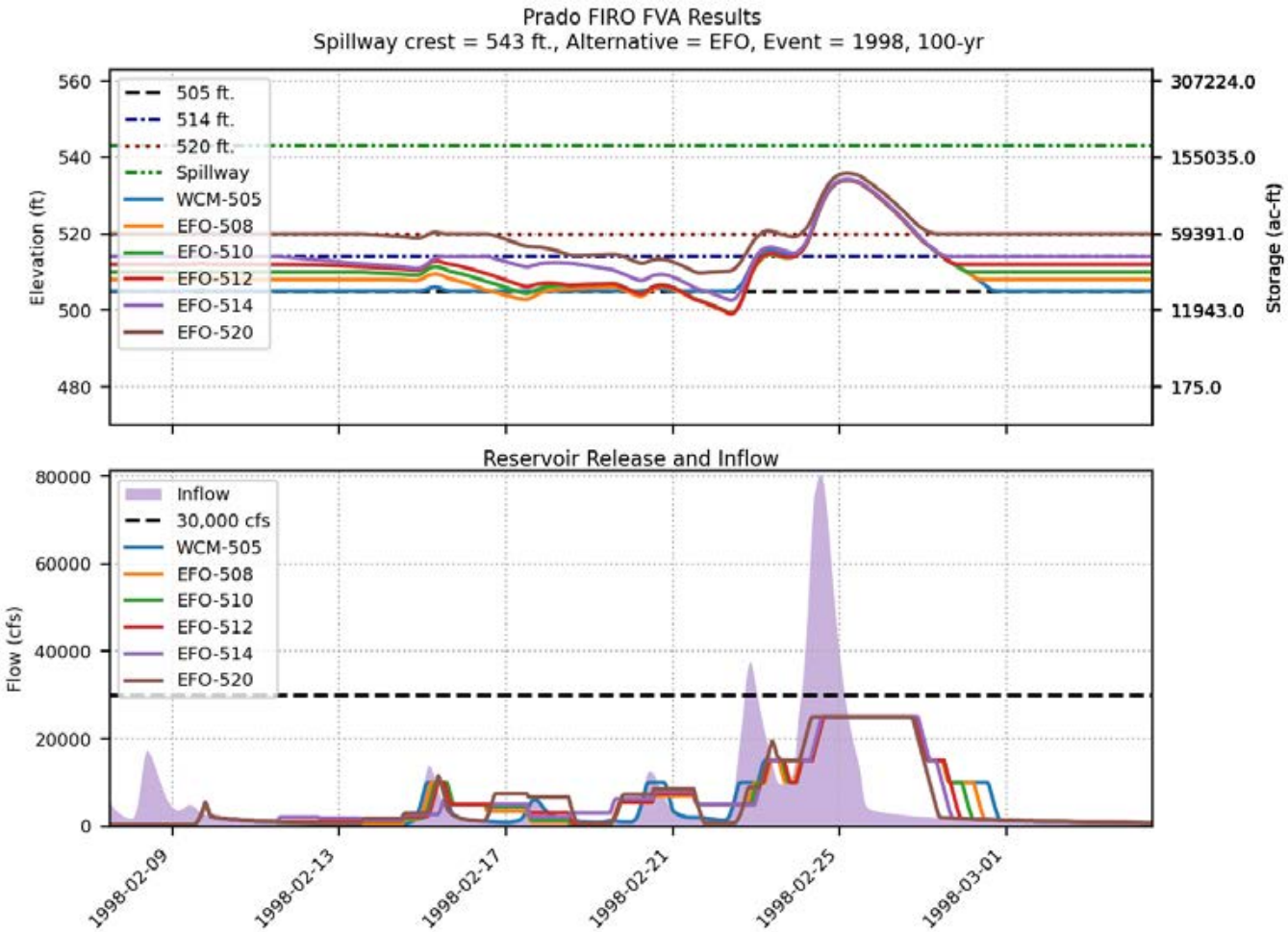
2010-12-29


Prado FIRO FVA Results
Spillway crest = 543 ft., Alternative = EFO, Event = 1998, 100-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
EFO-508
EFO-510
EFO-512
EFO-514
EFO-520
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
WCM-505
EFO-508
EFO-510
EFO-512
EFO-514
EFO-520
80000
60000
40000
20000
0
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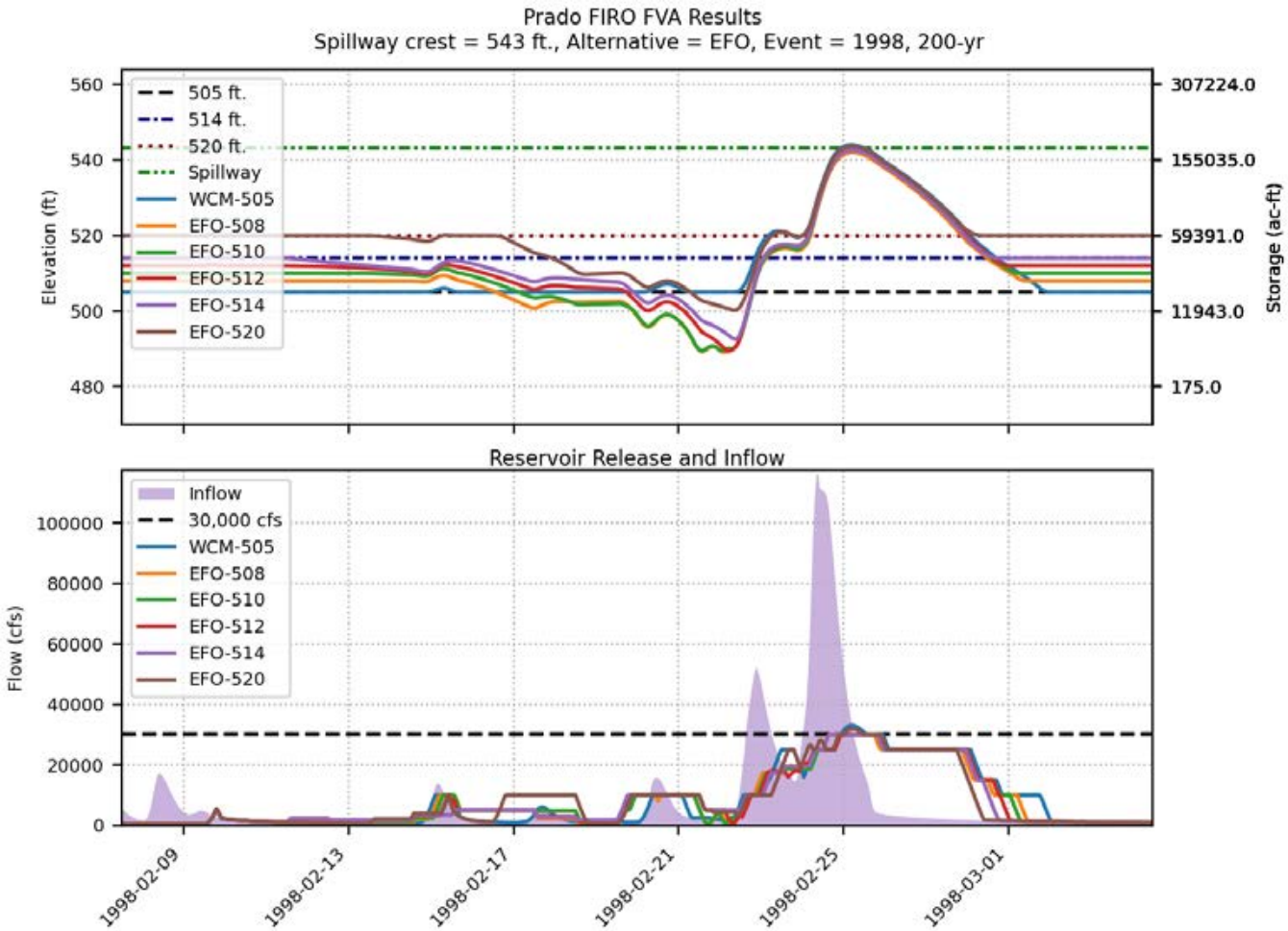
1998-02-21
1998-02-25
1998-03-01


Prado FIRO FVA Results
Spillway crest = 543 ft., Alternative = EFO, Event = 1998, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
EFO-508
EFO-510
EFO-512
EFO-514
EFO-520
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
EFO-508
EFO-510
EFO-512
EFO-514
EFO-520
Flow (cfs)
100000
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20000
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1998-02-13
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1998-02-21
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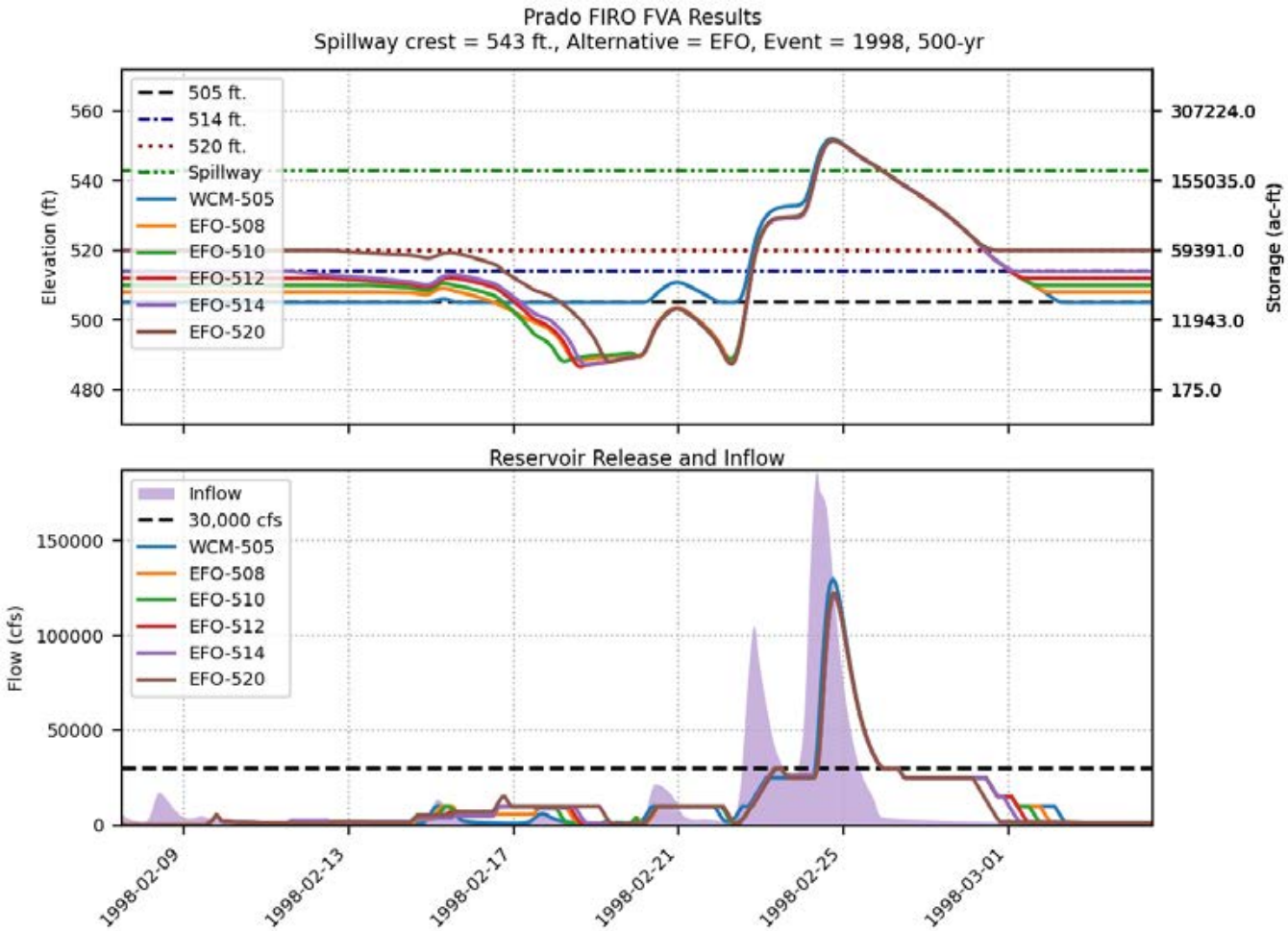
1998-03-01


Prado FIRO FVA Results
Spillway crest = 543 ft., Alternative = EFO, Event = 1998, 500-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
EFO-508
EFO-510
EFO-512
EFO-514
EFO-520
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
EFO-508
EFO-510
EFO-512
EFO-514
EFO-520
Flow (cfs)
150000
100000
50000
0
1998-02-09
1998-02-13
1998-02-17
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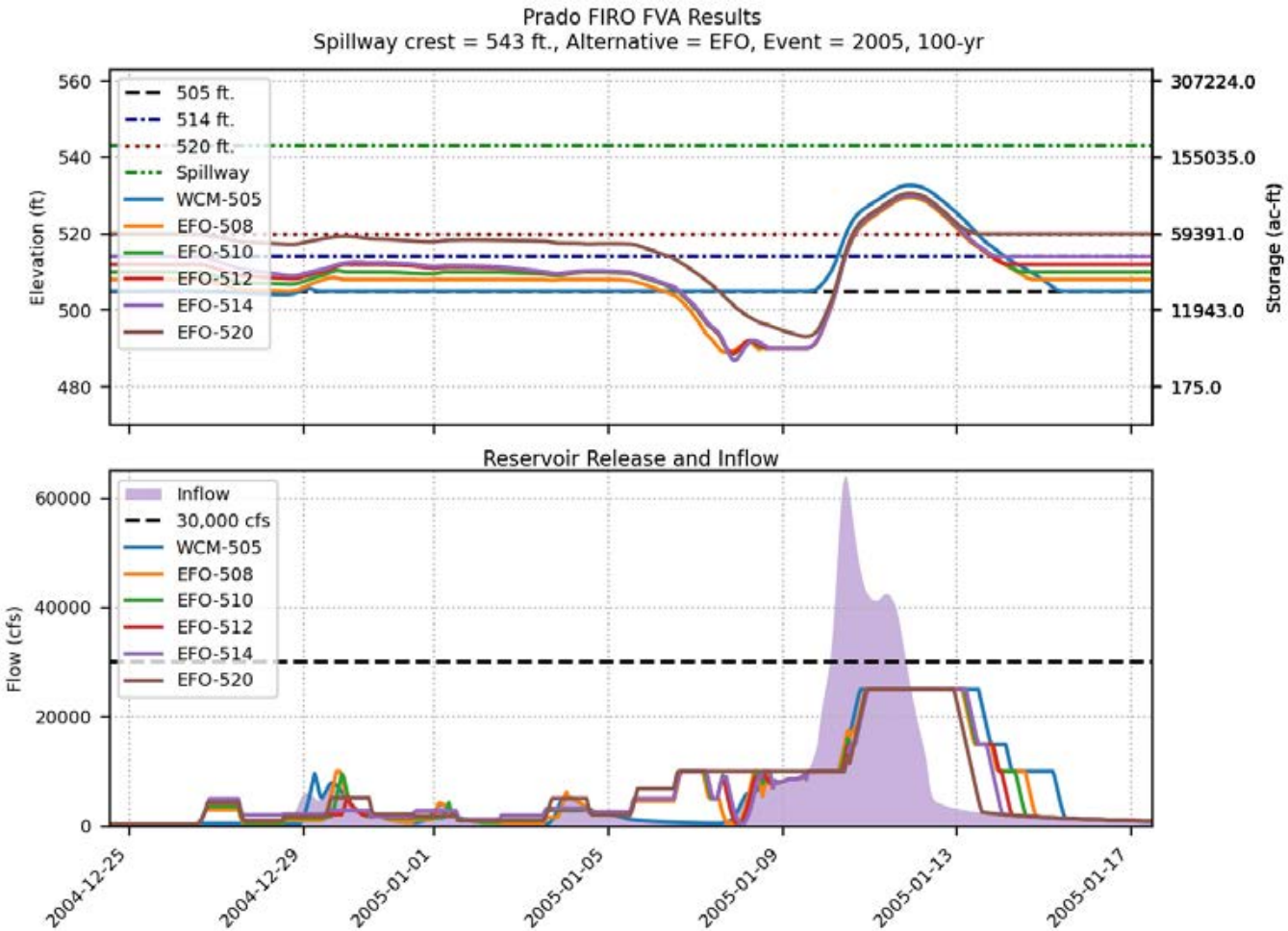
1998-03-01


Prado FIRO FVA Results
Spillway crest = 543 ft., Alternative = EFO, Event = 2005, 100-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
EFO-508
EFO-510
EFO-512
EFO-514
EFO-520
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
WCM-505
EFO-508
EFO-510
EFO-512
EFO-514
EFO-520
60000
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2004-12-29
2005-01-01
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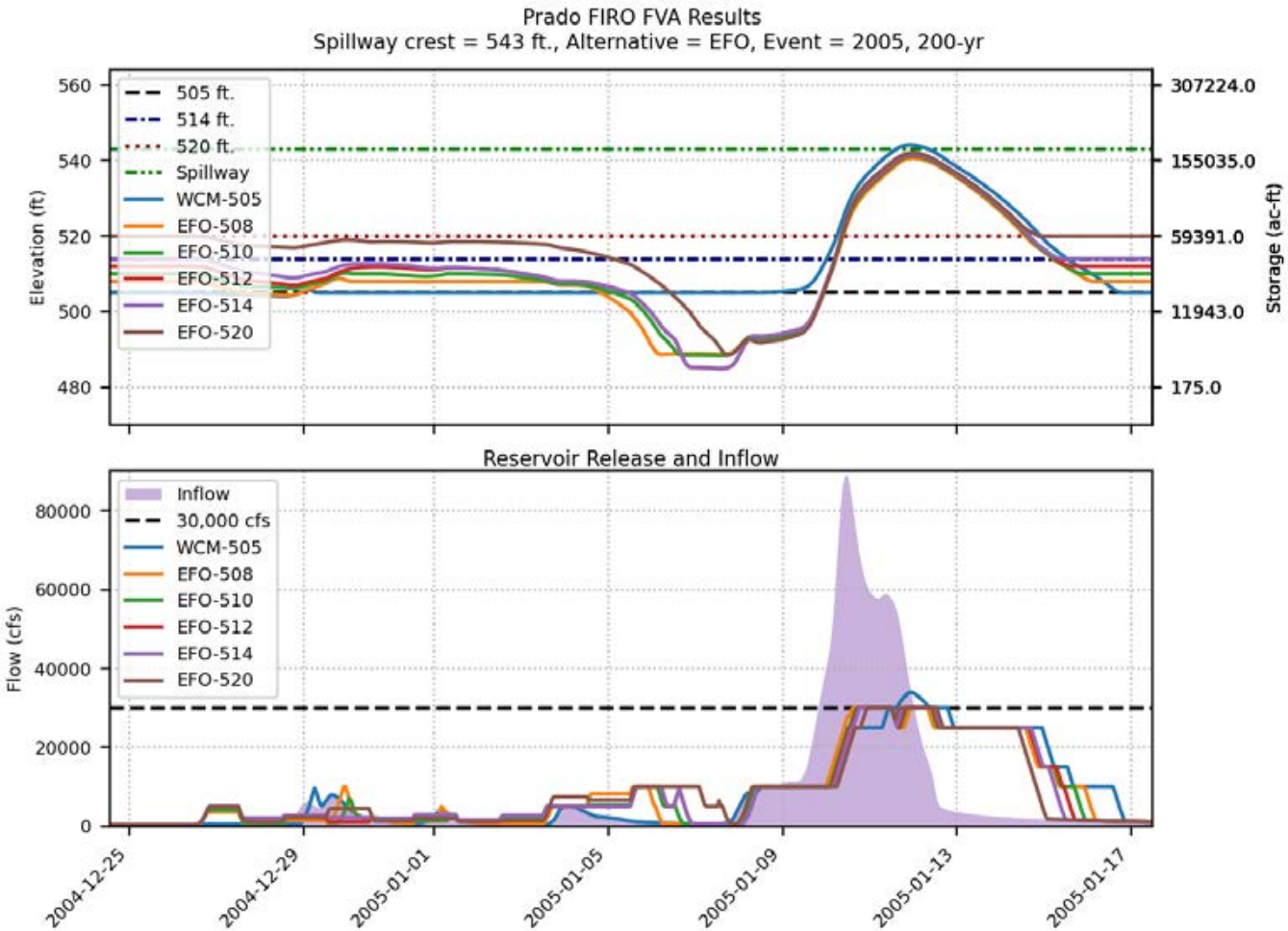
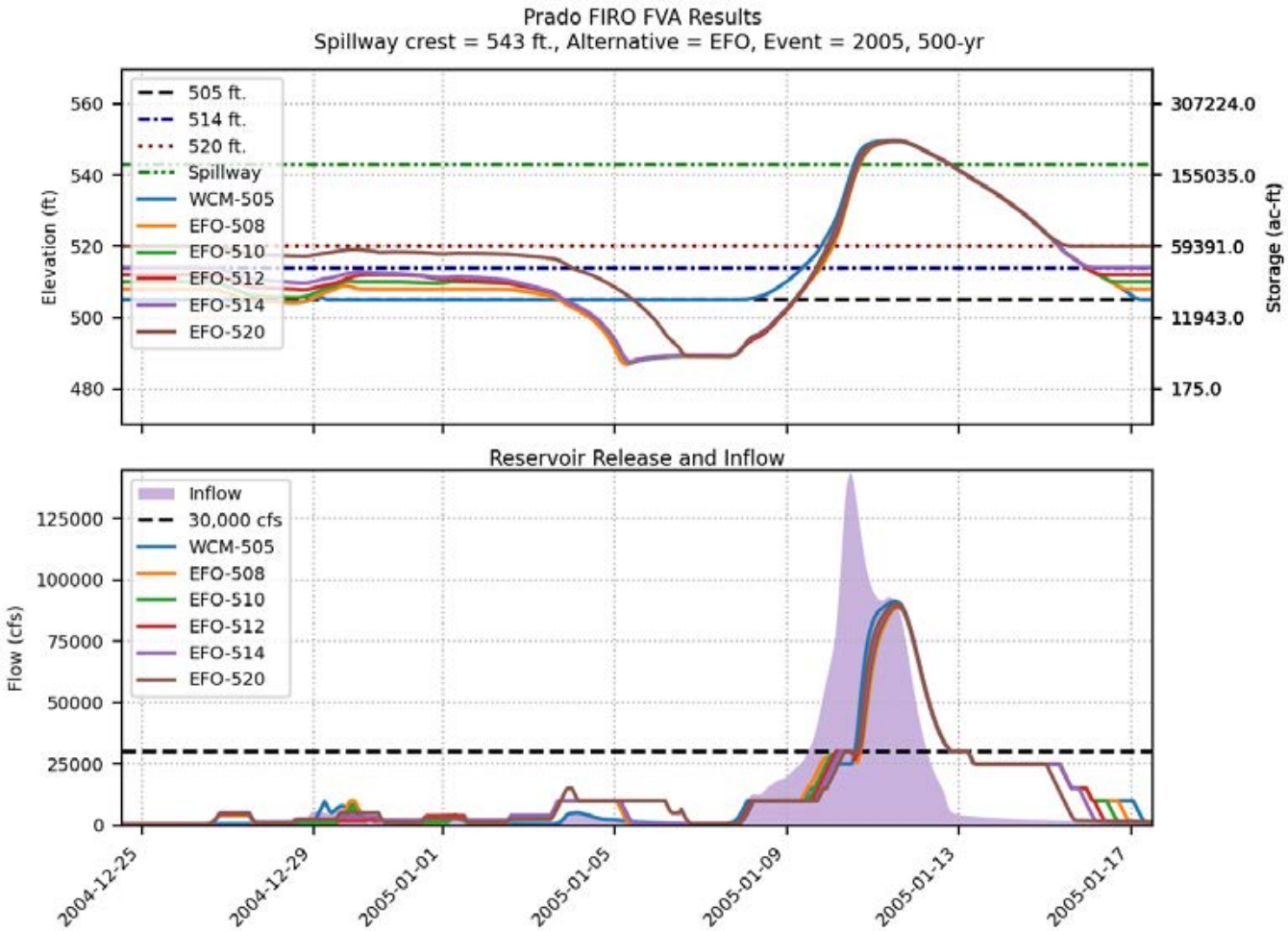

Prado FIRO FVA Results
Spillway crest = 543 ft., Alternative = EFO, Event = 2005, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
EFO-508
EFO-510
EFO-512
EFO-514
EFO-520
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
EFO-508
EFO-510
EFO-512
EFO-514
EFO-520
Flow (cfs)
80000
60000
40000
20000
0
2004-12-25
2004-12-29
2005-01-01
2005-01-05
2005-01-09
2005-01-13
2005-01-17


Prado FIRO FVA Results
Spillway crest = 543 ft., Alternative = EFO, Event = 2005, 500-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
EFO-508
EFO-510
EFO-512
EFO-514
EFO-520
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
EFO-508
EFO-510
EFO-512
EFO-514
EFO-520
Flow (cfs)
125000
100000
75000
50000
25000
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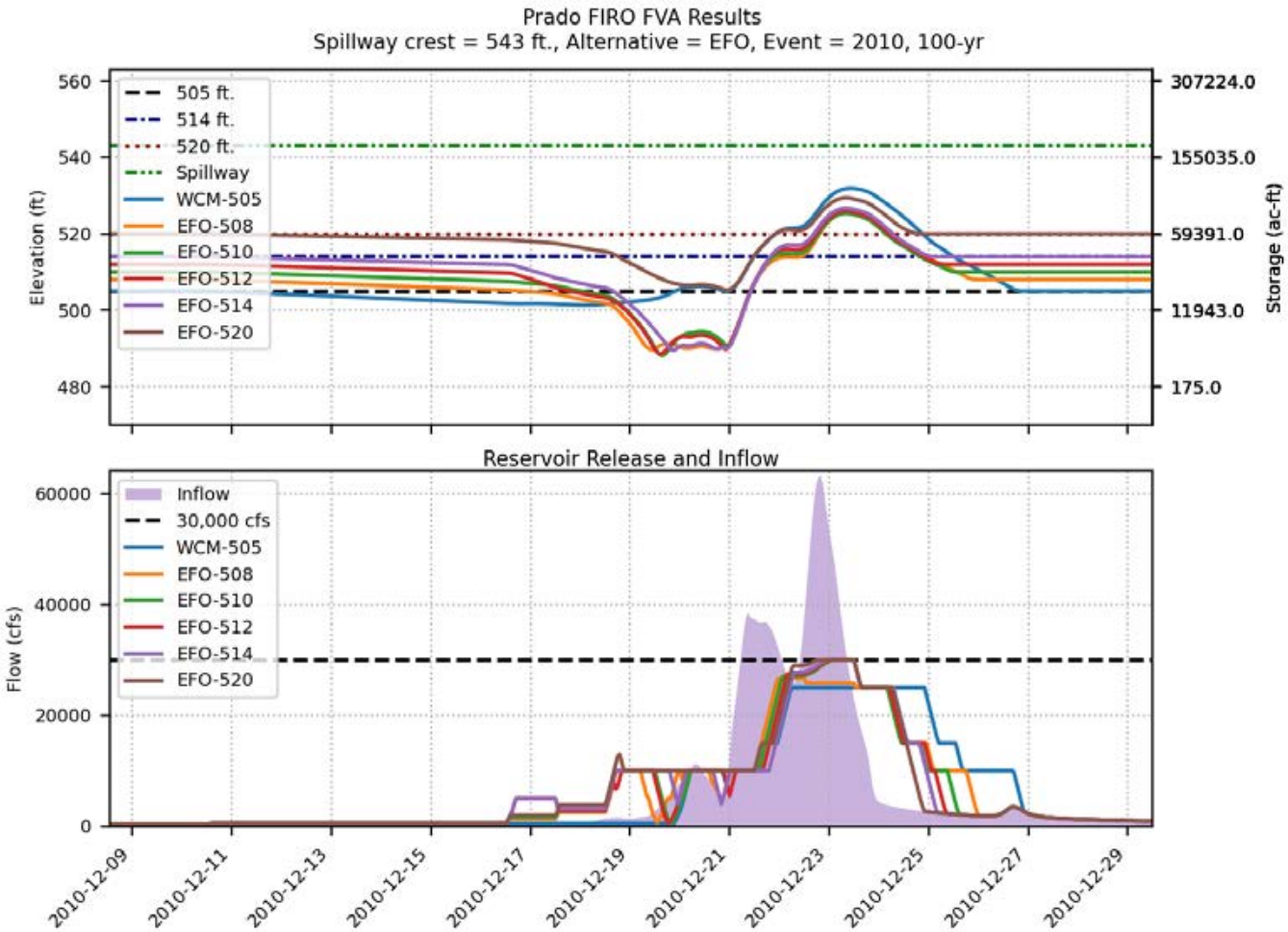
2004-12-29
2005-01-01
2005-01-05
2005-01-09
2005-01-13
2005-01-17


Prado FIRO FVA Results
Spillway crest = 543 ft., Alternative = EFO, Event = 2010, 100-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
EFO-508
EFO-510
EFO-512
EFO-514
EFO-520
Elevation (ft)
Storage (ac-ft)
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307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
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EFO-510
EFO-512
EFO-514
EFO-520
Flow (cfs)
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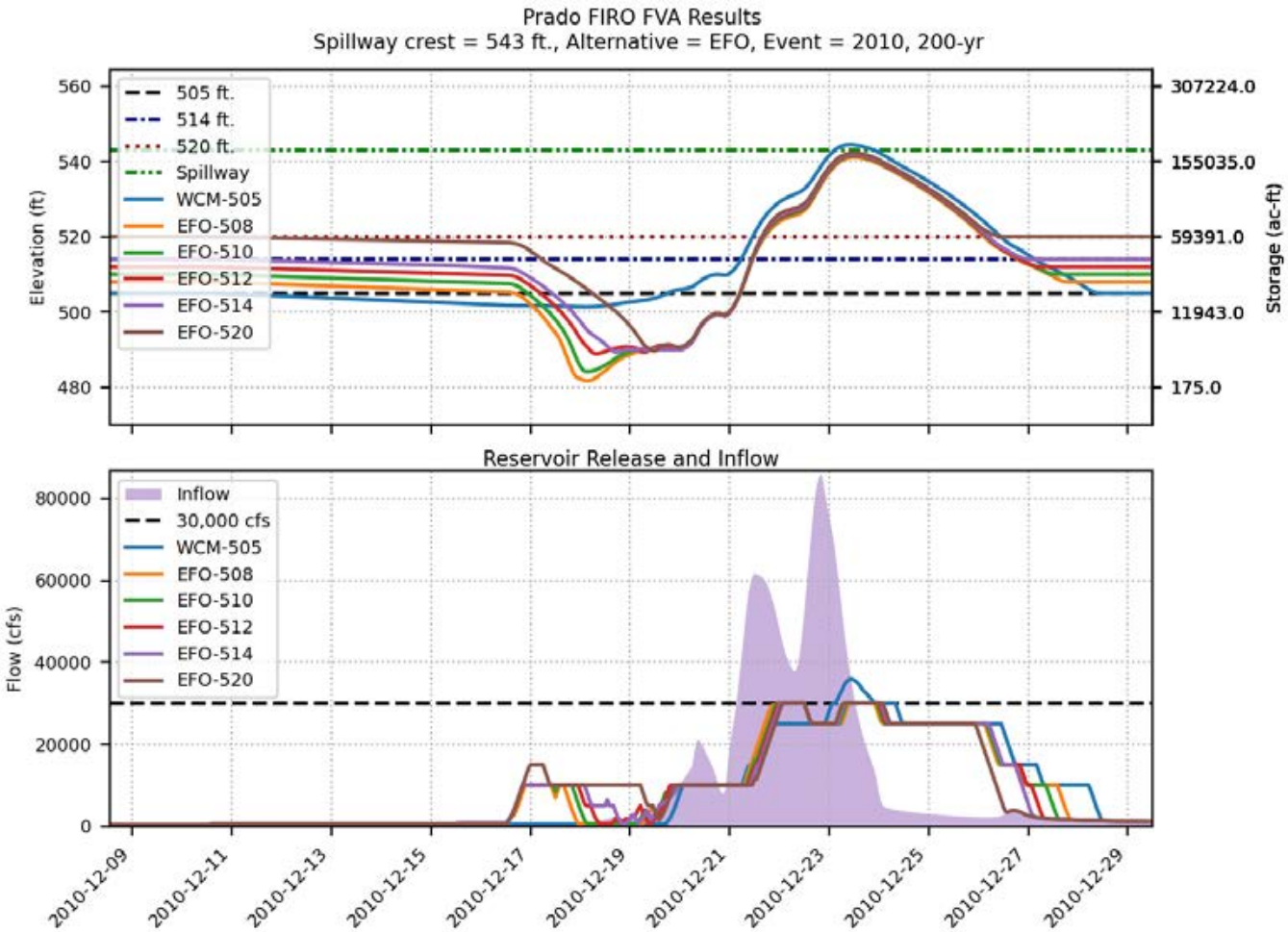
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505 ft.
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EFO-510
EFO-512
EFO-514
EFO-520
Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
Inflow
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EFO-508
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EFO-514
EFO-520
Flow (cfs)
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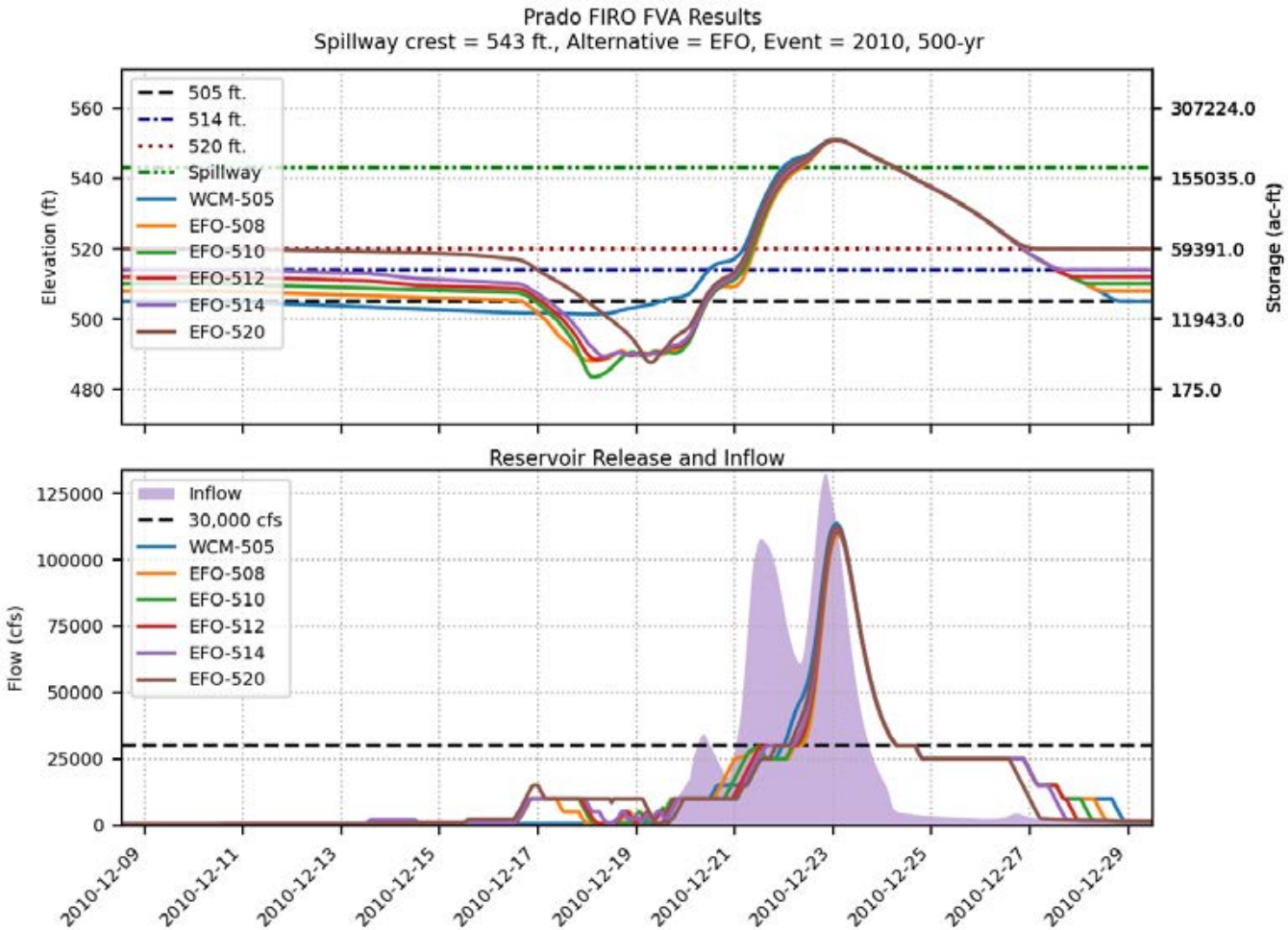
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EFO-510
EFO-512
EFO-514
EFO-520
Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
Inflow
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EFO-508
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EFO-512
EFO-514
EFO-520
Flow (cfs)
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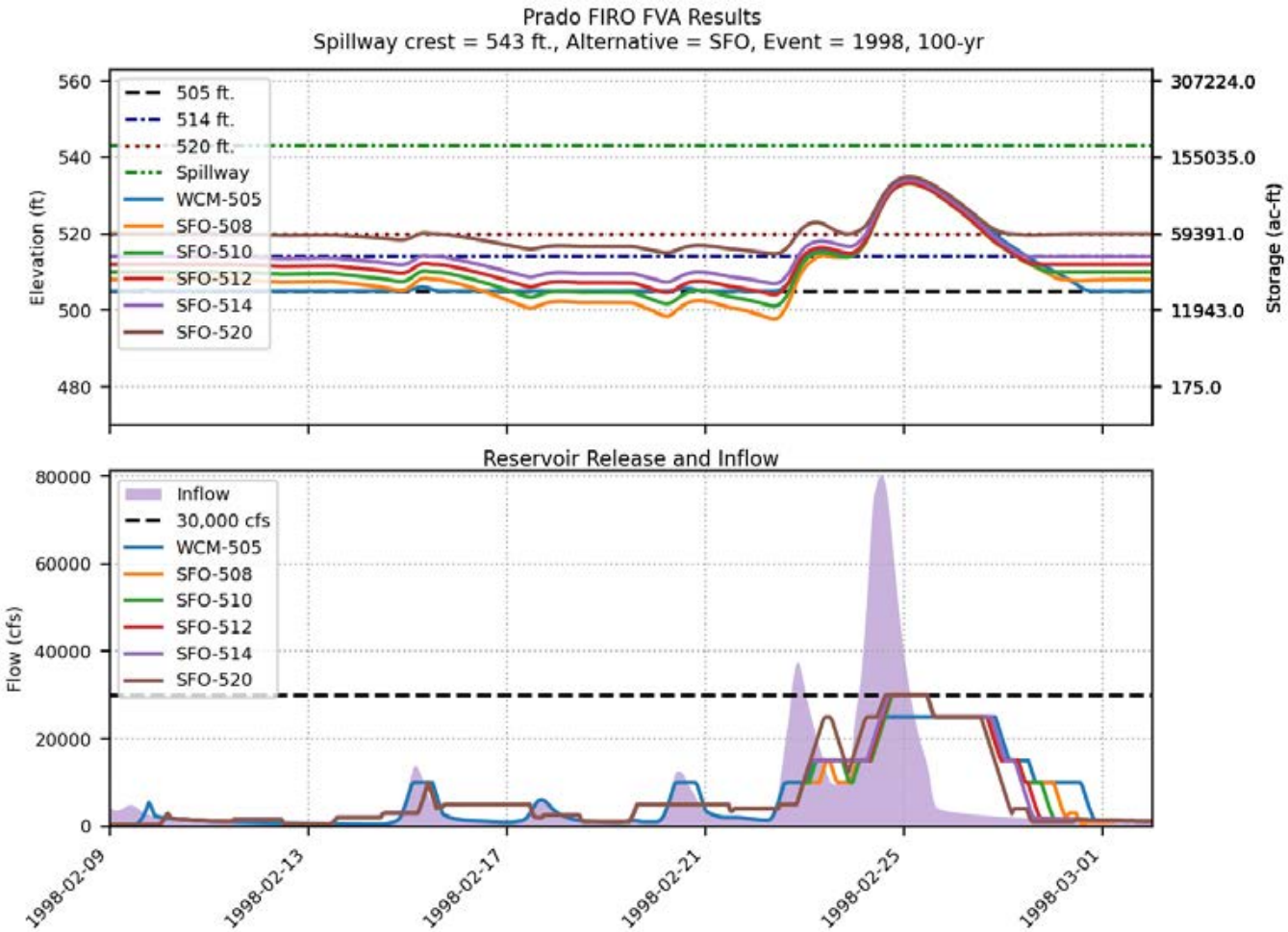
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Elevation (ft)
Storage (ac-ft)
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520 ft.
Spillway
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Reservoir Release and Inflow
Flow (cfs)
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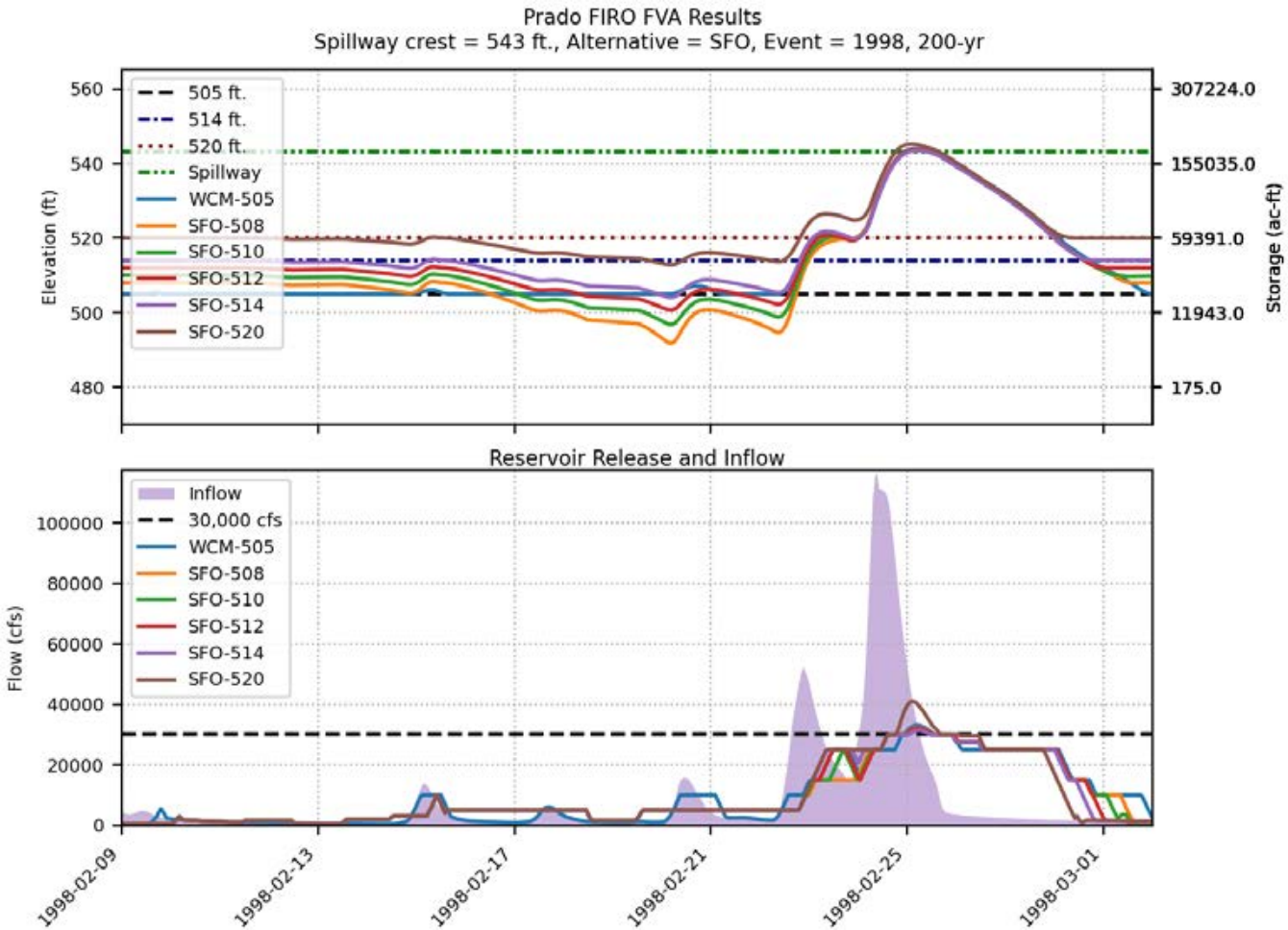
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SFO-512
SFO-514
SFO-520
Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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Flow (cfs)
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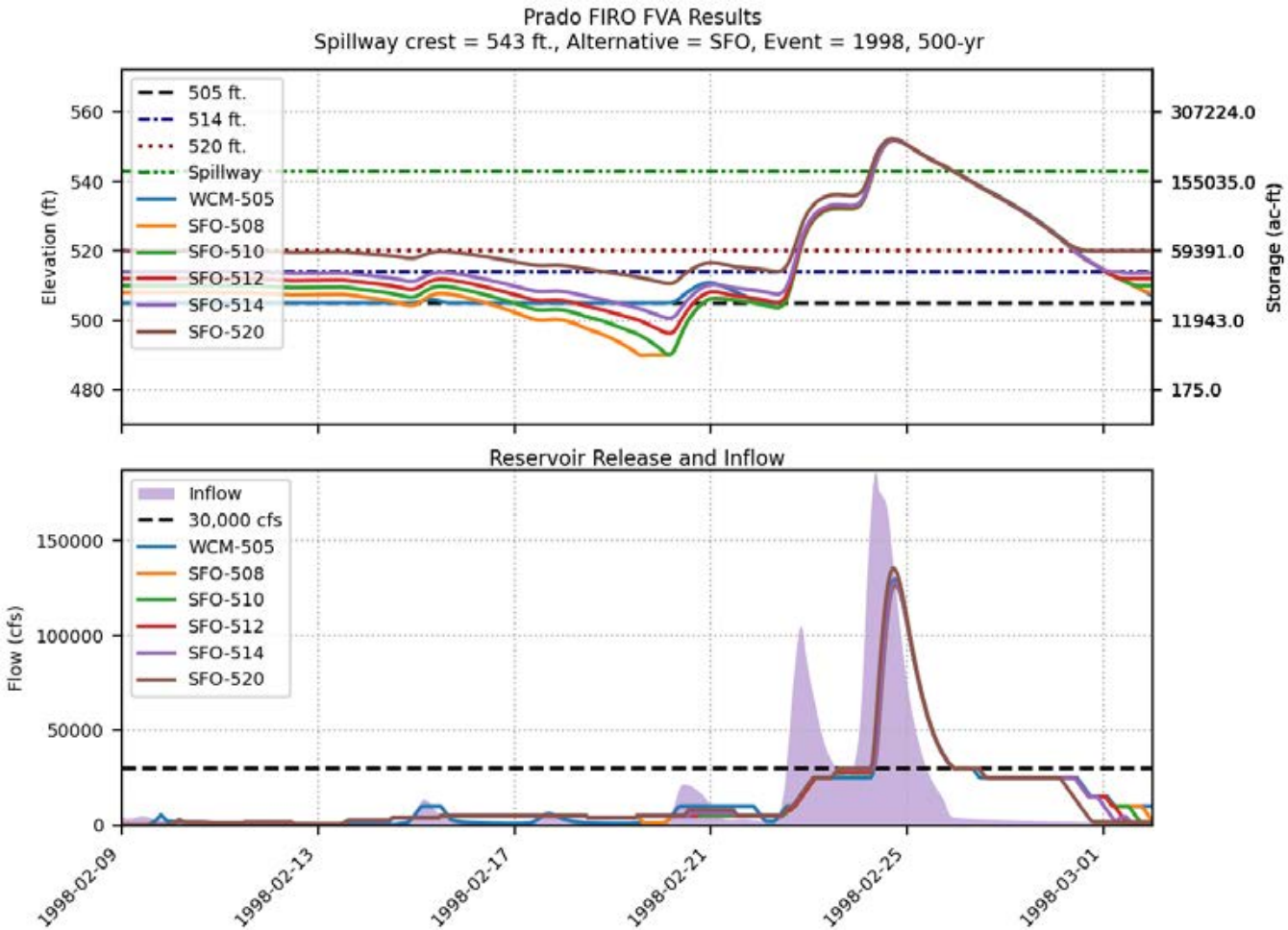
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Elevation (ft)
Storage (ac-ft)
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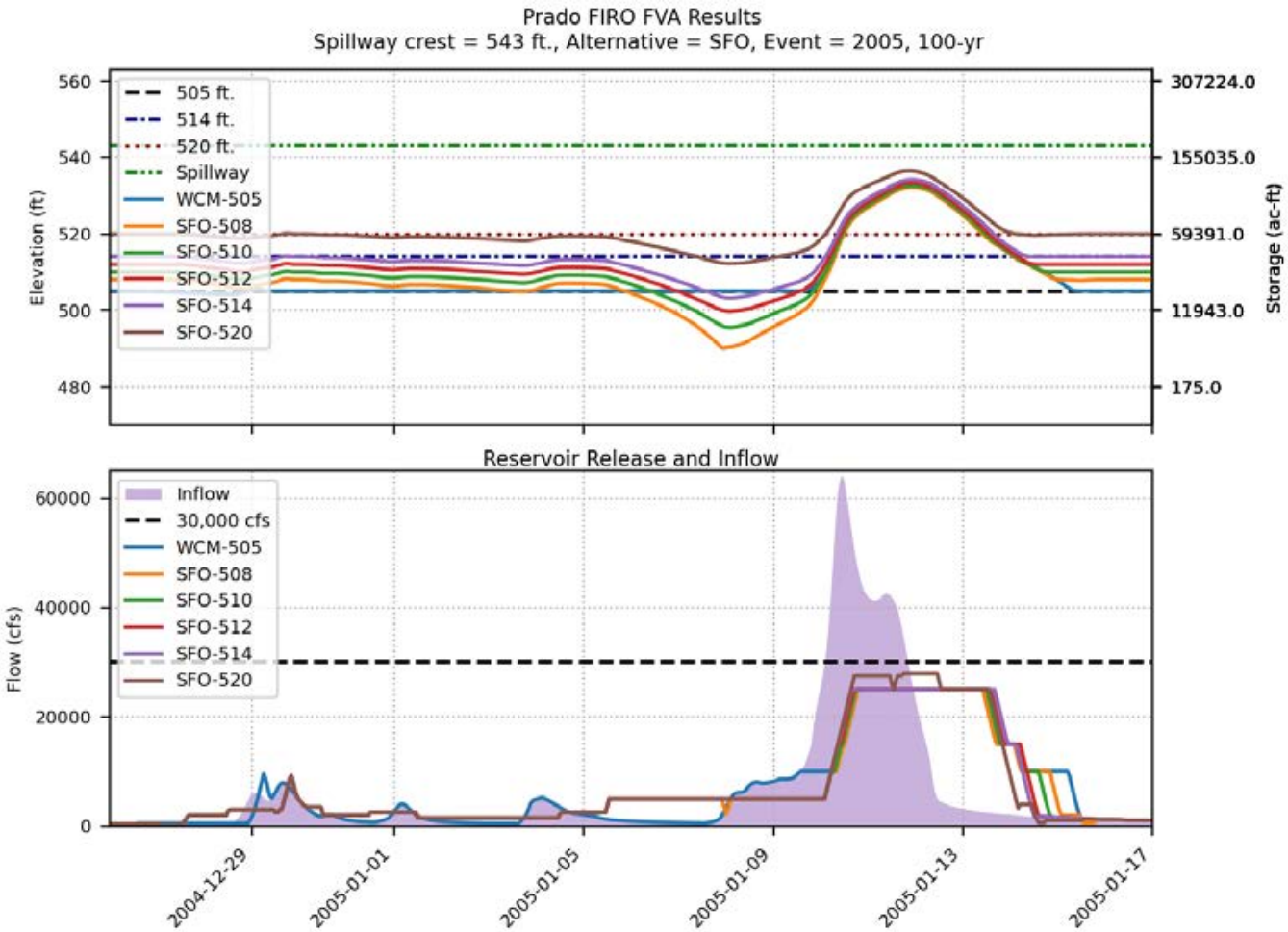
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Spillway
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Elevation (ft)
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Flow (cfs)
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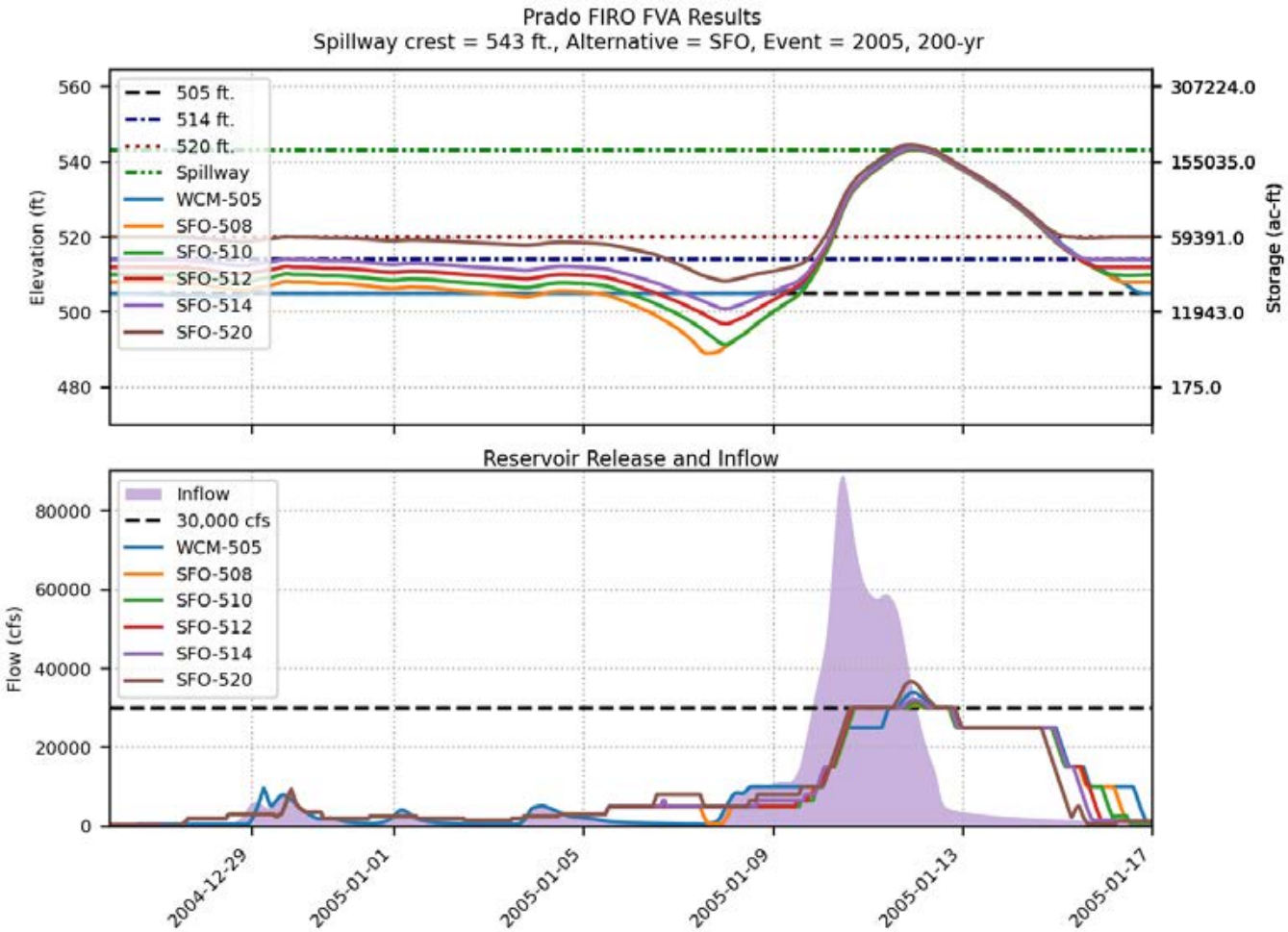
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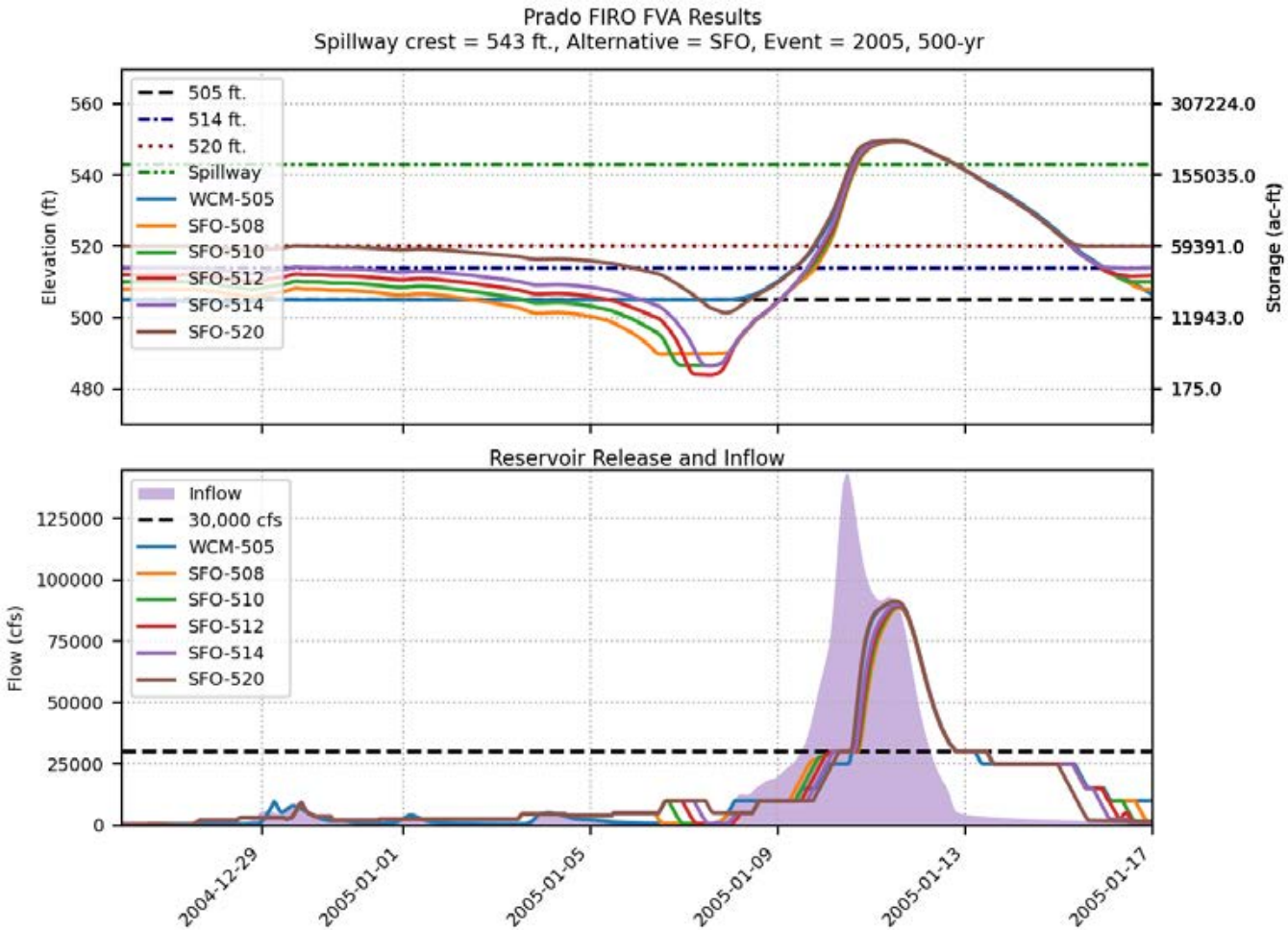
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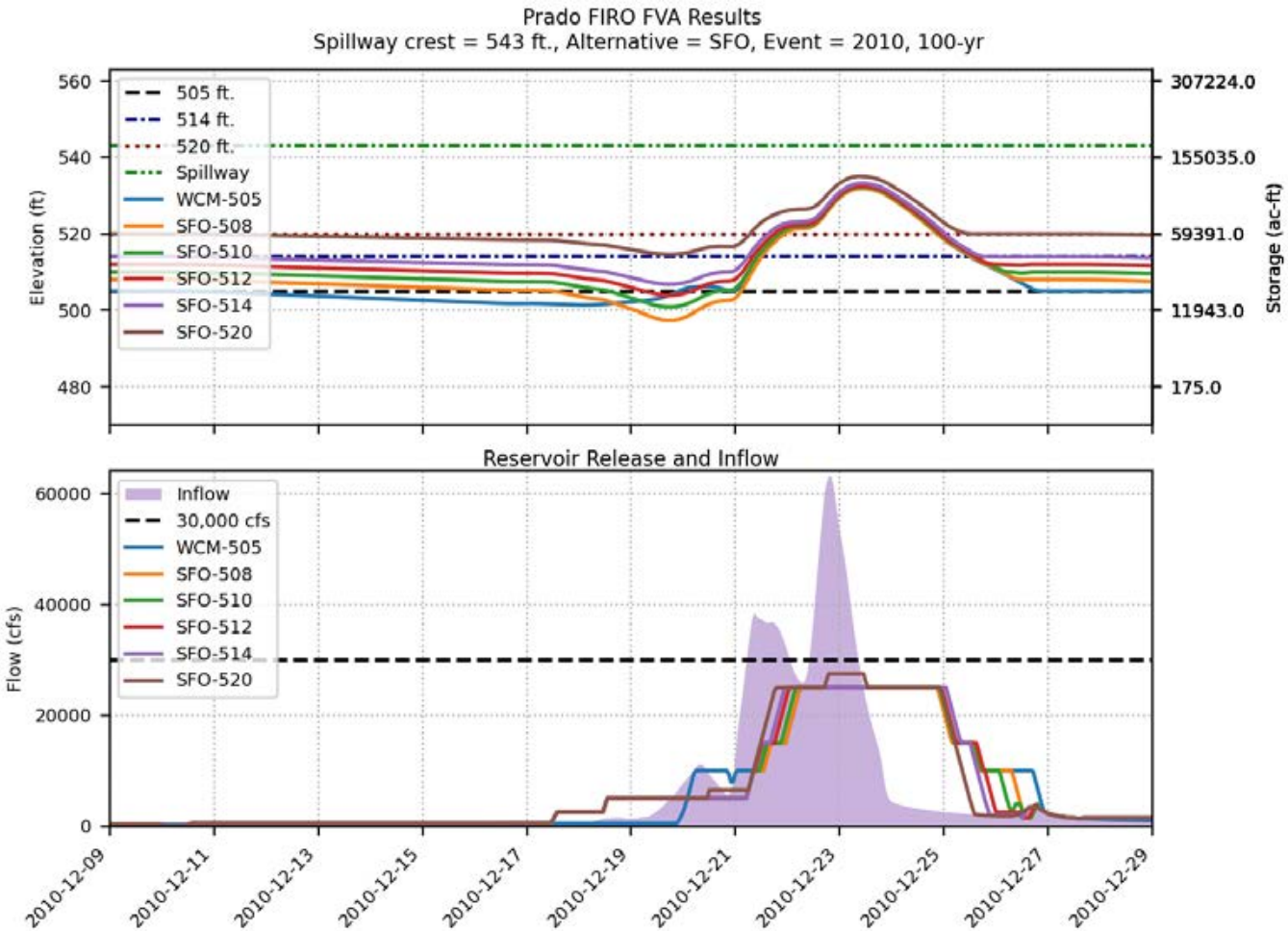
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Storage (ac-ft)
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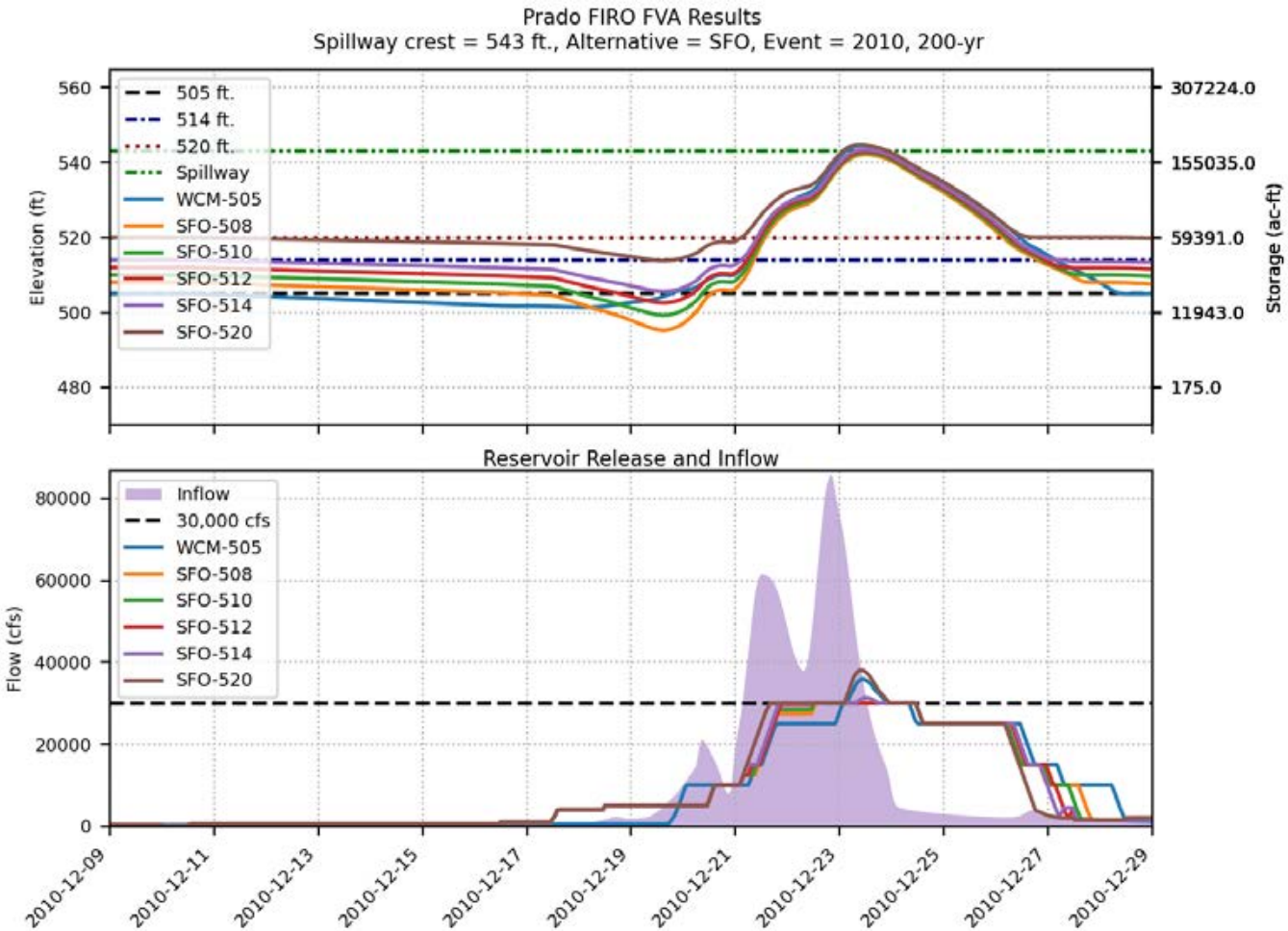
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Reservoir Release and Inflow
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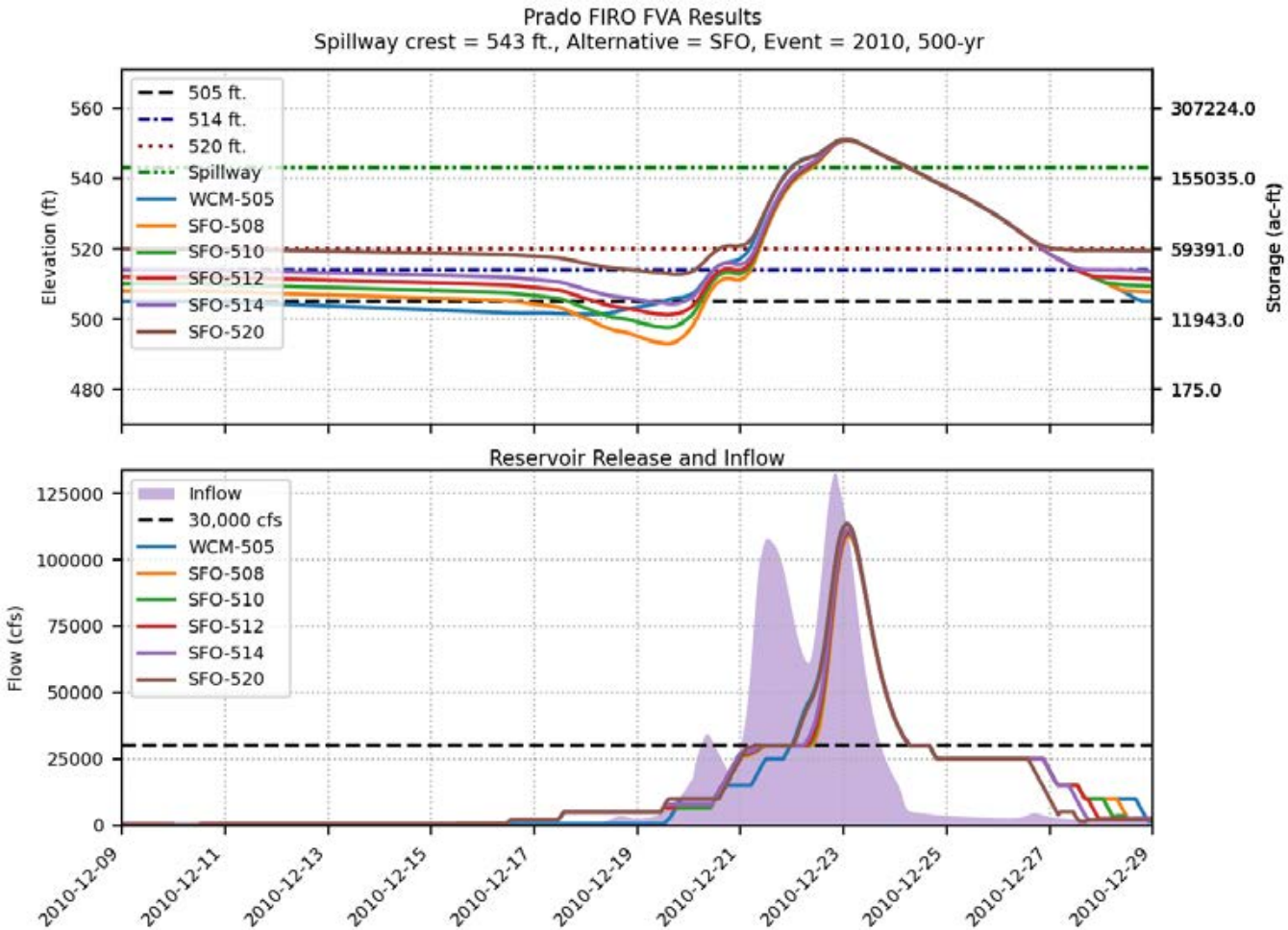
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Elevation (ft)
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Reservoir Release and Inflow
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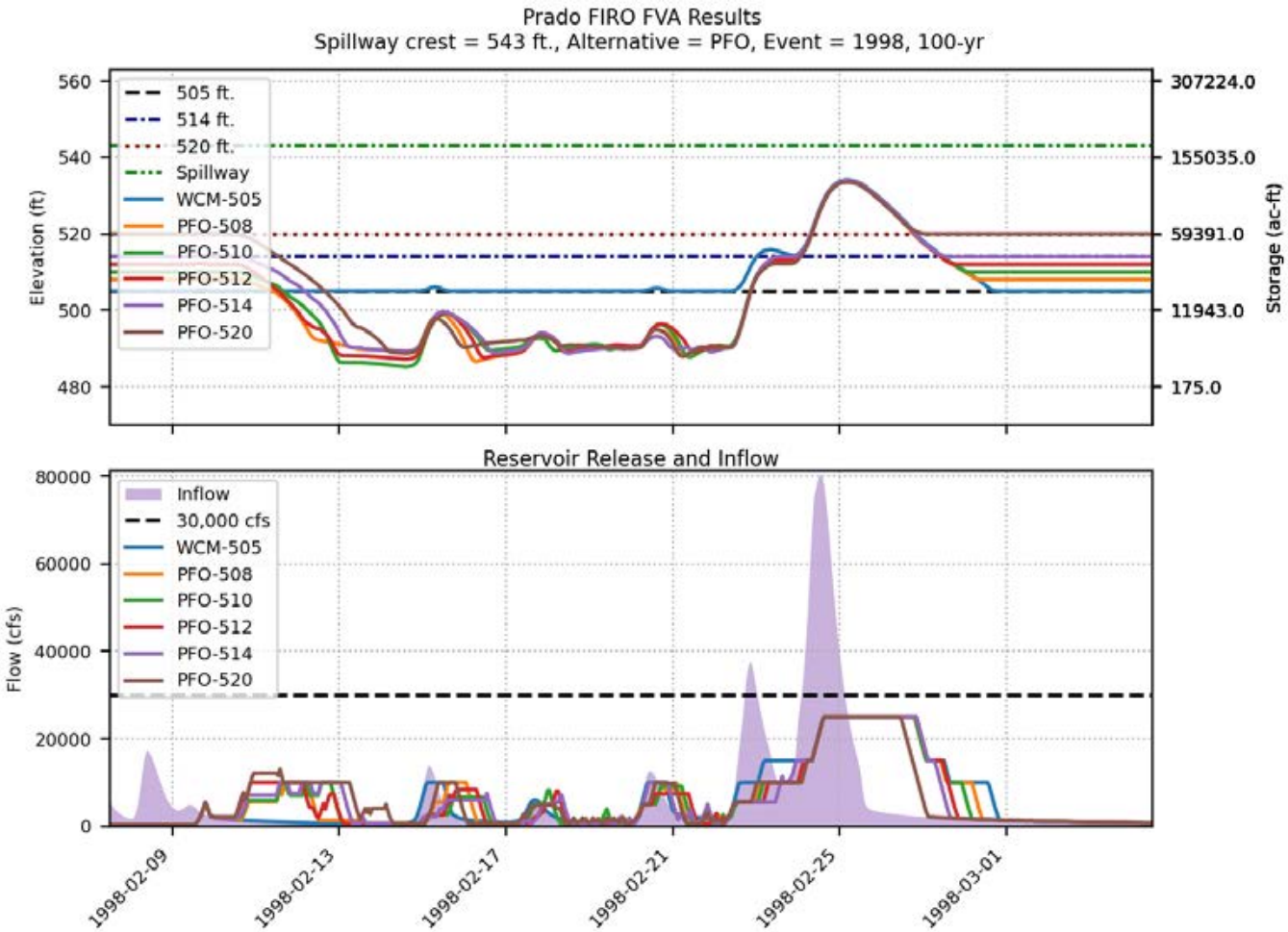
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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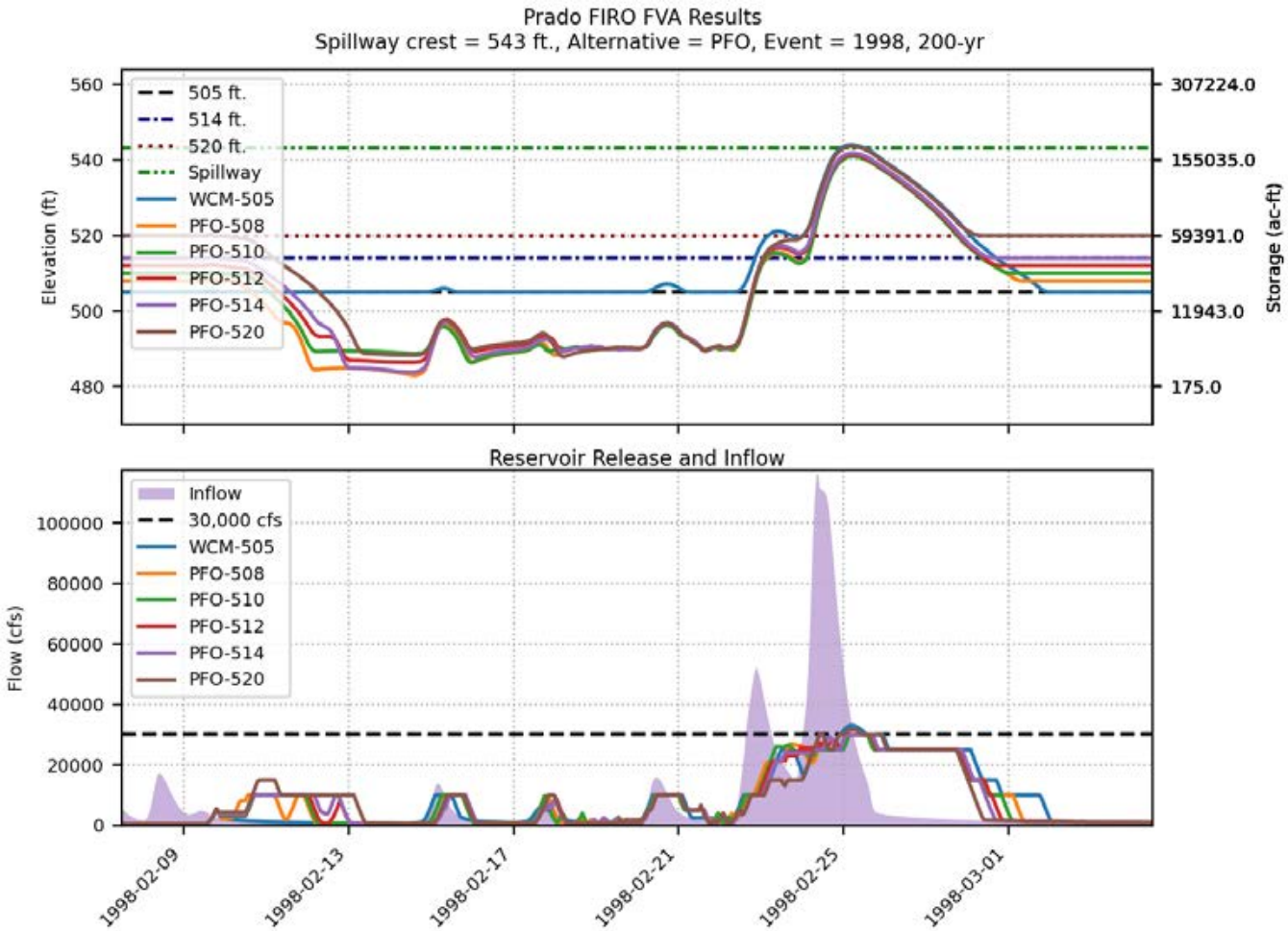
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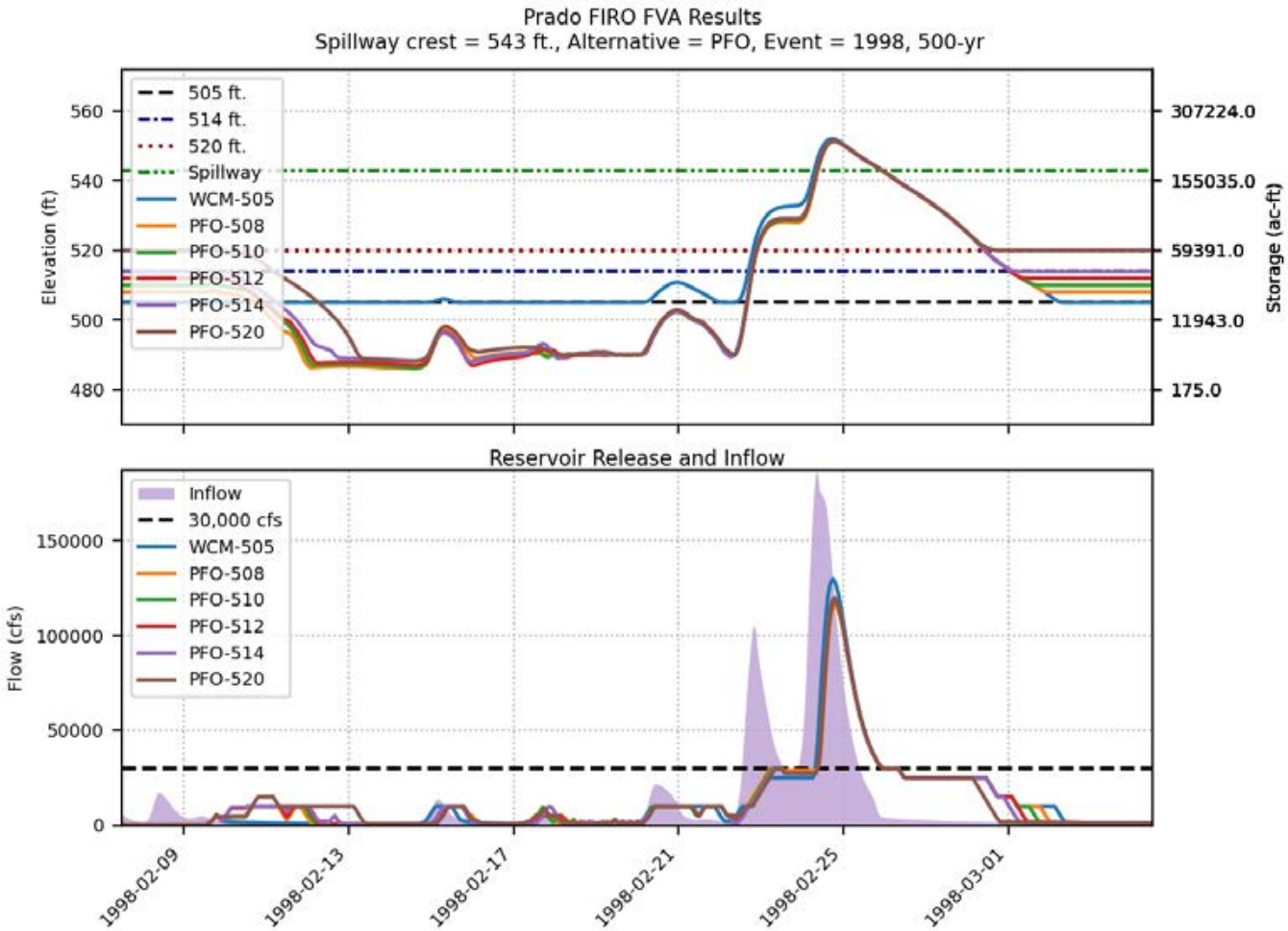
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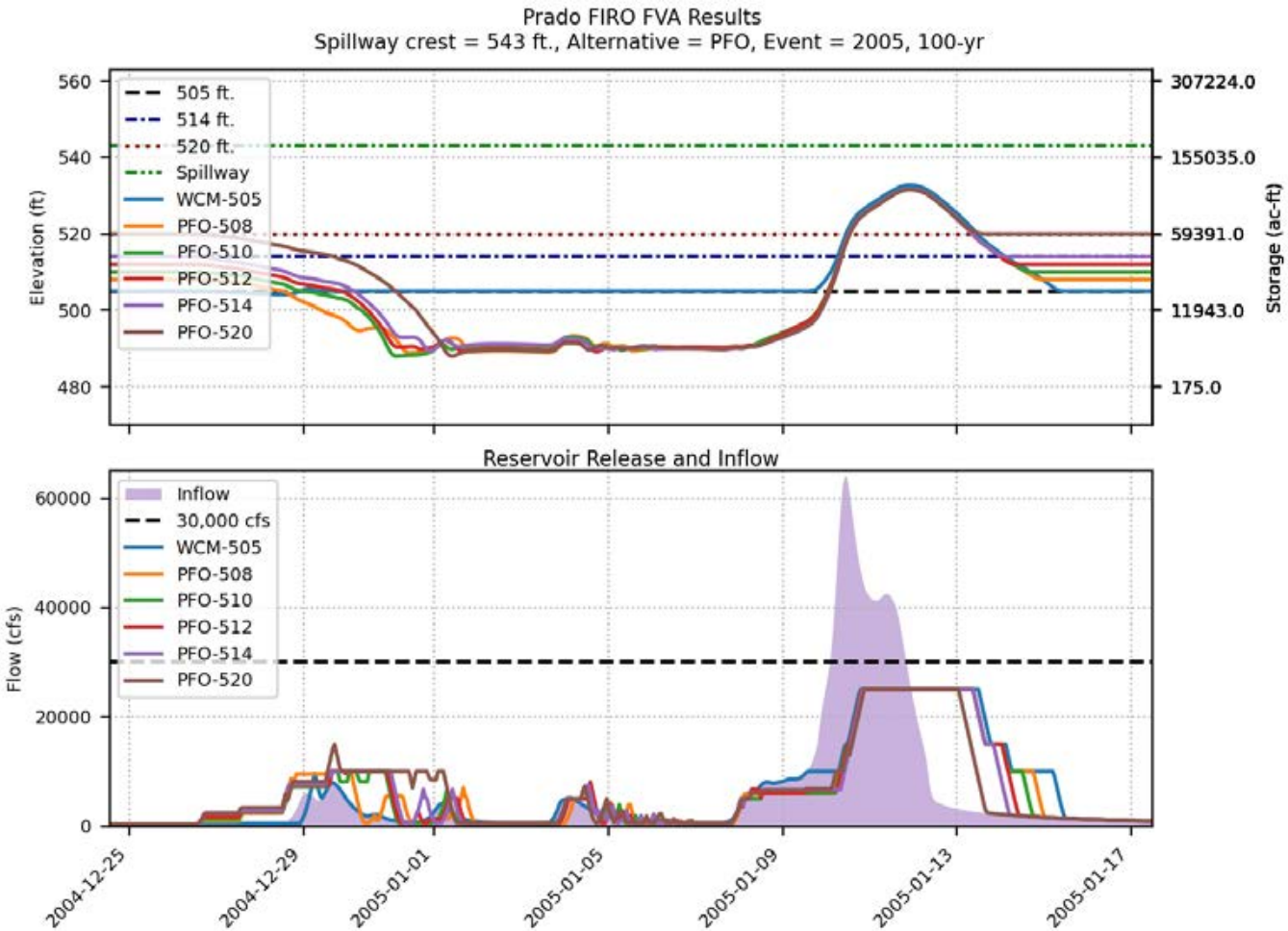
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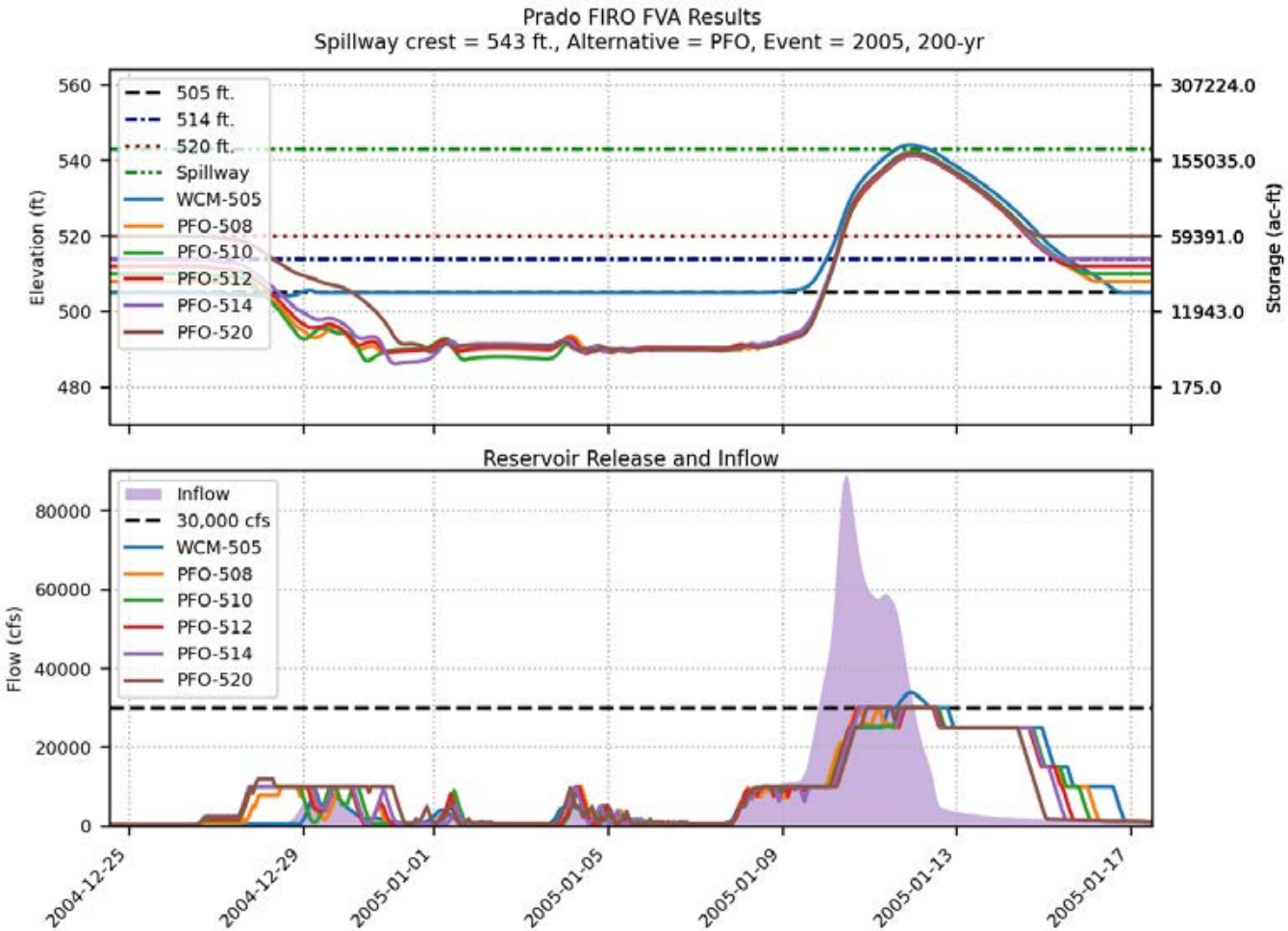
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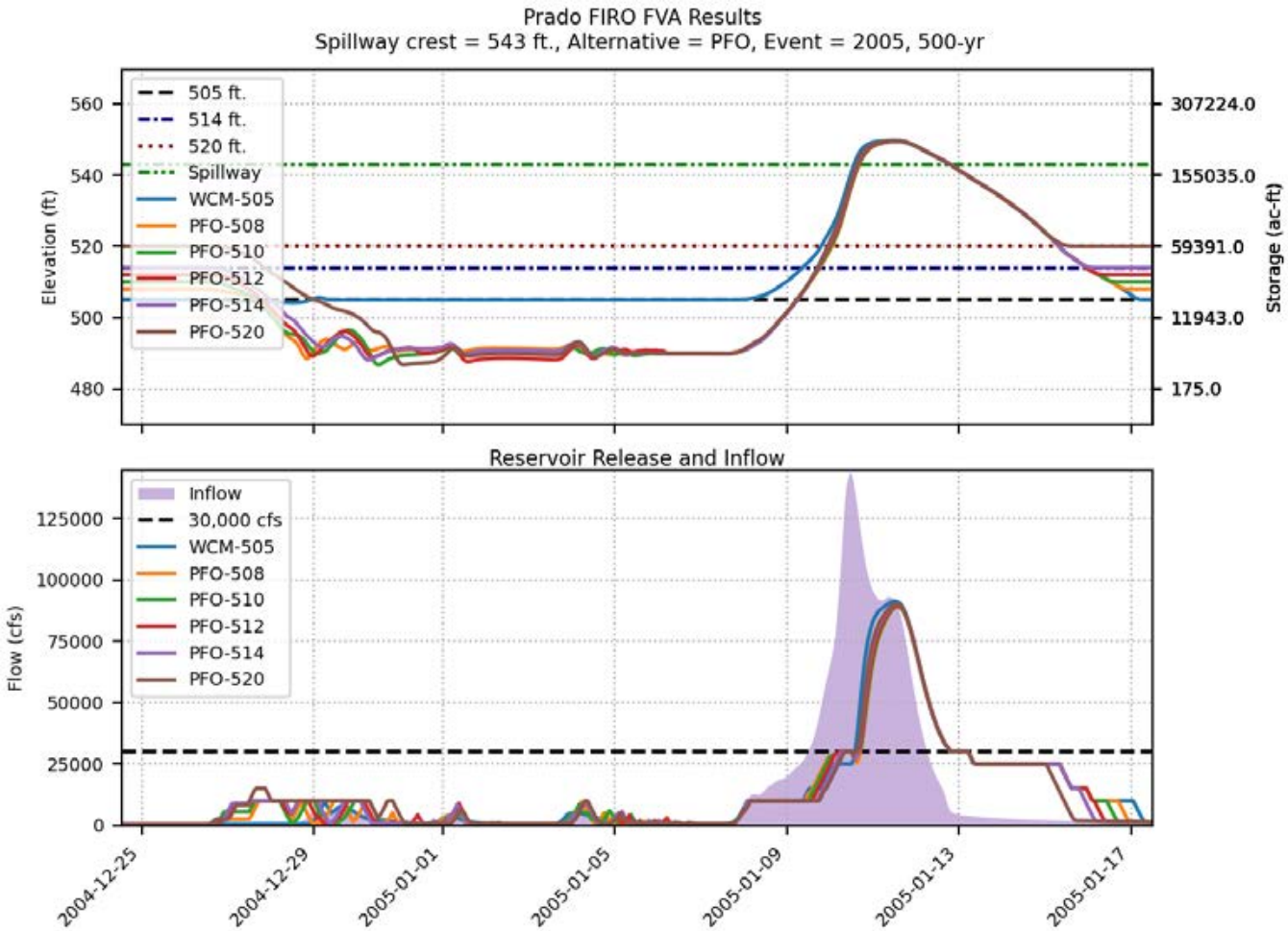
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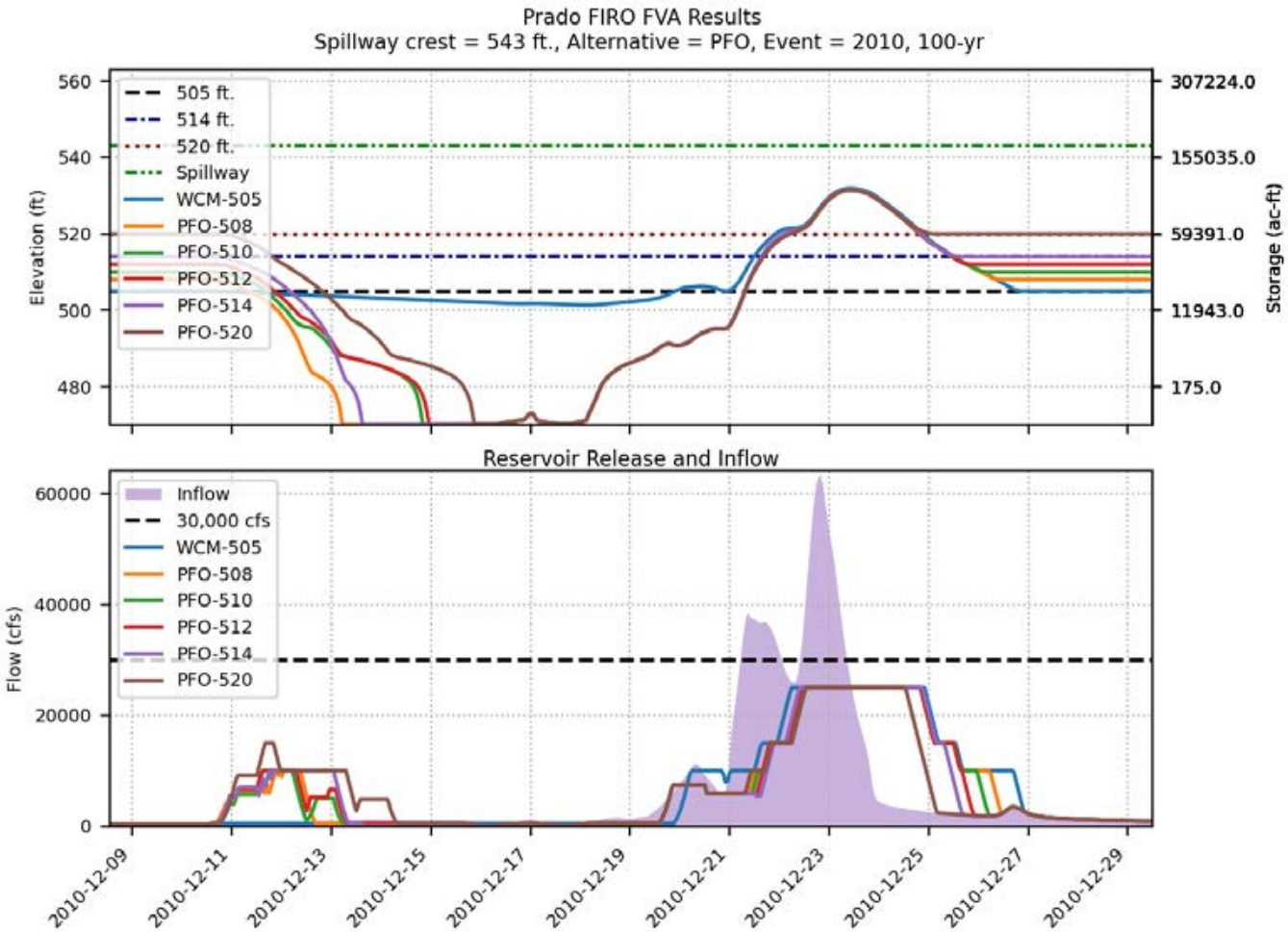
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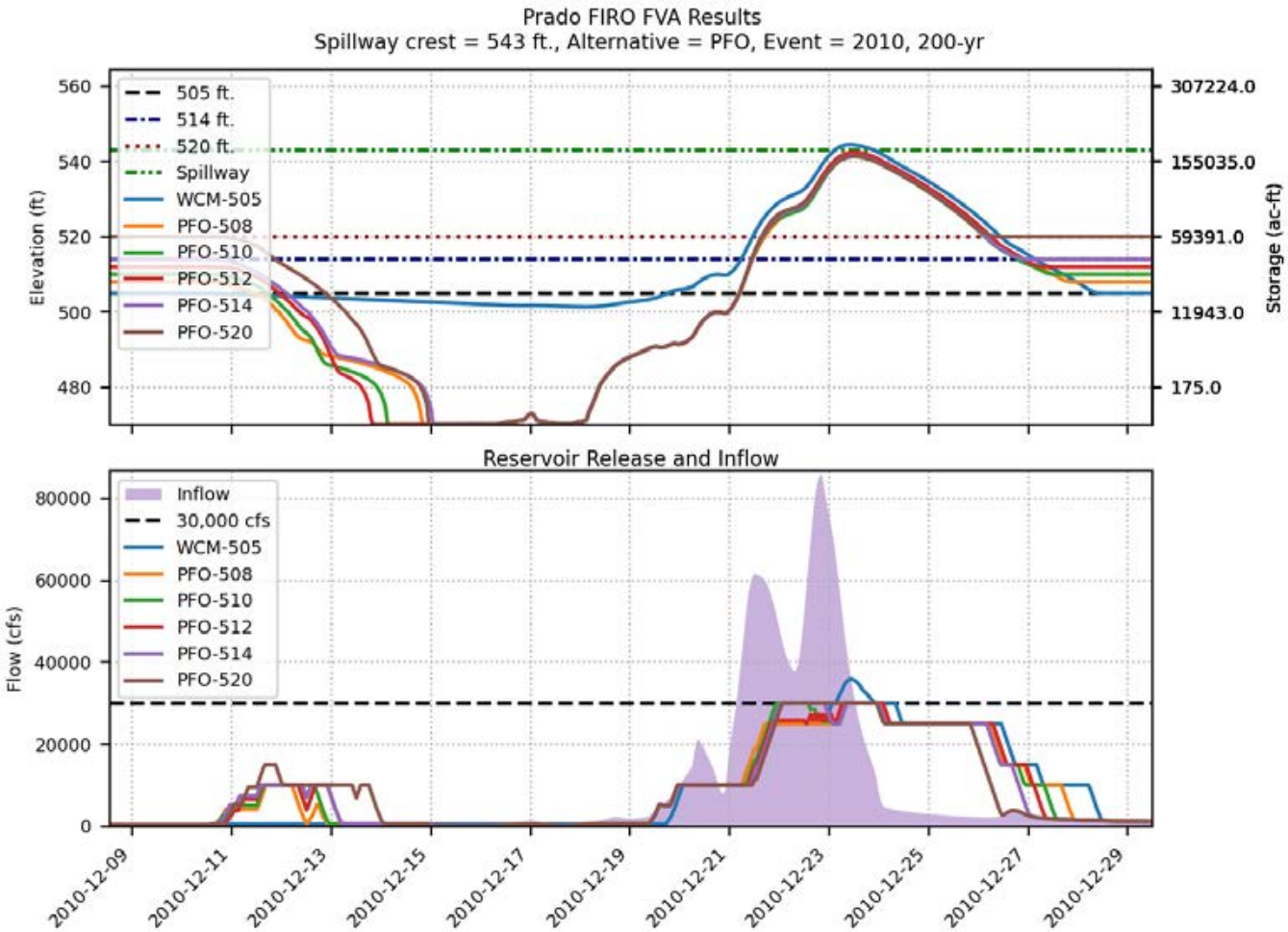
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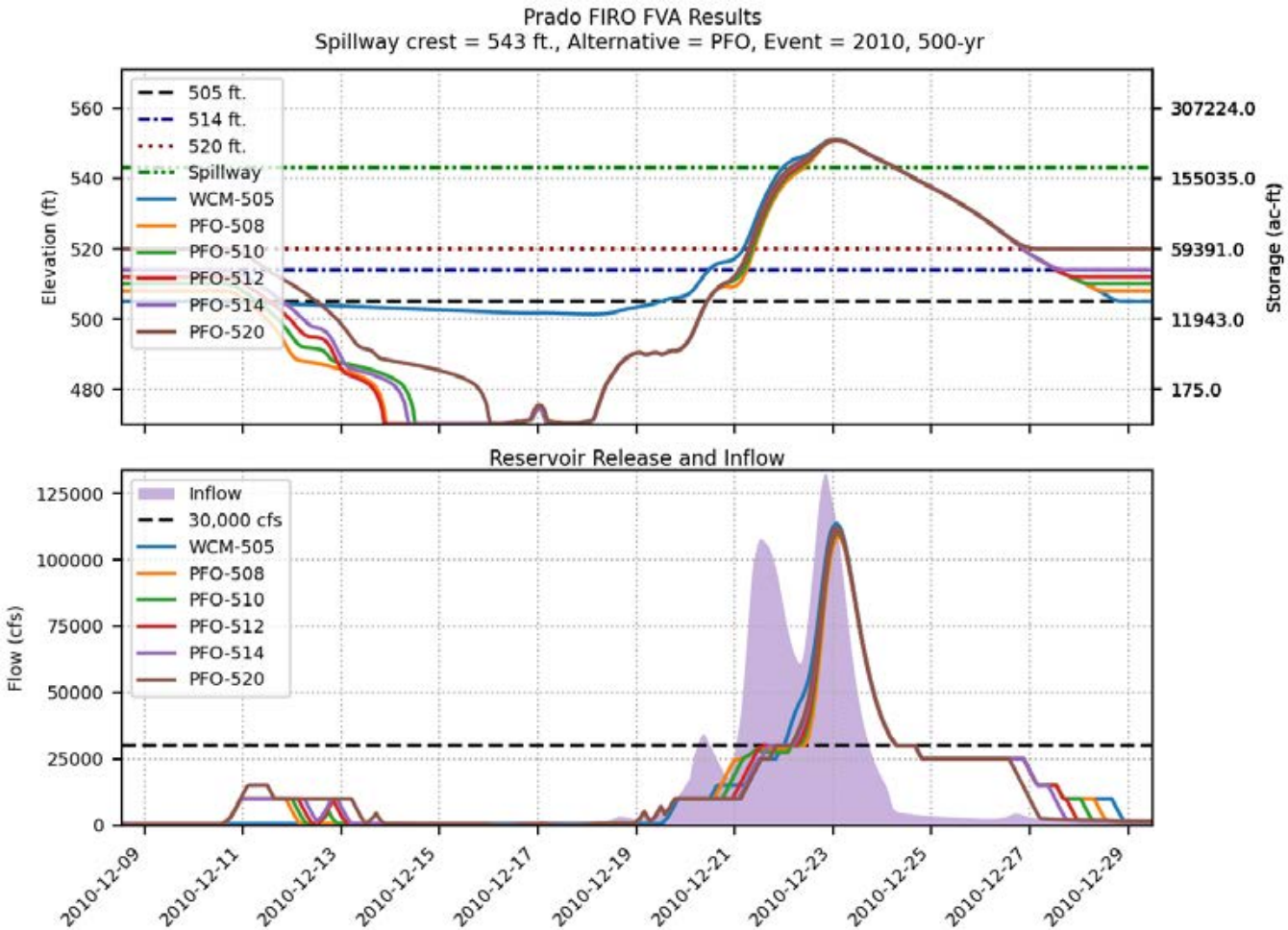
Prado FIRO FVA Results
Spillway crest = 543 ft., Alternative = PFO, Event = 2010, 500-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
PFO-508
PFO-510
PFO-512
PFO-514
PFO-520
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
PFO-508
PFO-510
PFO-512
PFO-514
PFO-520
Flow (cfs)
125000
100000
75000
50000
25000
0
2010-12-09
2010-12-11
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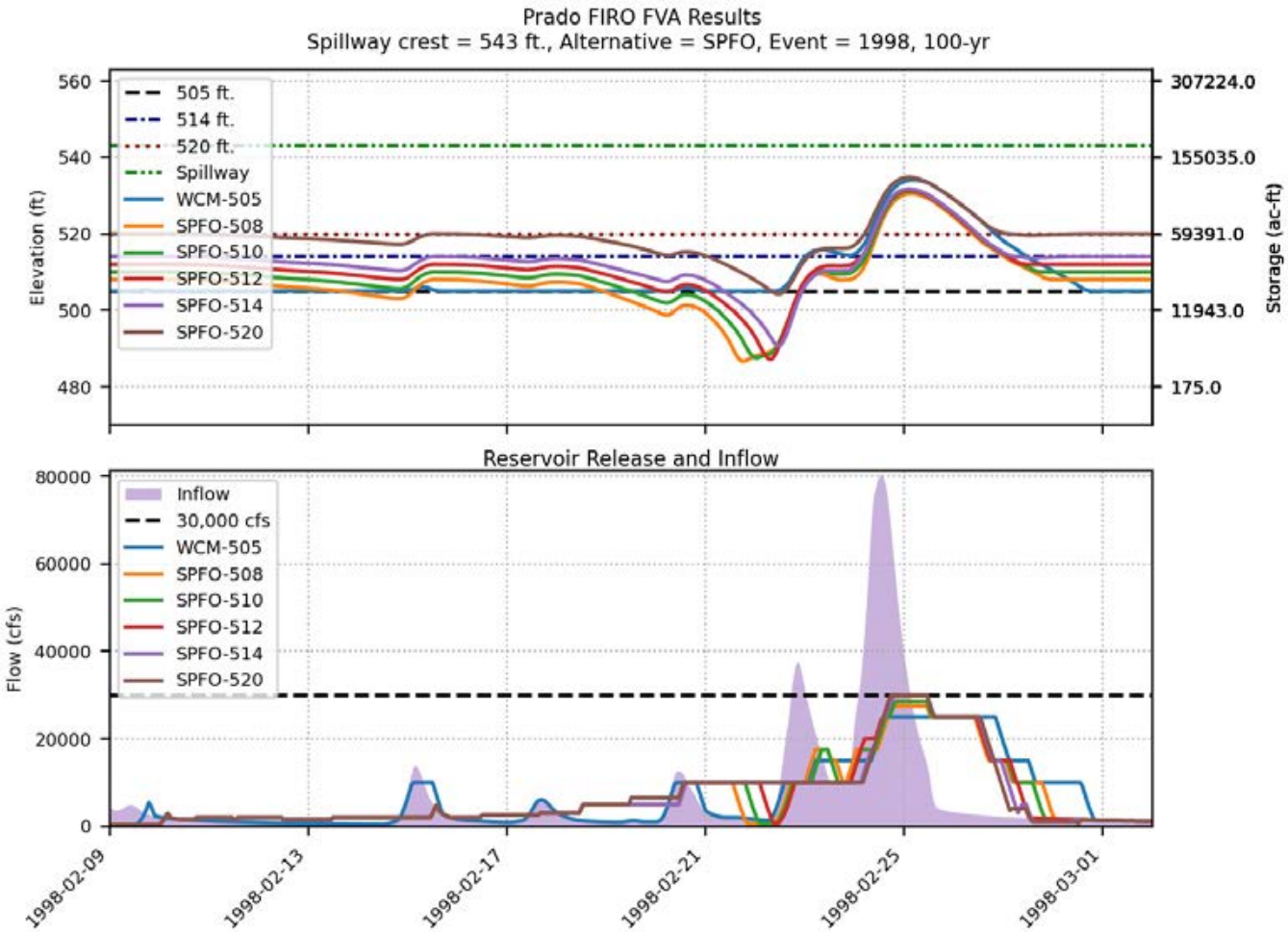
Prado FIRO FVA Results
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505 ft.
514 ft.
520 ft.
Spillway
WCM-505
SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
Flow (cfs)
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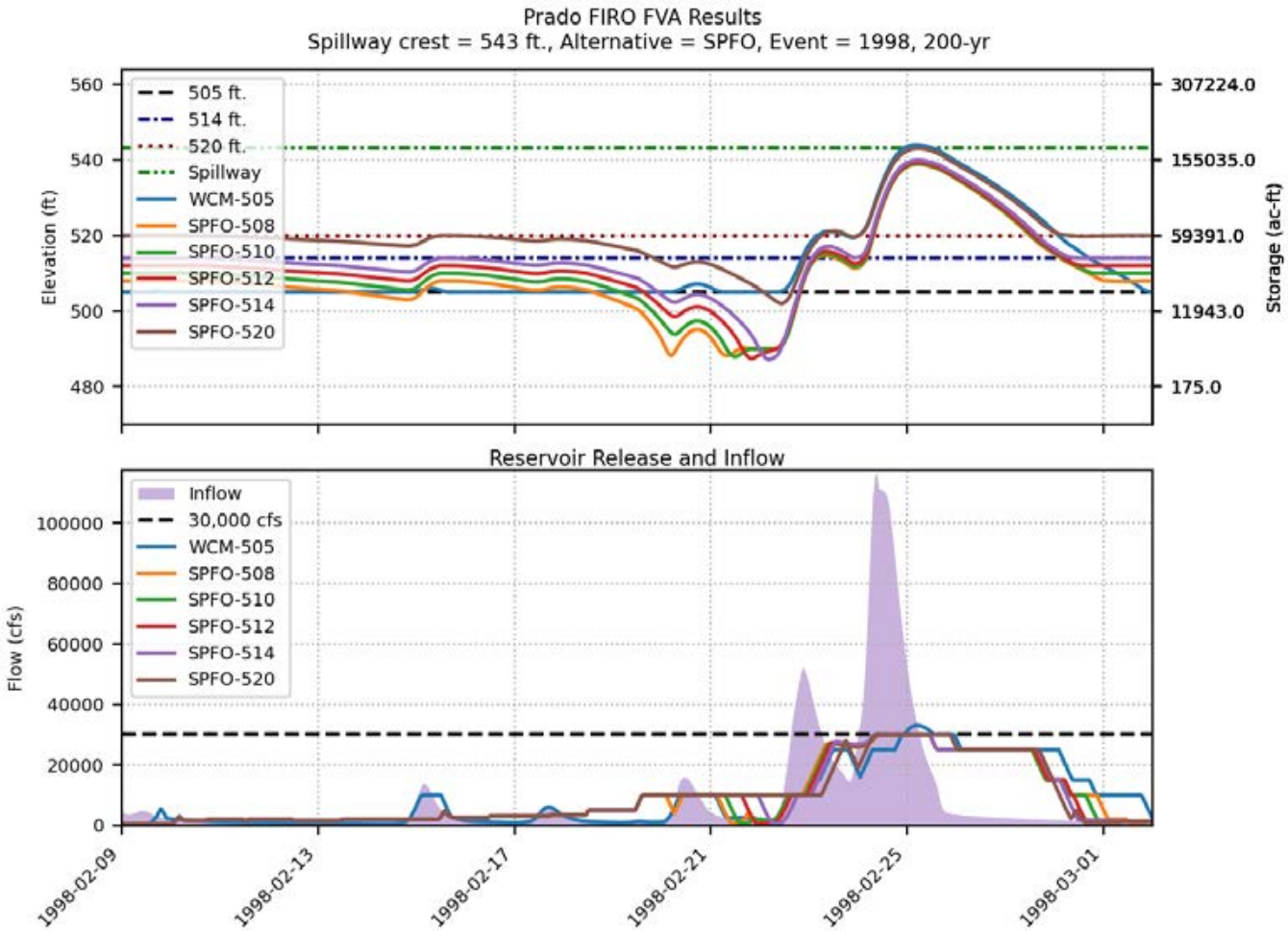
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Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
WCM-505
SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
100000
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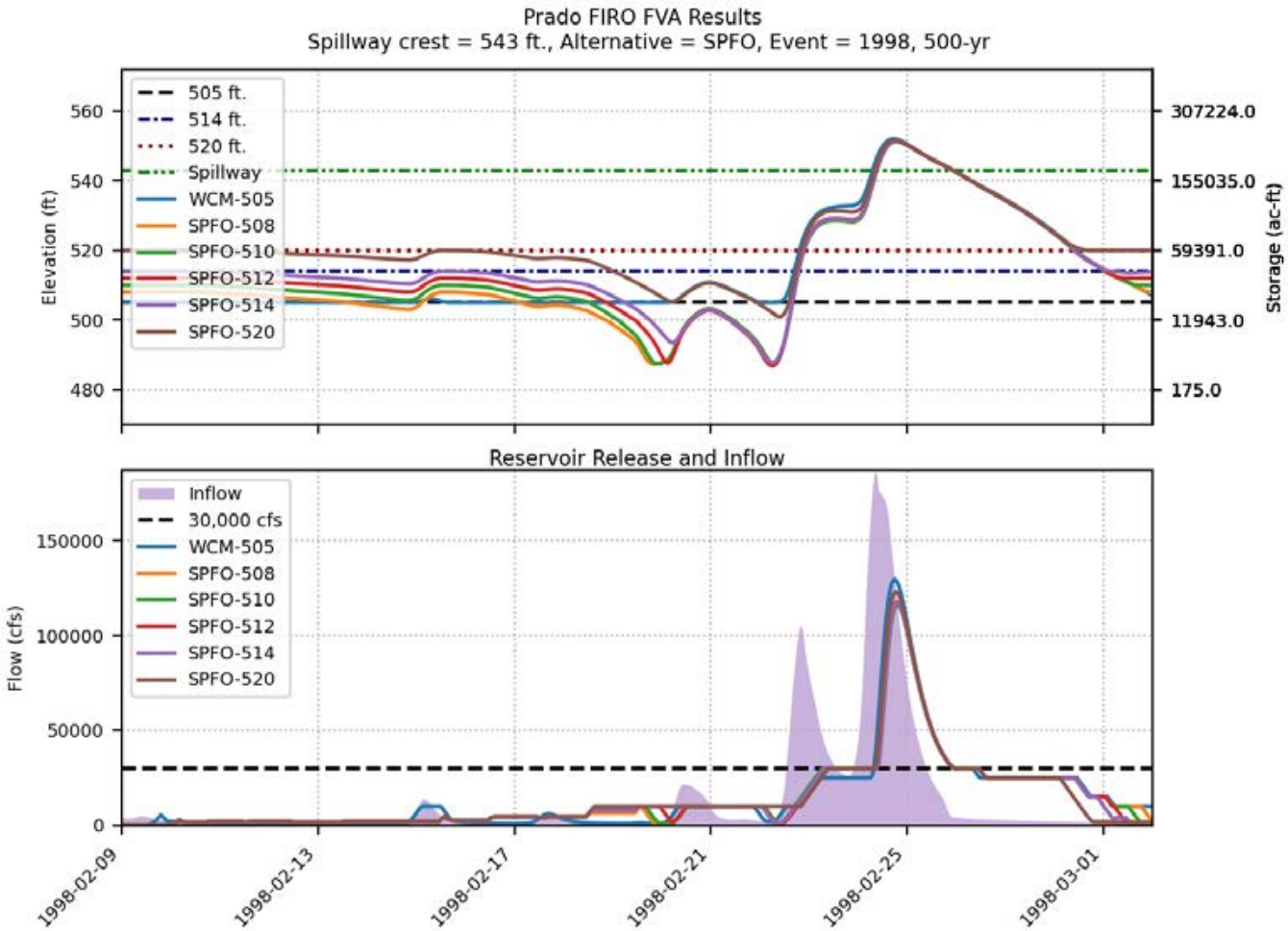
Prado FIRO FVA Results
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505 ft.
514 ft.
520 ft.
Spillway
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SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
Elevation (ft)
Storage (ac-ft)
560
540
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500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
Flow (cfs)
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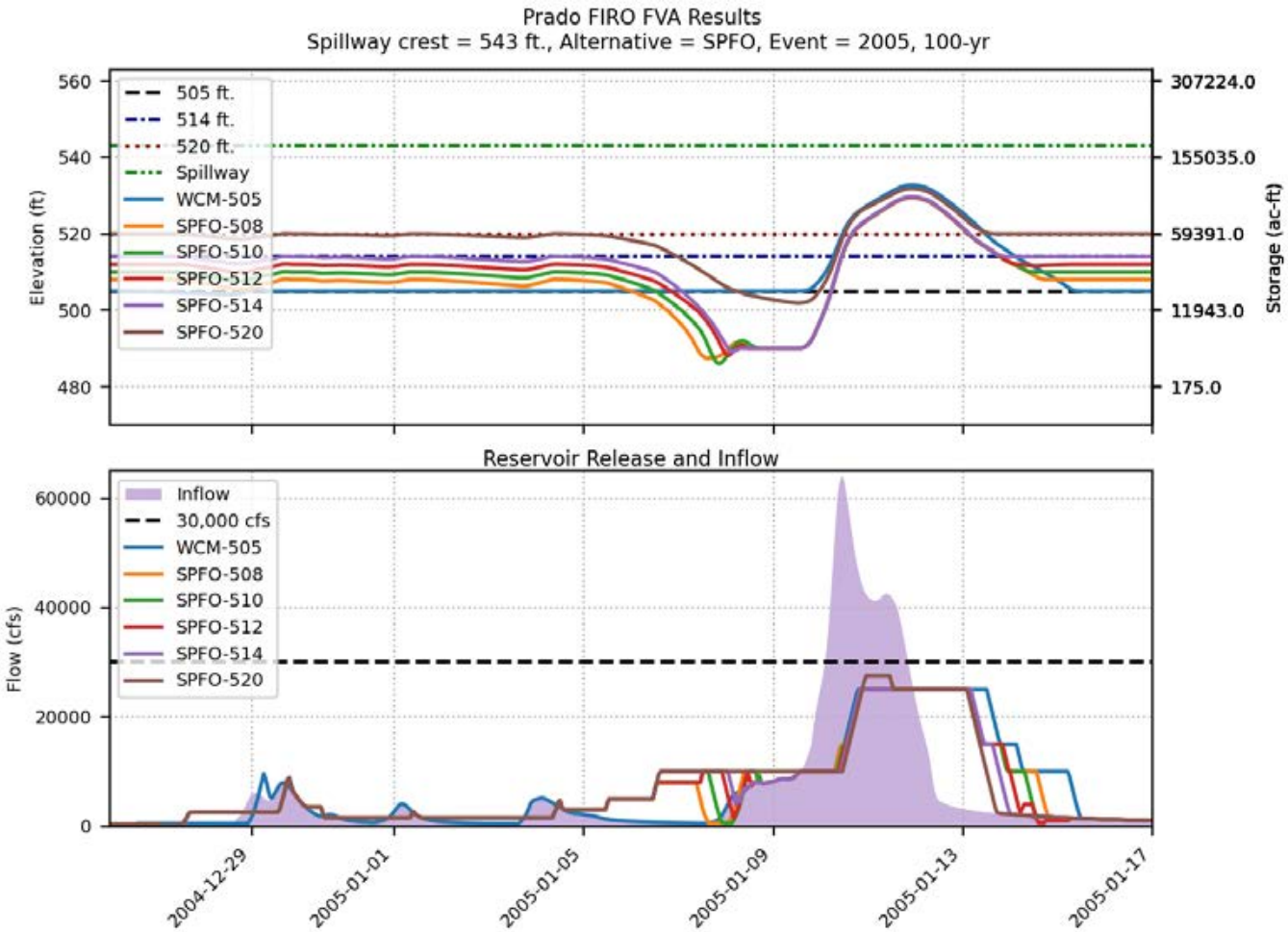
Prado FIRO FVA Results
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505 ft.
514 ft.
520 ft.
Spillway
WCM-505
SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
Elevation (ft)
Storage (ac-ft)
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500
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307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
Flow (cfs)
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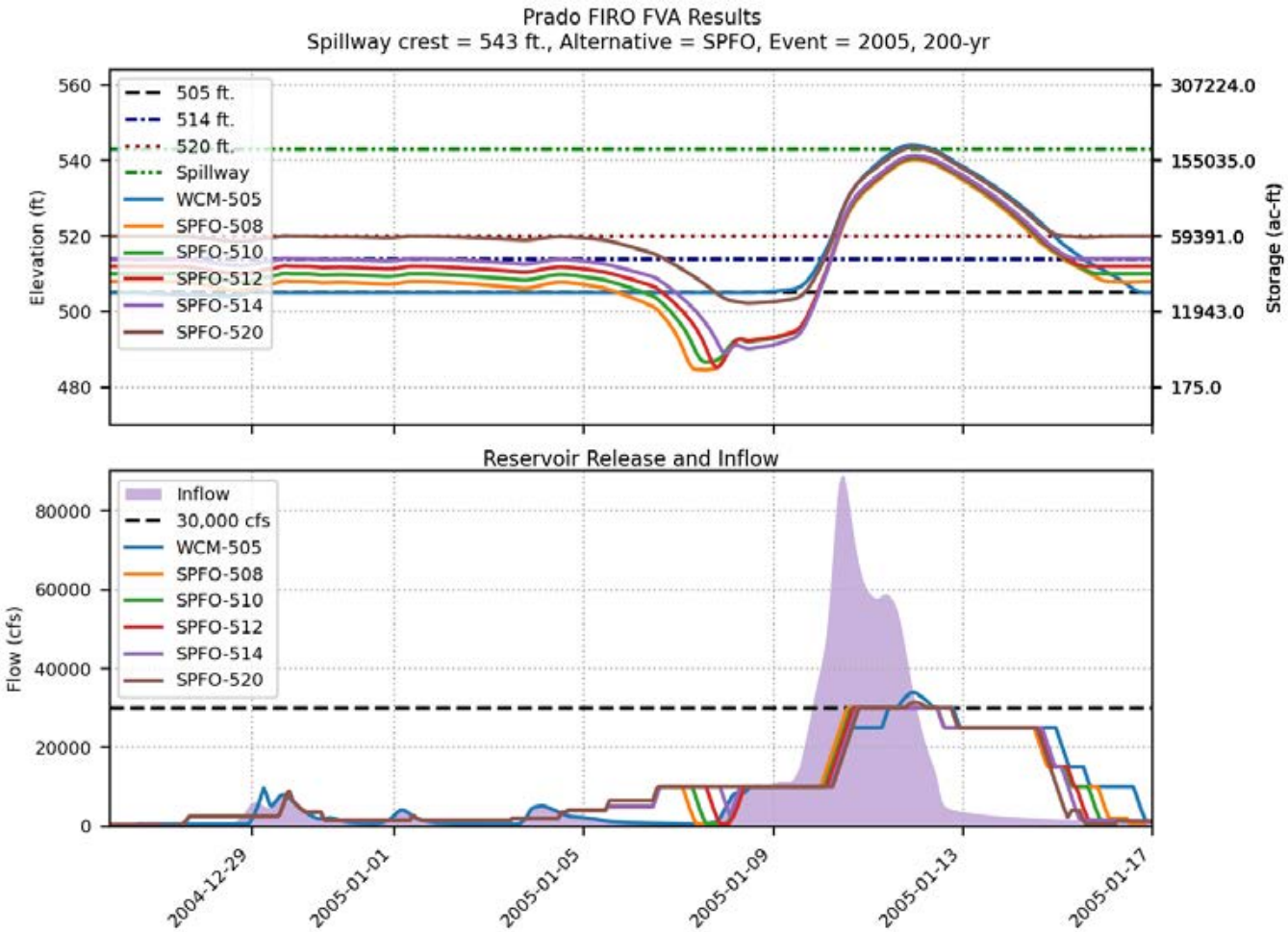
Prado FIRO FVA Results
Spillway crest = 543 ft., Alternative = SPFO, Event = 2005, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
Elevation (ft)
Storage (ac-ft)
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307224.0
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59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
Flow (cfs)
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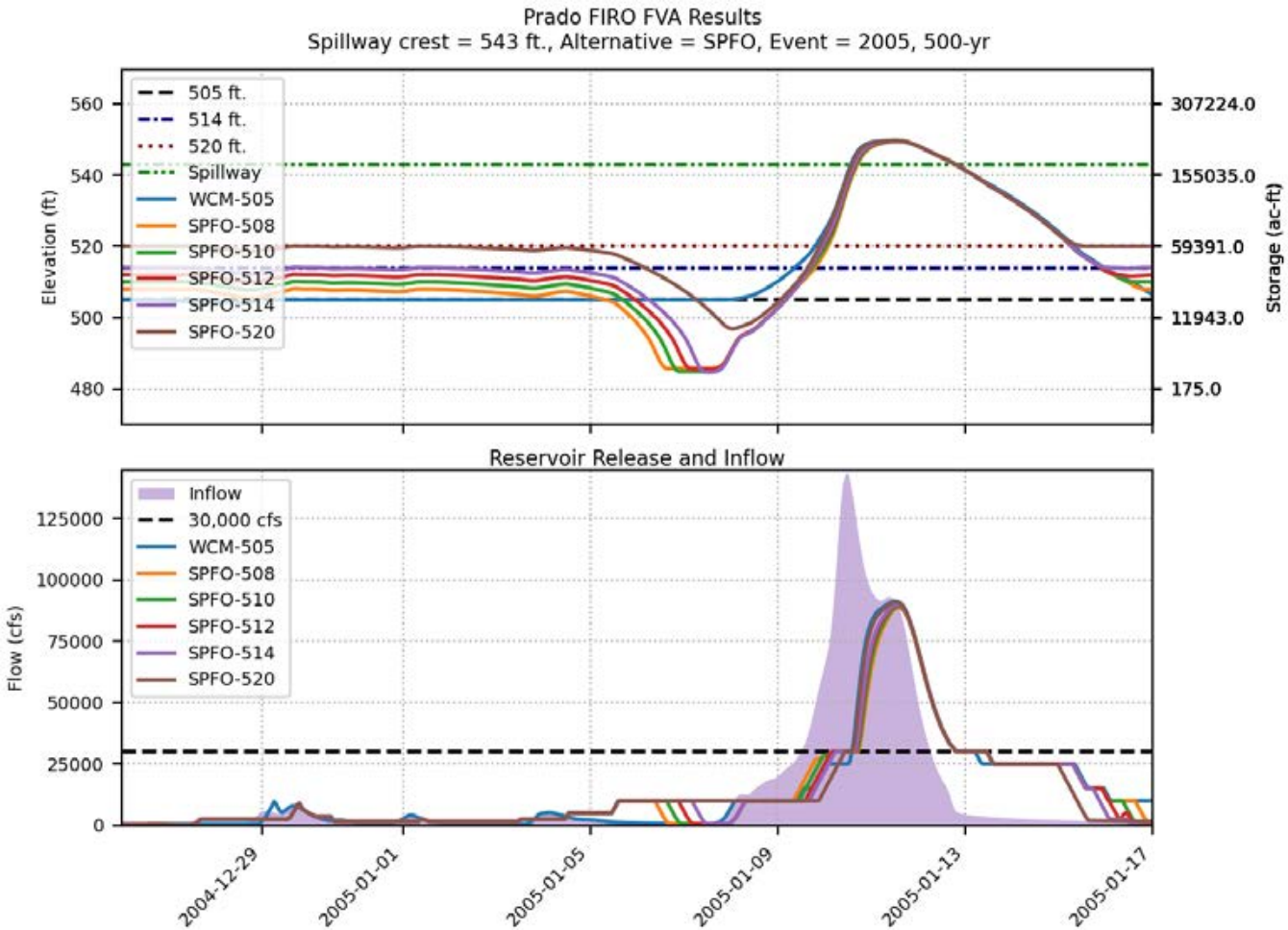
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Spillway crest = 543 ft., Alternative = SPFO, Event = 2005, 500-yr
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520 ft.
Spillway
WCM-505
SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
Elevation (ft)
Storage (ac-ft)
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500
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307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
Flow (cfs)
125000
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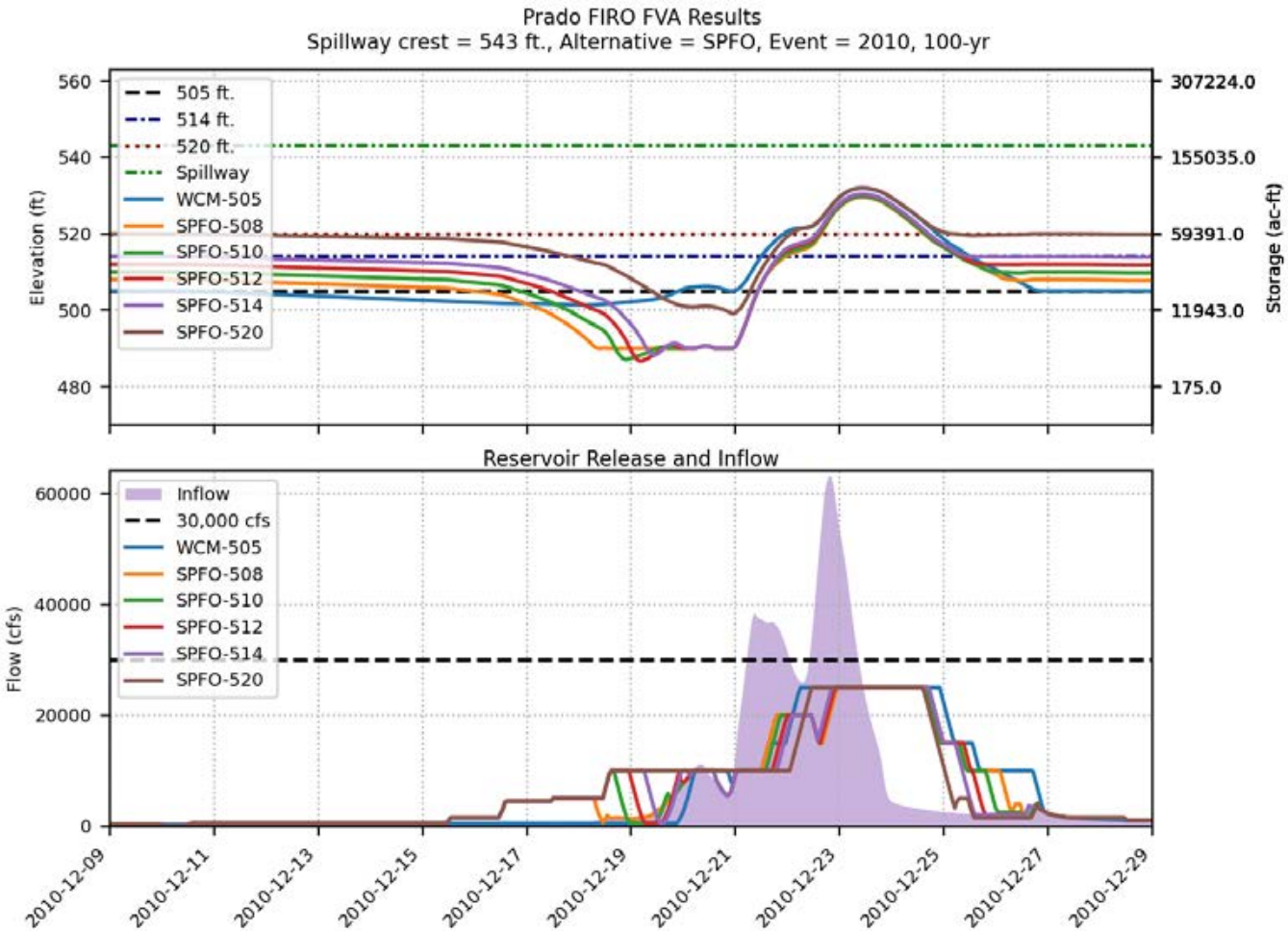
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Spillway crest = 543 ft., Alternative = SPFO, Event = 2010, 100-yr
Elevation (ft)
Storage (ac-ft)
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514 ft.
520 ft.
Spillway
WCM-505
SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
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307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
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SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
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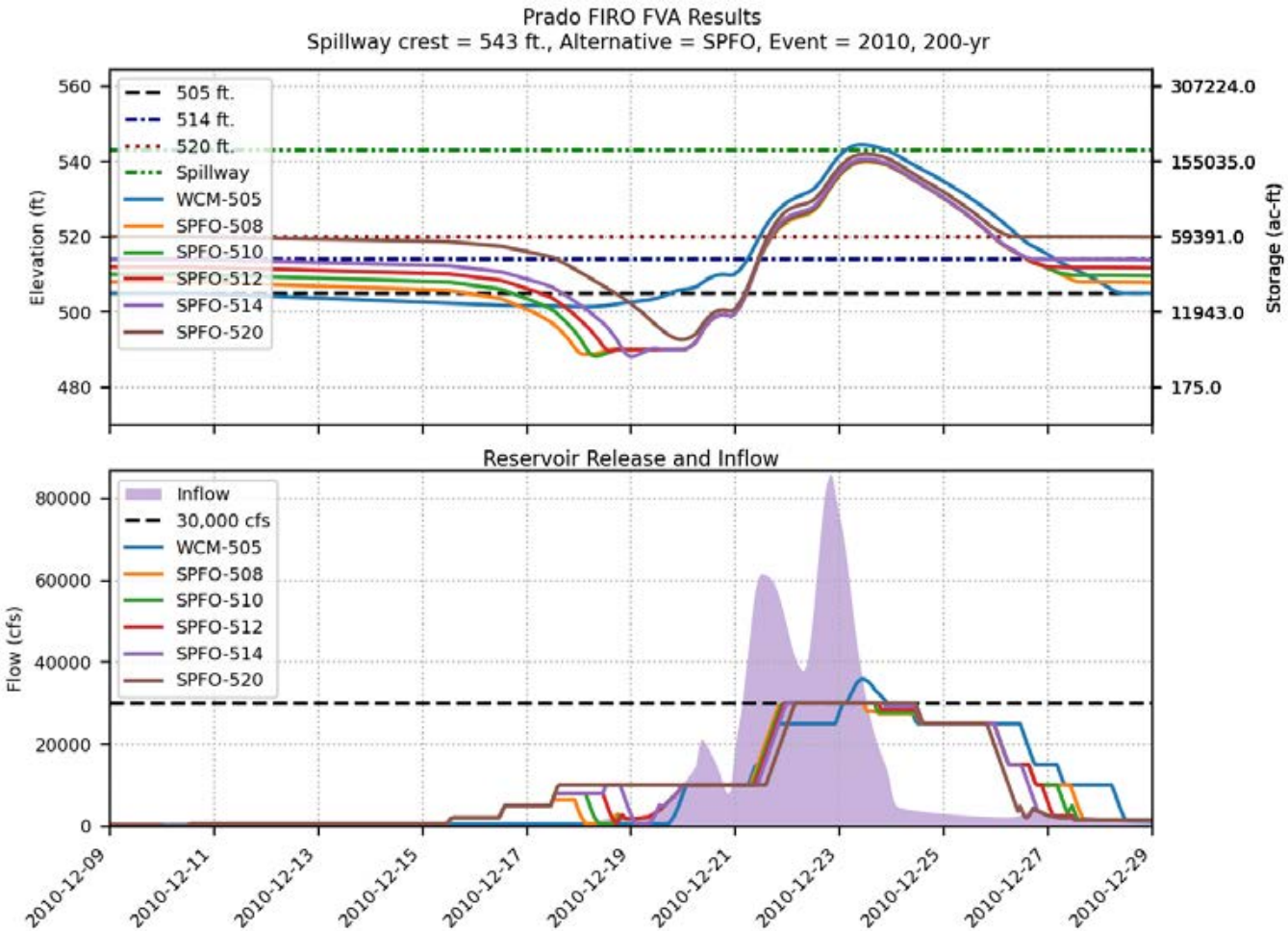
Prado FIRO FVA Results
Spillway crest = 543 ft., Alternative = SPFO, Event = 2010, 200-yr
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514 ft.
520 ft.
Spillway
WCM-505
SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
Elevation (ft)
Storage (ac-ft)
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500
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307224.0
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59391.0
11943.0
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Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
Flow (cfs)
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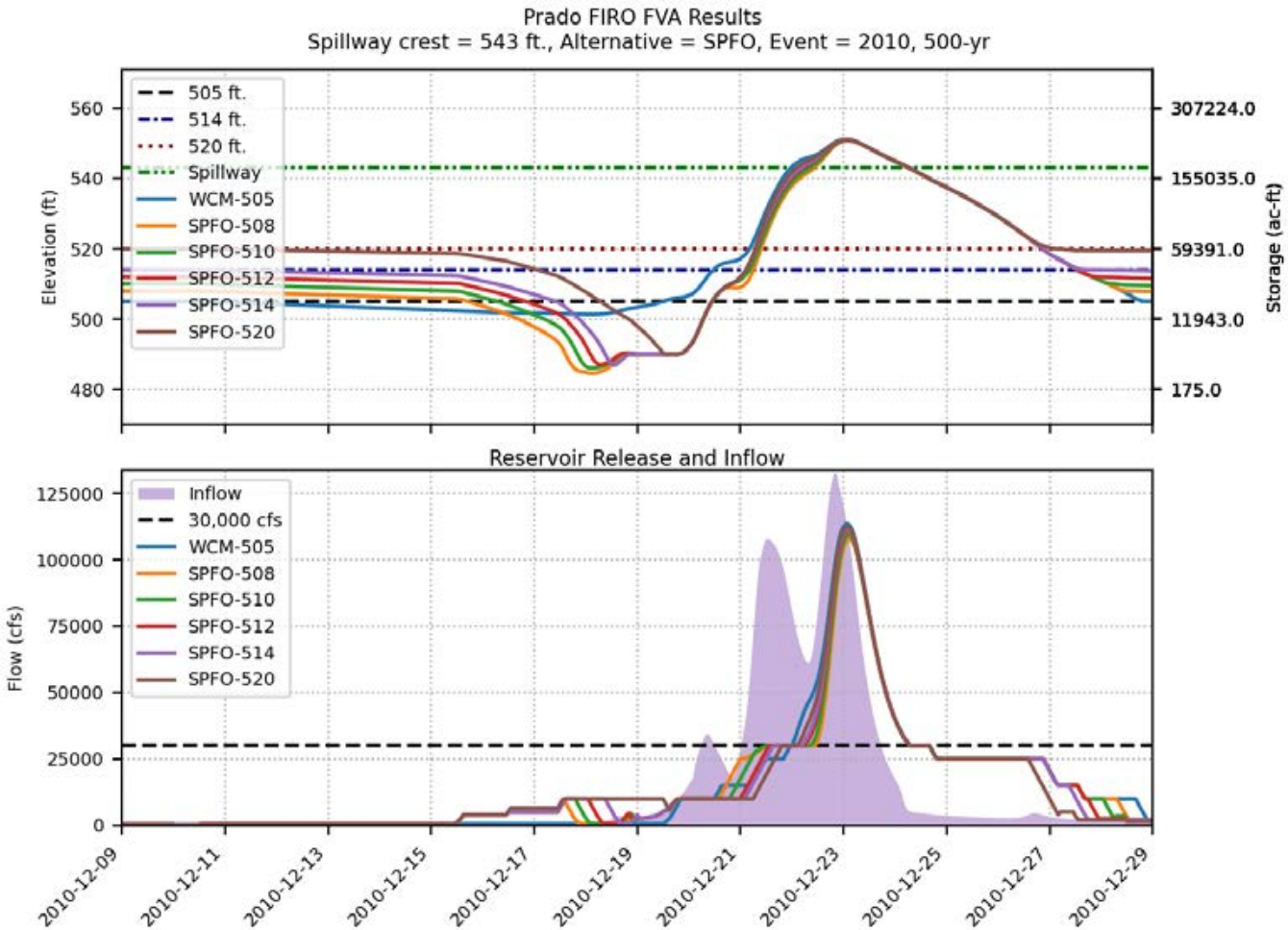
Prado FIRO FVA Results
Spillway crest = 543 ft., Alternative = SPFO, Event = 2010, 500-yr
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514 ft.
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Spillway
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SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
Elevation (ft)
Storage (ac-ft)
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520
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307224.0
155035.0
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Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
SPFO-508
SPFO-510
SPFO-512
SPFO-514
SPFO-520
Flow (cfs)
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75000
50000
25000
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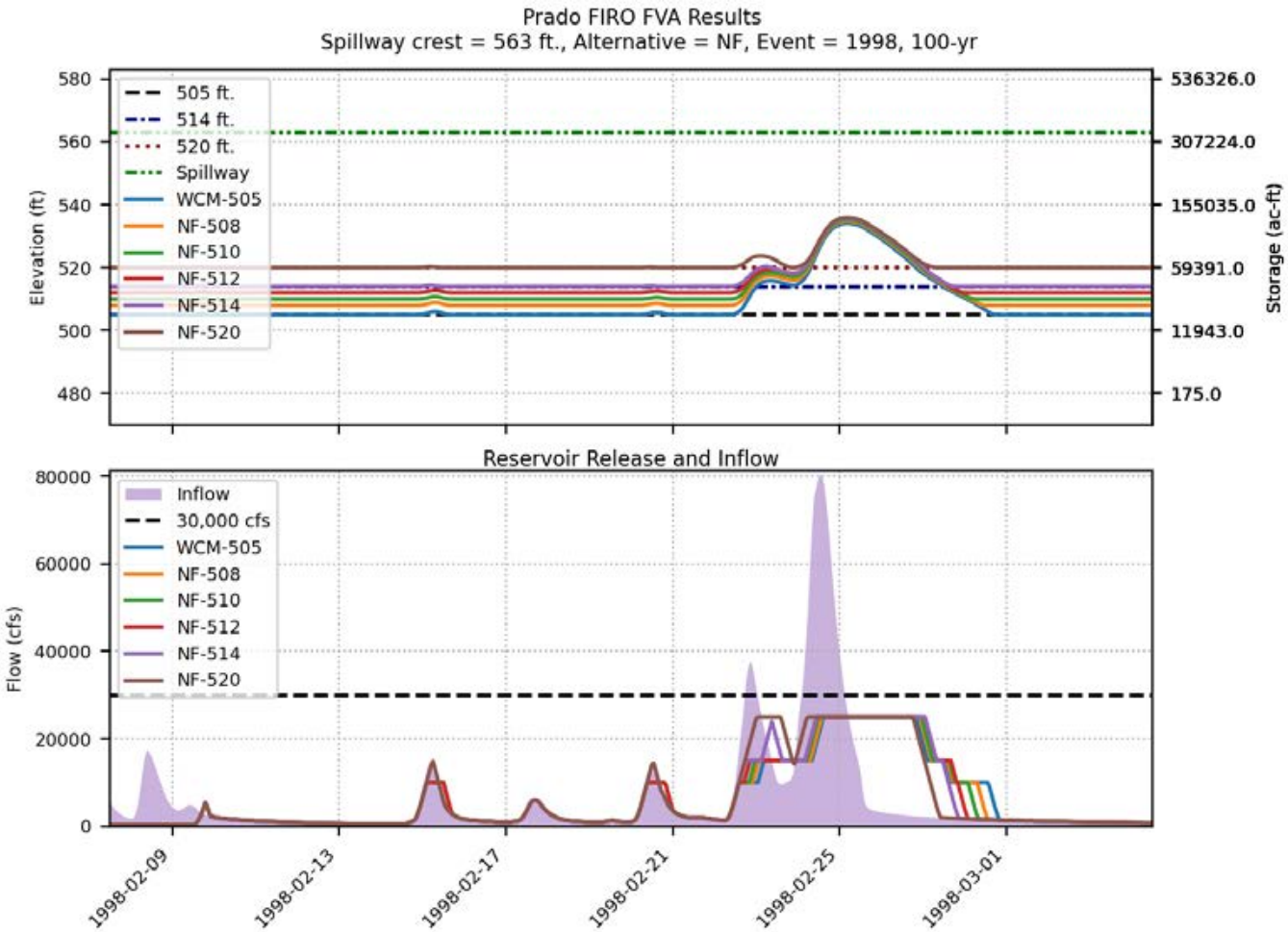
Prado FIRO FVA Results
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Elevation (ft)
Storage (ac-ft)
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514 ft.
520 ft.
Spillway
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
580
560
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520
500
480
536326.0
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59391.0
11943.0
175.0
Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
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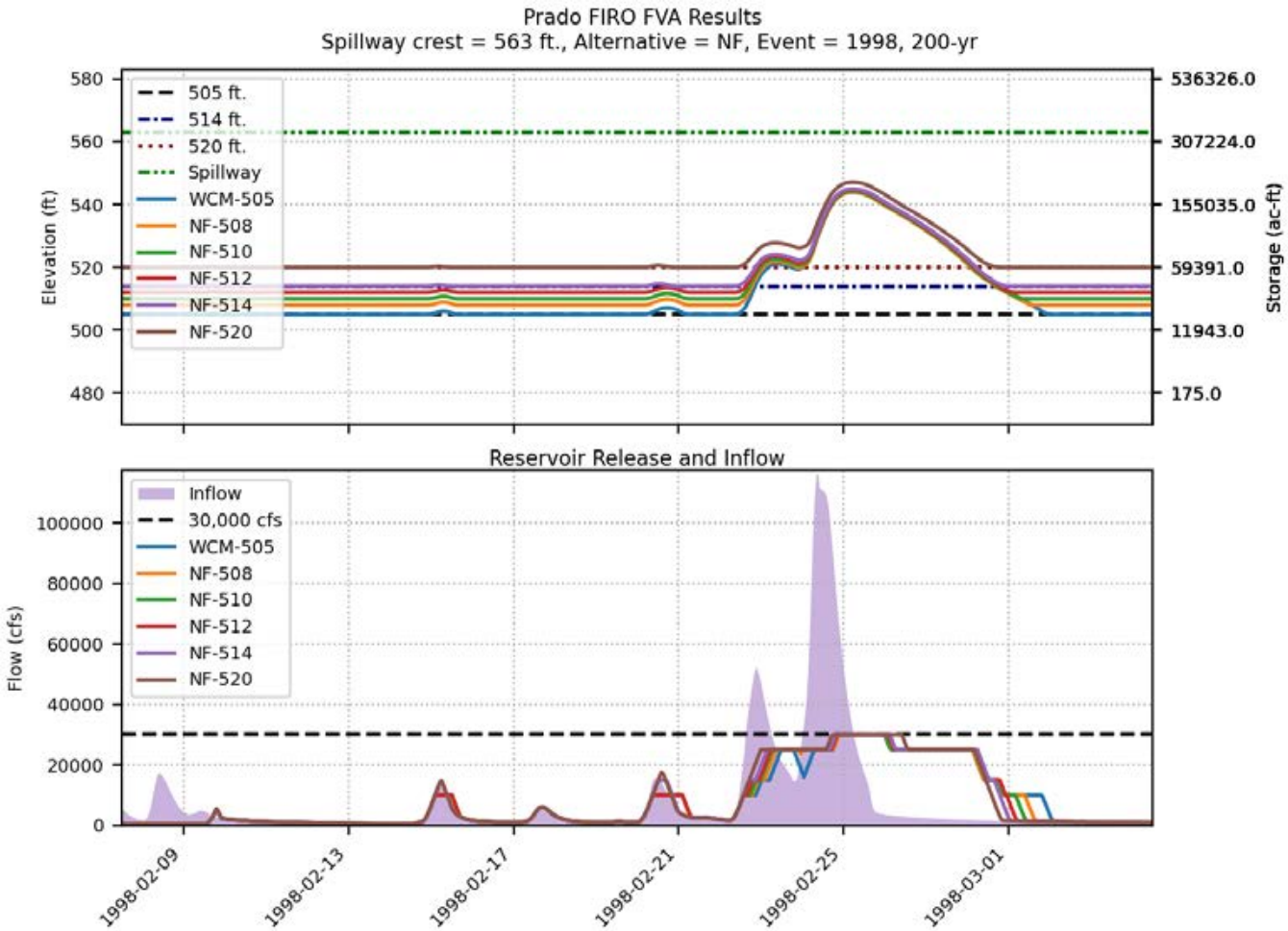
Prado FIRO FVA Results
Spillway crest = 563 ft., Alternative = NF, Event = 1998, 200-yr
Elevation (ft)
Storage (ac-ft)
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514 ft.
520 ft.
Spillway
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
580
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540
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11943.0
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Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
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NF-508
NF-510
NF-512
NF-514
NF-520
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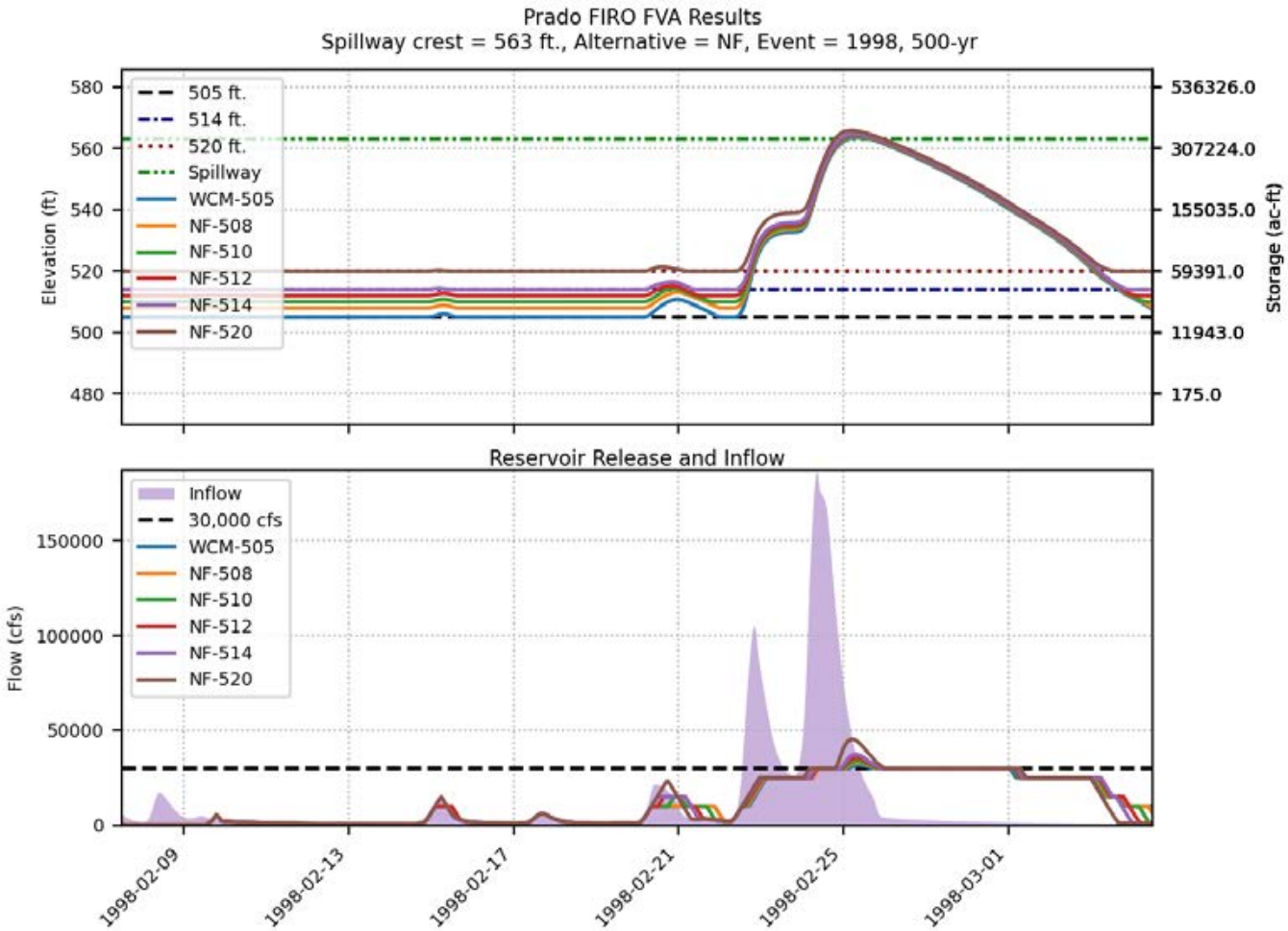
Prado FIRO FVA Results
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514 ft.
520 ft.
Spillway
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NF-508
NF-510
NF-512
NF-514
NF-520
Elevation (ft)
Storage (ac-ft)
580
560
540
520
500
480
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155035.0
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175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Flow (cfs)
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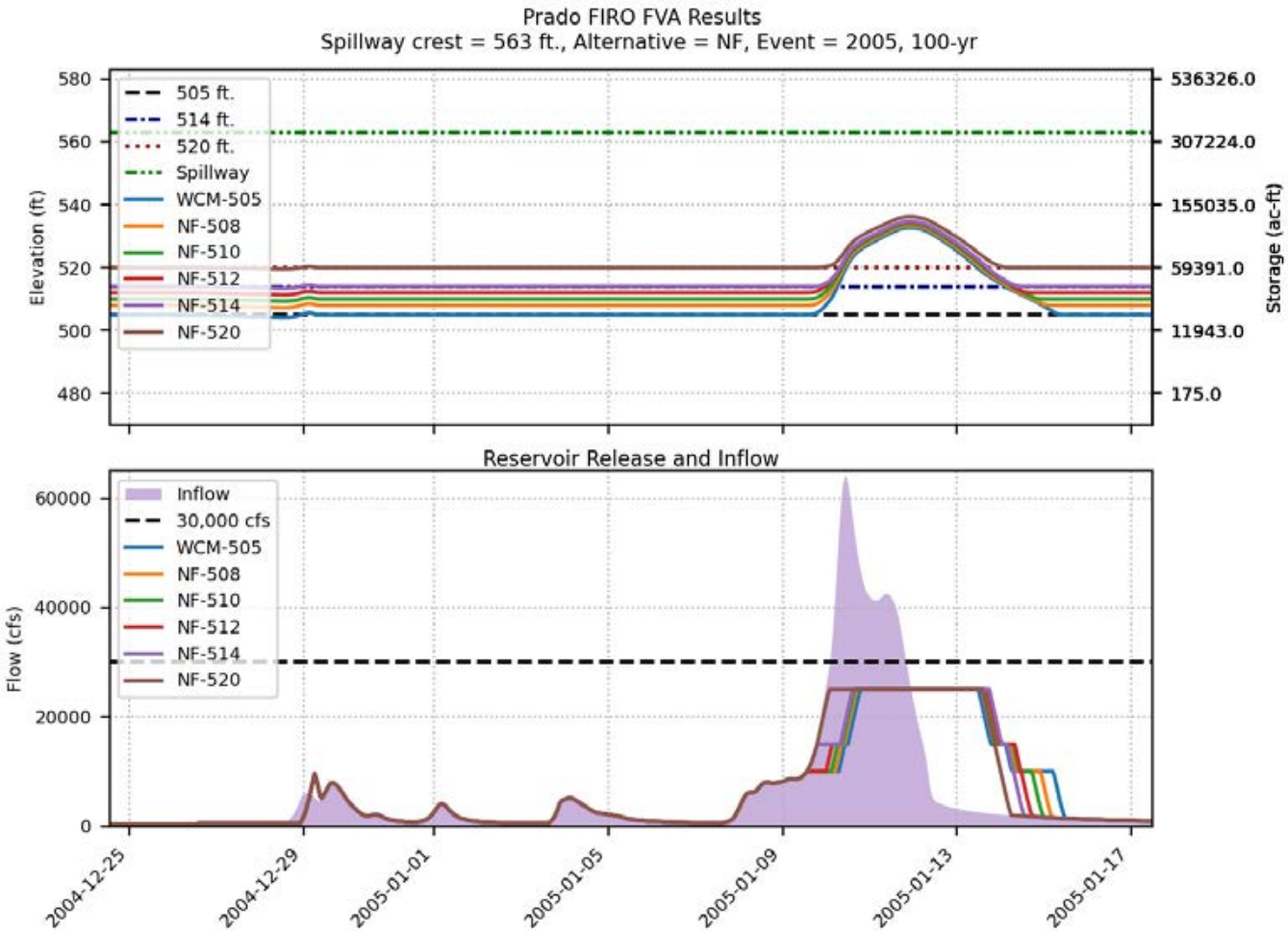
Prado FIRO FVA Results
Spillway crest = 563 ft., Alternative = NF, Event = 2005, 100-yr
Elevation (ft)
Storage (ac-ft)
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514 ft.
520 ft.
Spillway
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
580
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540
520
500
480
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155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Flow (cfs)
Inflow
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NF-508
NF-510
NF-512
NF-514
NF-520
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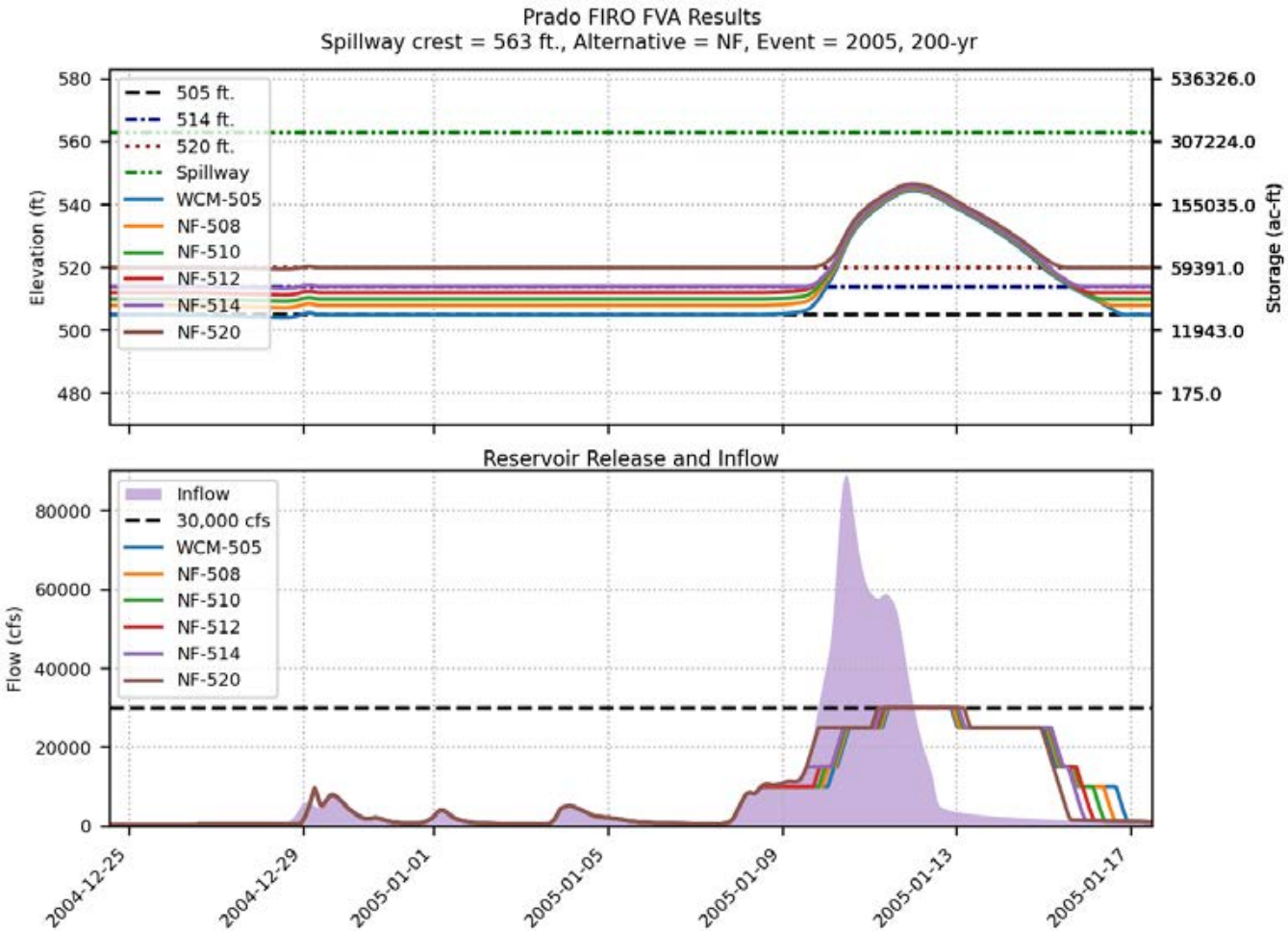
Prado FIRO FVA Results
Spillway crest = 563 ft., Alternative = NF, Event = 2005, 200-yr
Elevation (ft)
Storage (ac-ft)
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514 ft.
520 ft.
Spillway
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
580
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500
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155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
80000
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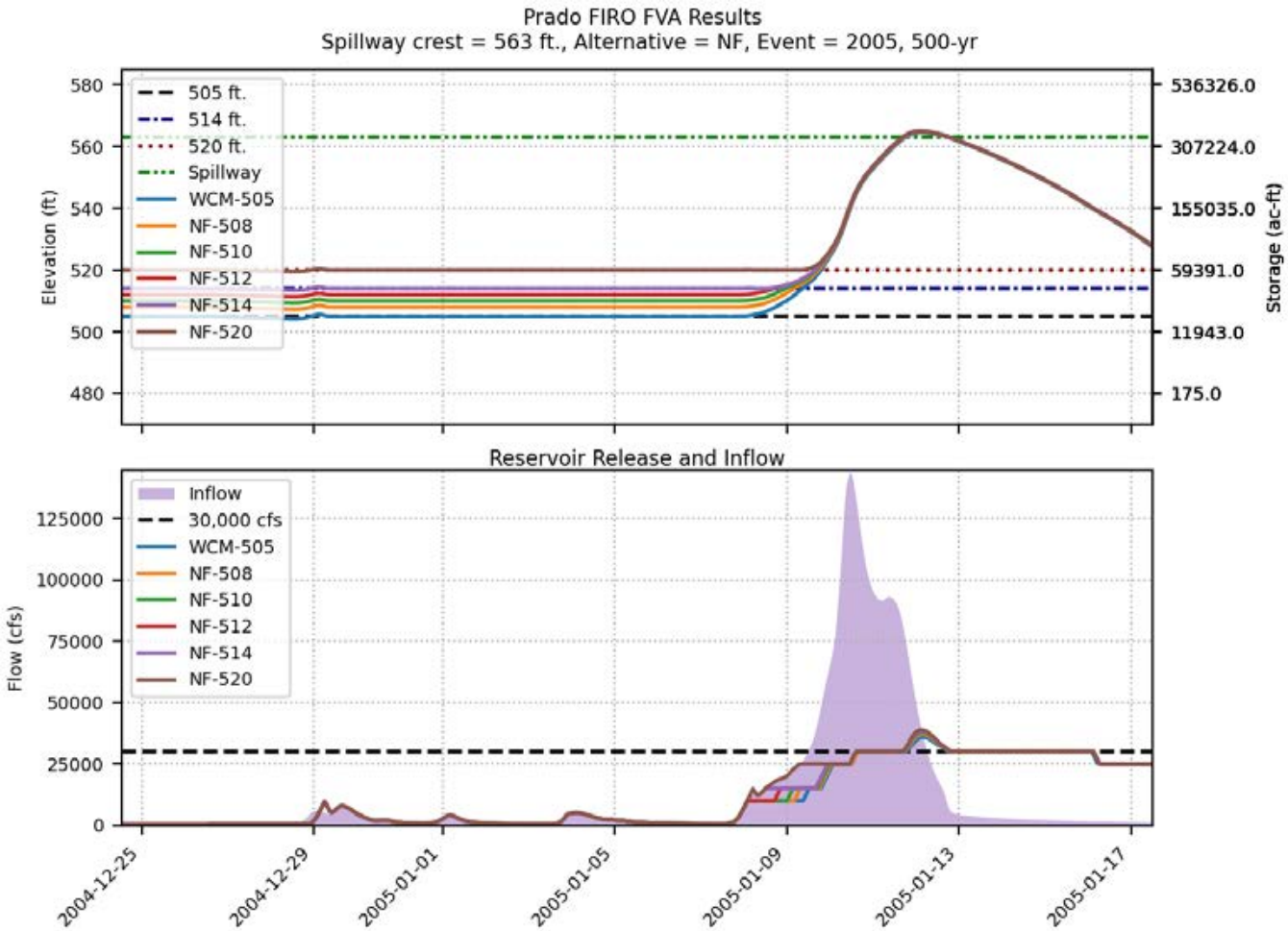
Prado FIRO FVA Results
Spillway crest = 563 ft., Alternative = NF, Event = 2005, 500-yr
Elevation (ft)
Storage (ac-ft)
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514 ft.
520 ft.
Spillway
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
580
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540
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500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
125000
100000
75000
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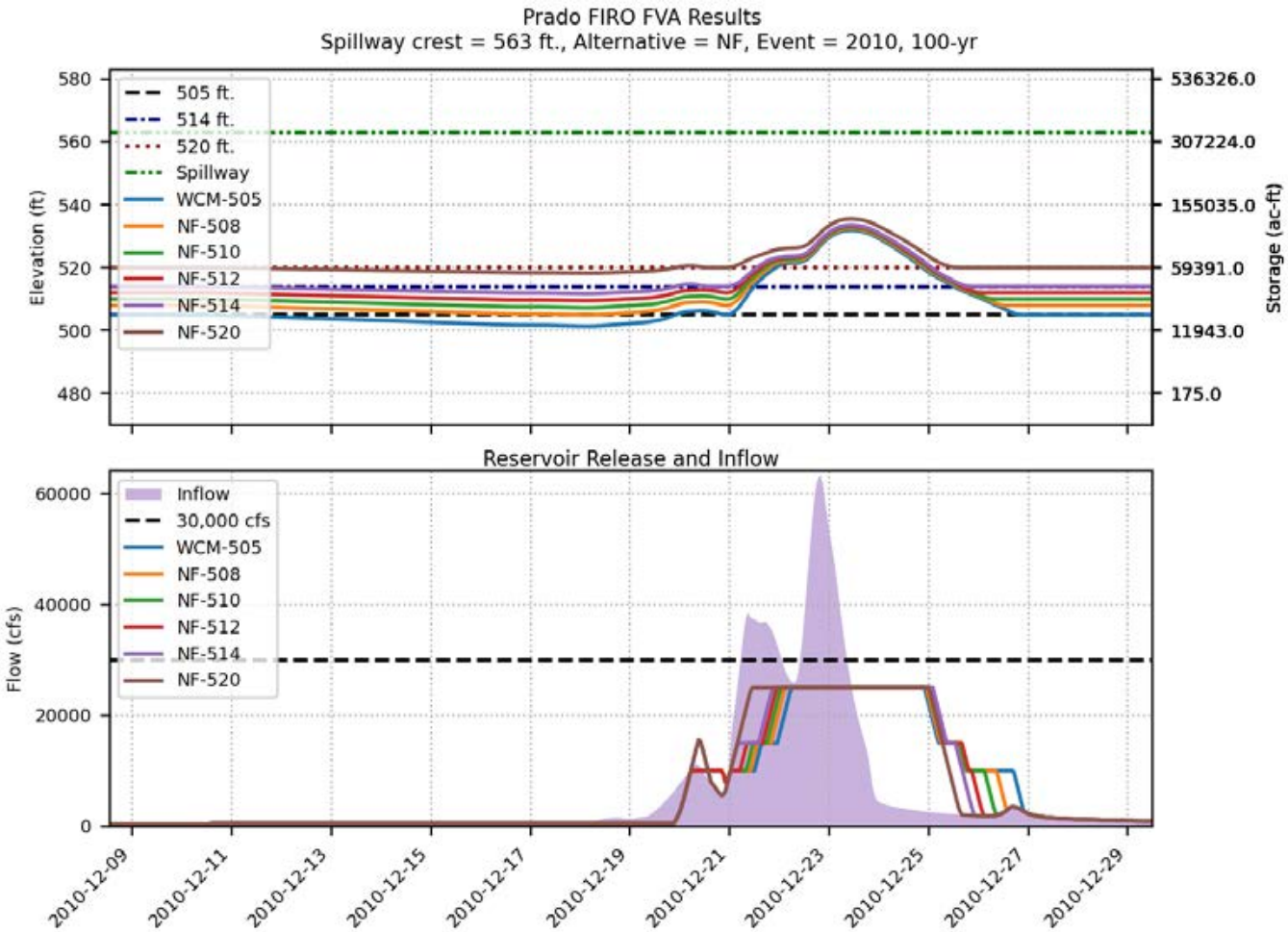
Prado FIRO FVA Results
Spillway crest = 563 ft., Alternative = NF, Event = 2010, 100-yr
Elevation (ft)
Storage (ac-ft)
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514 ft.
520 ft.
Spillway
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
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536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
WCM-505
NF-508
NF-510
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NF-514
NF-520
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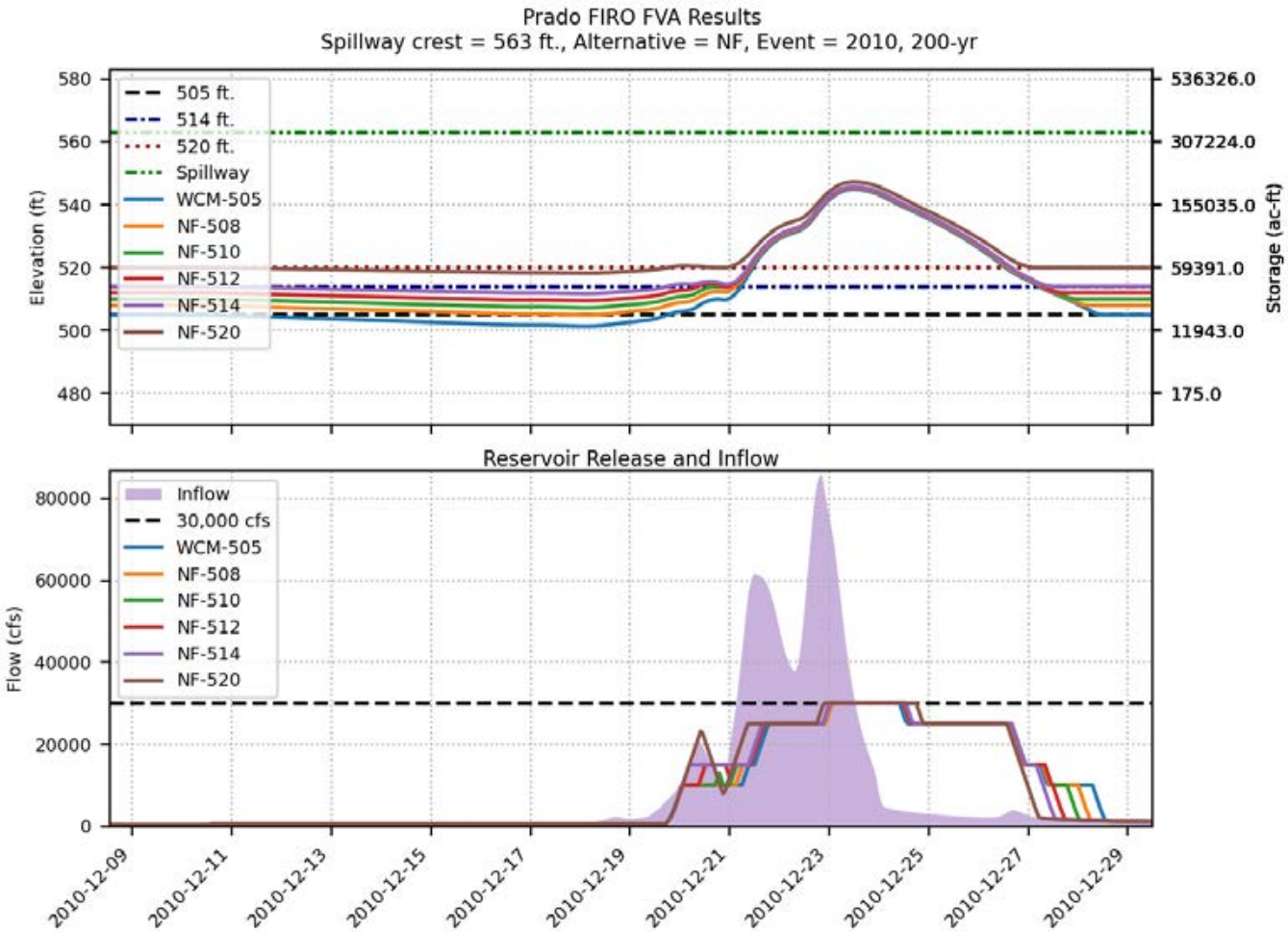
Prado FIRO FVA Results
Spillway crest = 563 ft., Alternative = NF, Event = 2010, 200-yr
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514 ft.
520 ft.
Spillway
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Elevation (ft)
Storage (ac-ft)
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536326.0
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59391.0
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Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
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NF-520
Flow (cfs)
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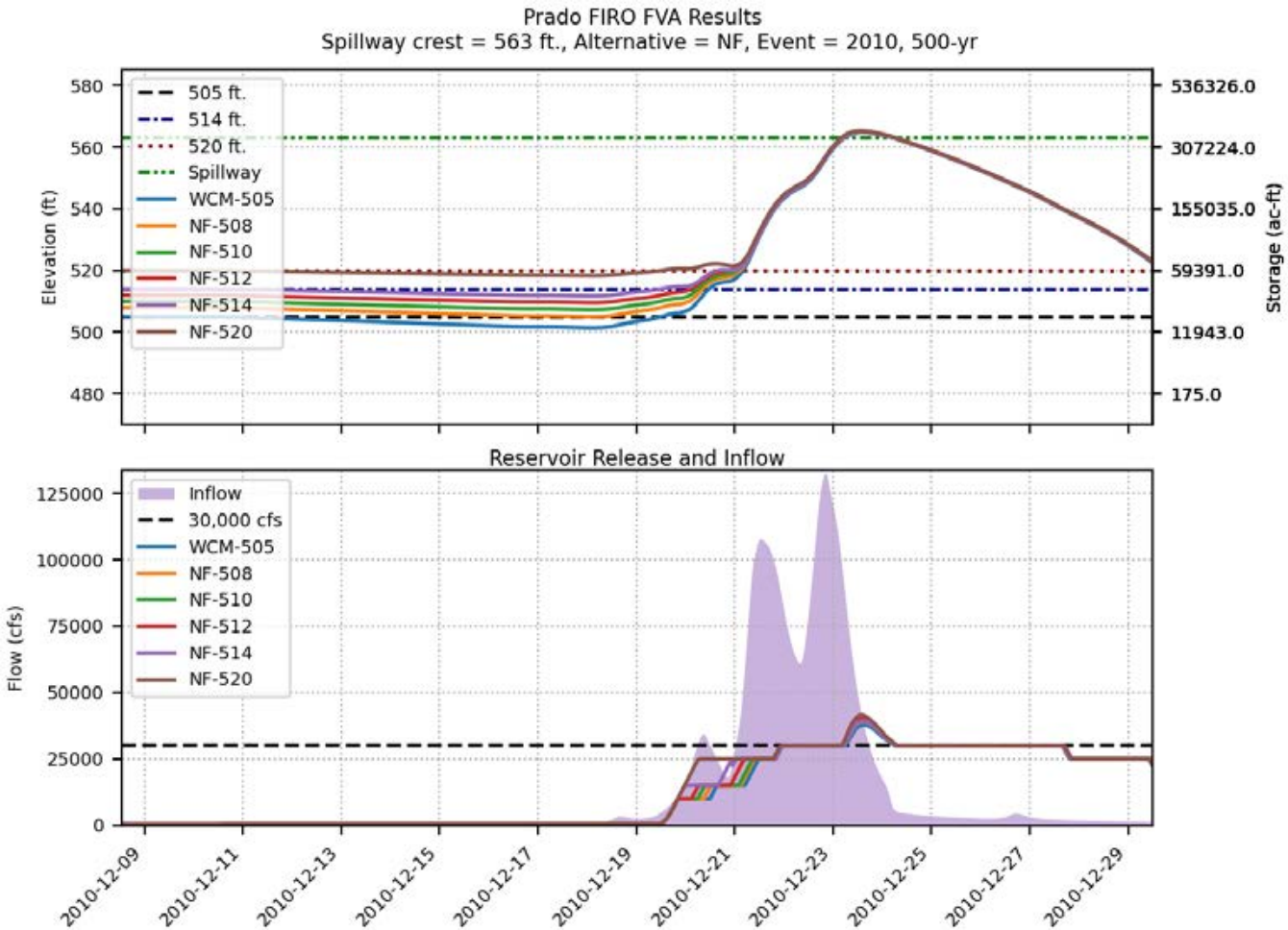
Prado FIRO FVA Results
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514 ft.
520 ft.
Spillway
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Elevation (ft)
Storage (ac-ft)
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536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM-505
NF-508
NF-510
NF-512
NF-514
NF-520
Flow (cfs)
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100000
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50000
25000
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2010-12-09
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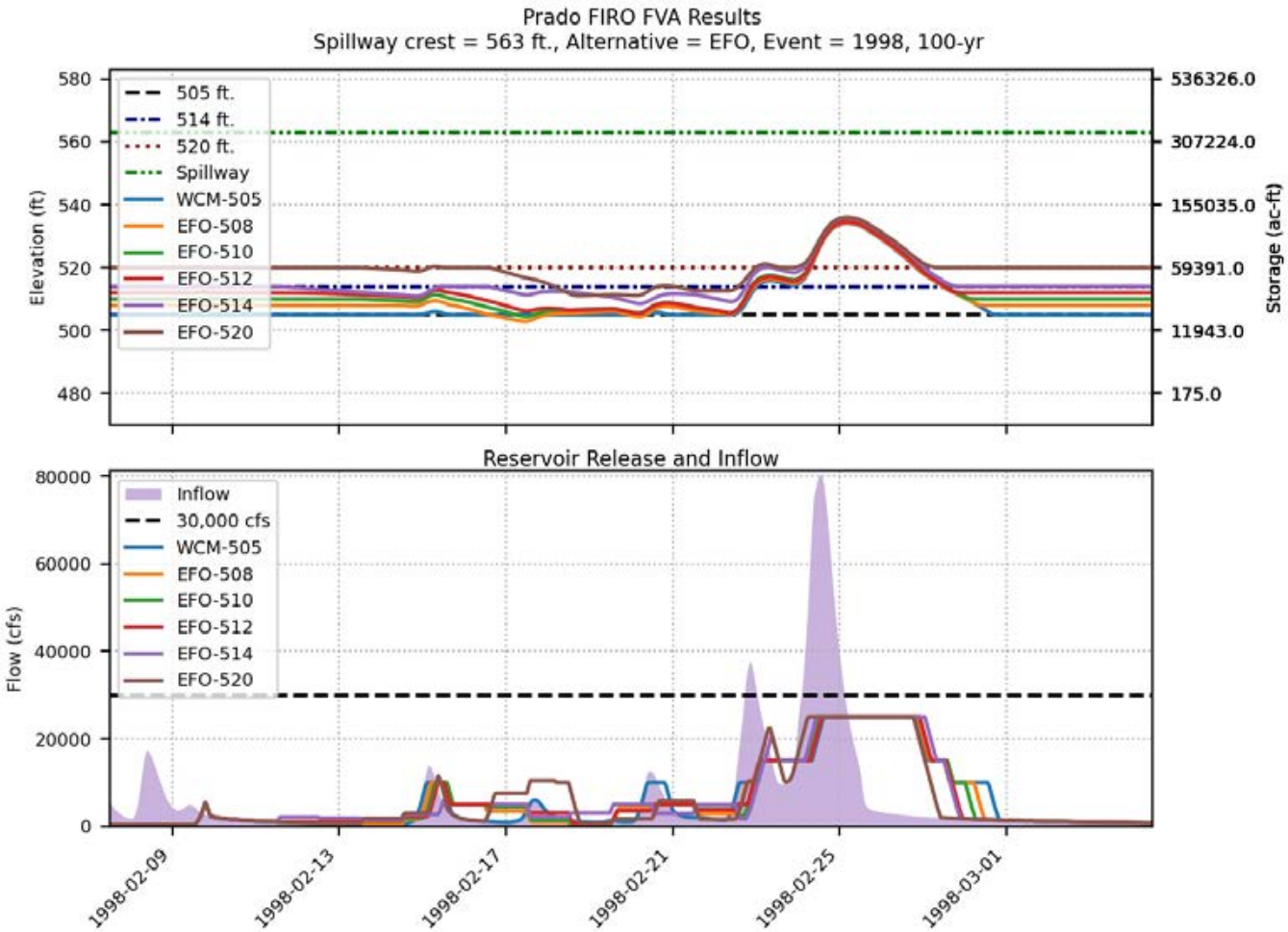
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Spillway crest = 563 ft., Alternative = EFO, Event = 1998, 100-yr
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Storage (ac-ft)
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514 ft.
520 ft.
Spillway
WCM-505
EFO-508
EFO-510
EFO-512
EFO-514
EFO-520
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536326.0
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11943.0
175.0
Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
WCM-505
EFO-508
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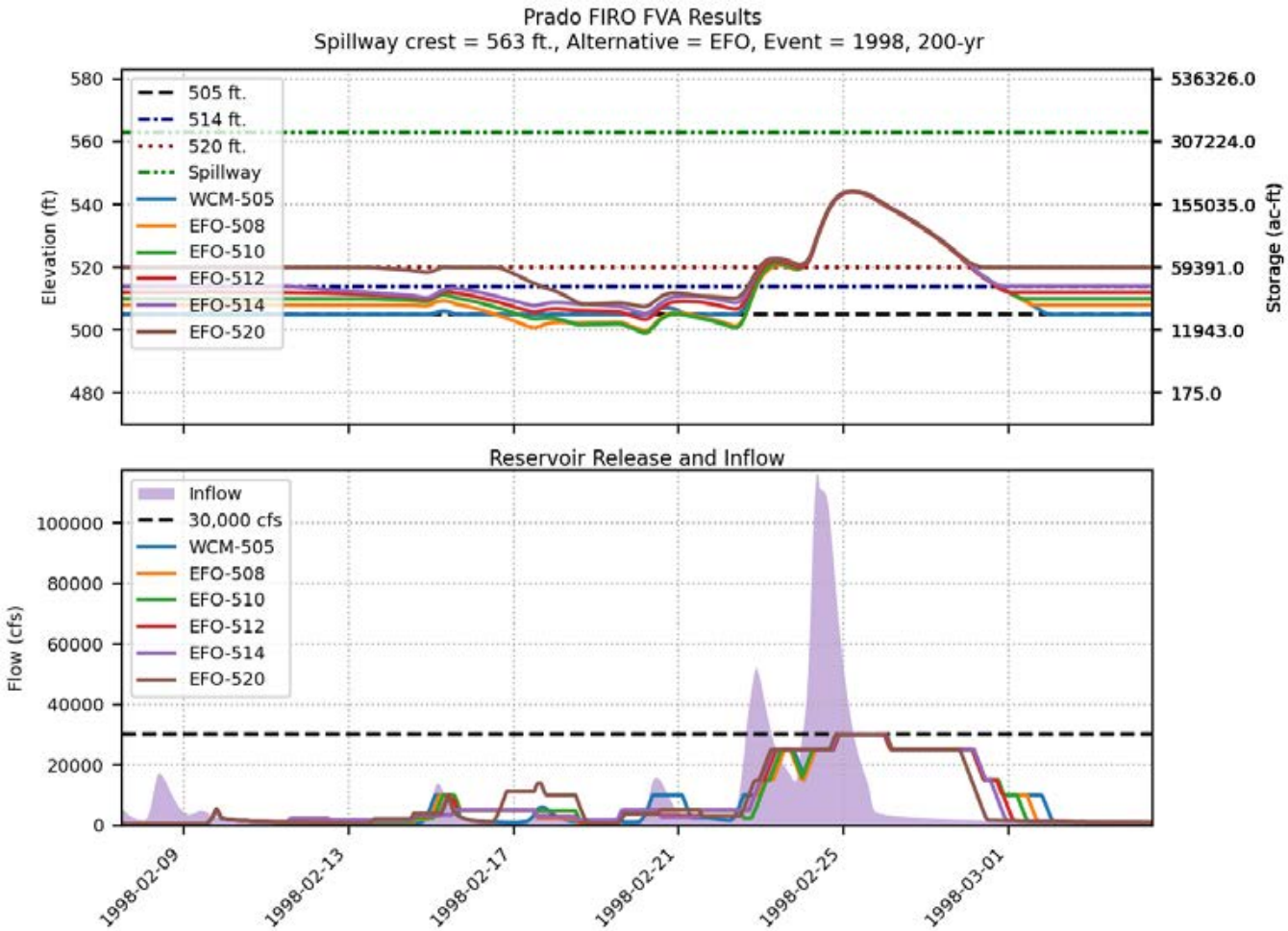
Prado FIRO FVA Results
Spillway crest = 563 ft., Alternative = EFO, Event = 1998, 200-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
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59391.0
11943.0
175.0
Reservoir Release and Inflow
Flow (cfs)
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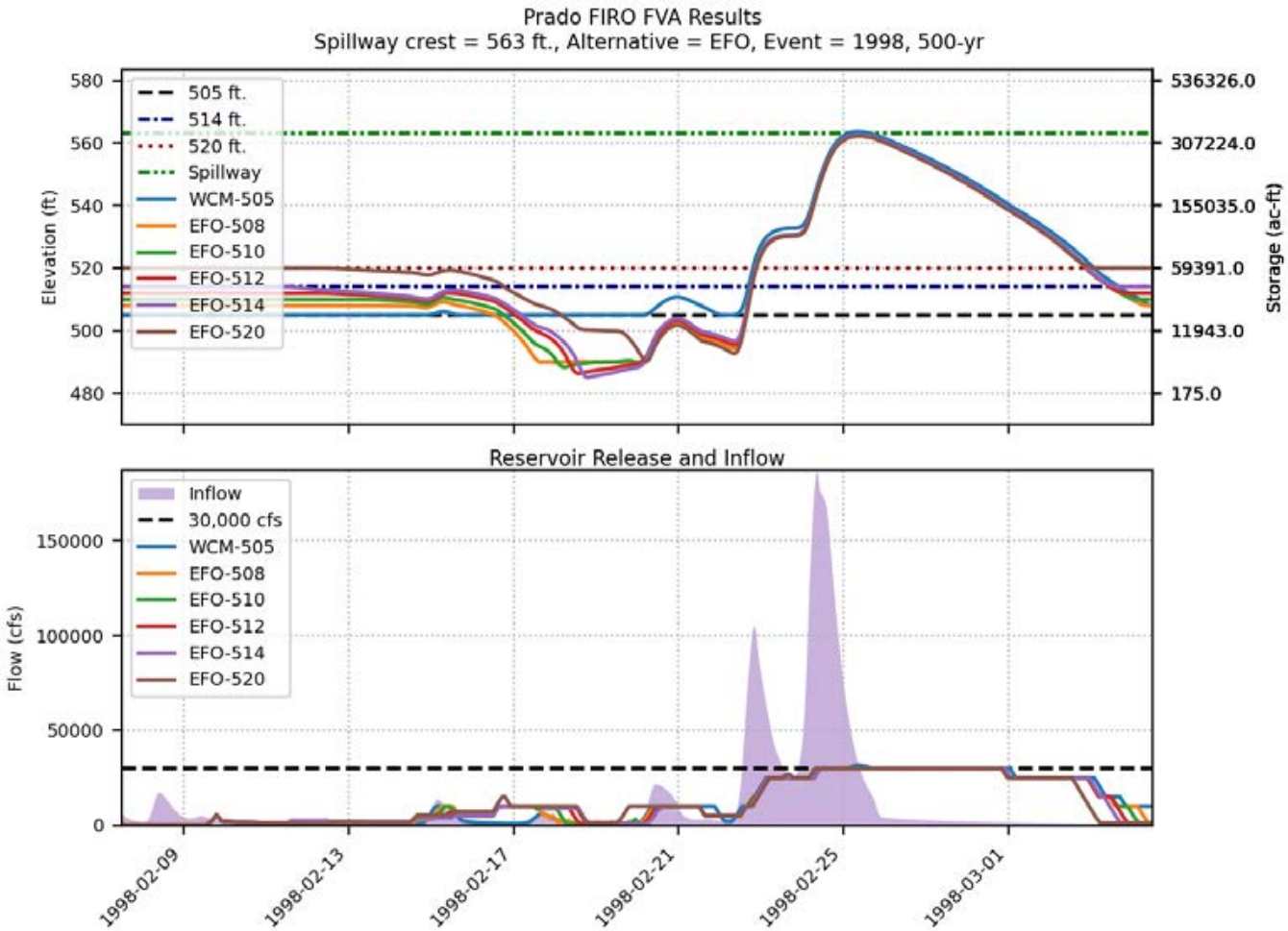
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Spillway crest = 563 ft., Alternative = EFO, Event = 1998, 500-yr
Elevation (ft)
Storage (ac-ft)
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514 ft.
520 ft.
Spillway
WCM-505
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EFO-510
EFO-512
EFO-514
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59391.0
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175.0
Reservoir Release and Inflow
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Inflow
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EFO-514
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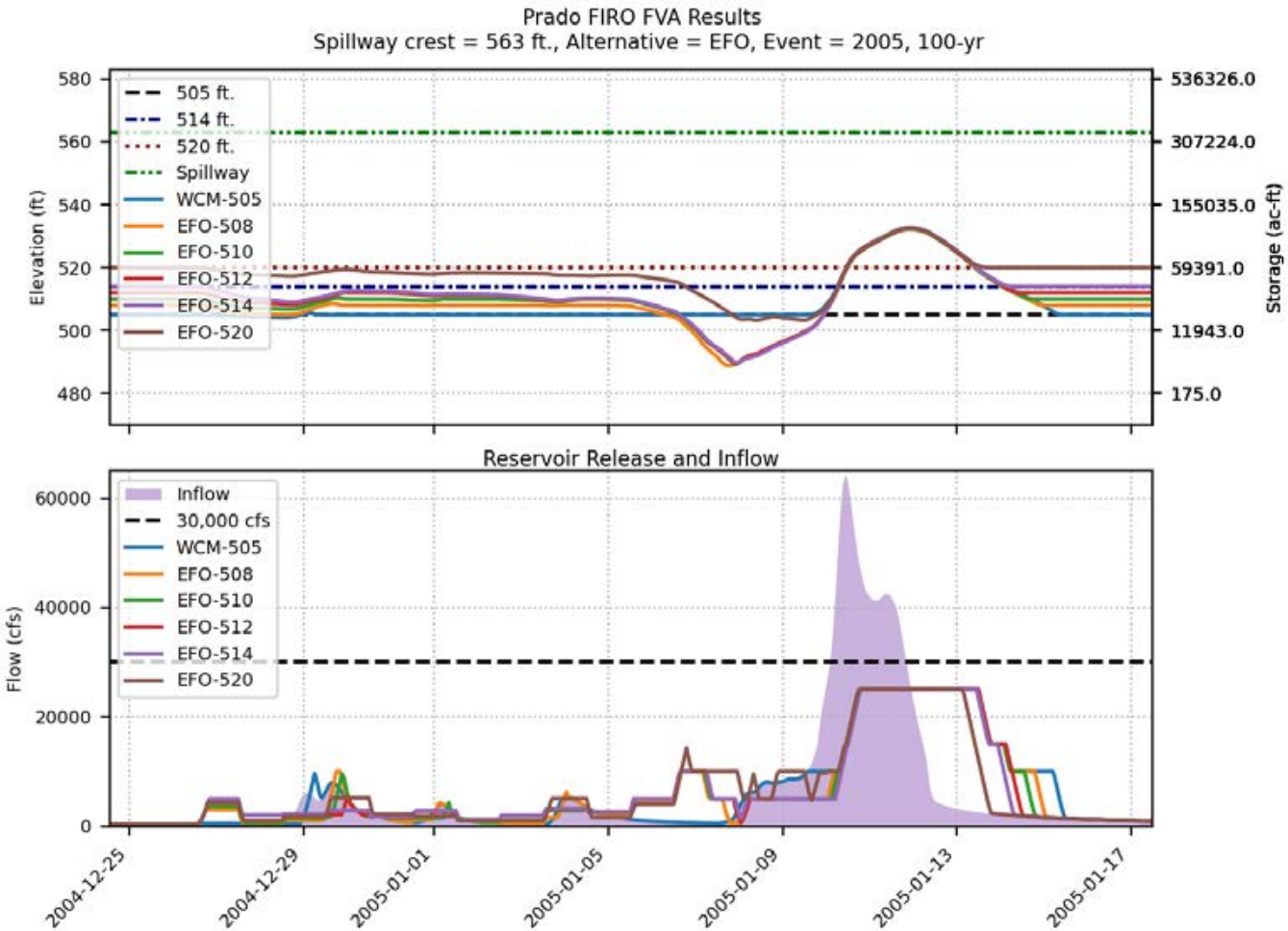
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Storage (ac-ft)
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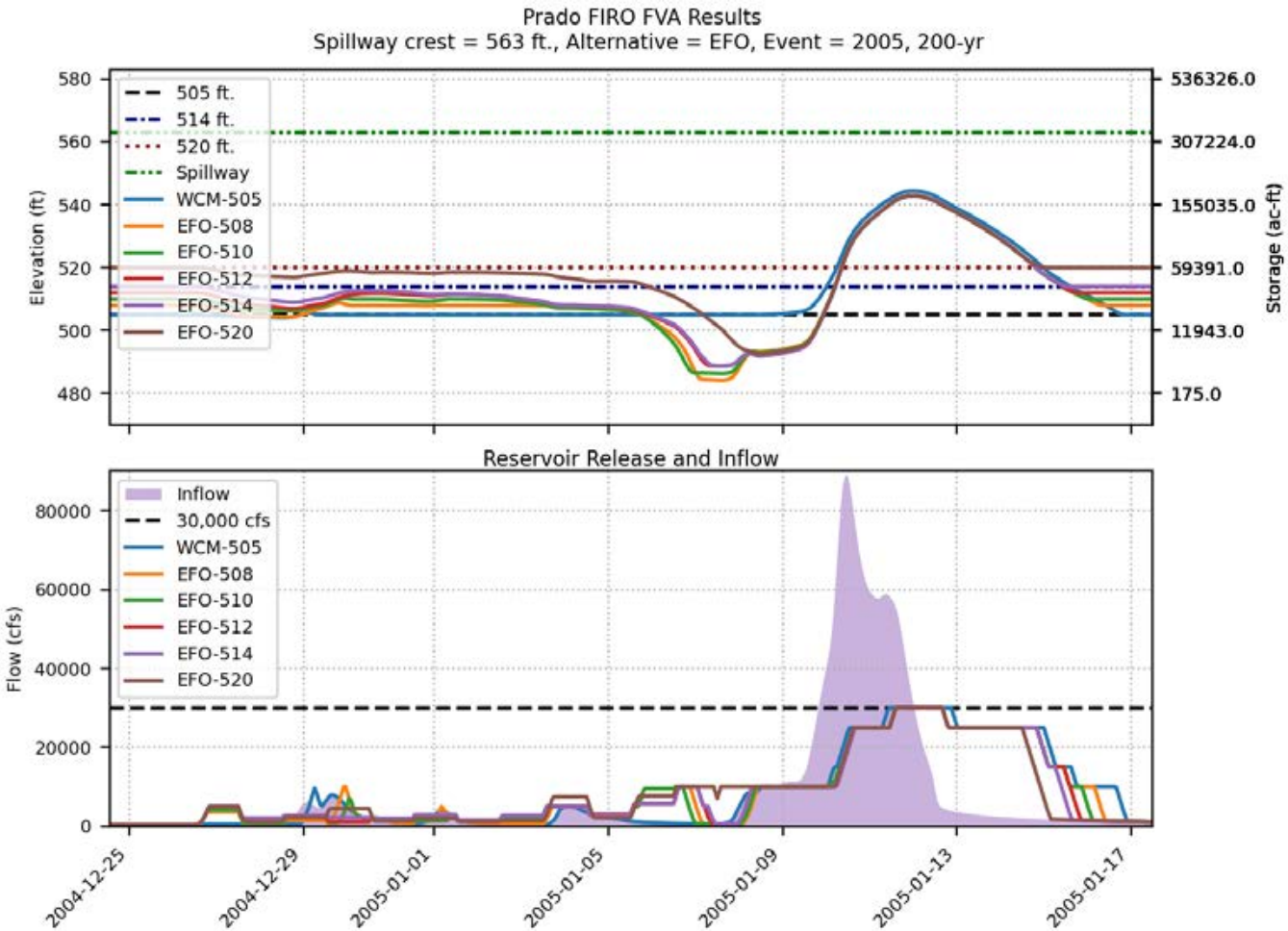
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Elevation (ft)
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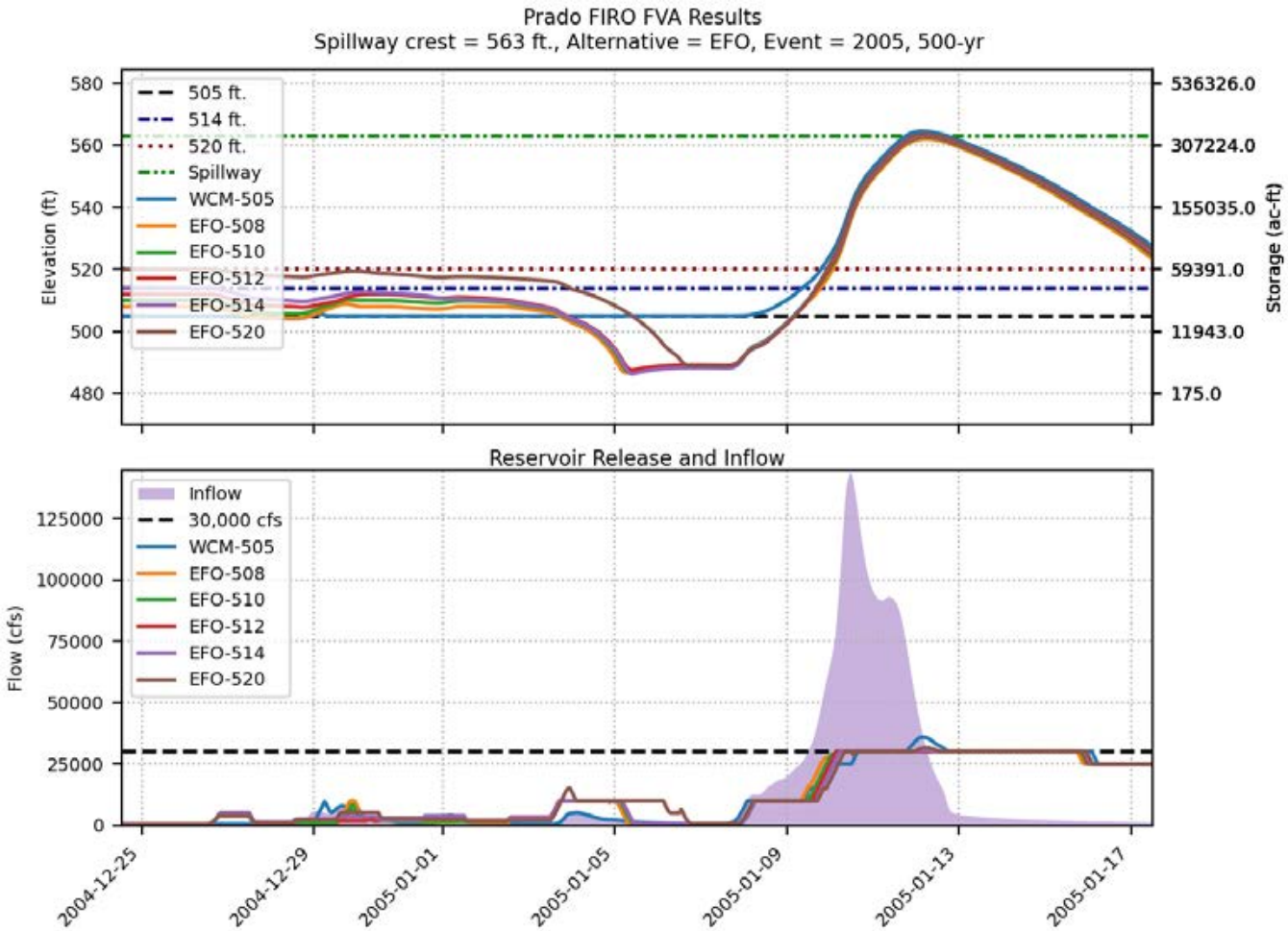
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Spillway crest = 563 ft., Alternative = EFO, Event = 2005, 500-yr
Elevation (ft)
Storage (ac-ft)
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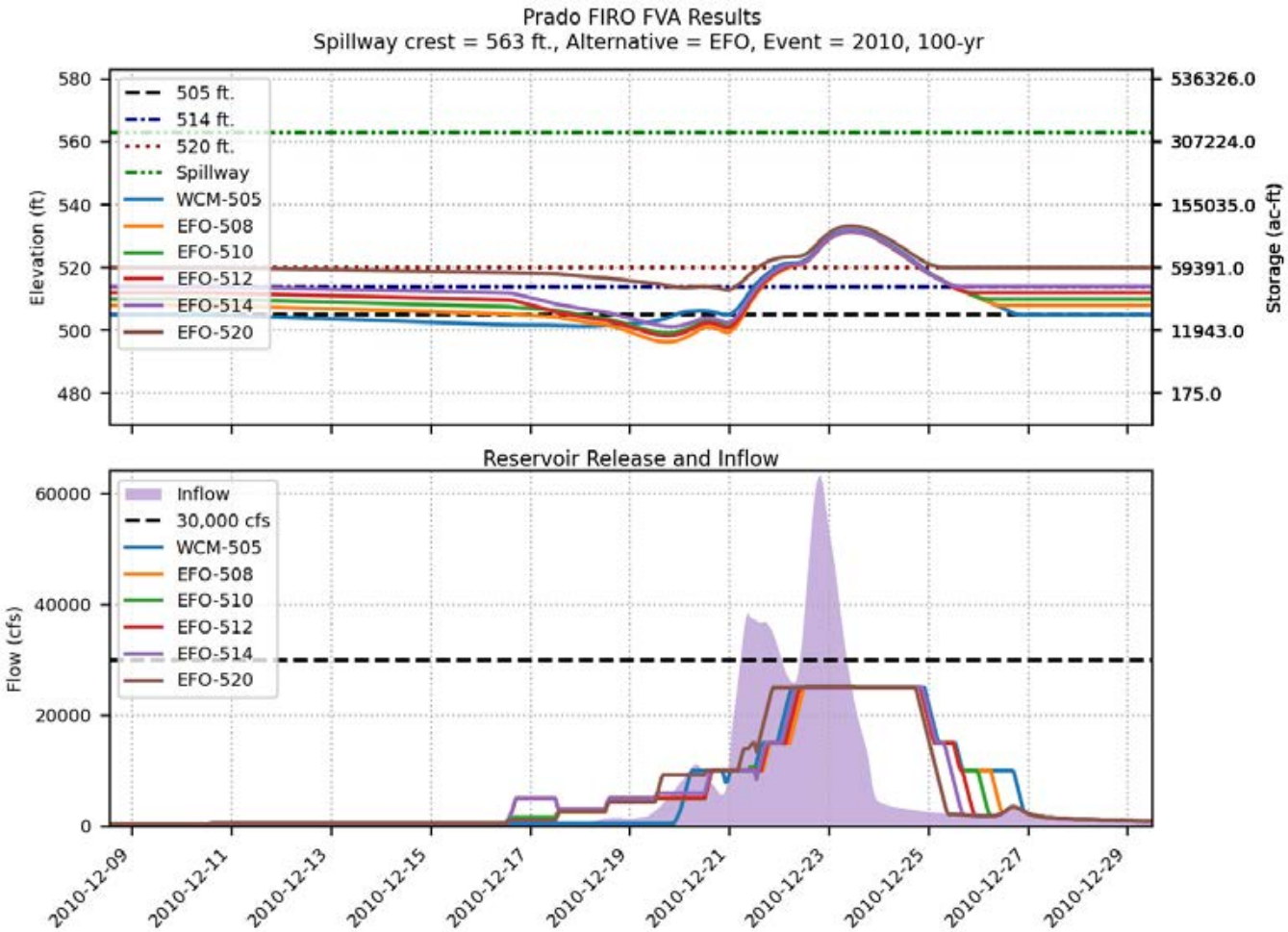
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Elevation (ft)
Storage (ac-ft)
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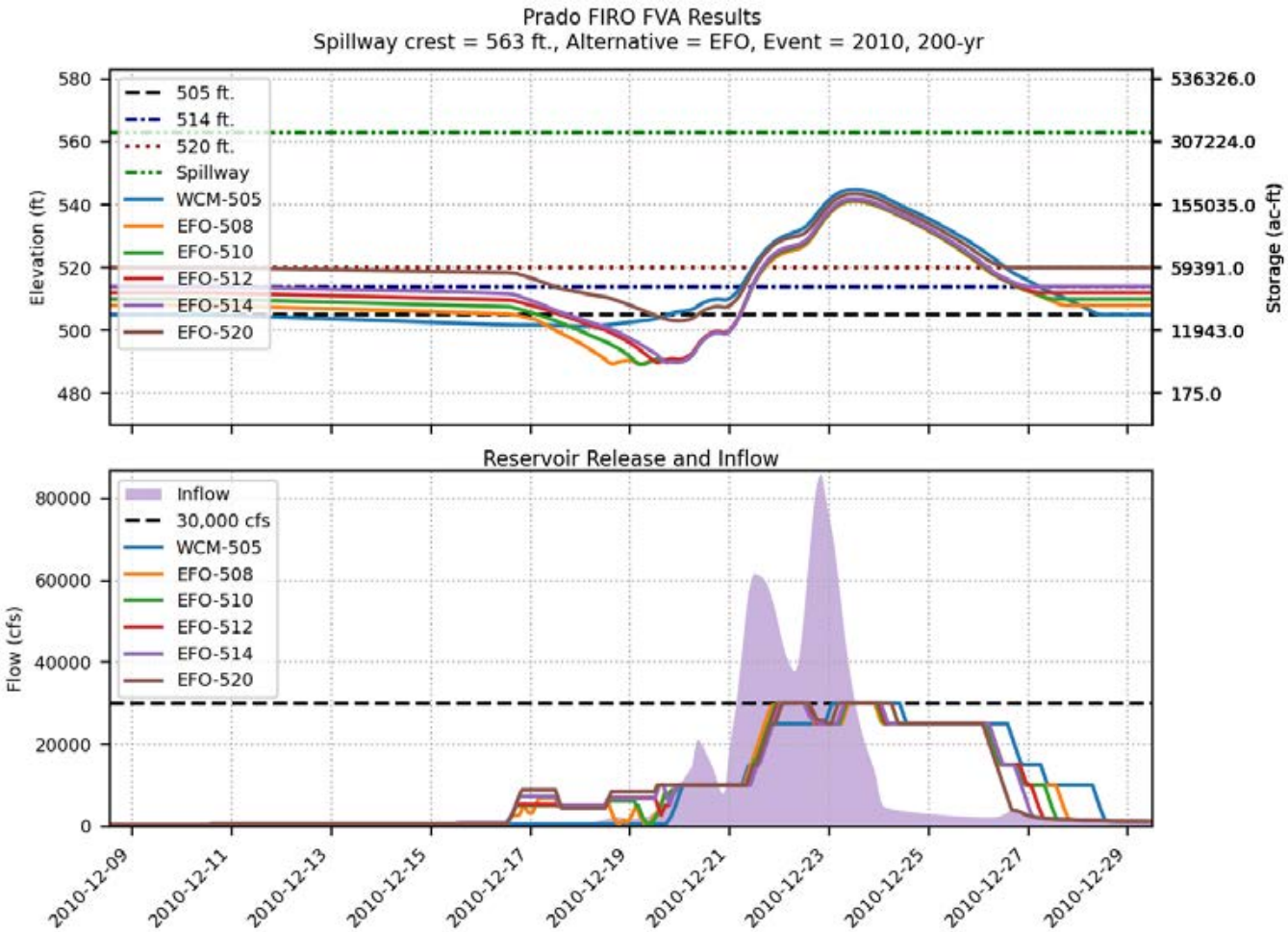
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Spillway crest = 563 ft., Alternative = EFO, Event = 2010, 200-yr
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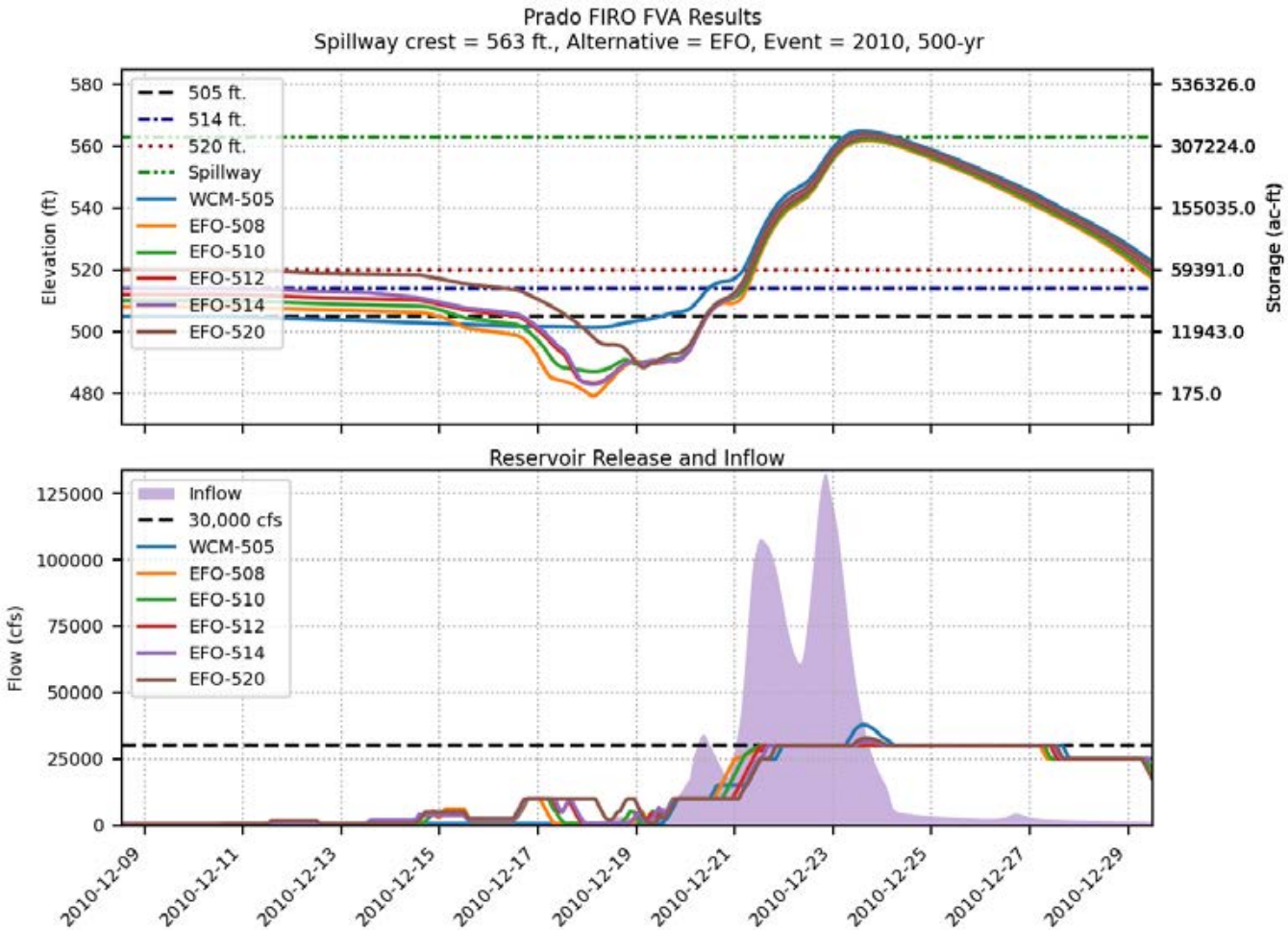
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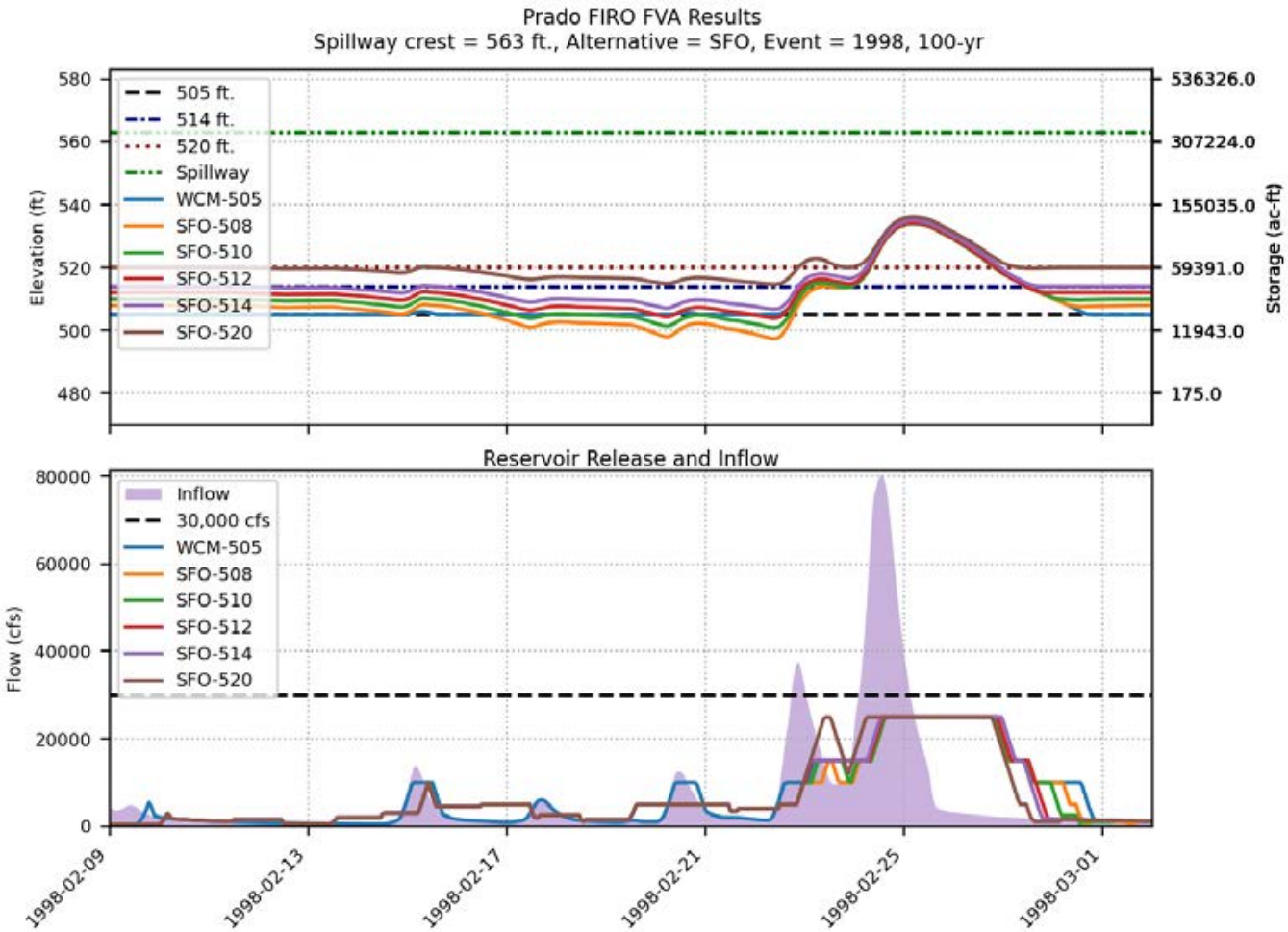
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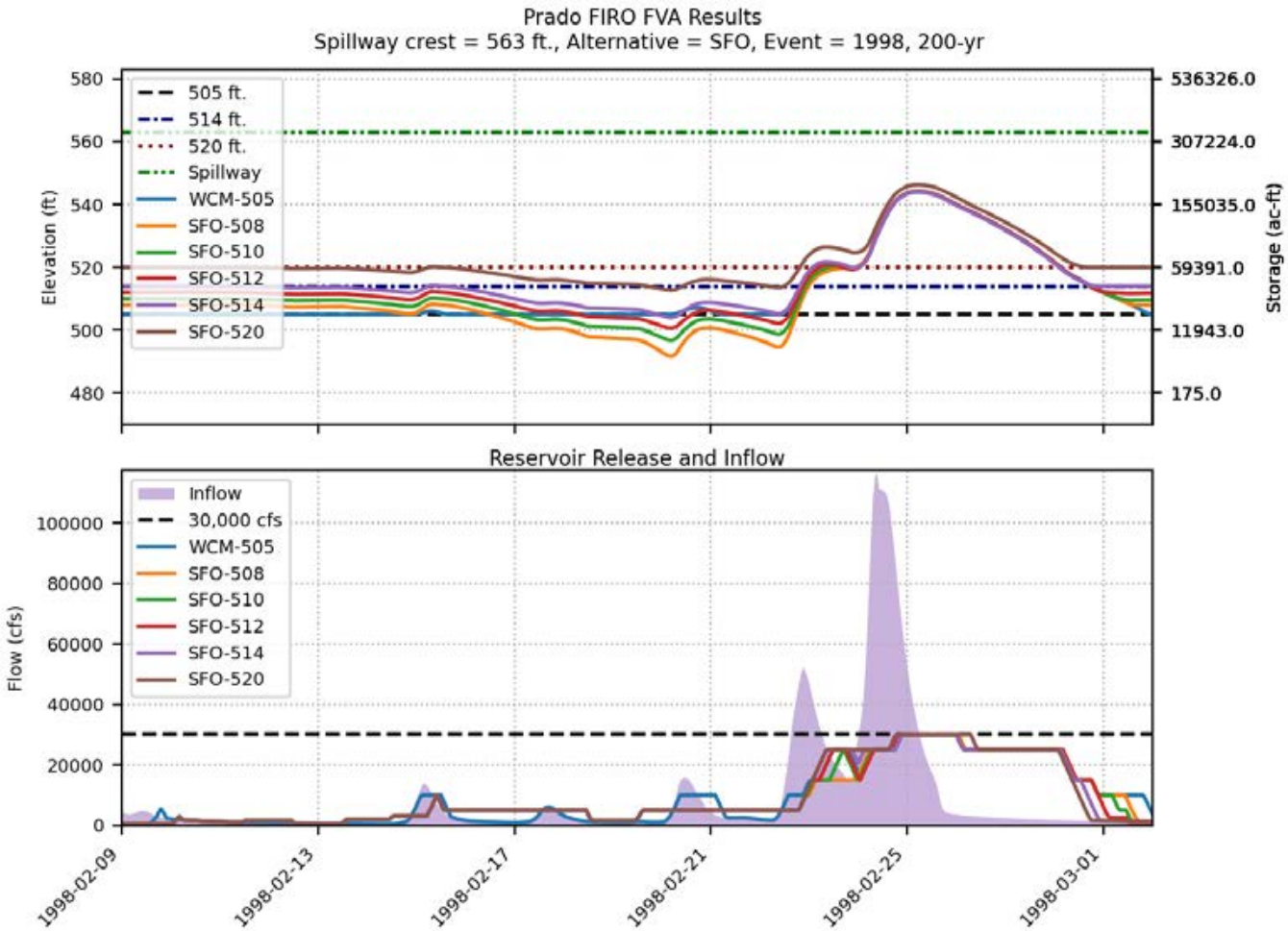
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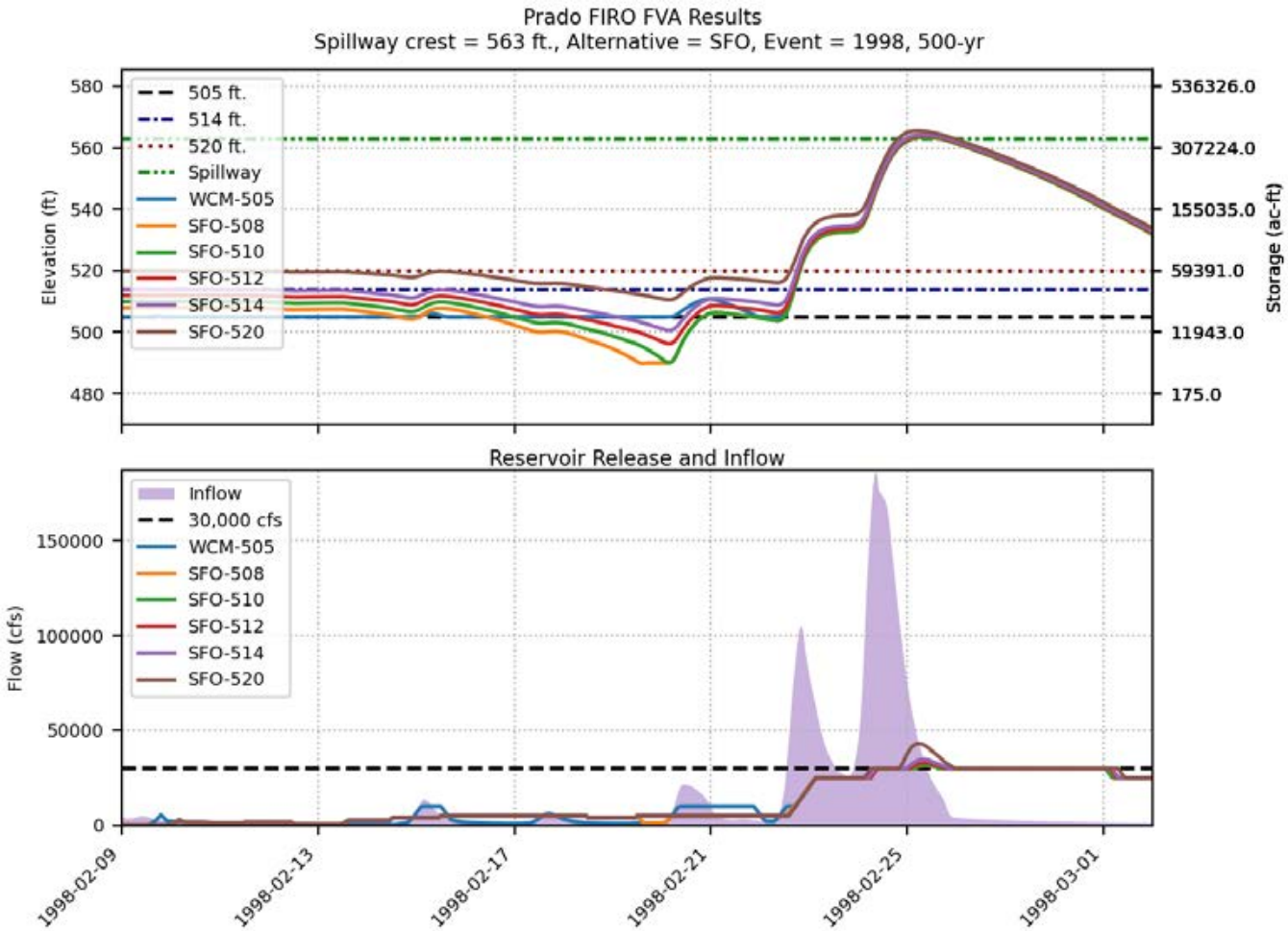
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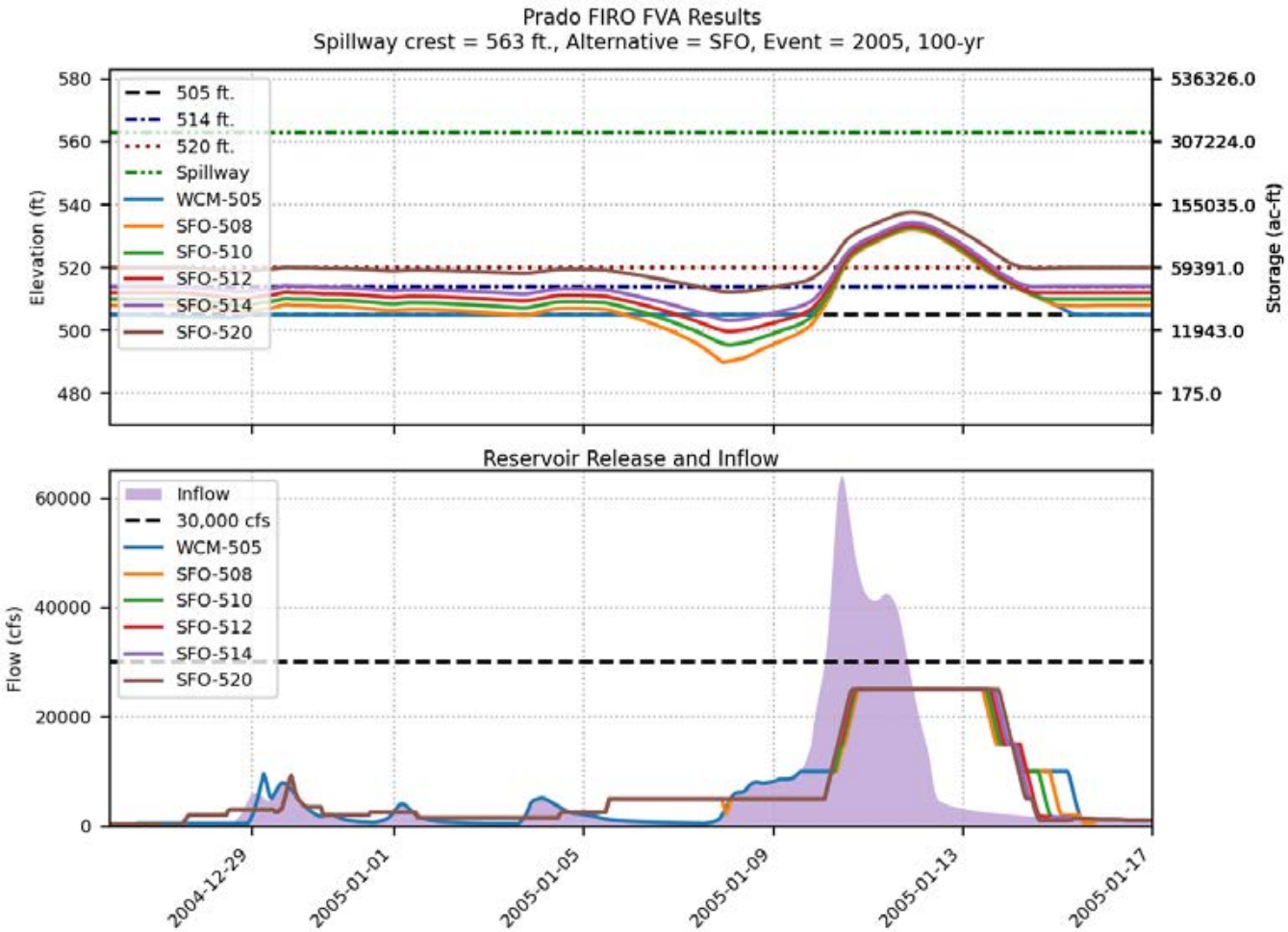
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Spillway crest = 563 ft., Alternative = SFO, Event = 2005, 100-yr
Elevation (ft)
Storage (ac-ft)
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514 ft.
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Reservoir Release and Inflow
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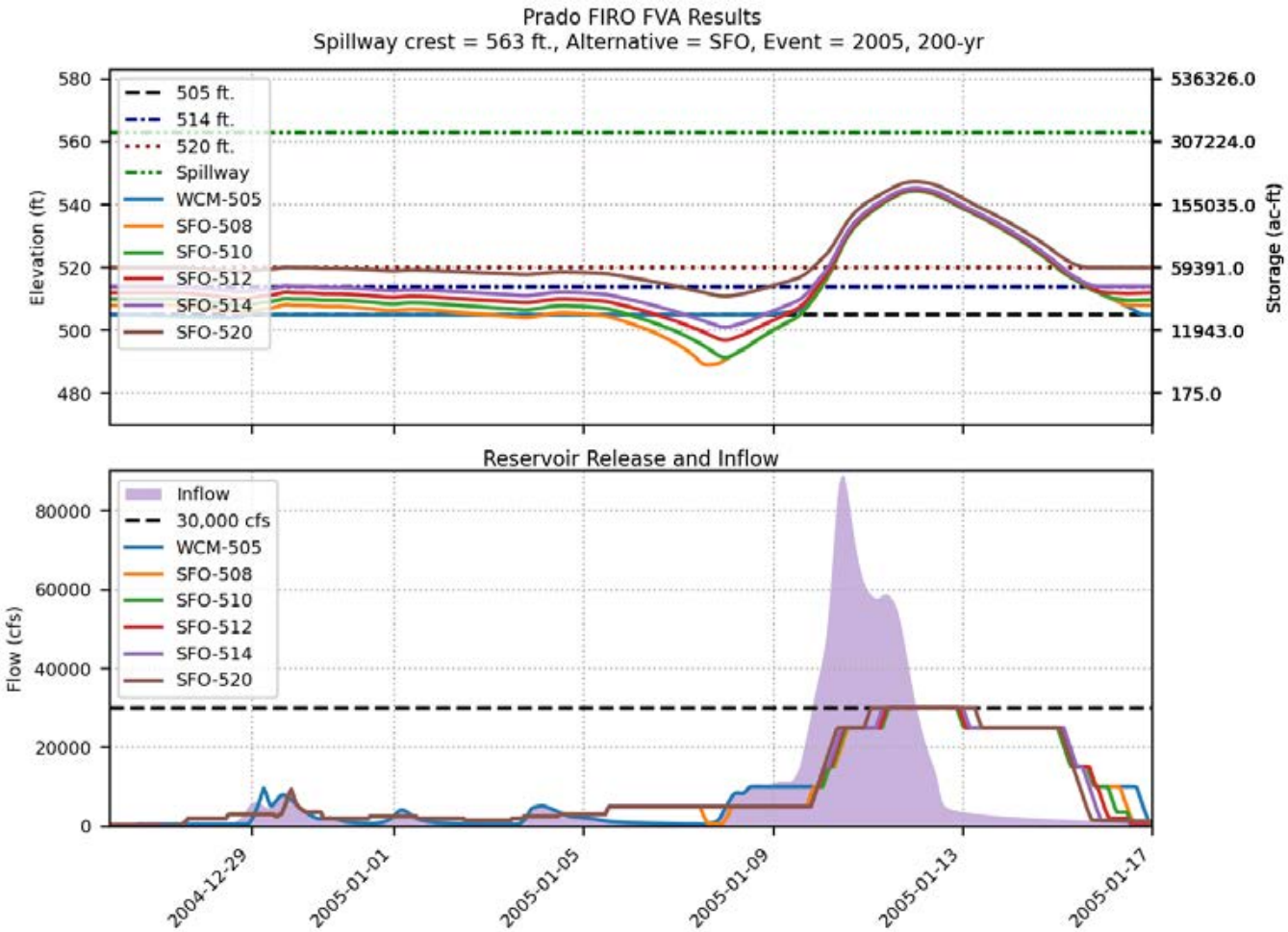
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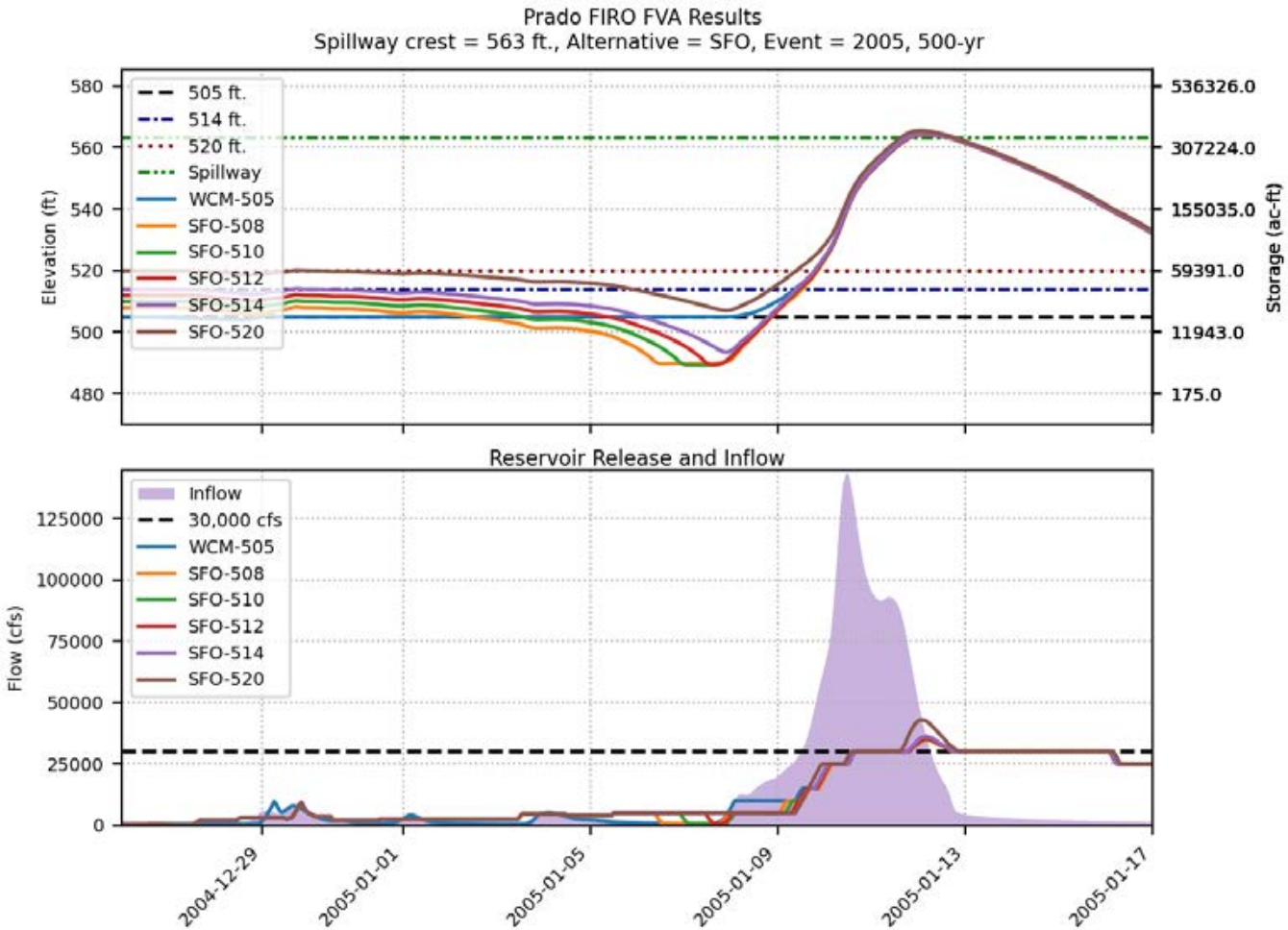
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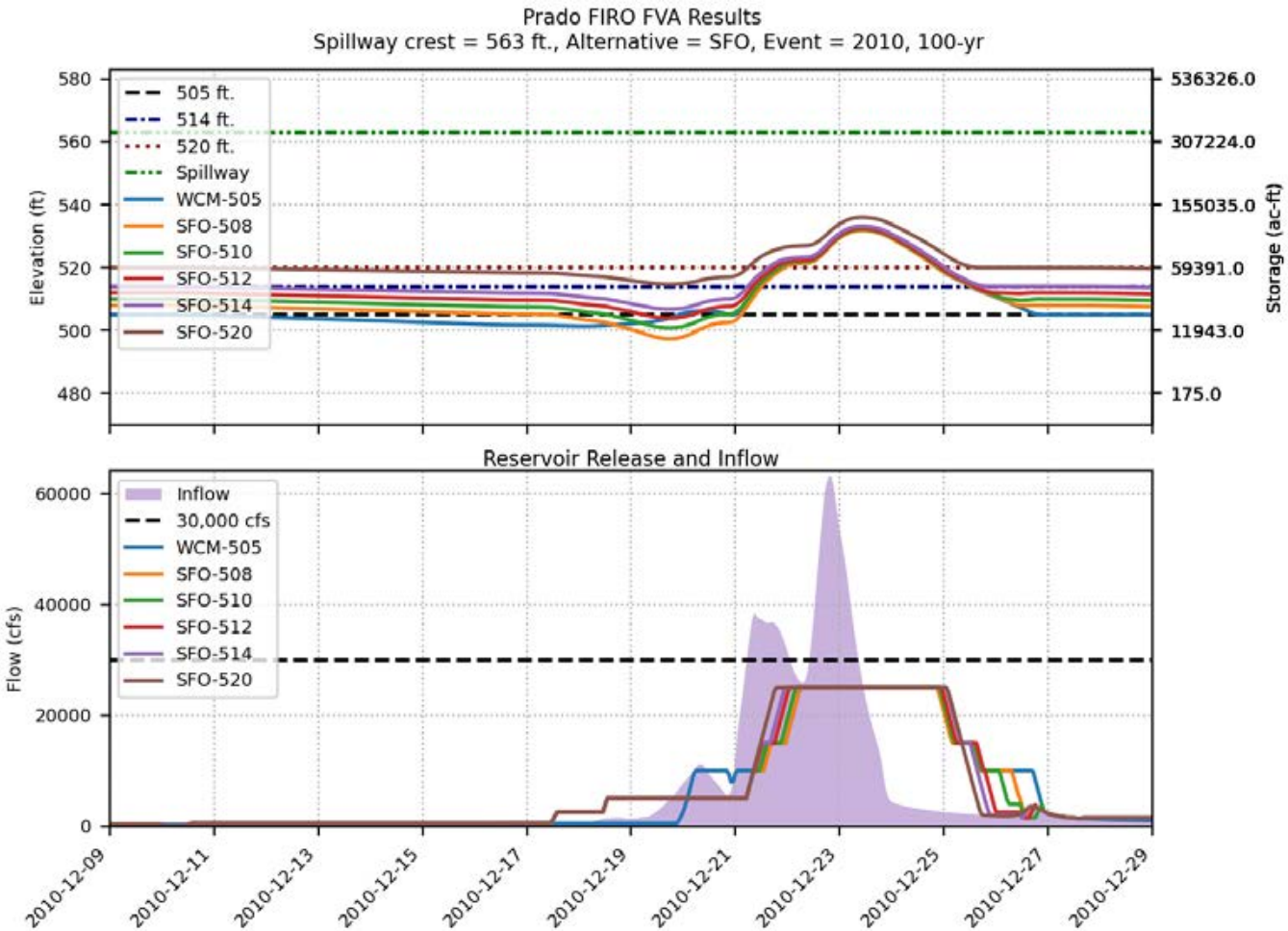
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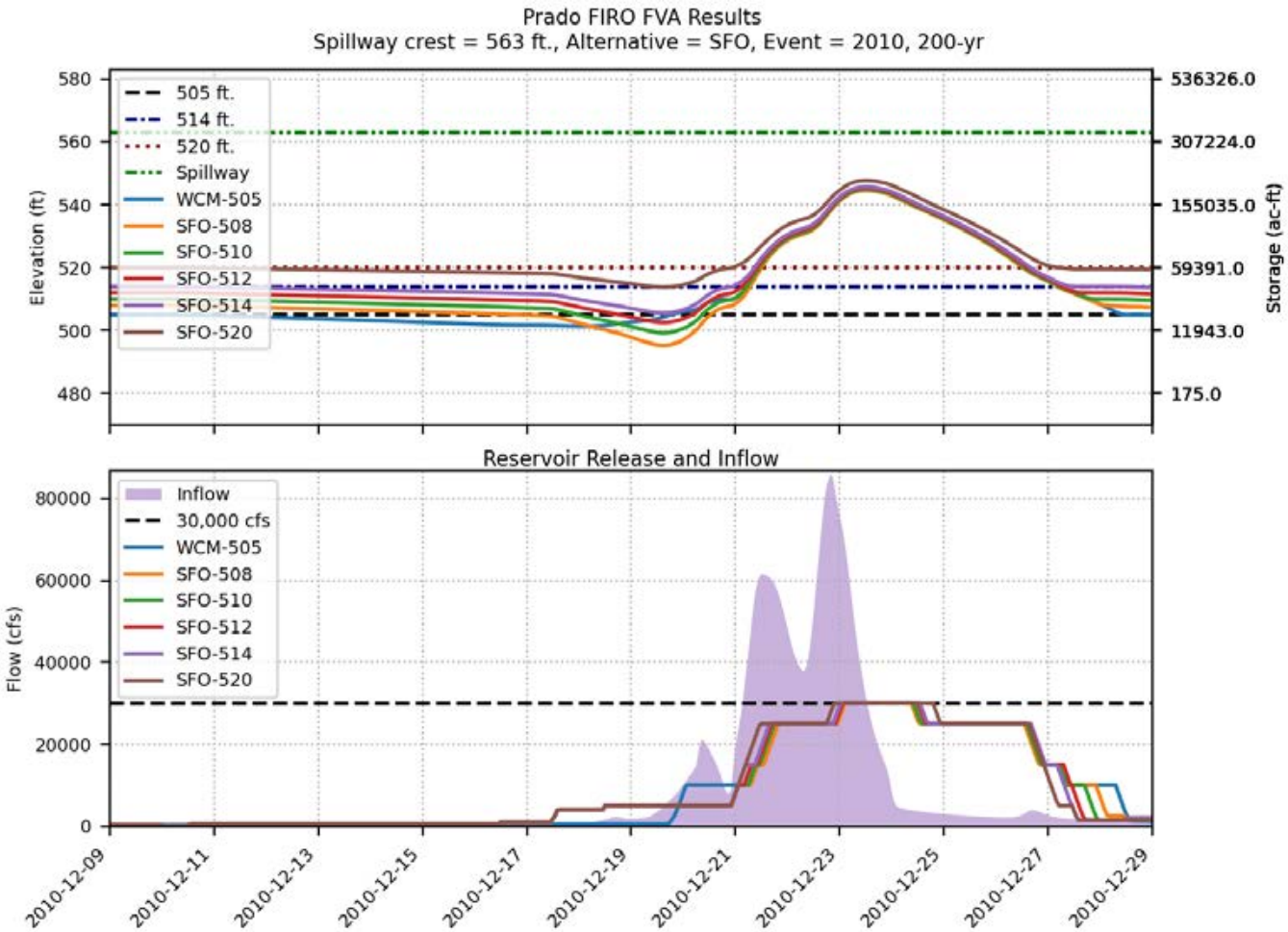
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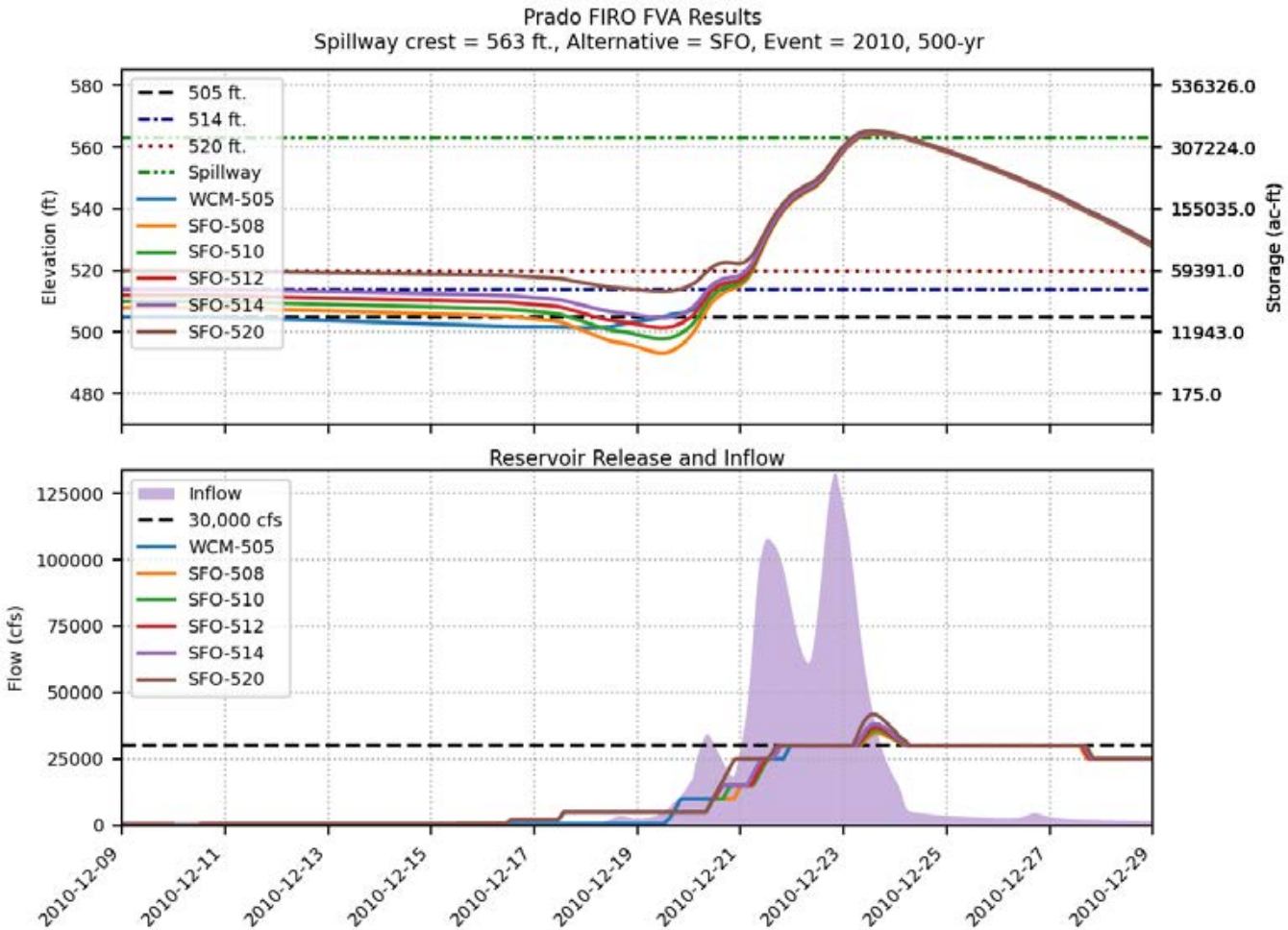
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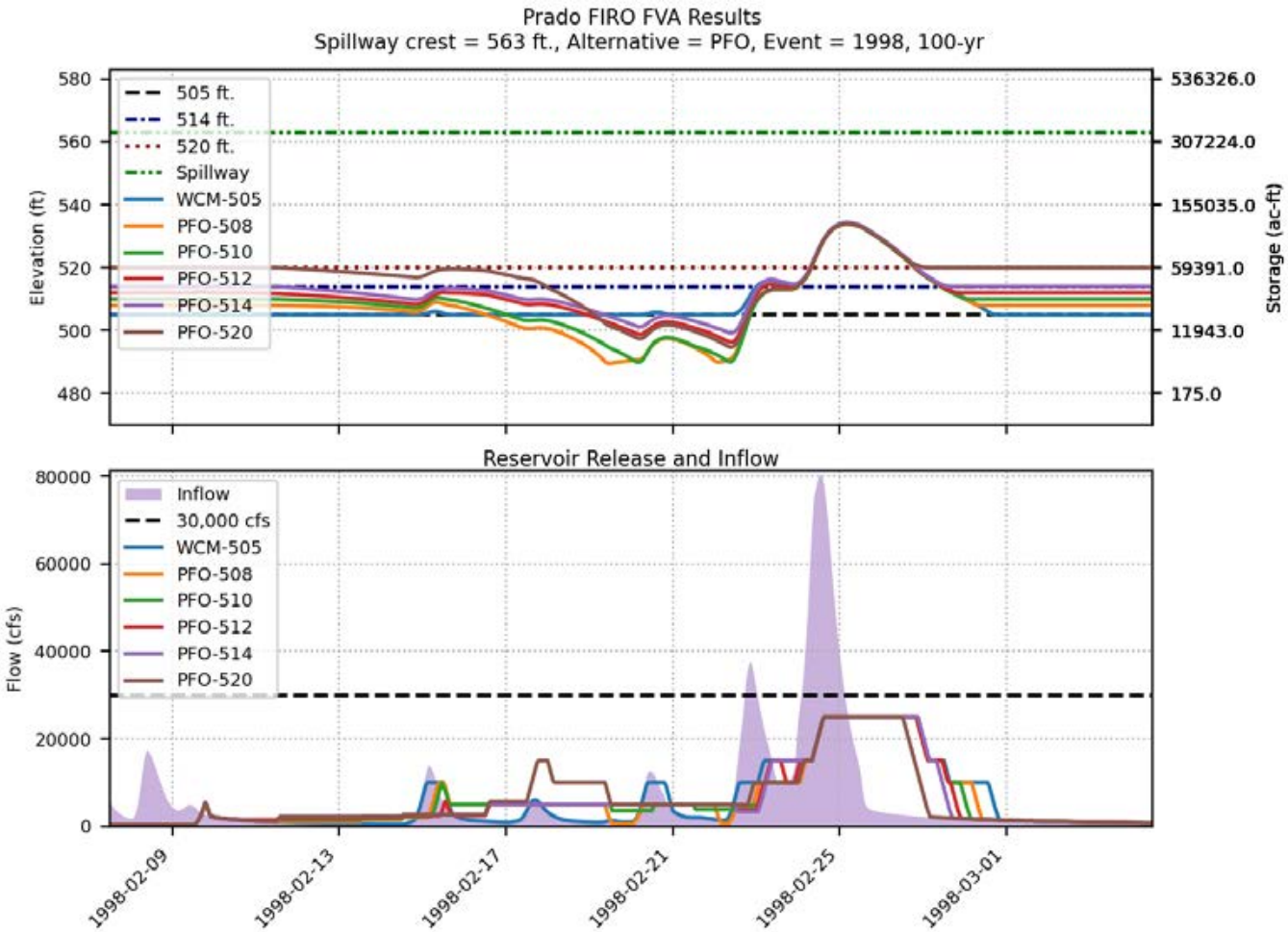
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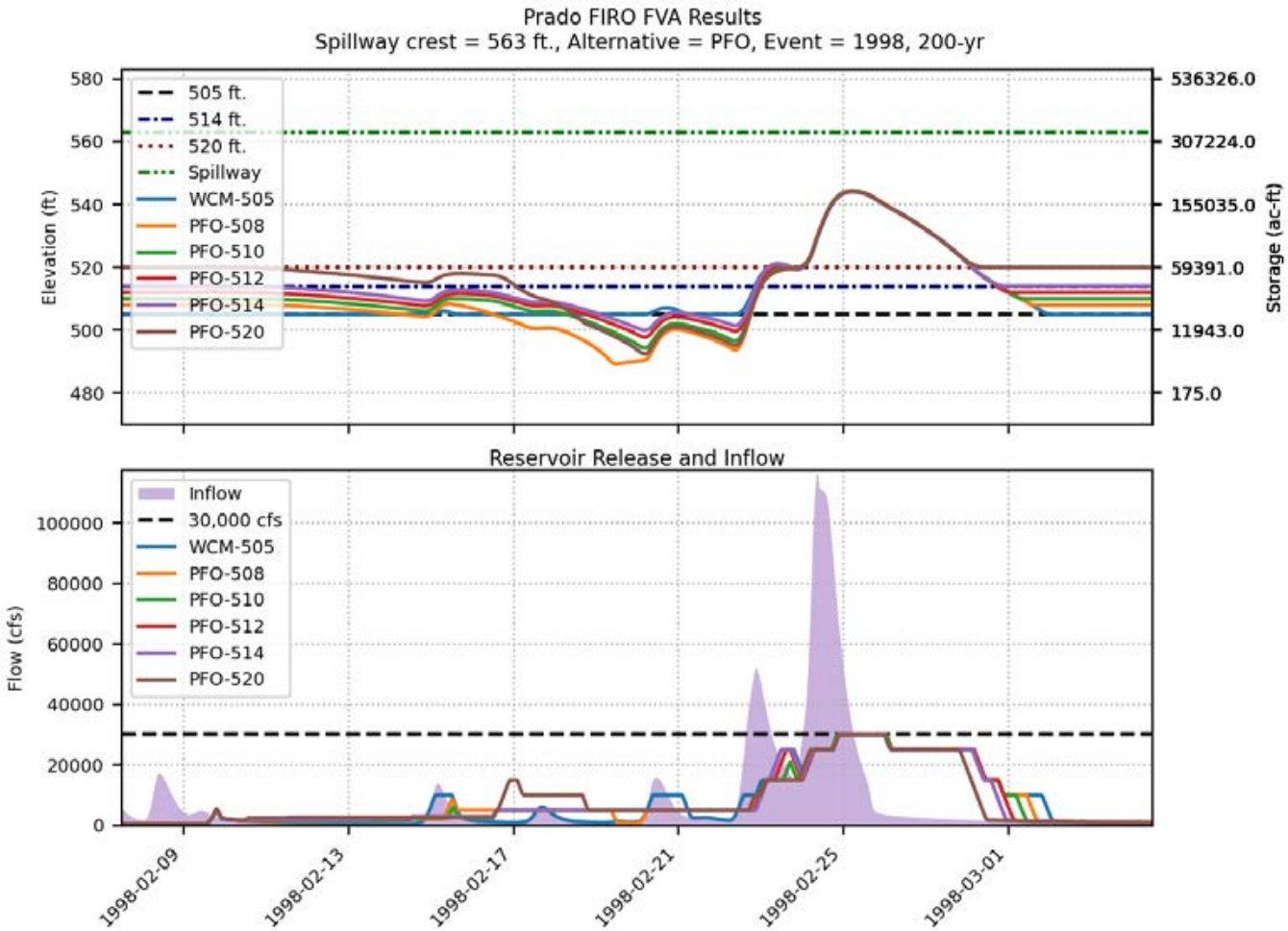
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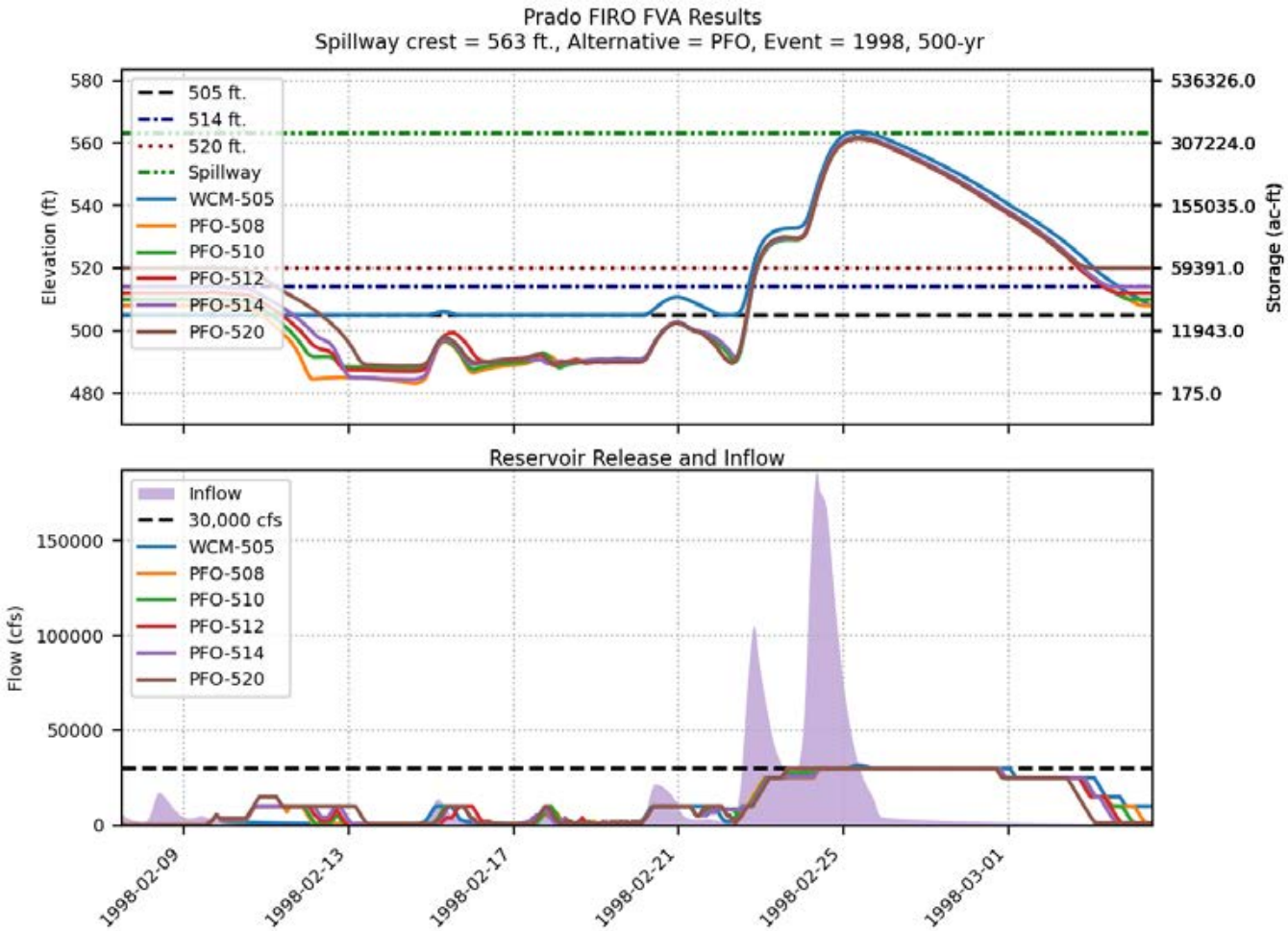
Prado FIRO FVA Results
Spillway crest = 563 ft., Alternative = PFO, Event = 1998, 500-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
WCM-505
PFO-508
PFO-510
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59391.0
11943.0
175.0
Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
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PFO-508
PFO-510
PFO-512
PFO-514
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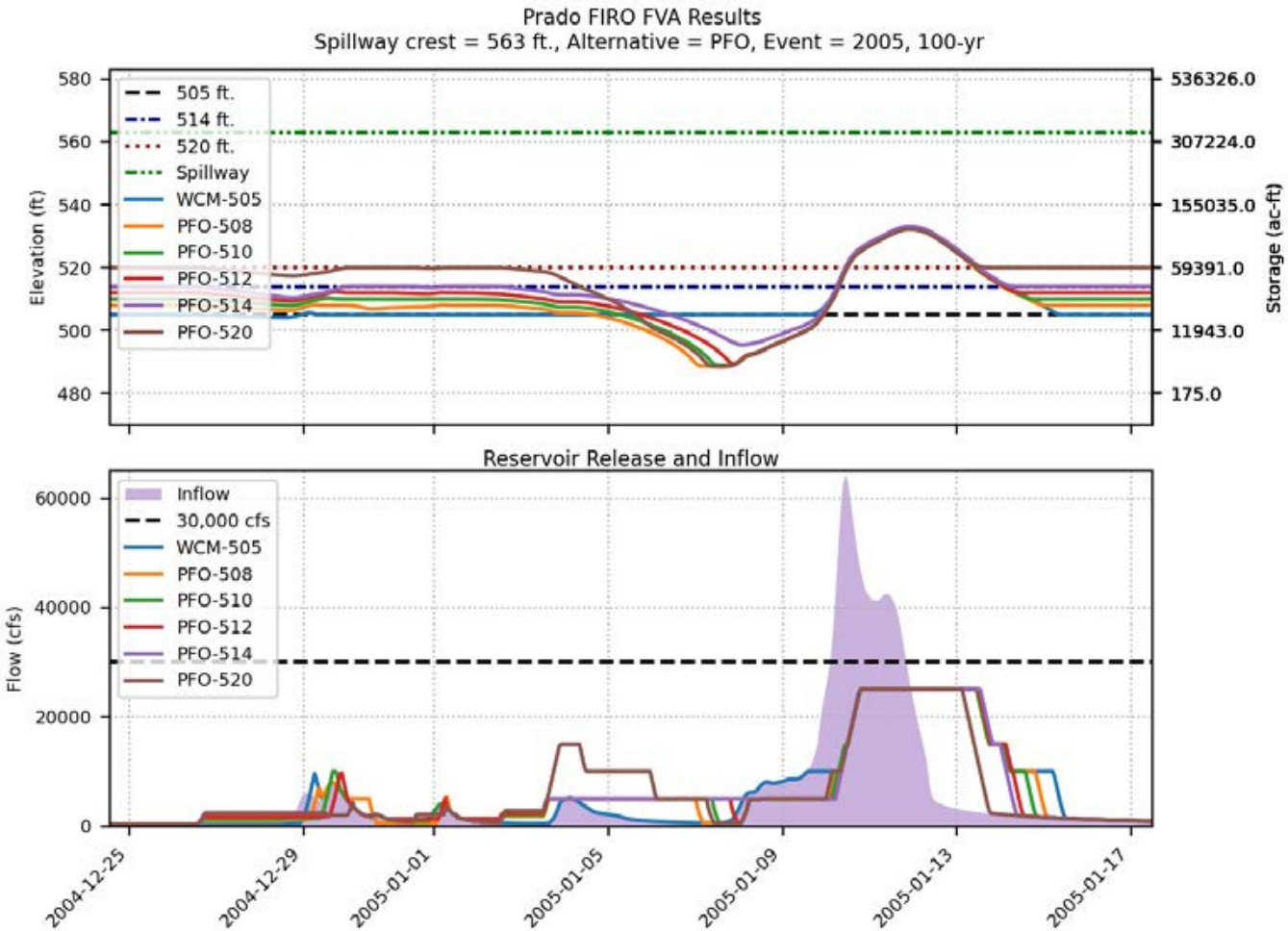
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Spillway crest = 563 ft., Alternative = PFO, Event = 2005, 100-yr
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PFO-510
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PFO-520
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536326.0
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PFO-508
PFO-510
PFO-512
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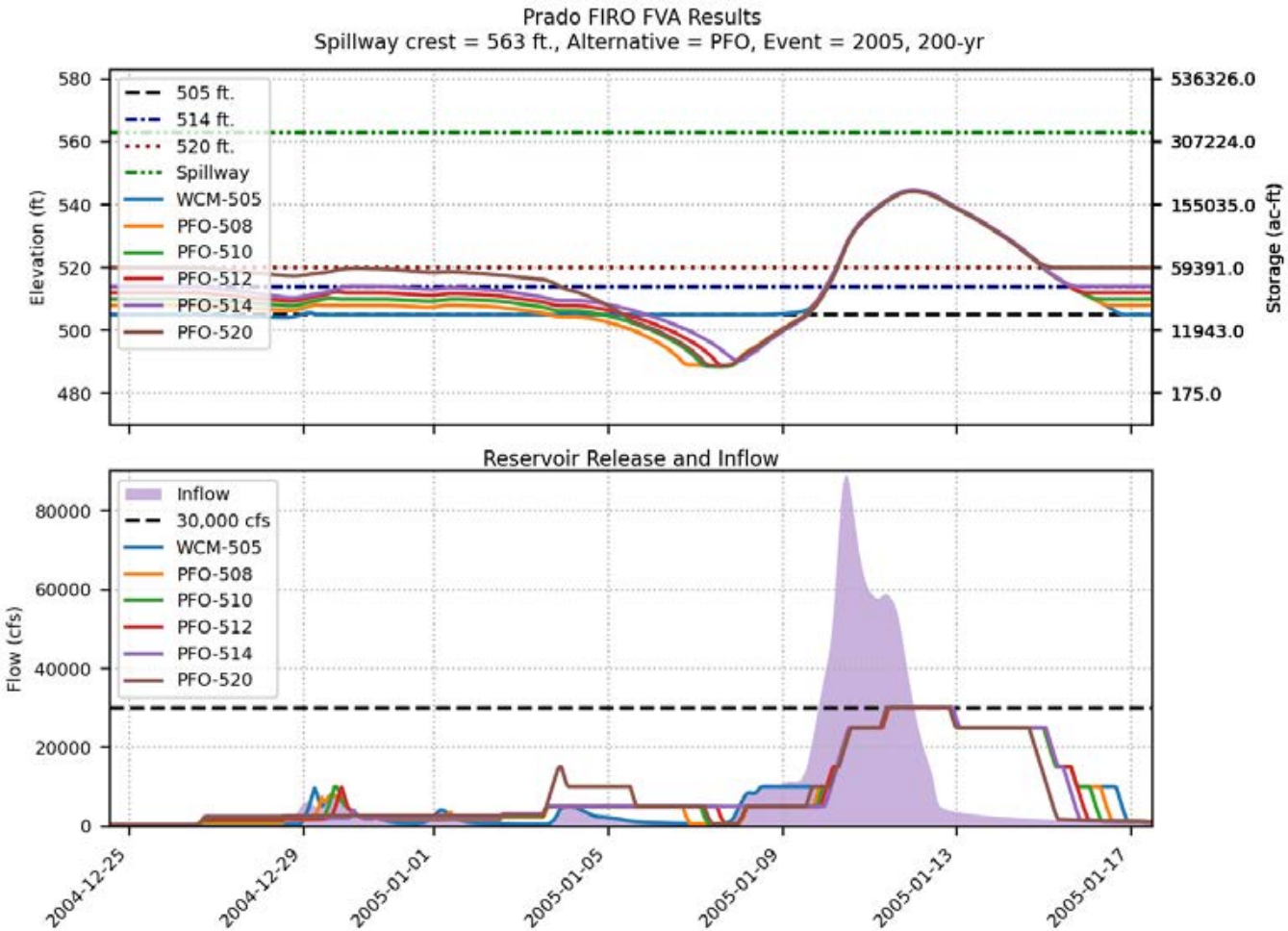
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Reservoir Release and Inflow
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PFO-508
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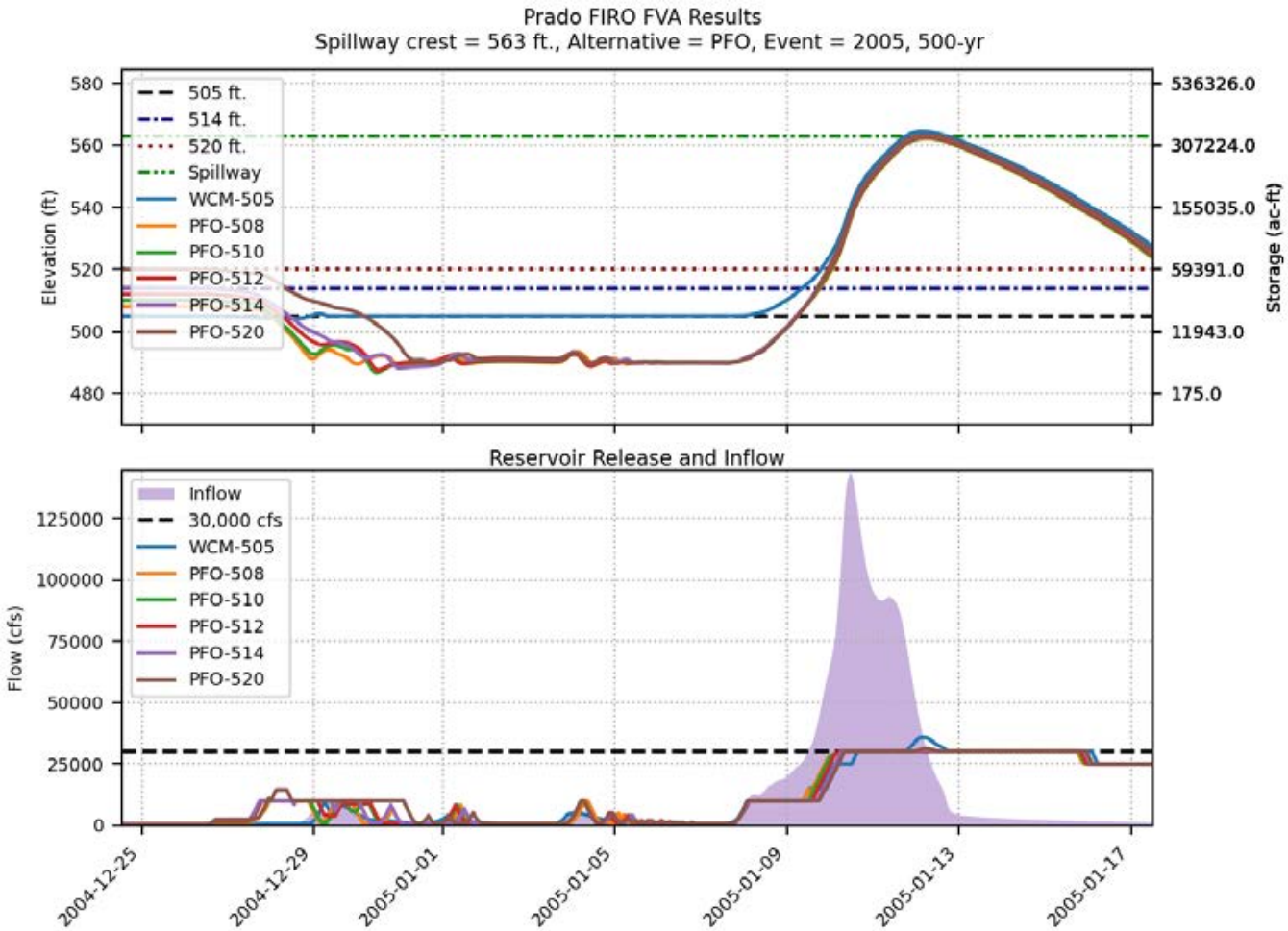
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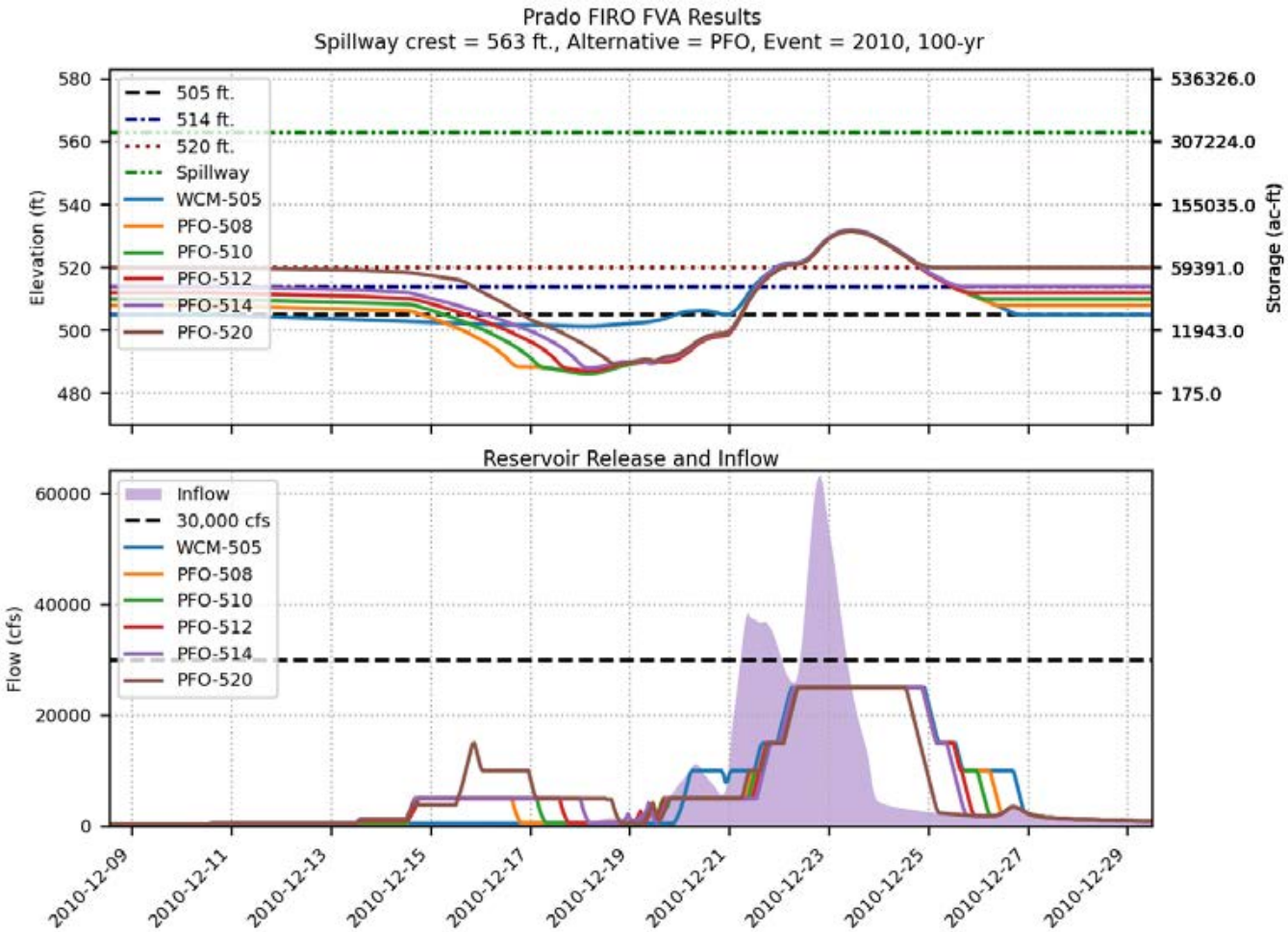
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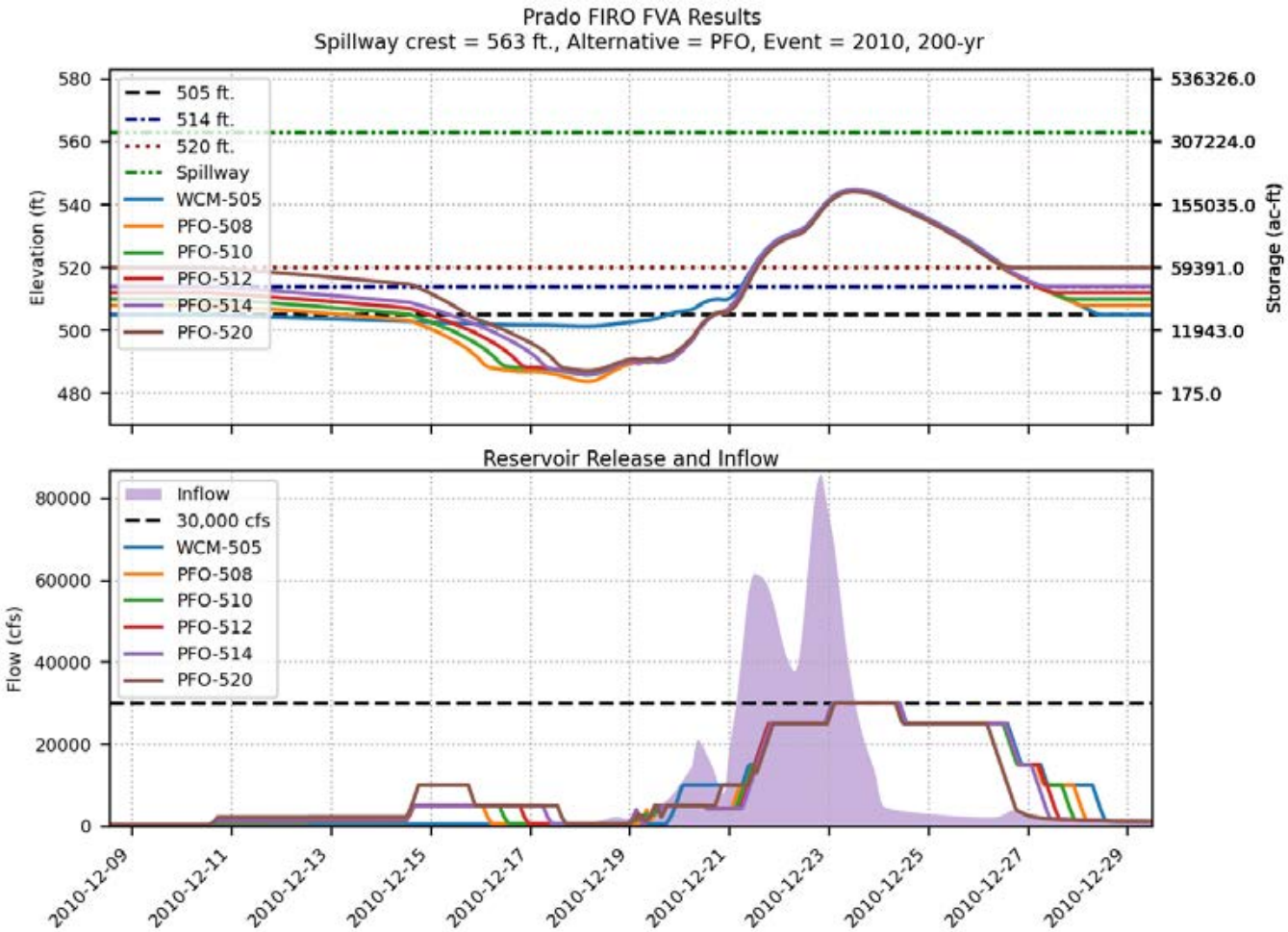
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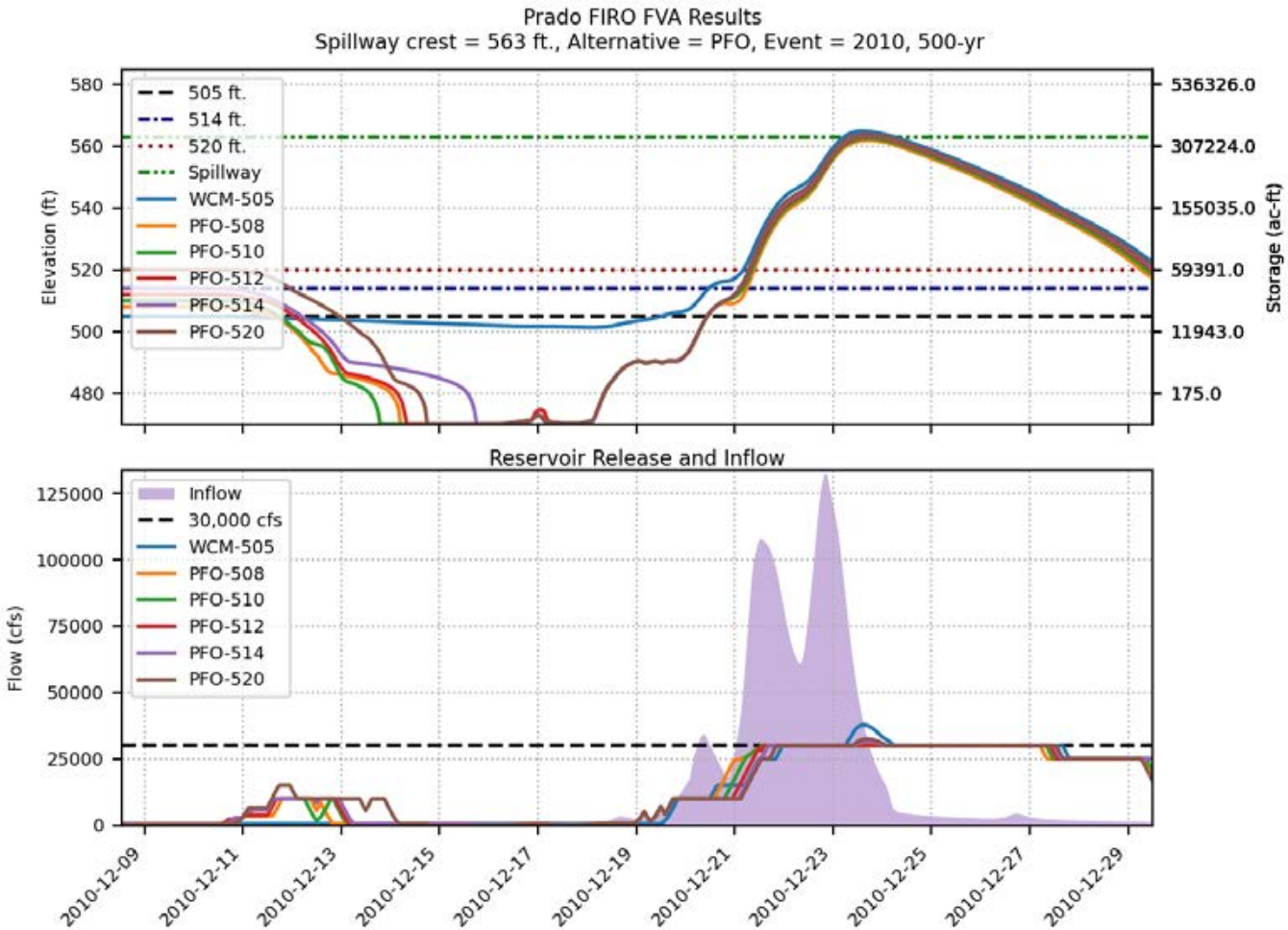
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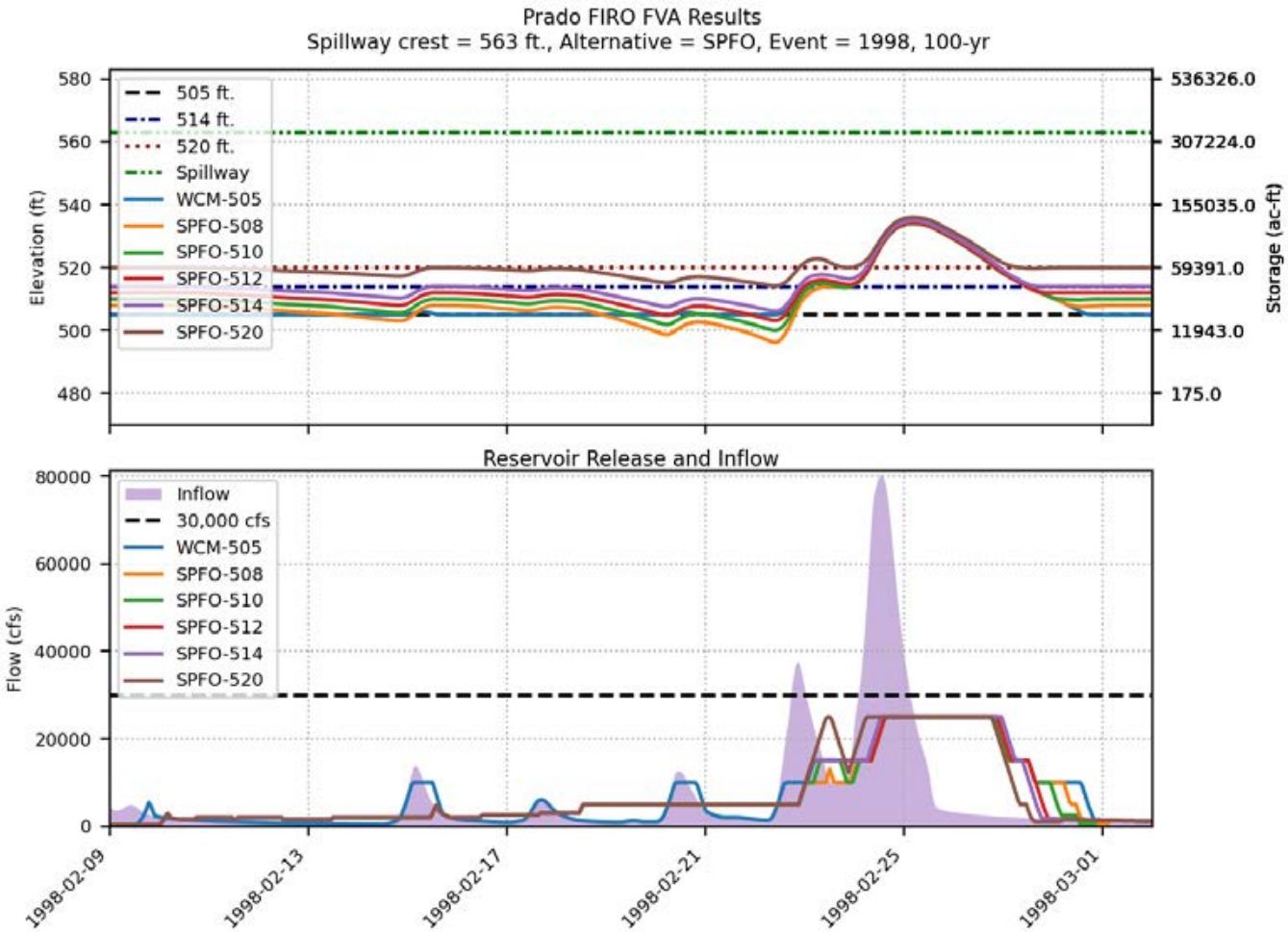
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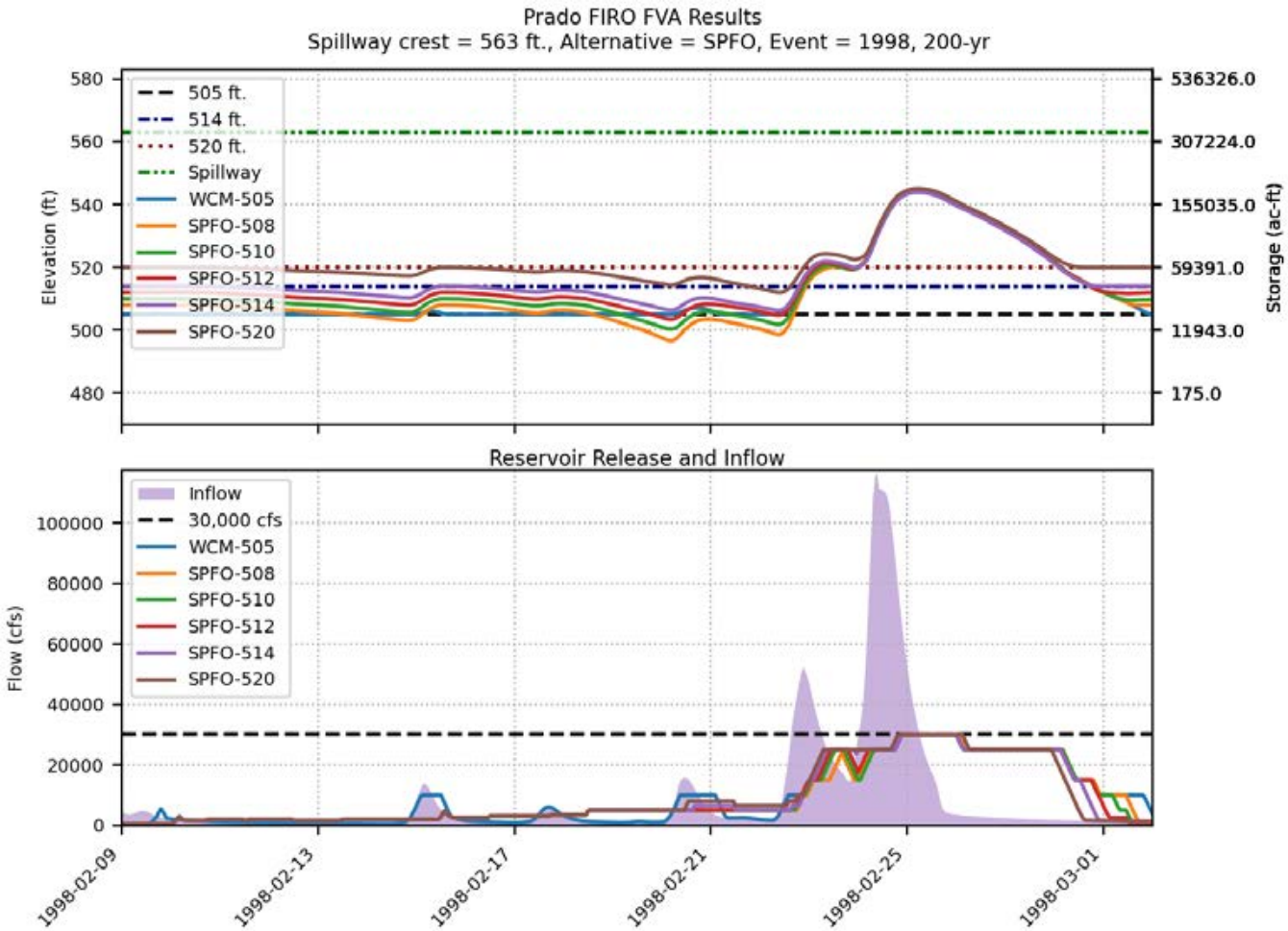
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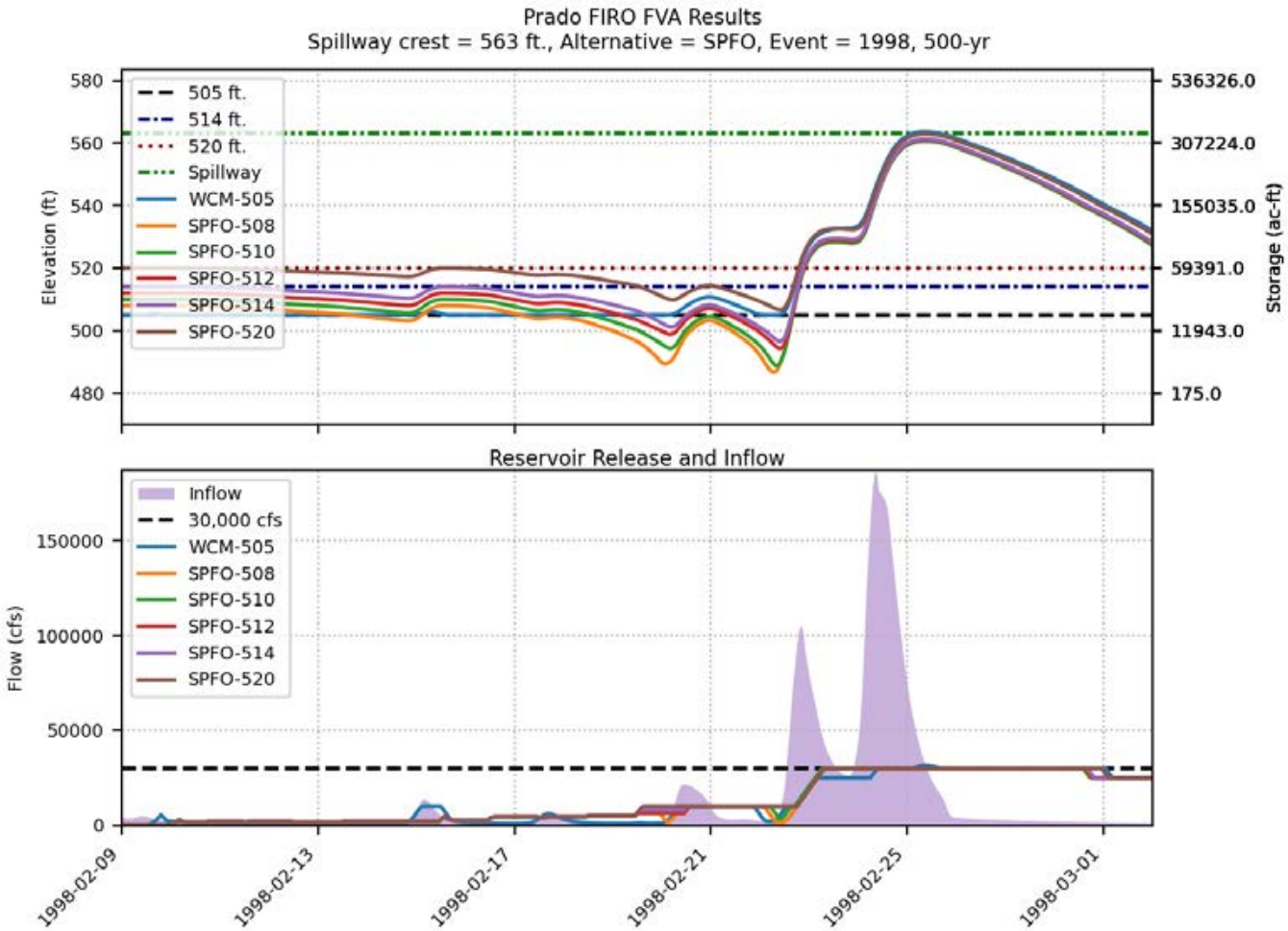
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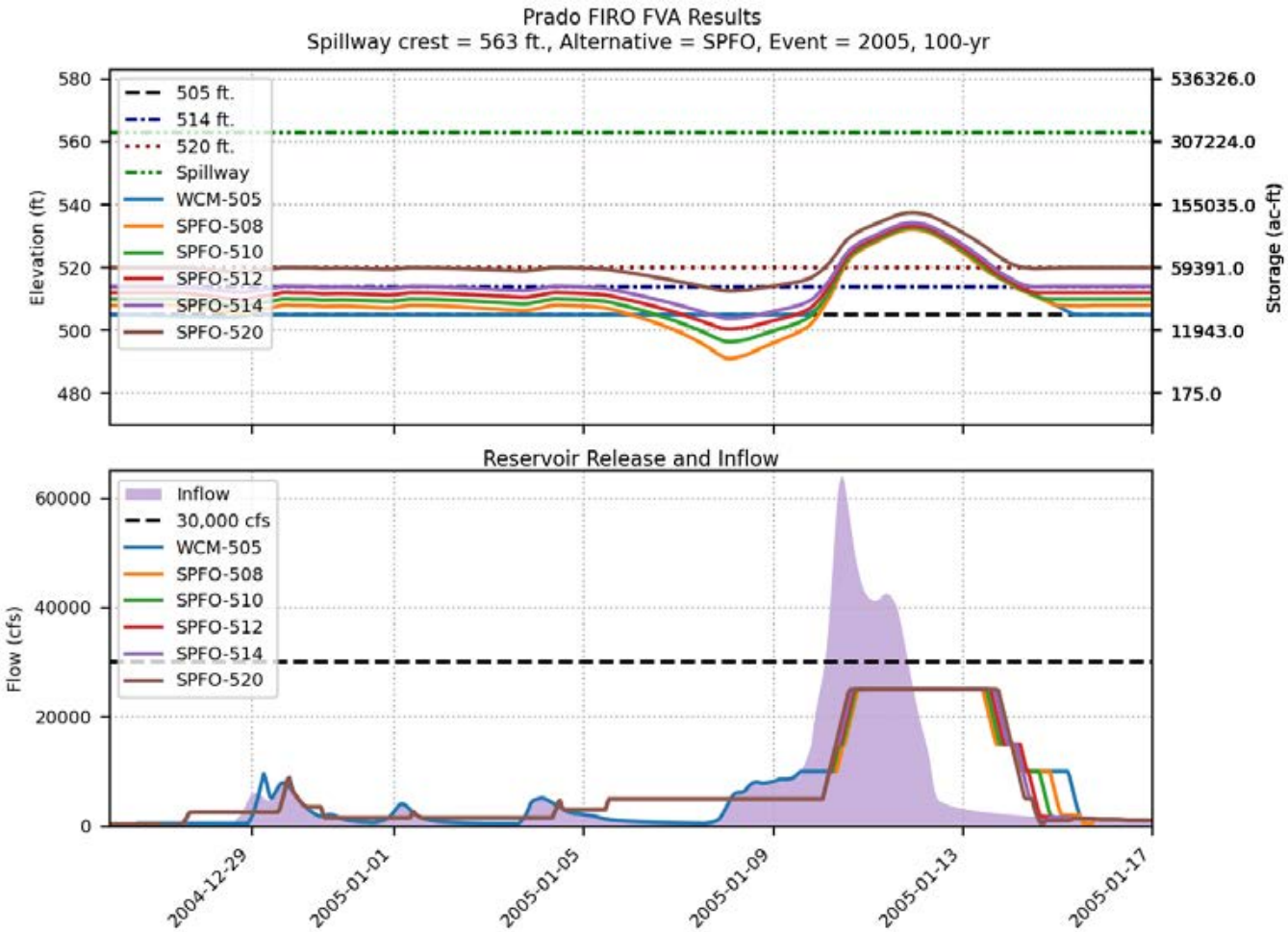
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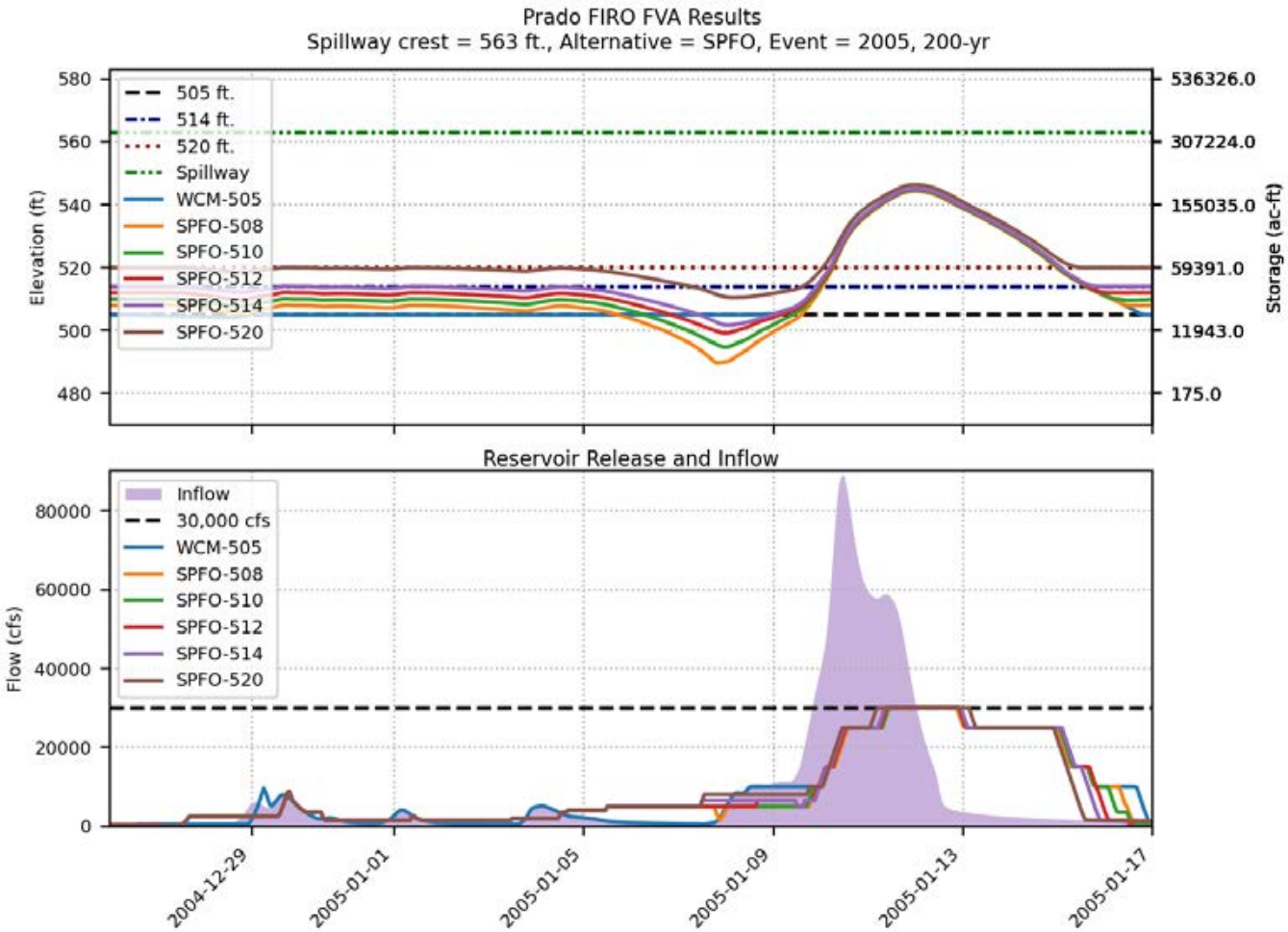
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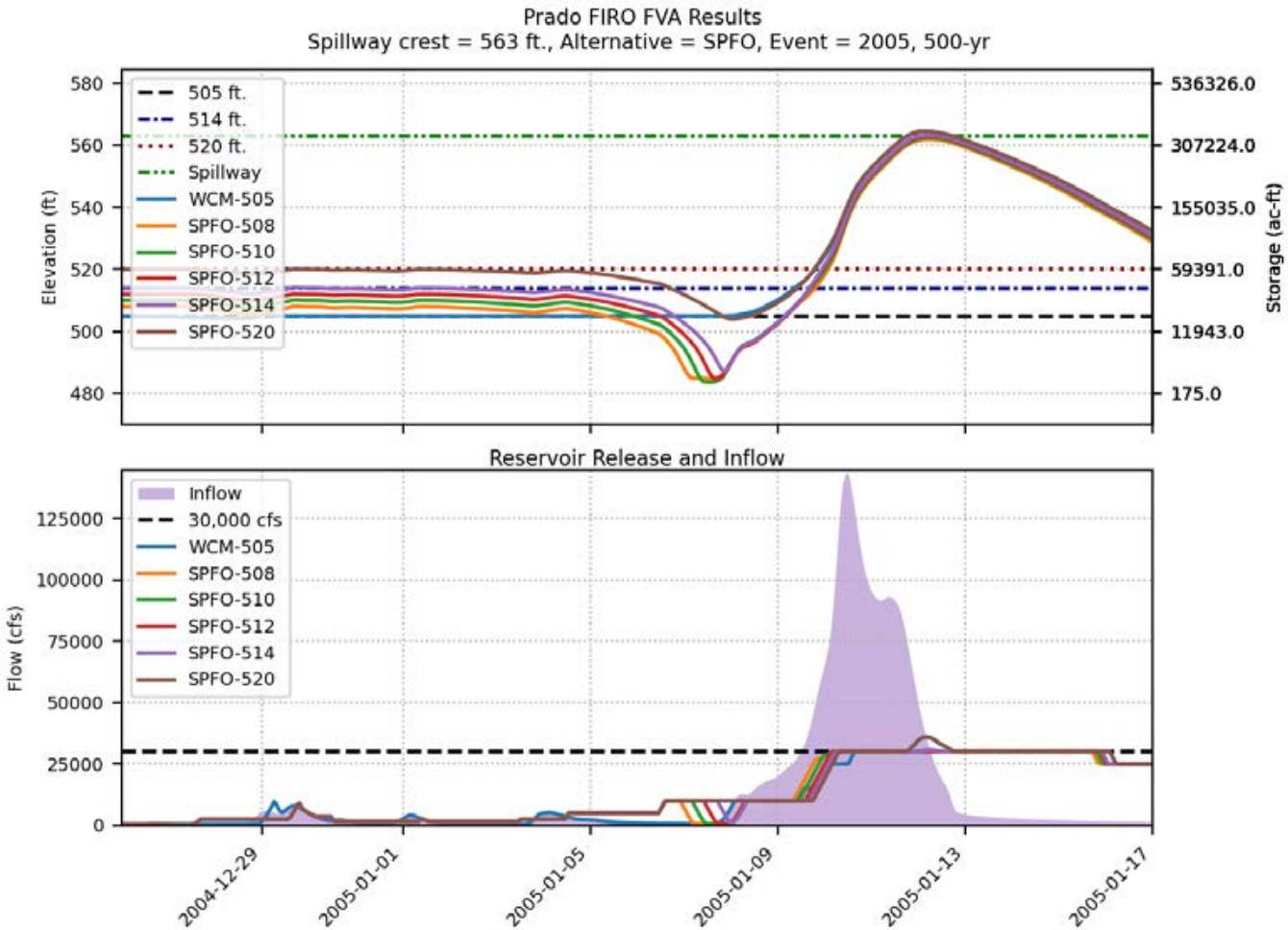
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Spillway crest = 563 ft., Alternative = SPFO, Event = 2005, 500-yr
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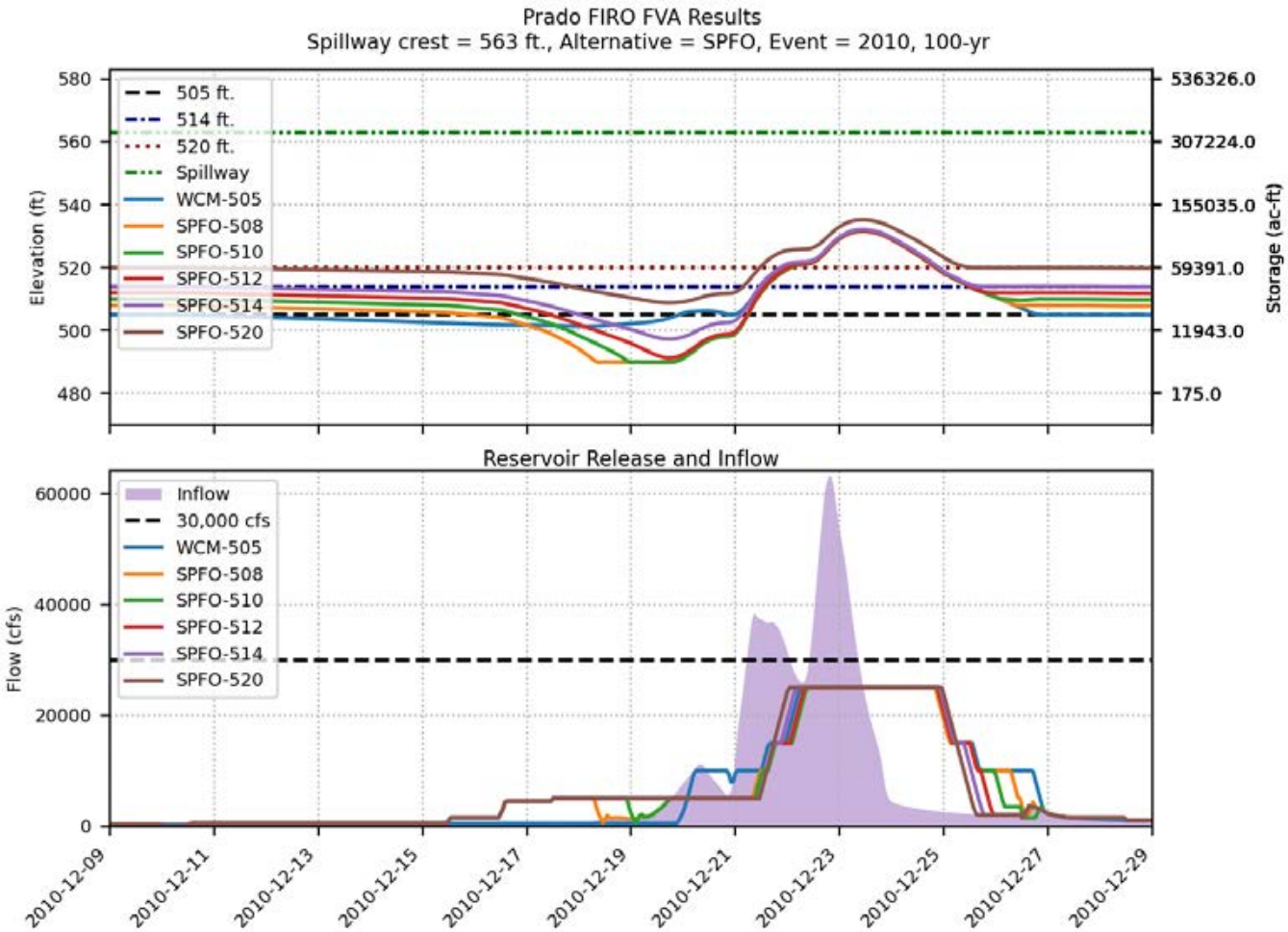
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Spillway crest = 563 ft., Alternative = SPFO, Event = 2010, 100-yr
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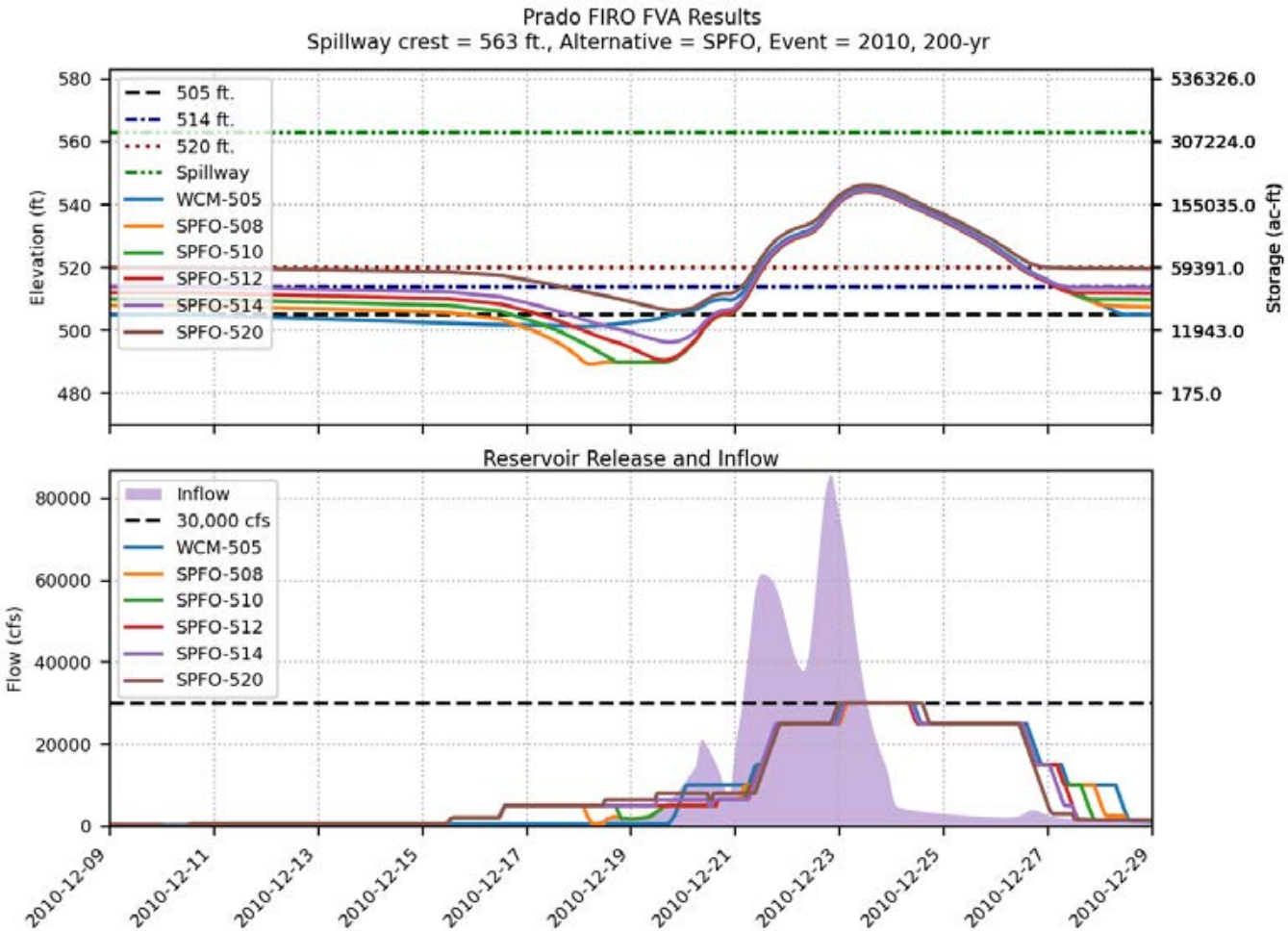
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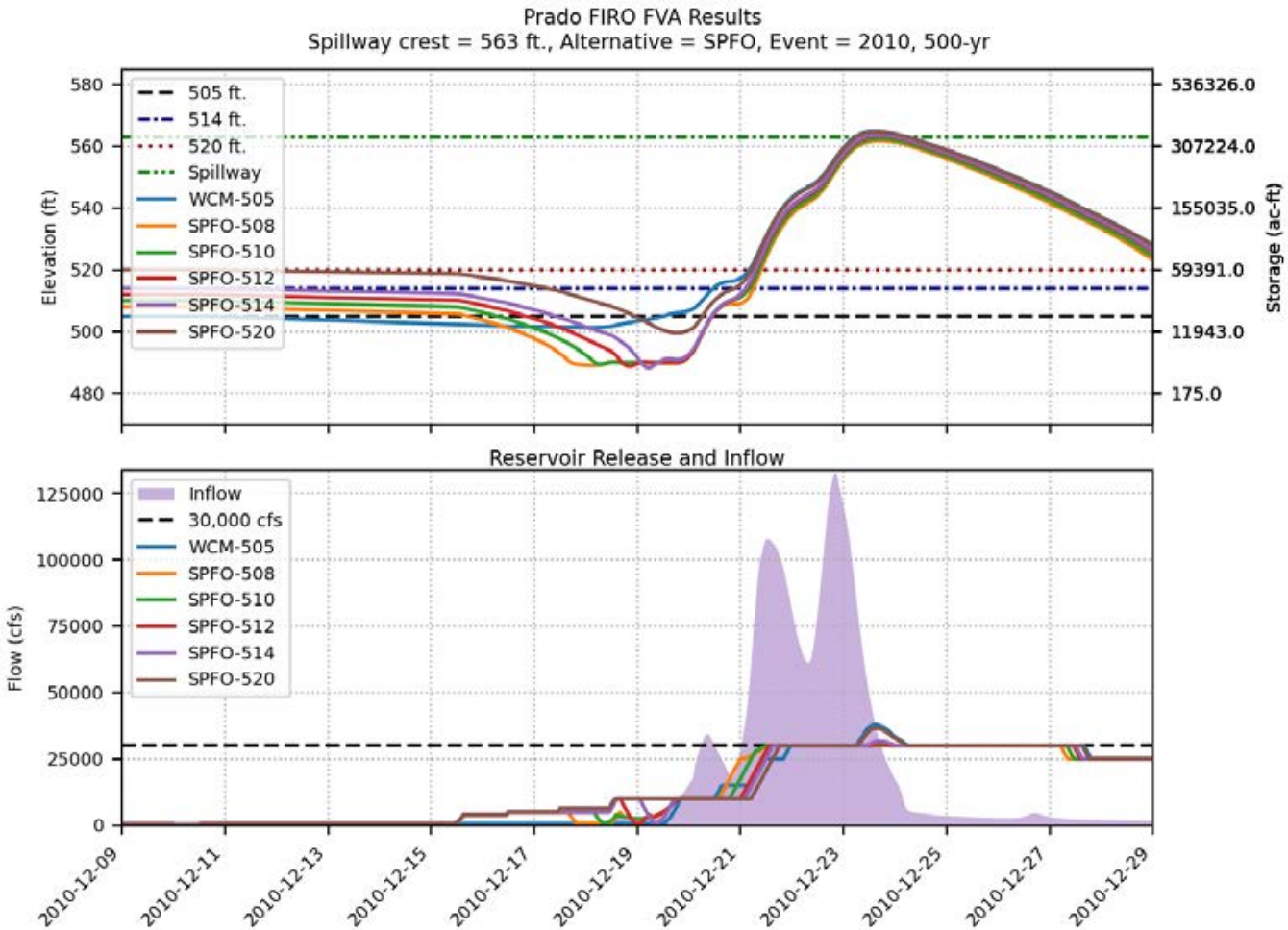
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2010-12-27
2010-12-29

Scaled Hindcast Events

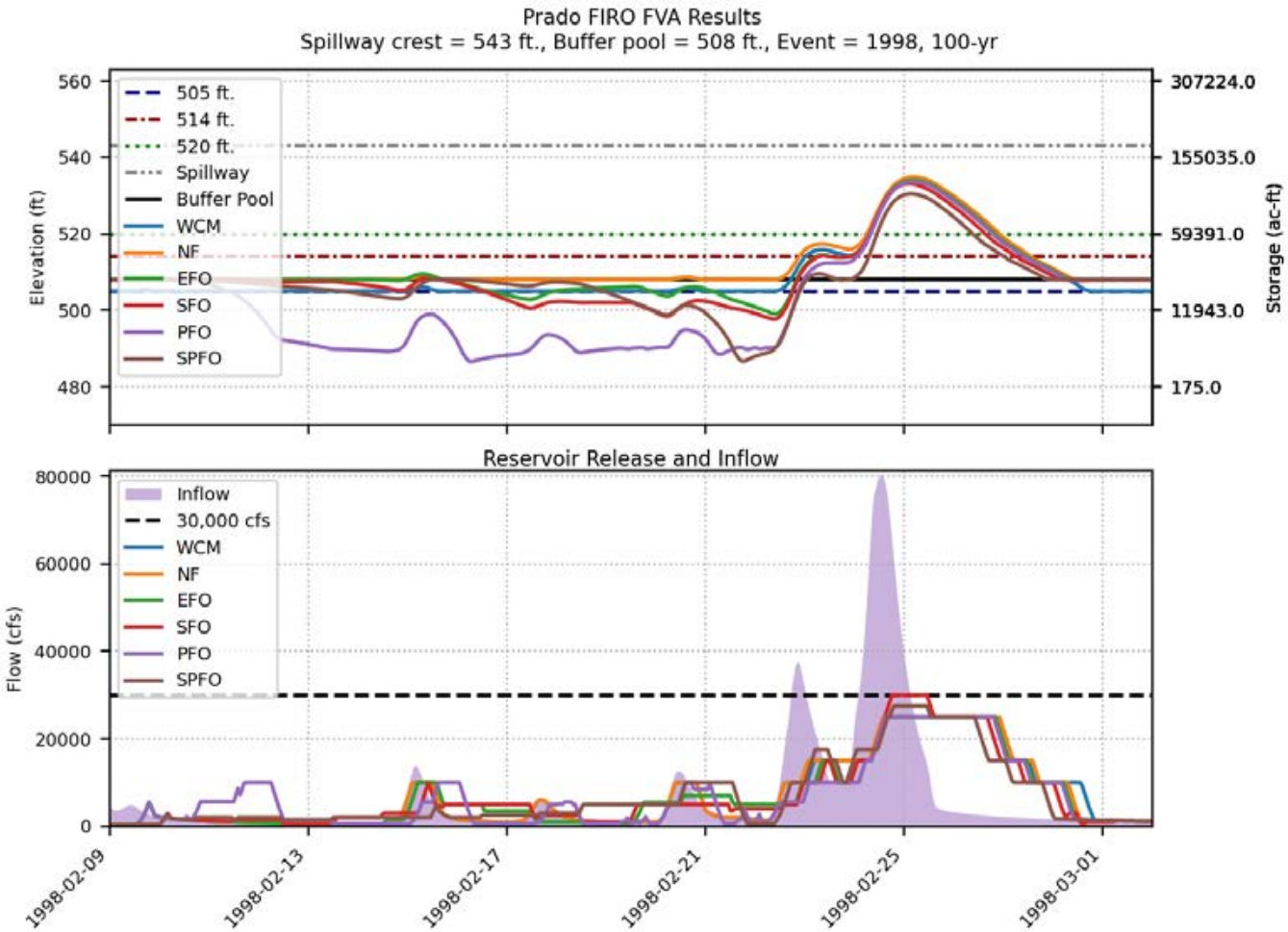
- Upper panel – Reservoir elevation/storage
- Lower panel – Reservoir inflow and release

- February 1998
- January 2006
- December 2010

- Scaled to 100-y, 200-yr, 500-yr 3-day inflow volume

Scaled Hindcast Events

- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’, 510’, 512’, 514’, 520’
- WCP alternatives in legend
  - WCM is 505’ Buffer Pool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Elevation (ft)
Storage (ac-ft)
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514 ft.
520 ft.
Spillway
Buffer Pool
WCM
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EFO
SFO
PFO
SPFO
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59391.0
11943.0
175.0
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Inflow
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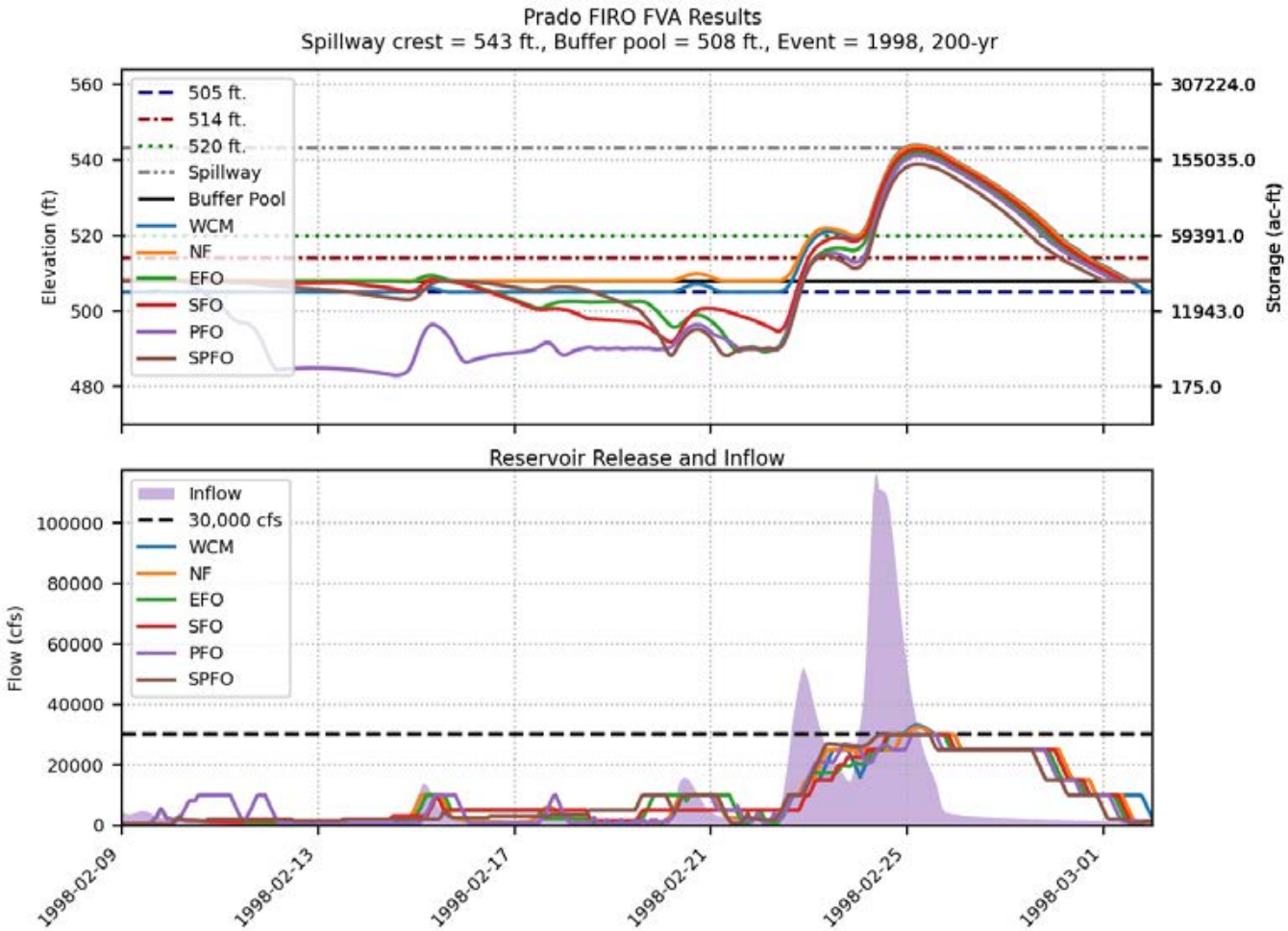
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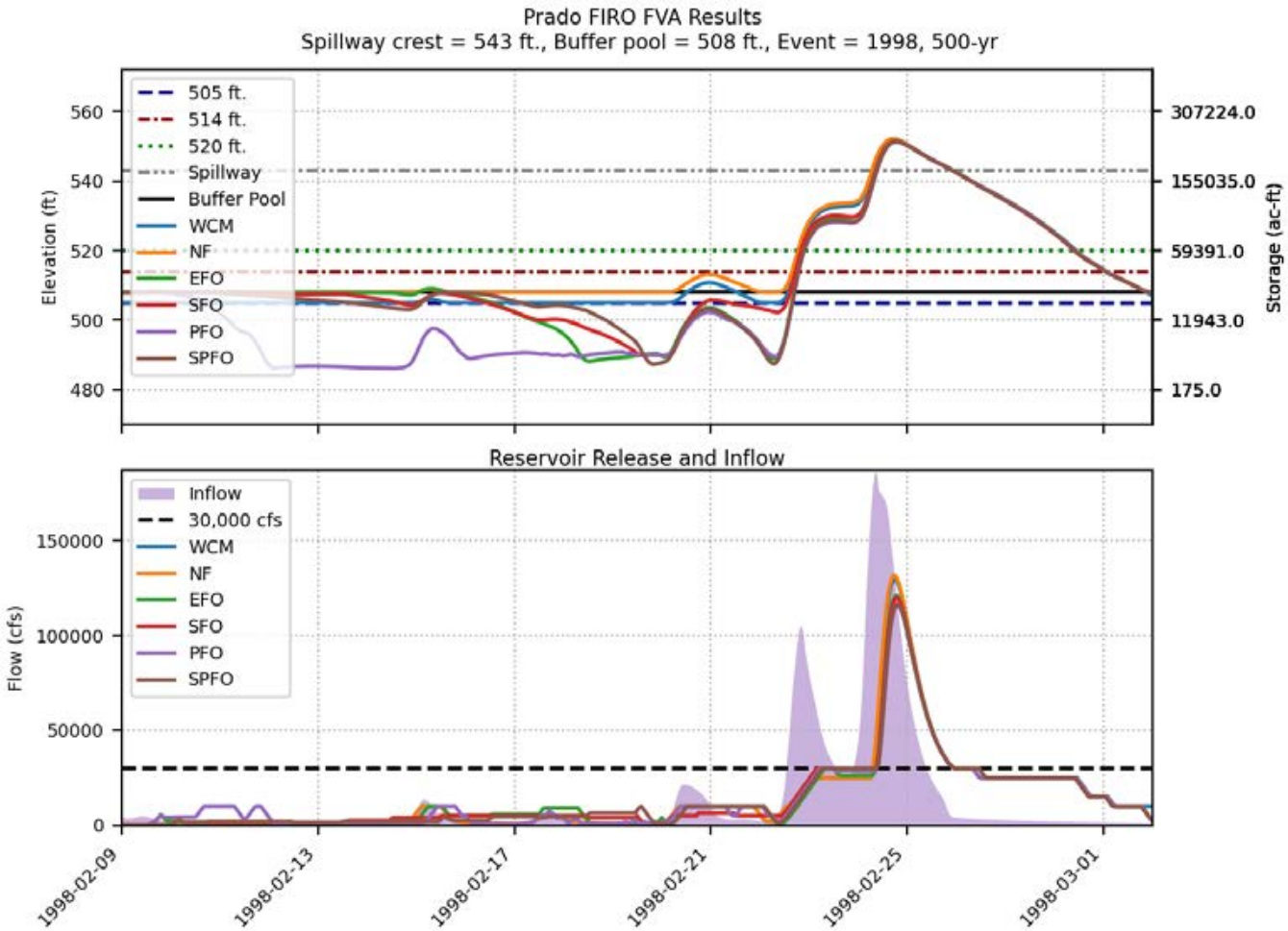
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EFO
SFO
PFO
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Storage (ac-ft)
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Inflow
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SPFO
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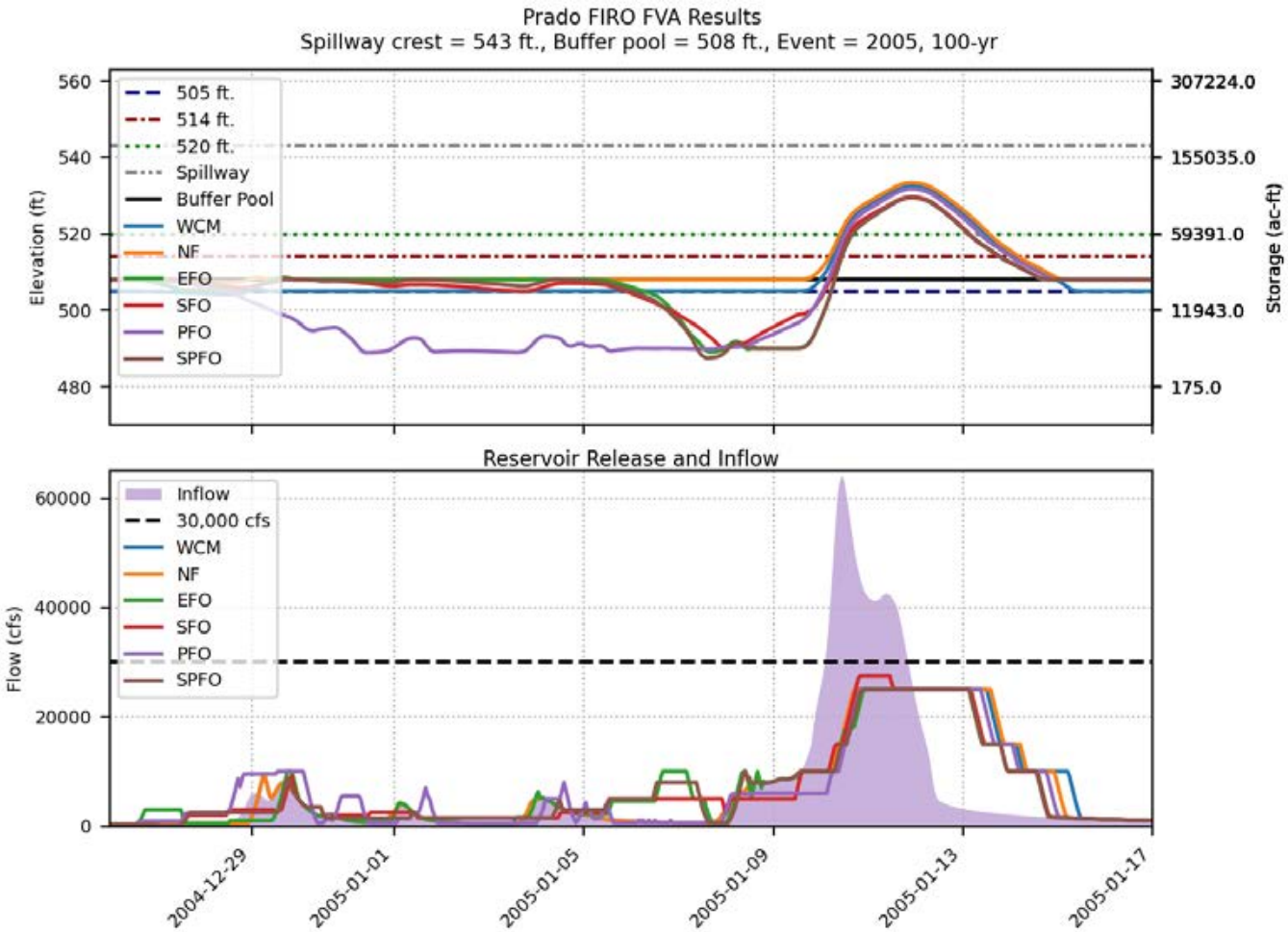
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Elevation (ft)
Storage (ac-ft)
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155035.0
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175.0
Reservoir Release and Inflow
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Flow (cfs)
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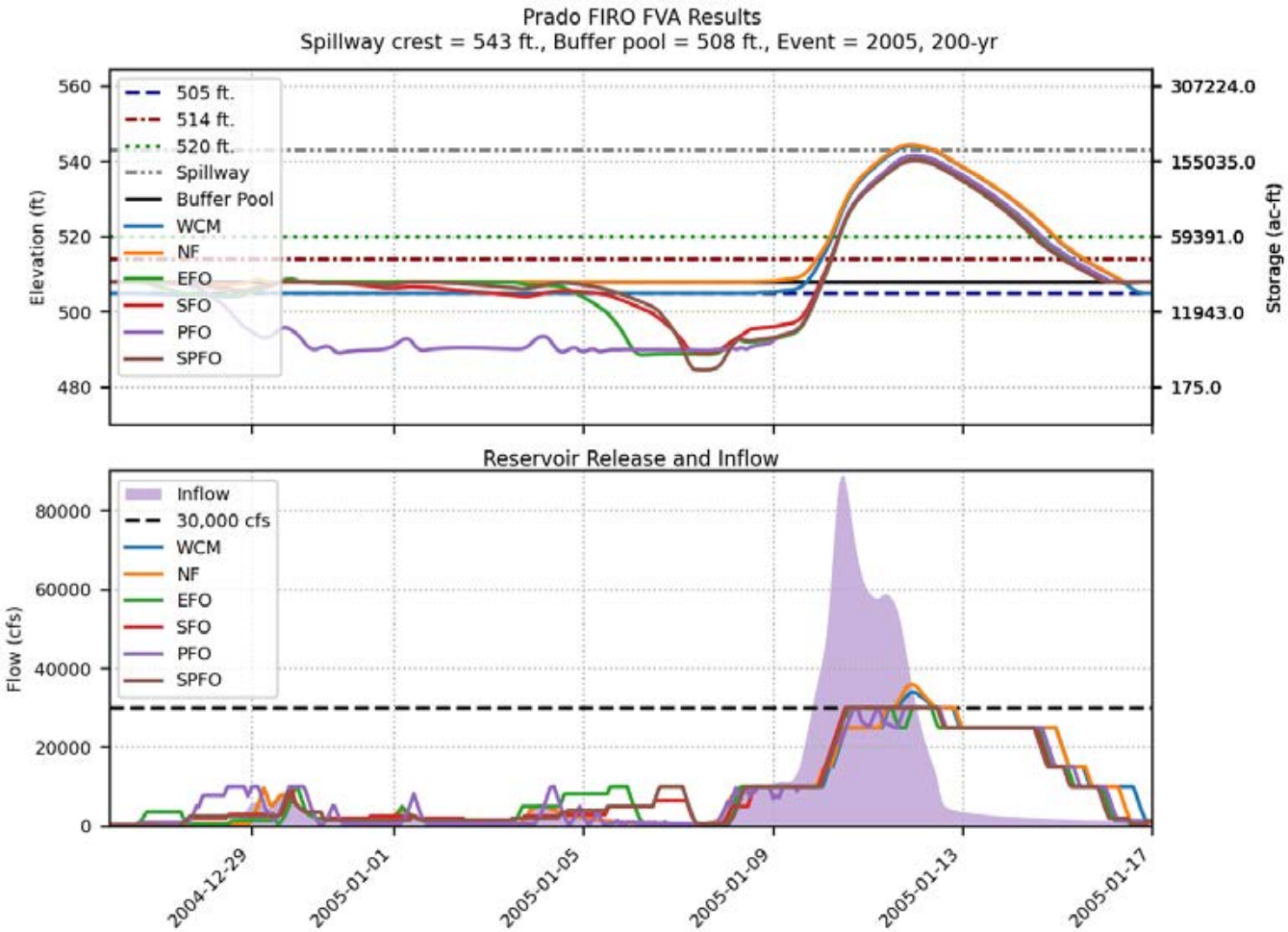
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 508 ft., Event = 2005, 200-yr
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Reservoir Release and Inflow
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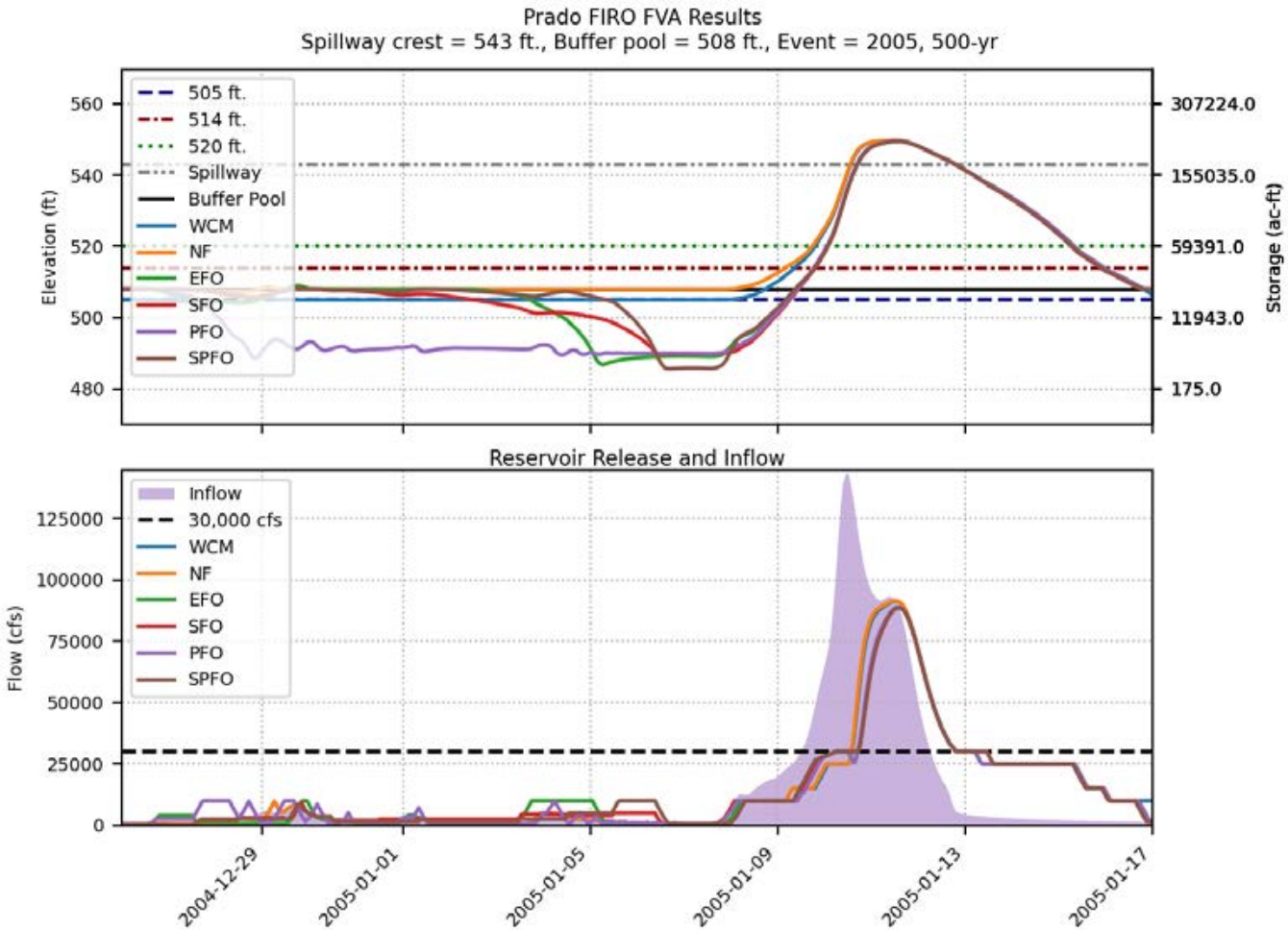
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Reservoir Release and Inflow
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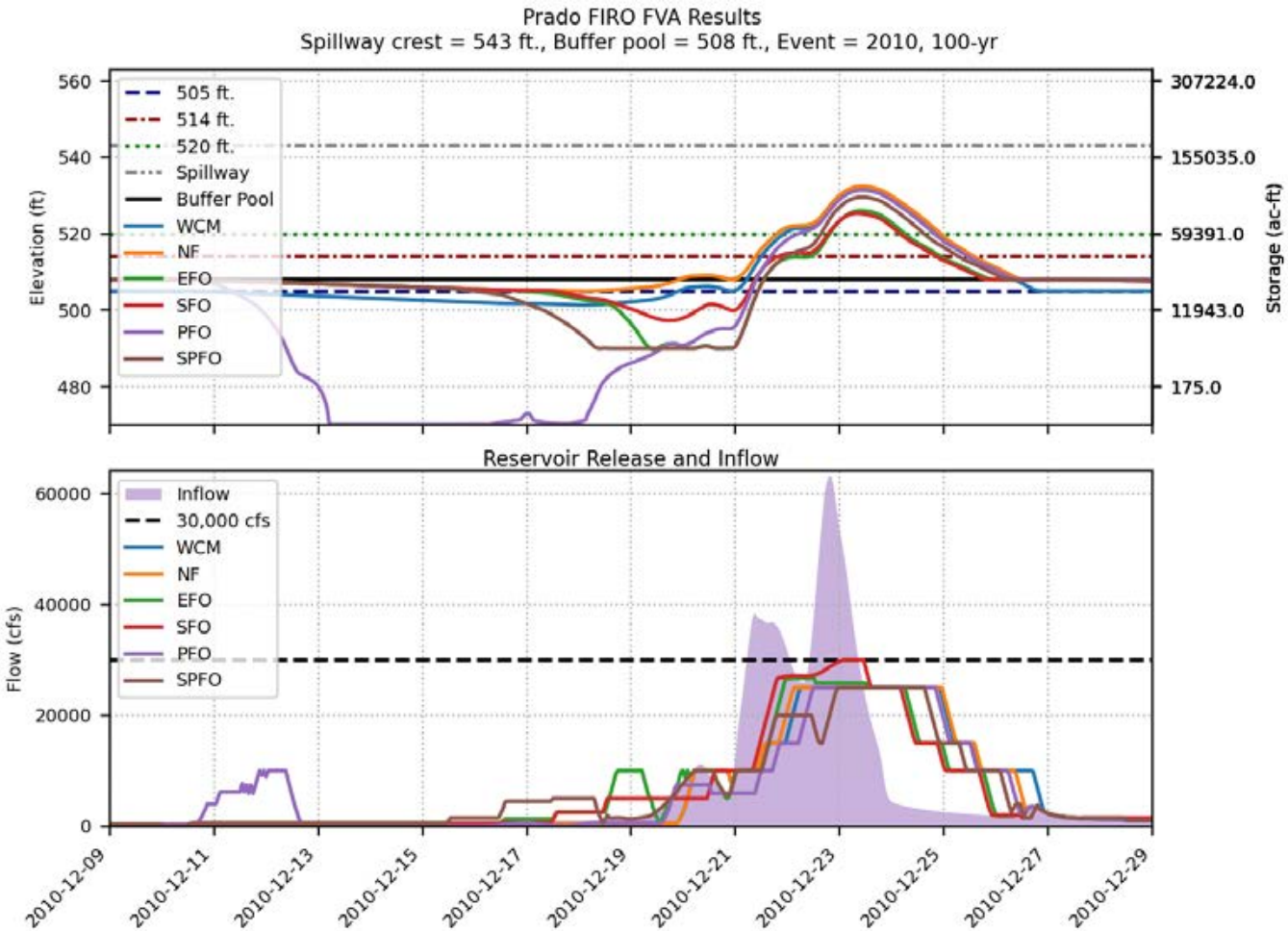
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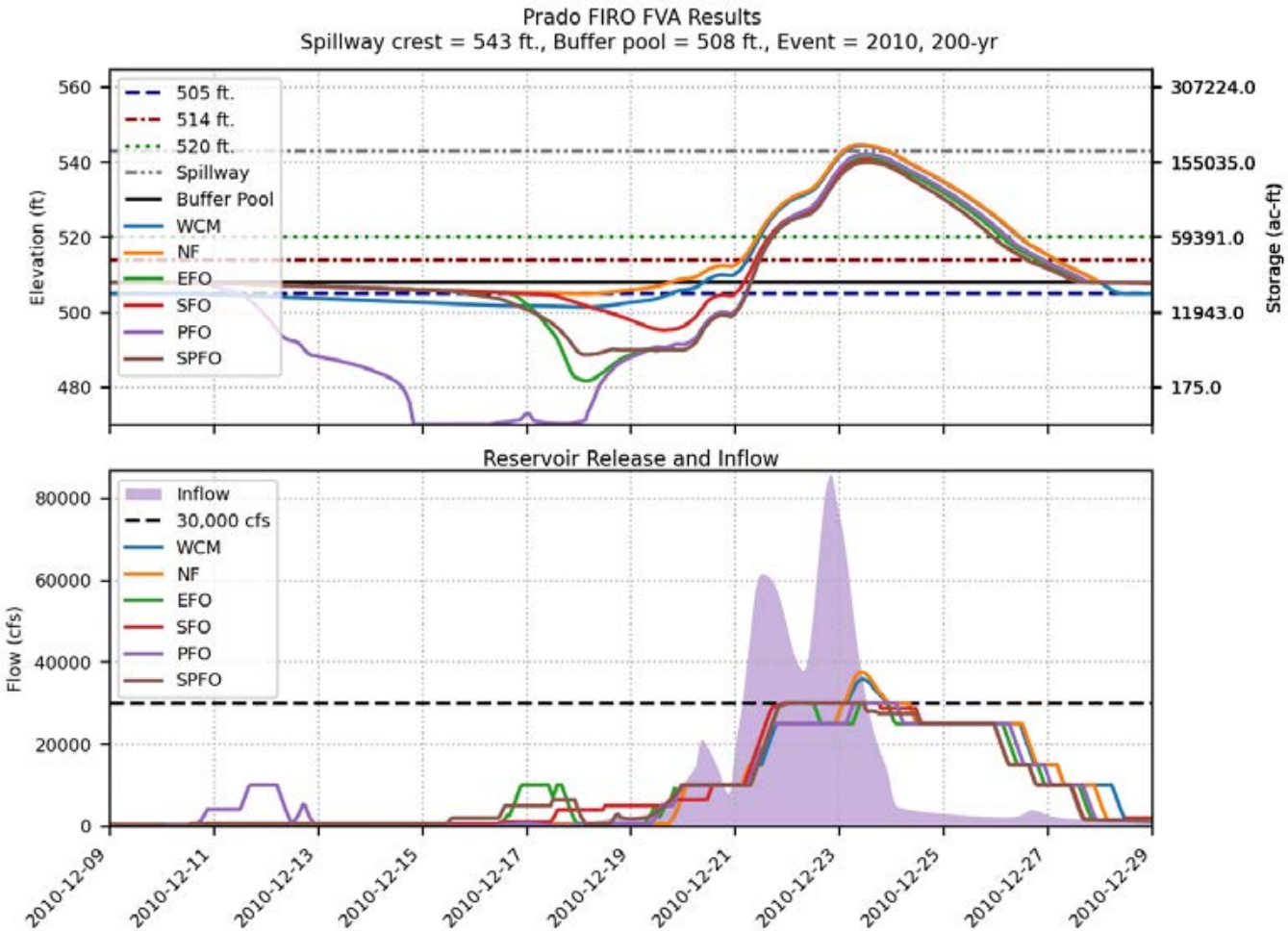
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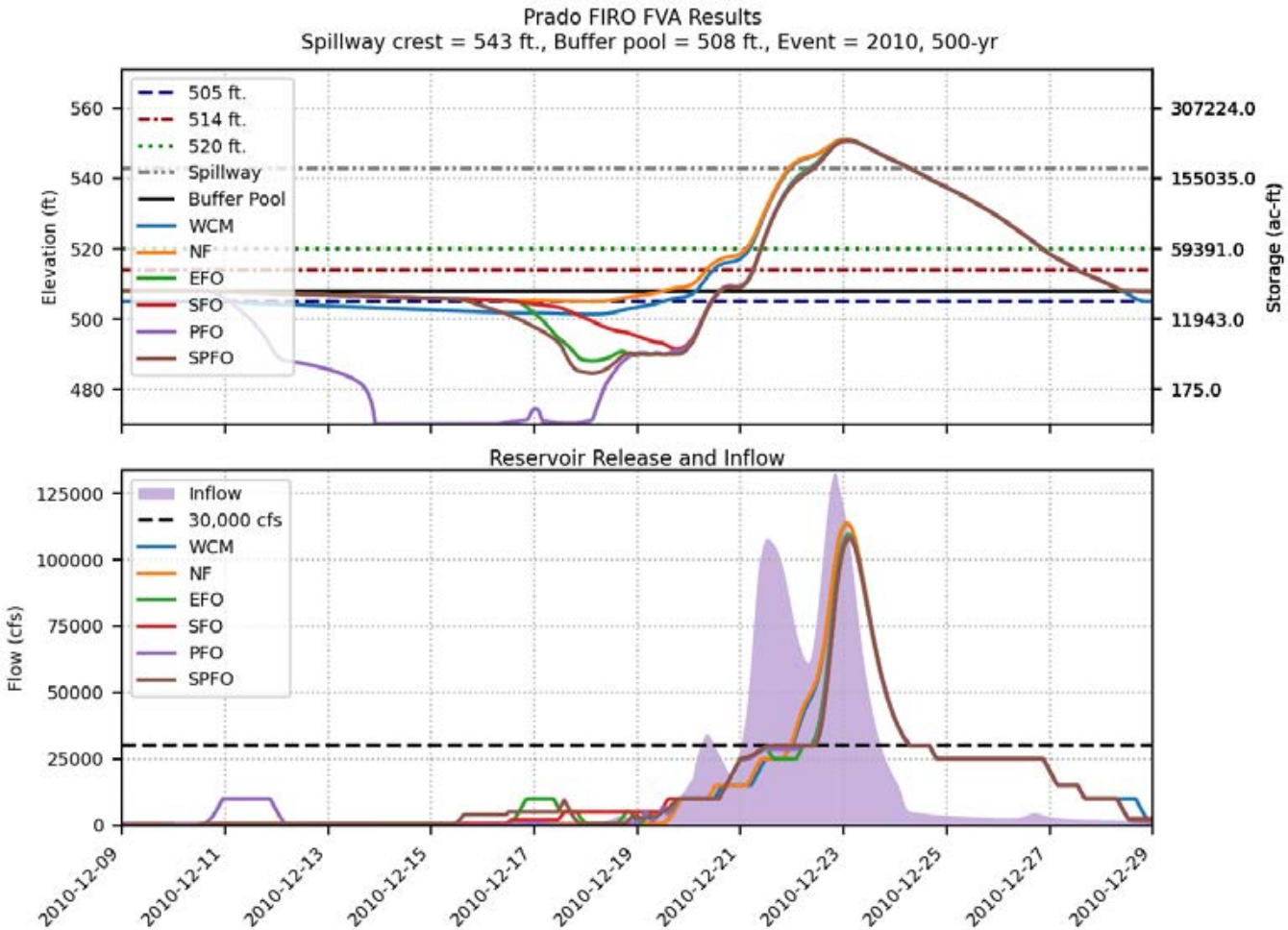
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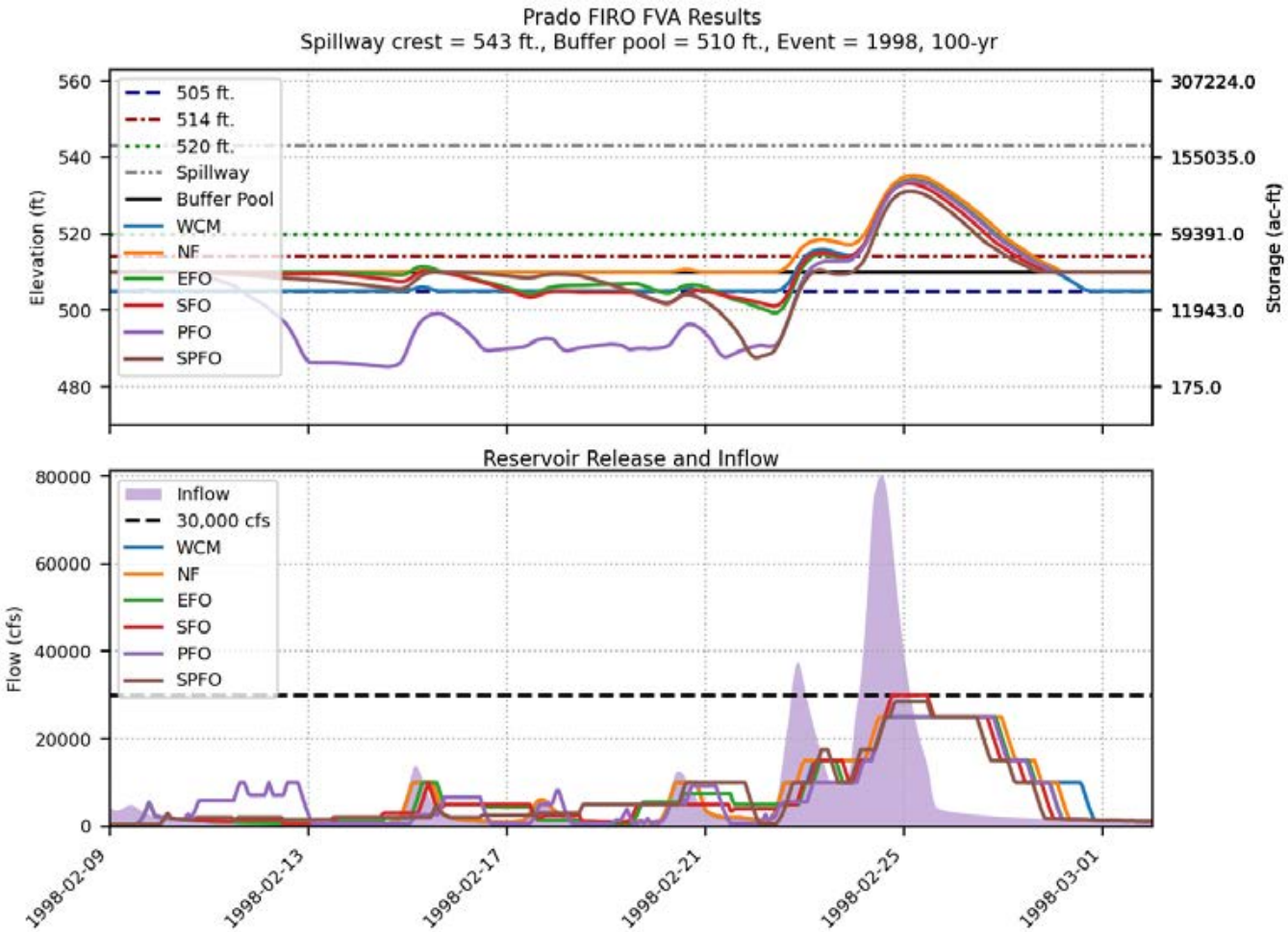
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 510 ft., Event = 1998, 100-yr
Elevation (ft)
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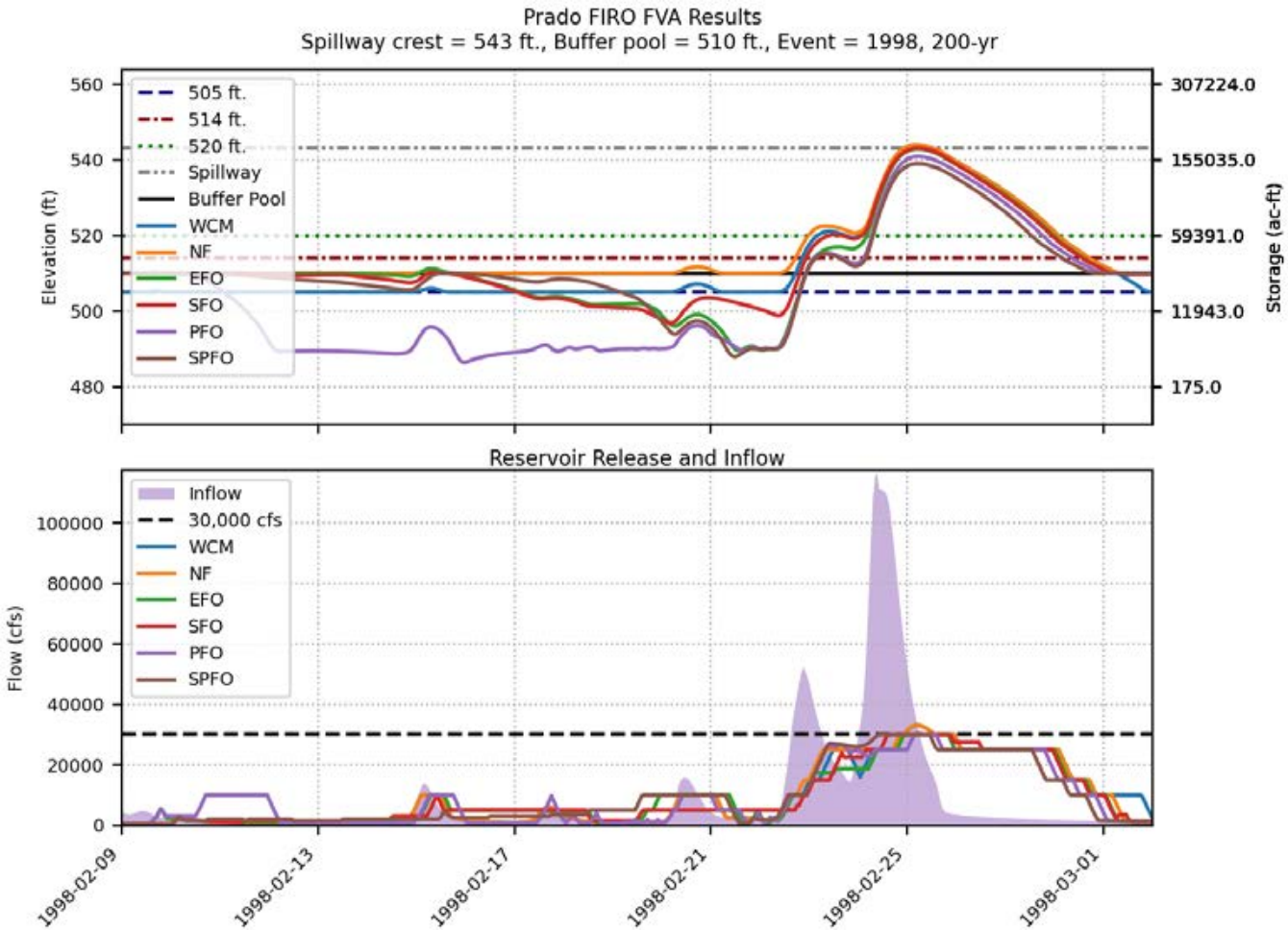
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Spillway crest = 543 ft., Buffer pool = 510 ft., Event = 1998, 200-yr
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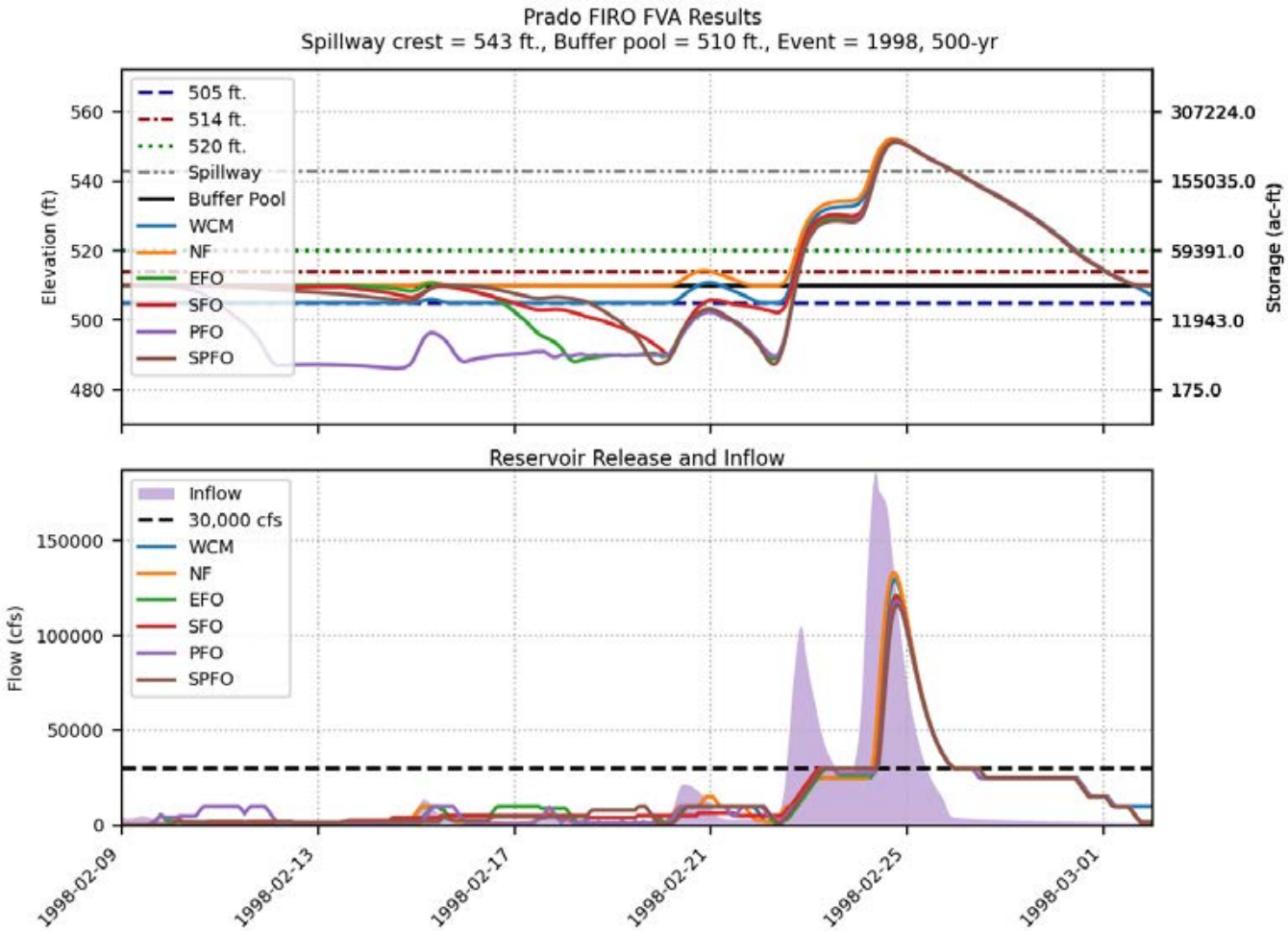
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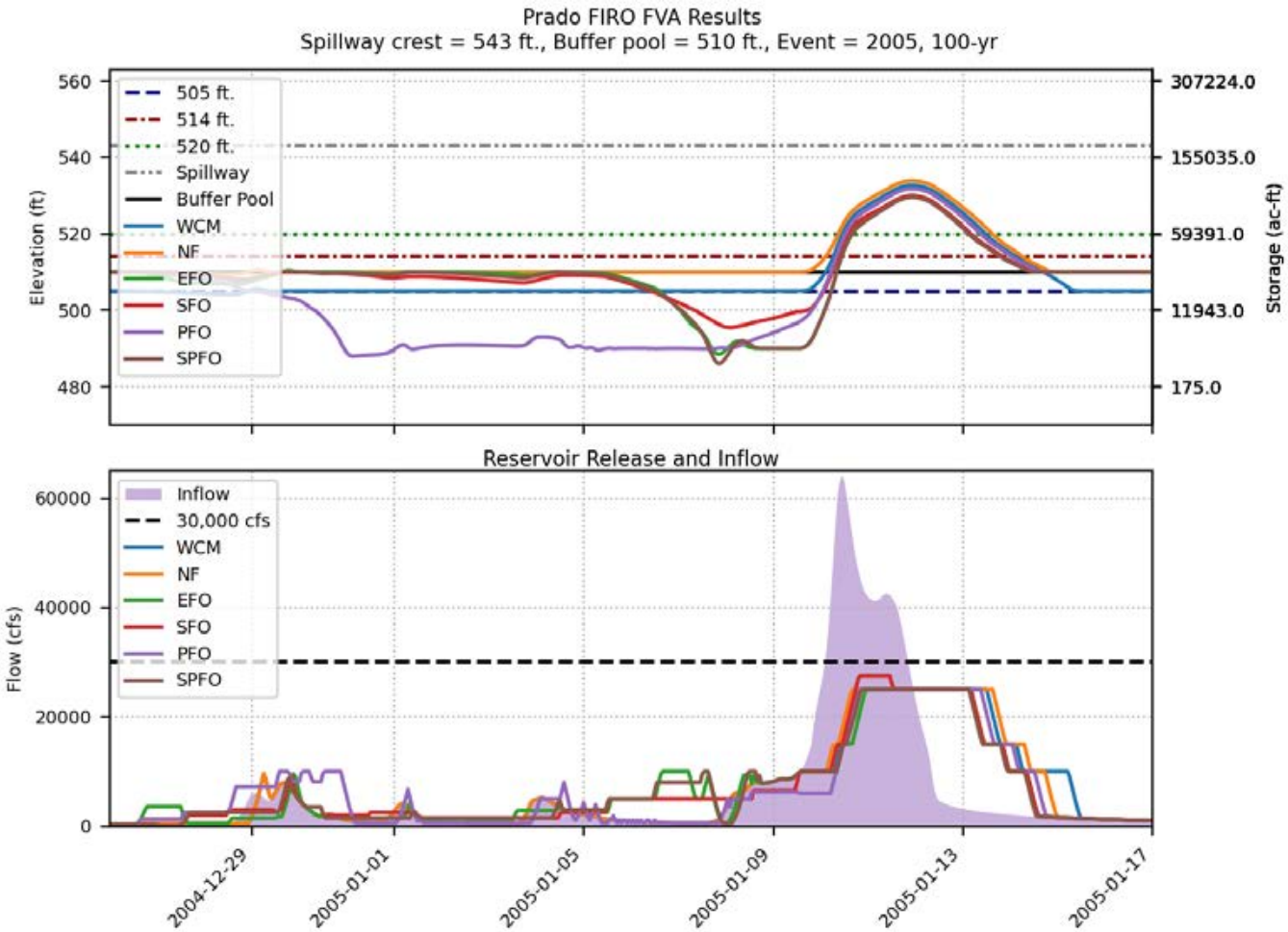
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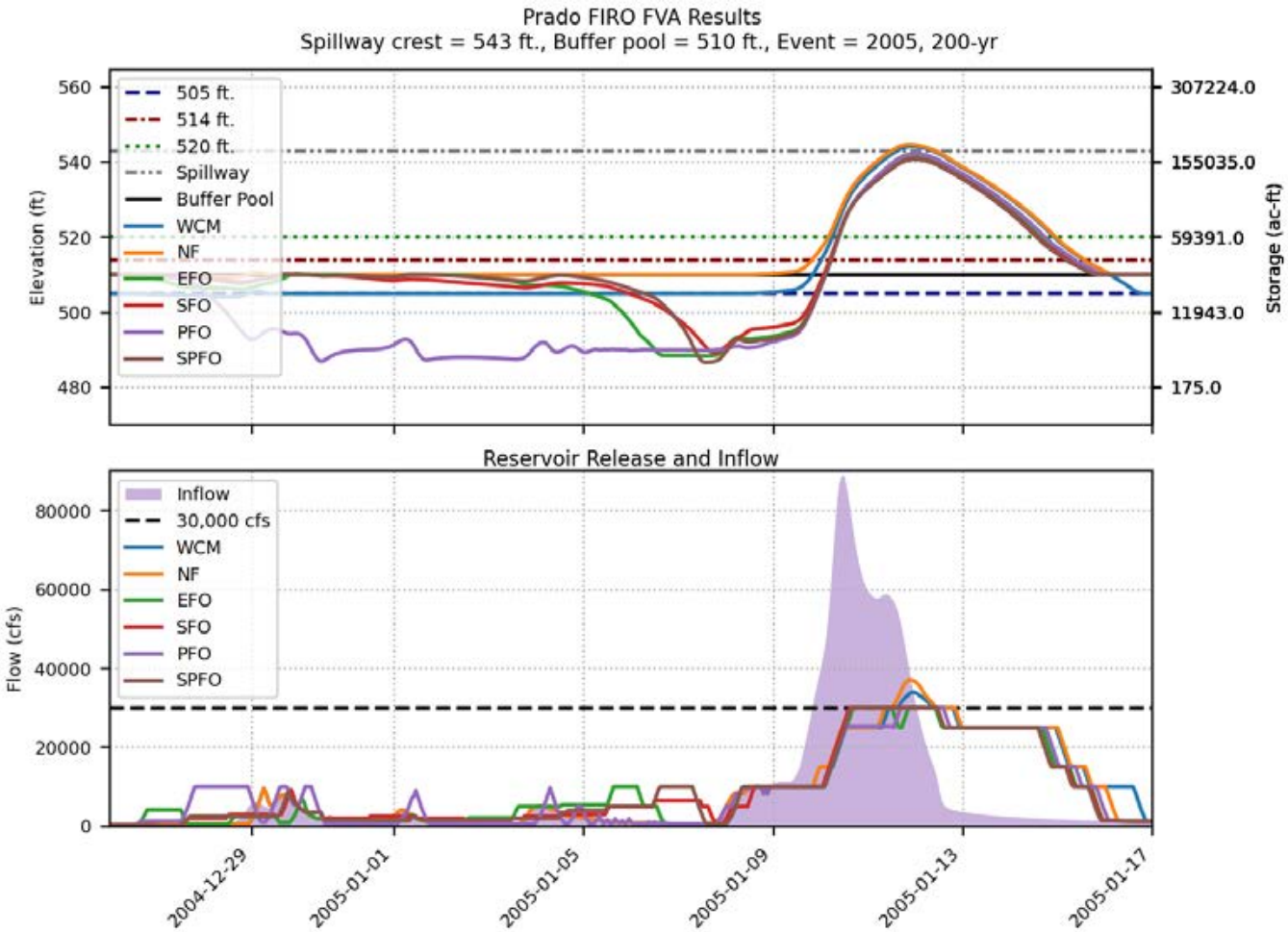
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Spillway crest = 543 ft., Buffer pool = 510 ft., Event = 2005, 200-yr
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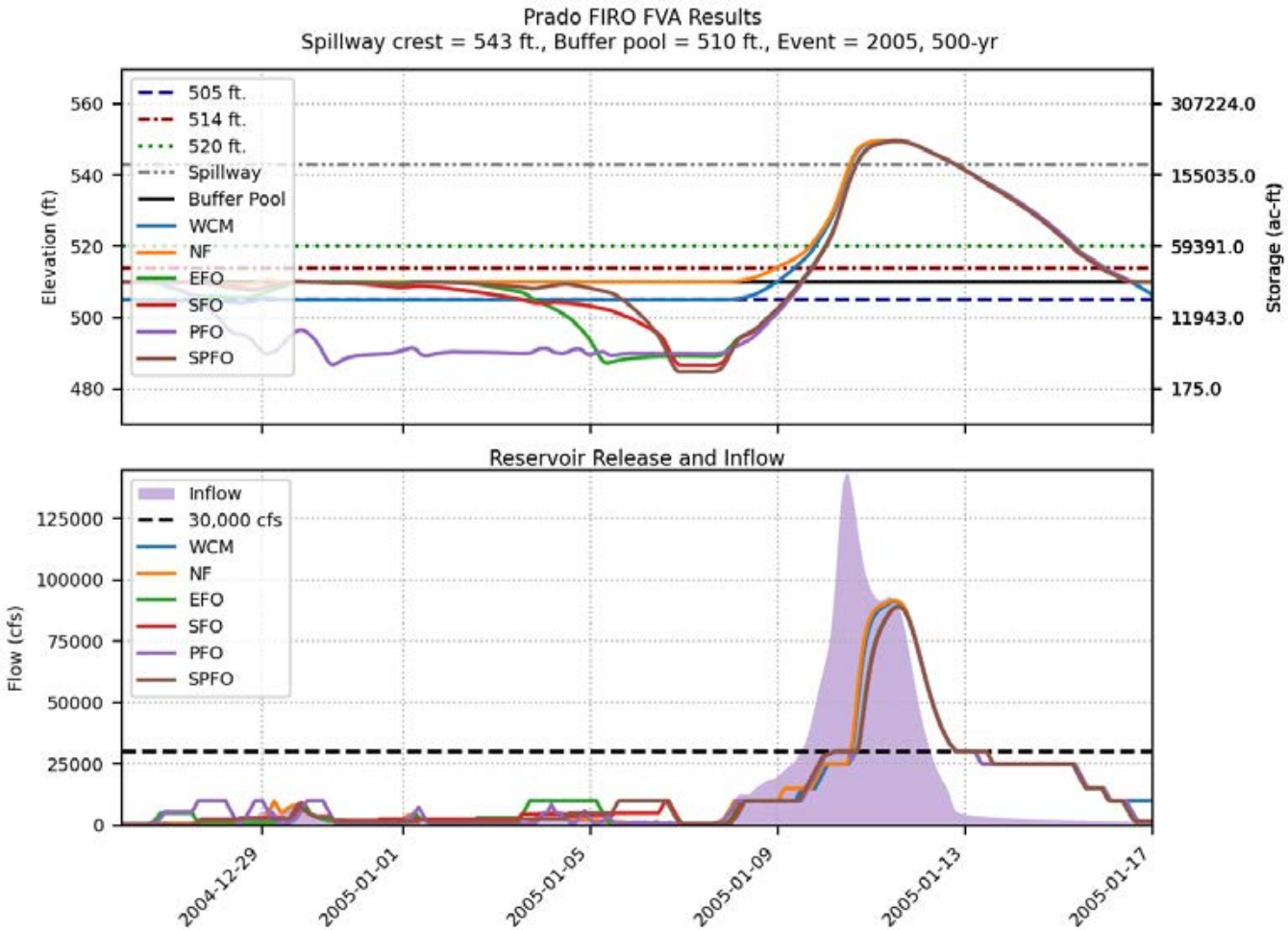
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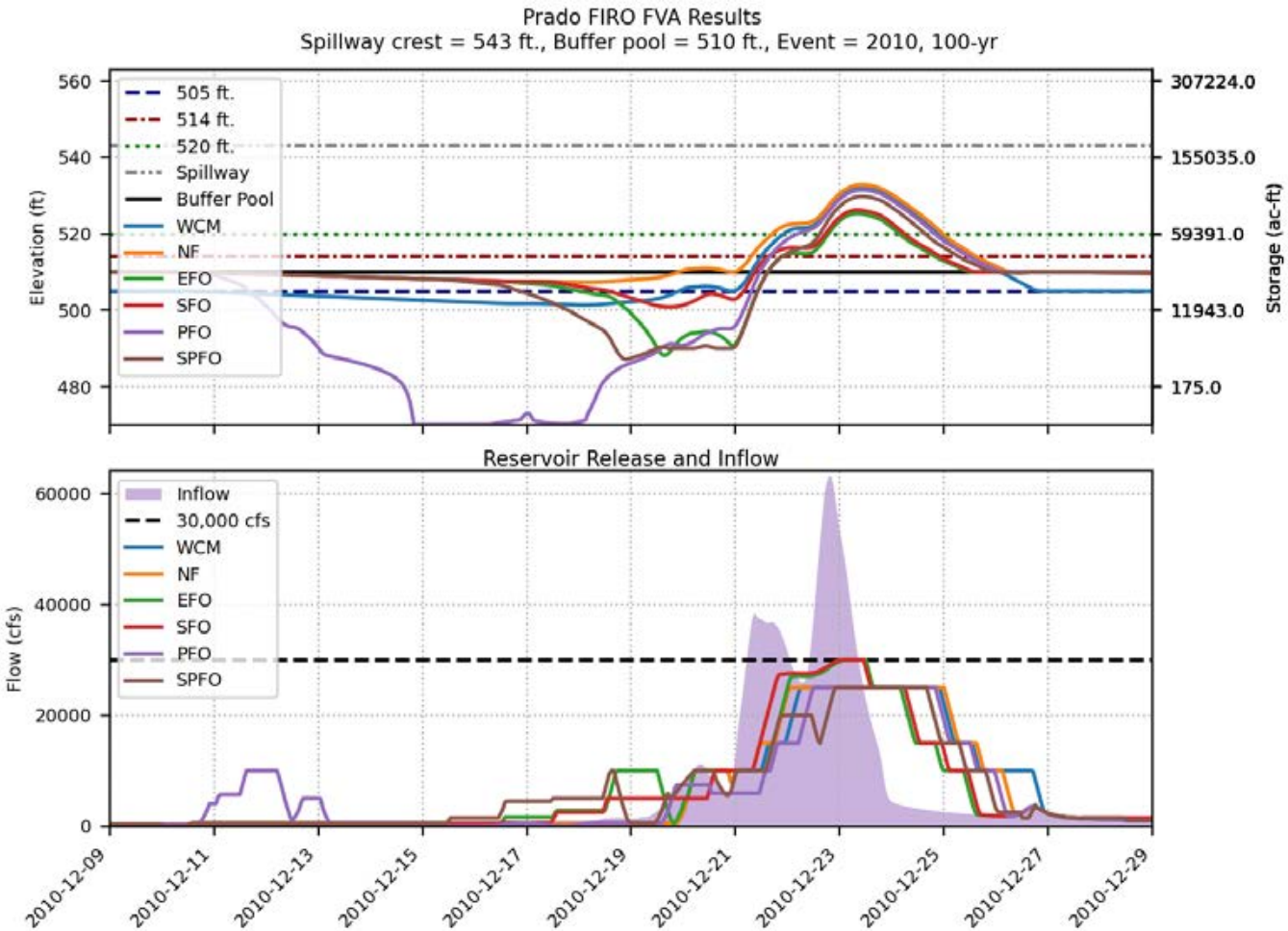
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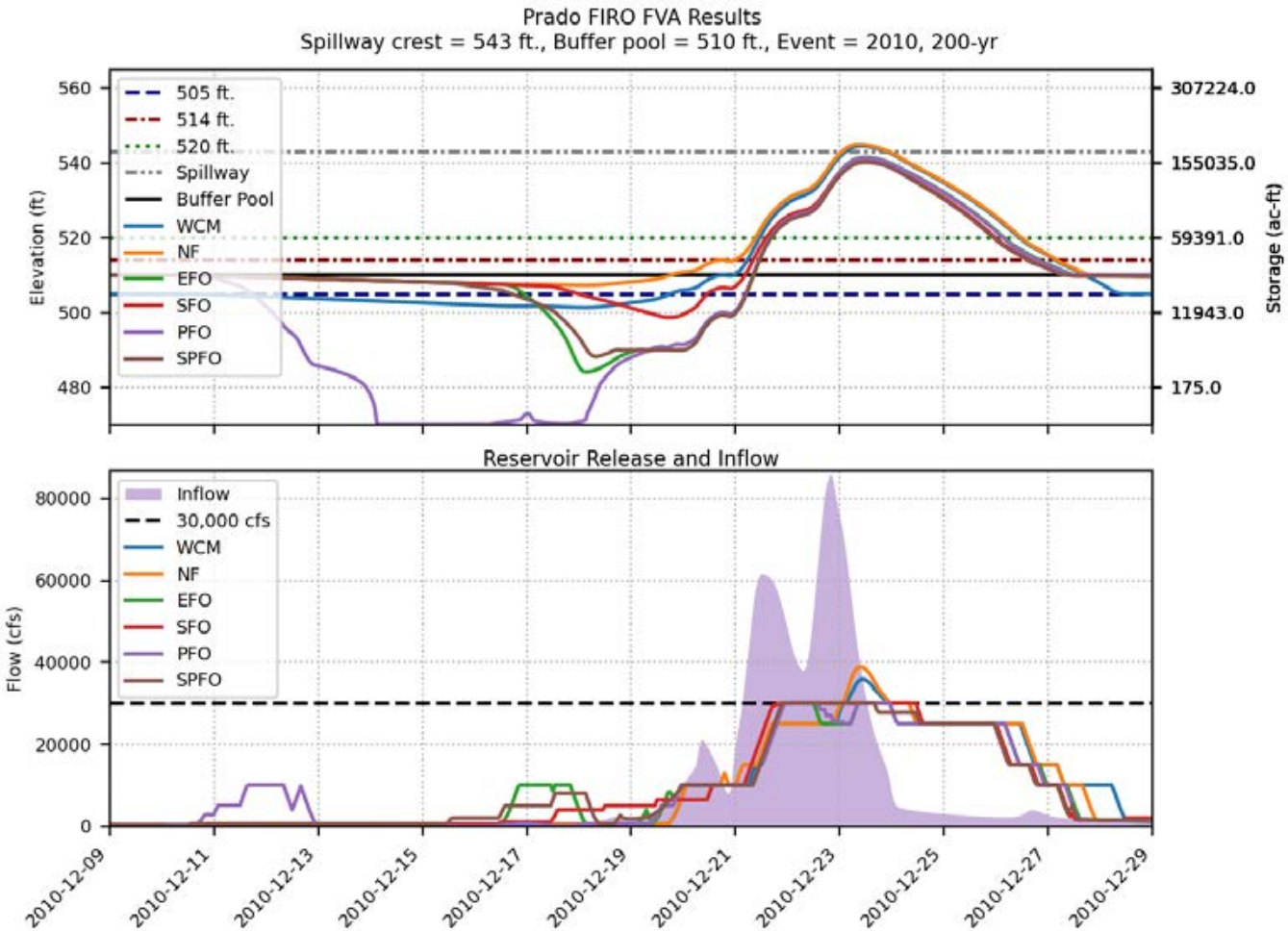
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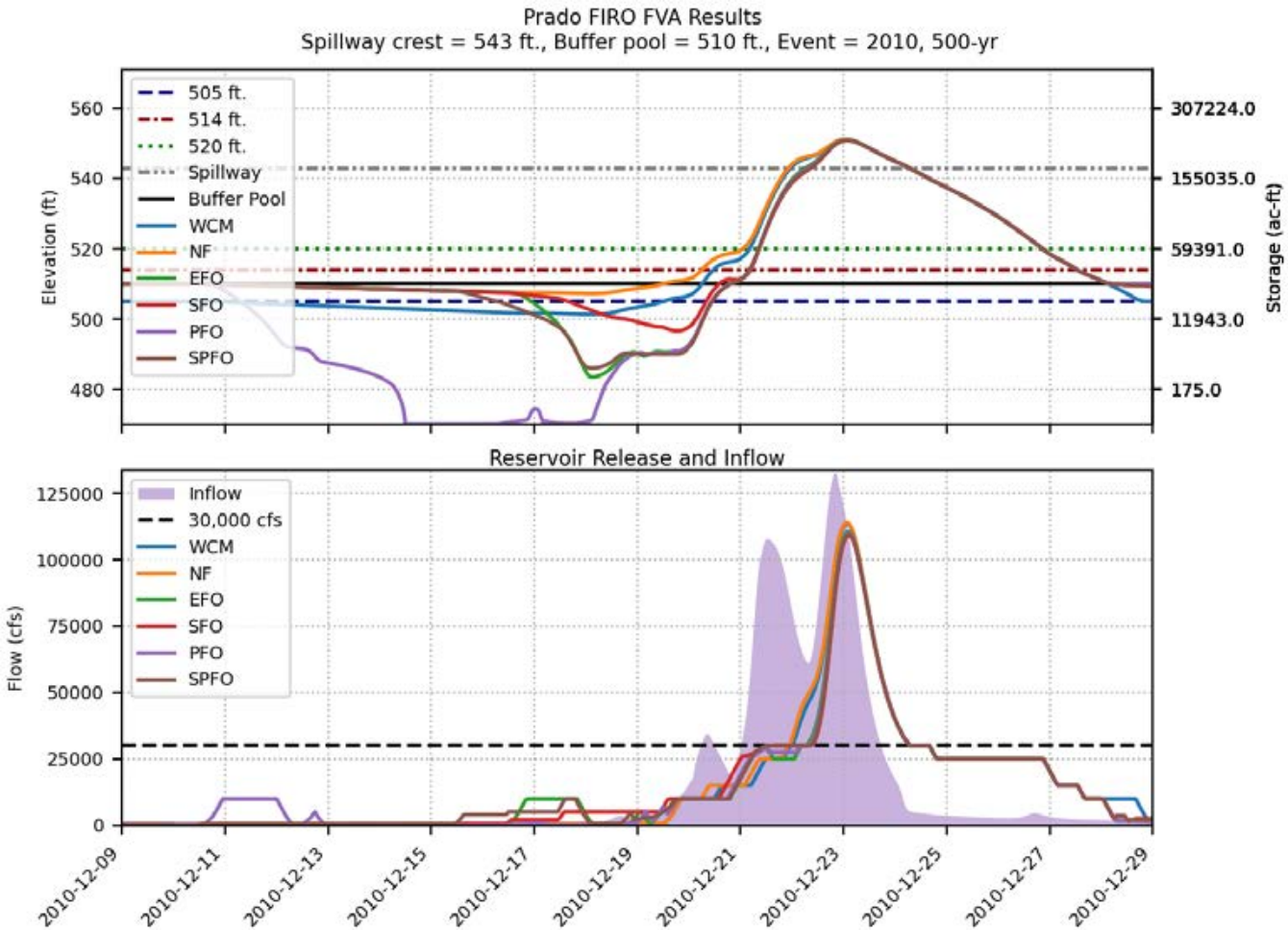
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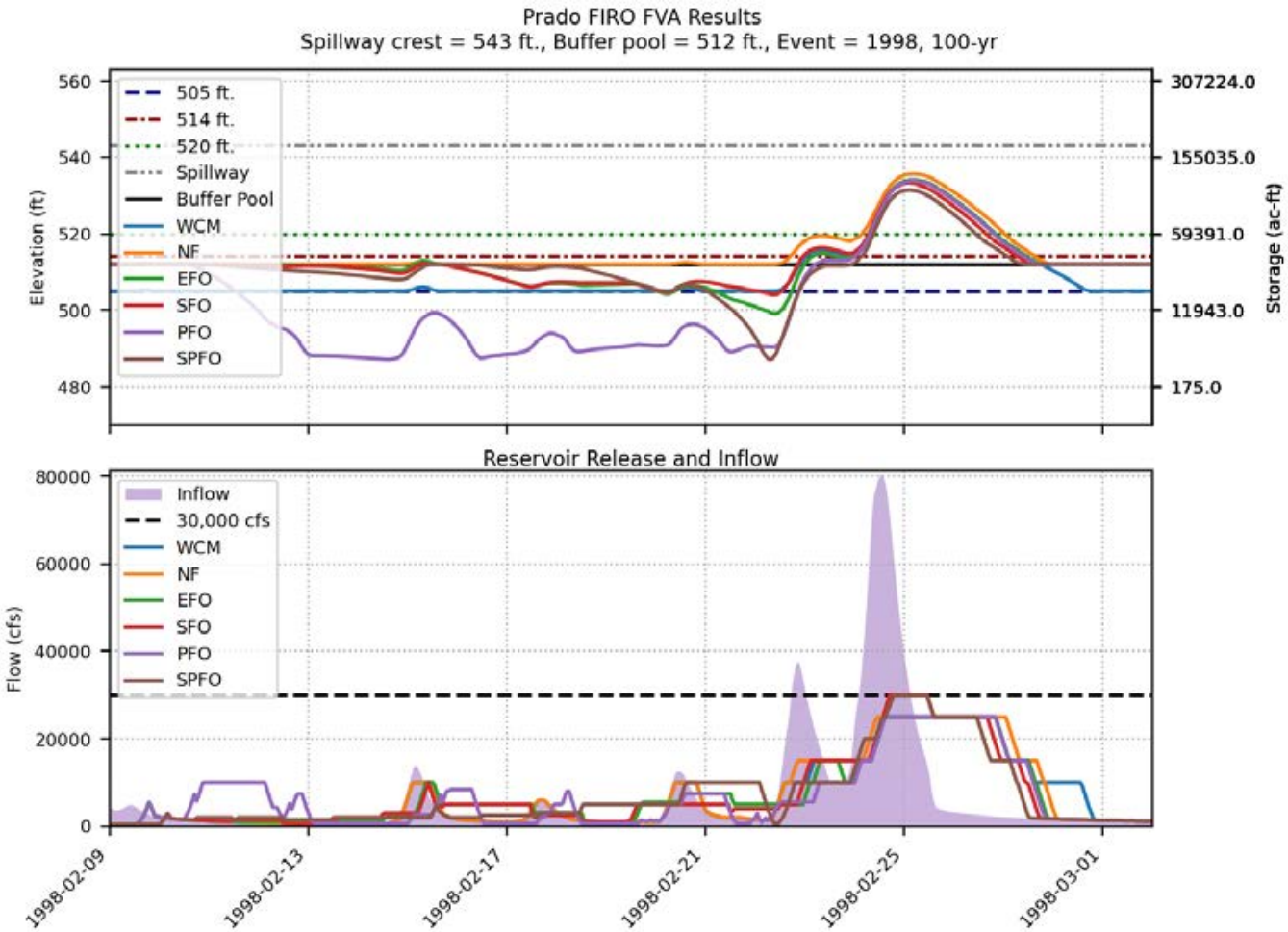
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Spillway crest = 543 ft., Buffer pool = 512 ft., Event = 1998, 100-yr
Elevation (ft)
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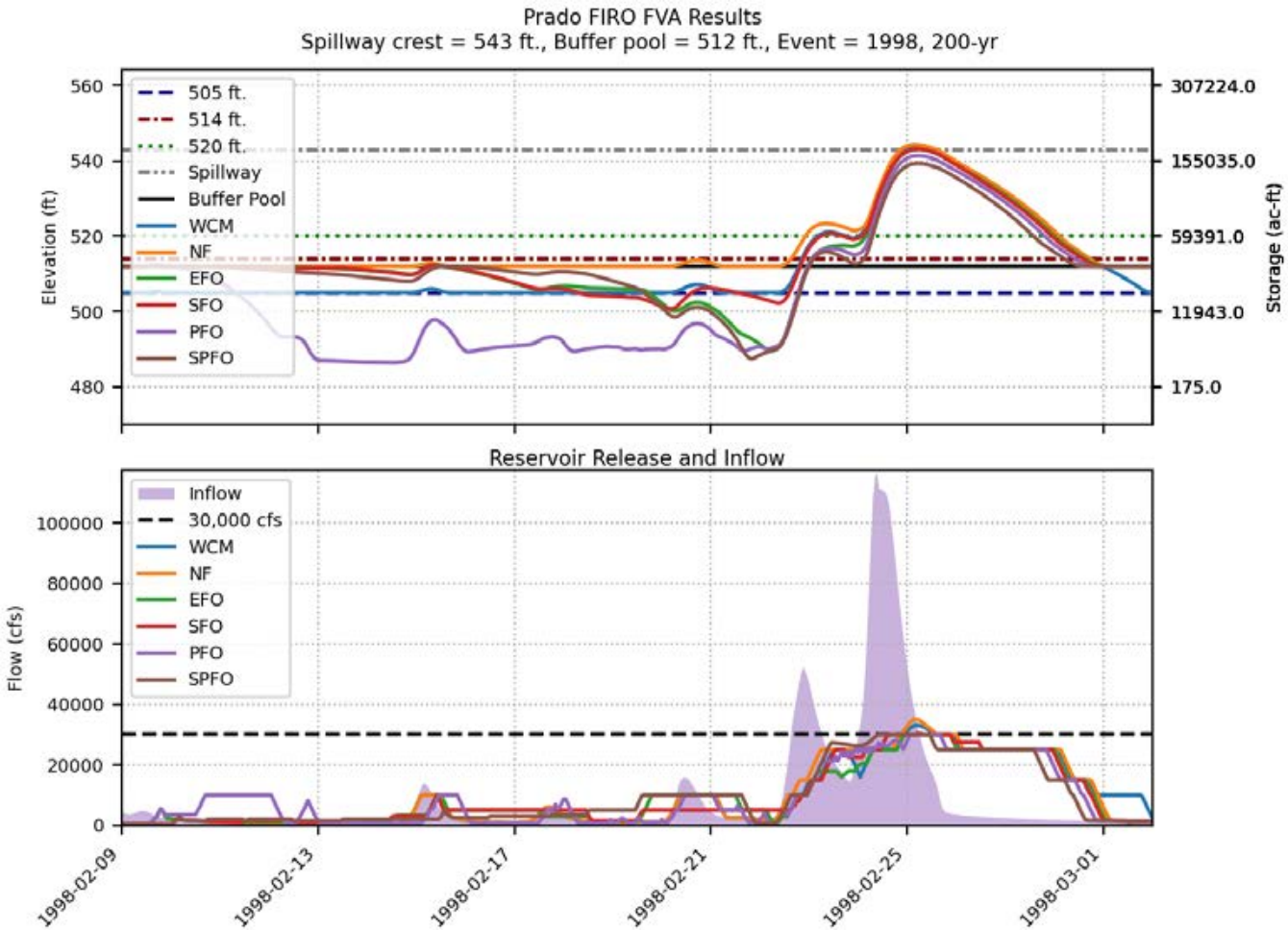
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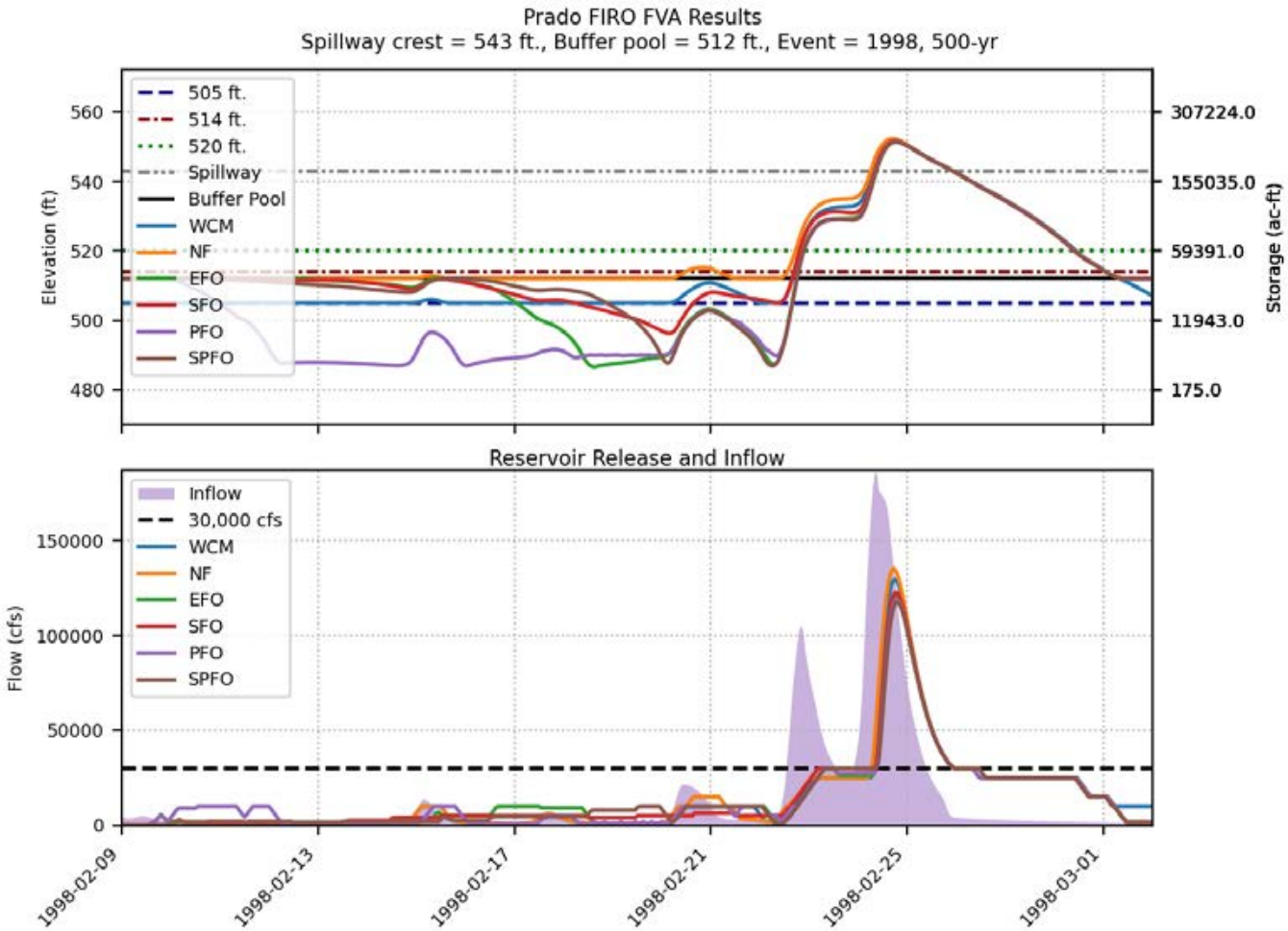
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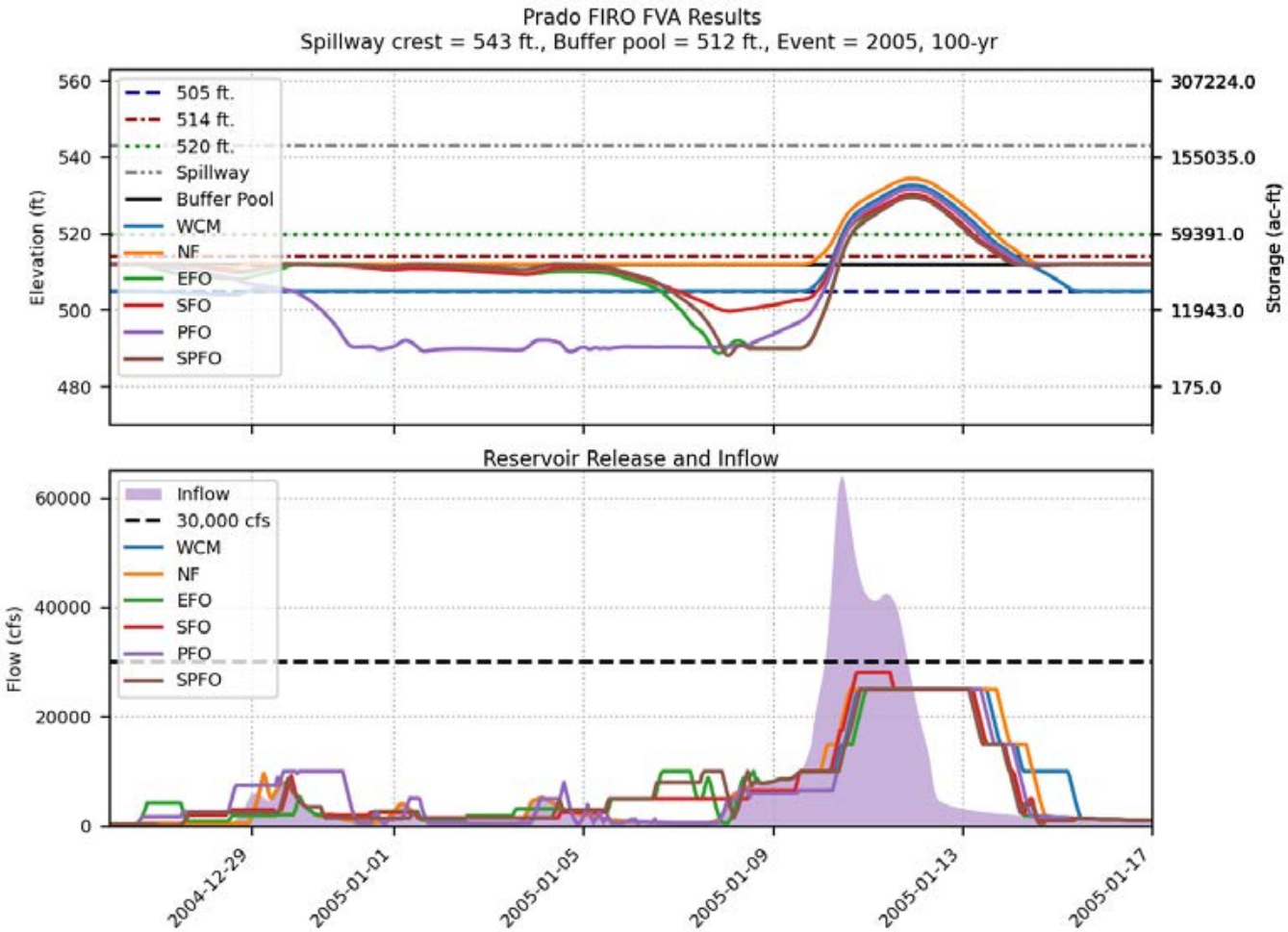
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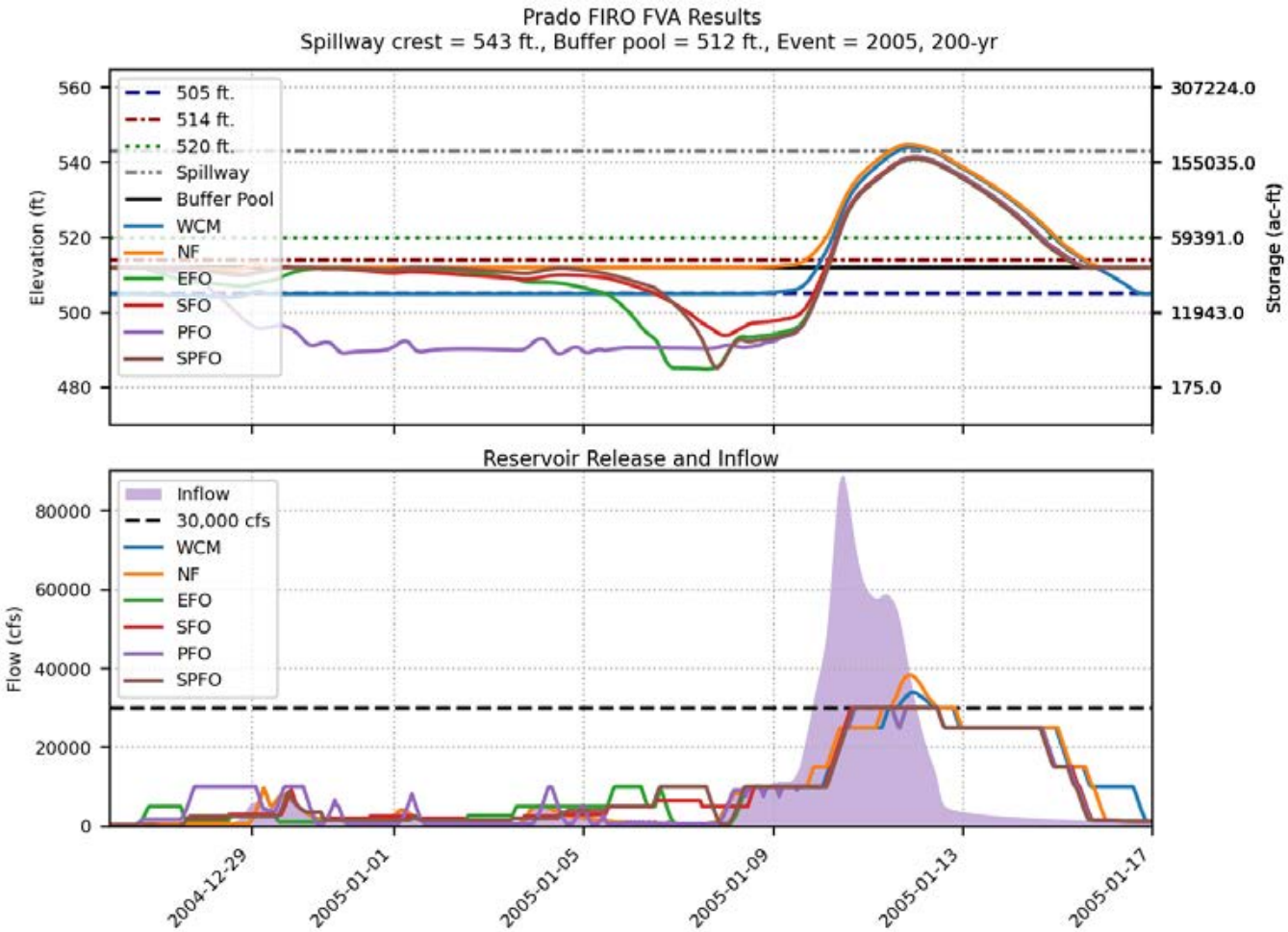
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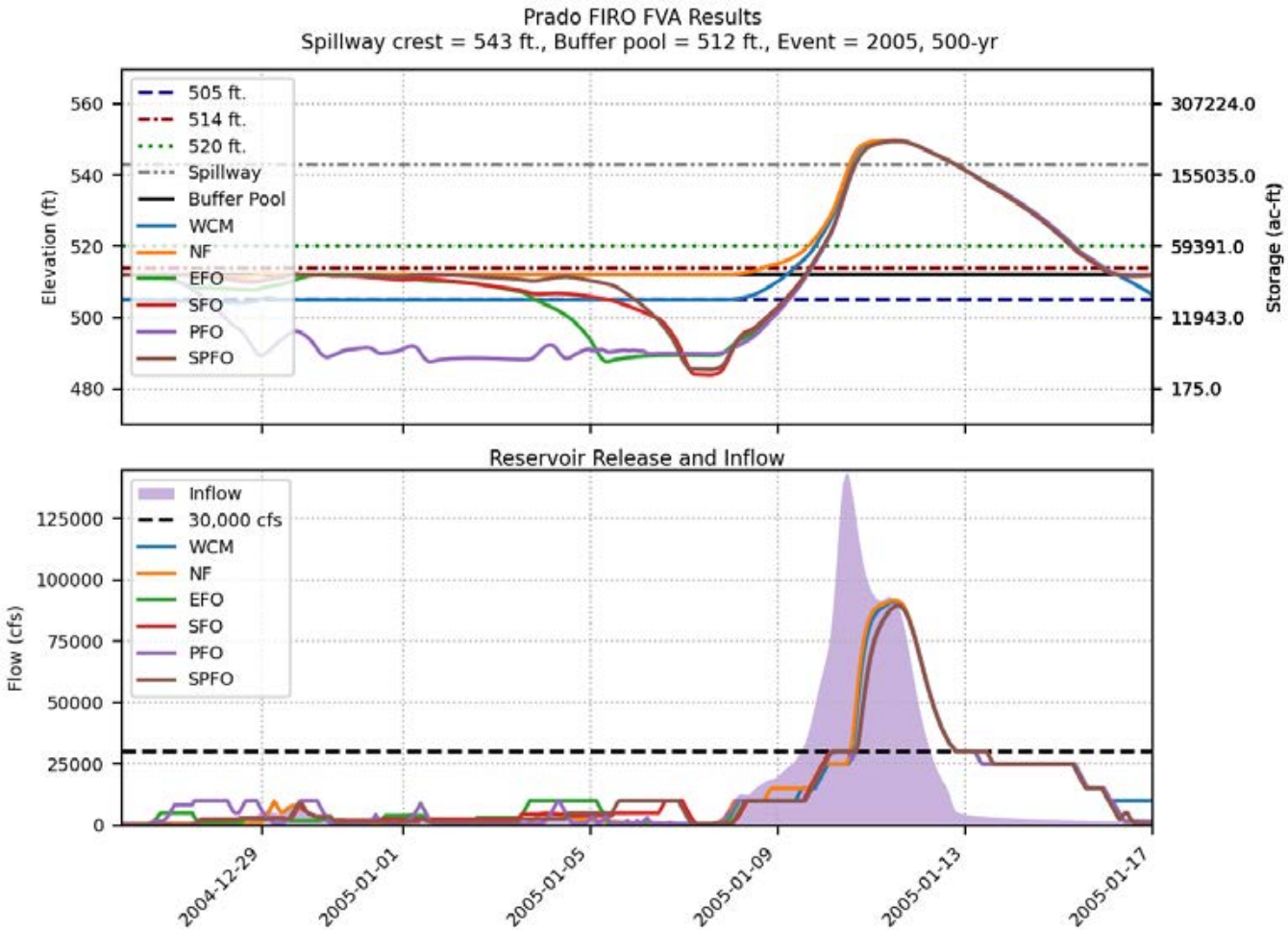
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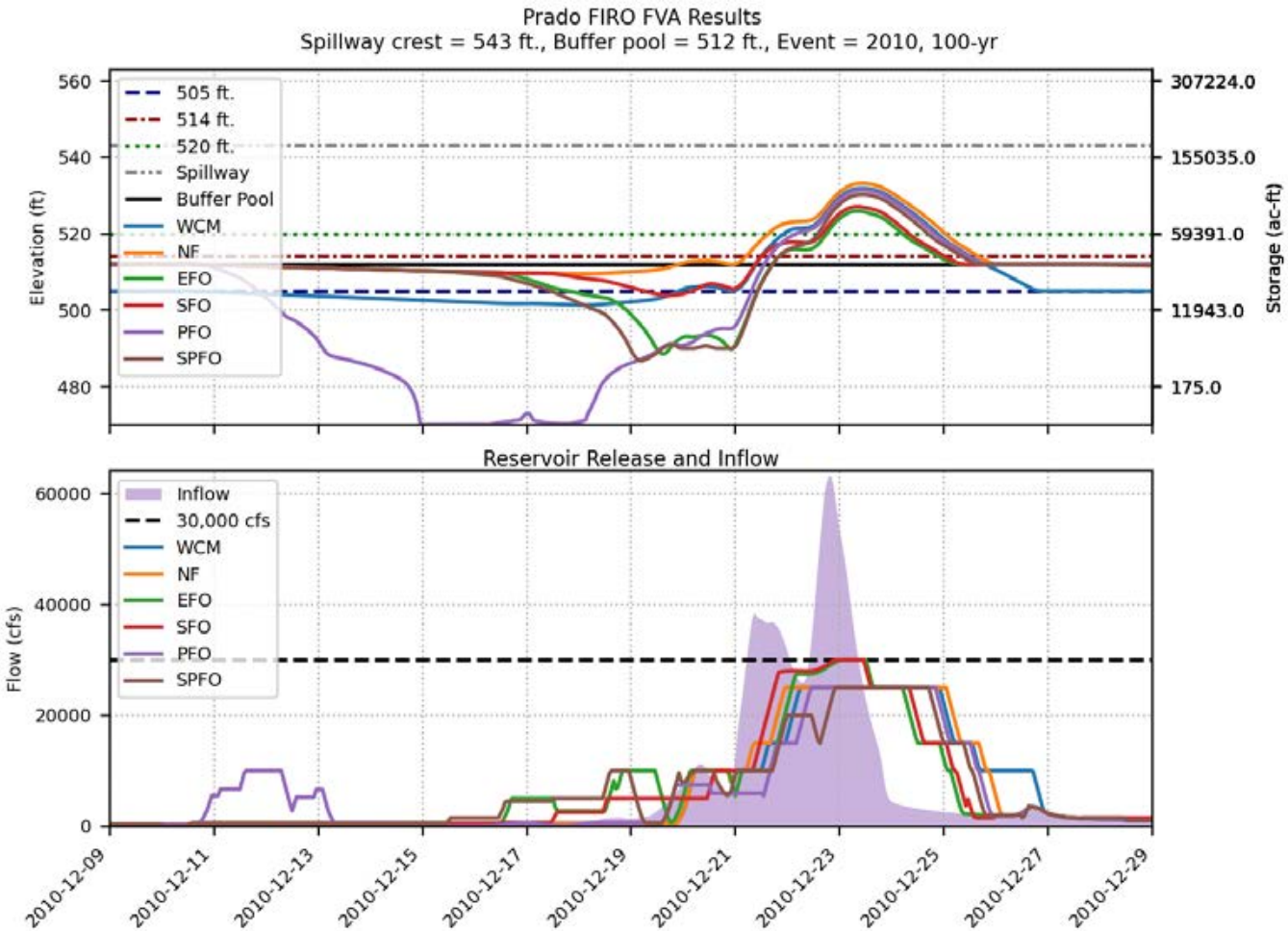
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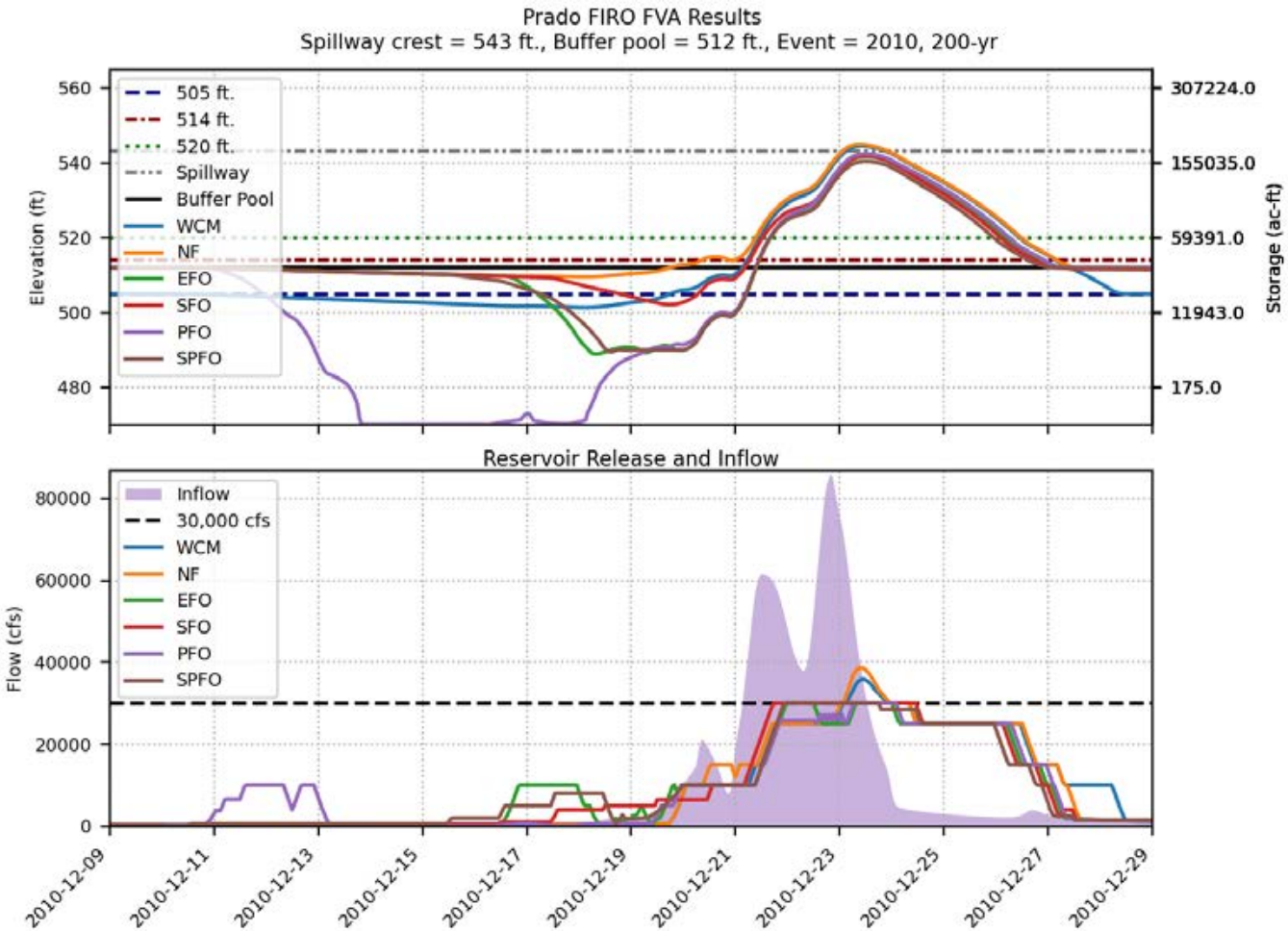
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 512 ft., Event = 2010, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
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PFO
SPFO
Elevation (ft)
Storage (ac-ft)
560
540
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500
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307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
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Flow (cfs)
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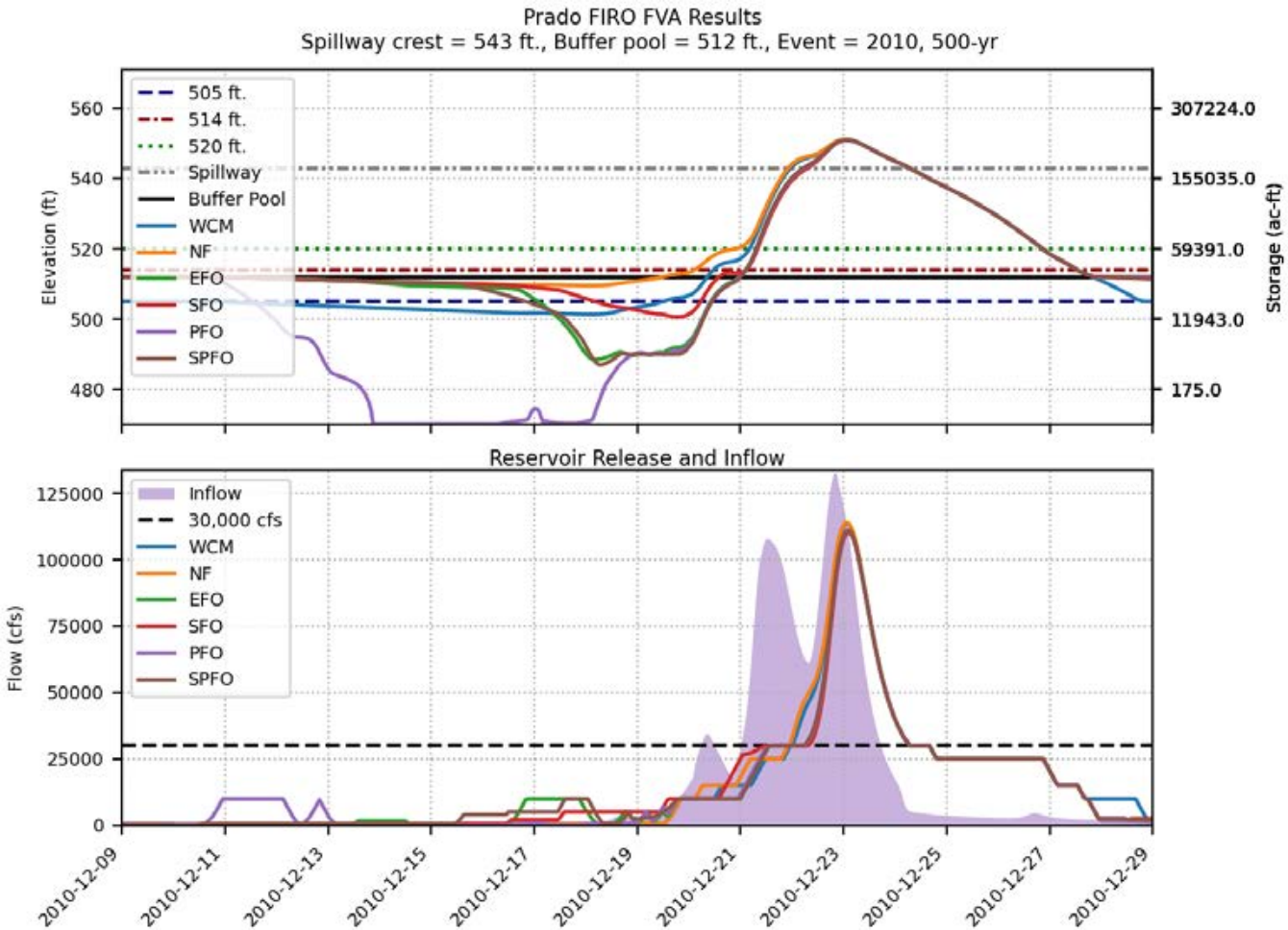
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 512 ft., Event = 2010, 500-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
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SPFO
Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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Flow (cfs)
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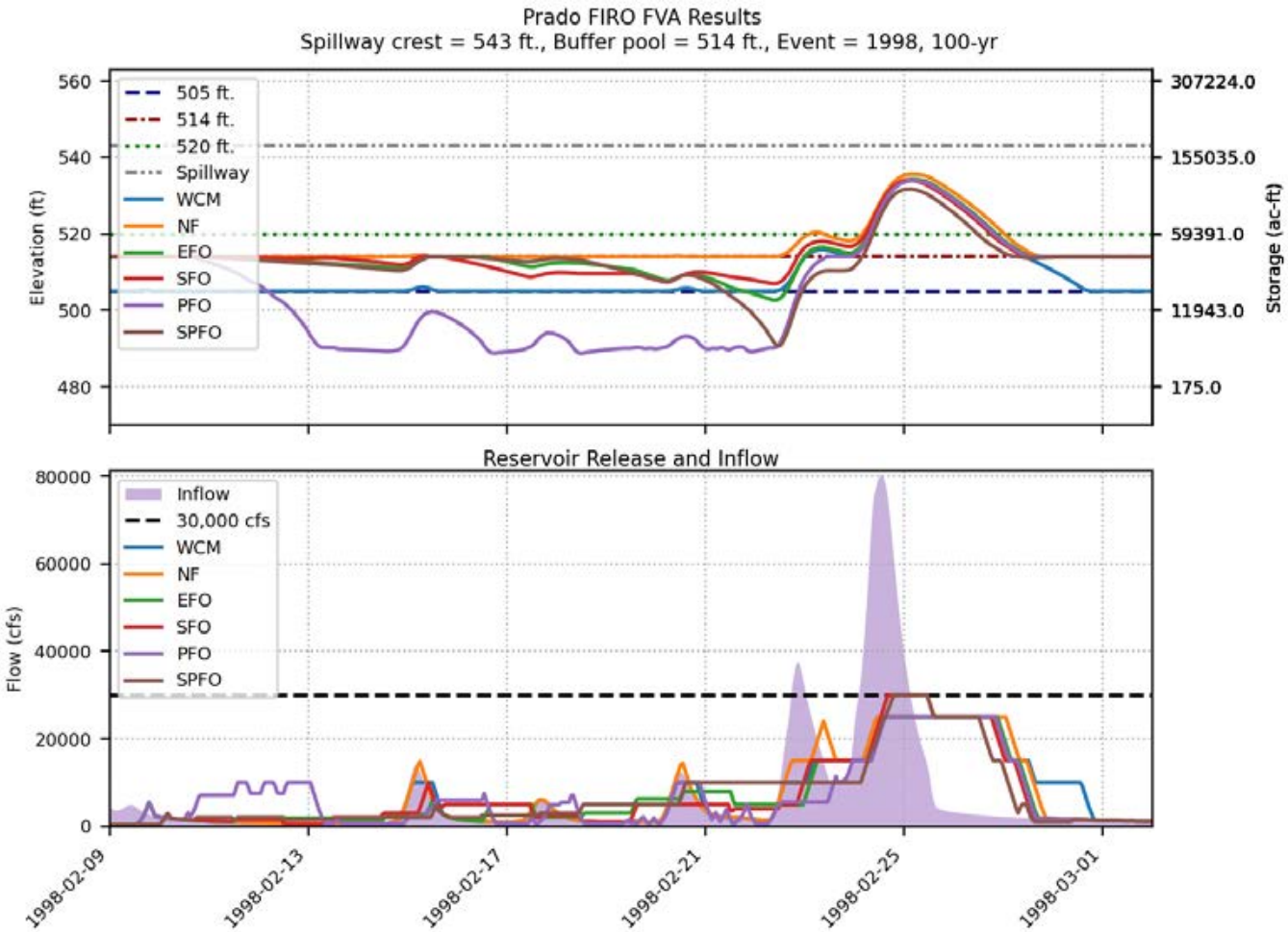
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505 ft.
514 ft.
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Spillway
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Elevation (ft)
Storage (ac-ft)
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175.0
Reservoir Release and Inflow
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Flow (cfs)
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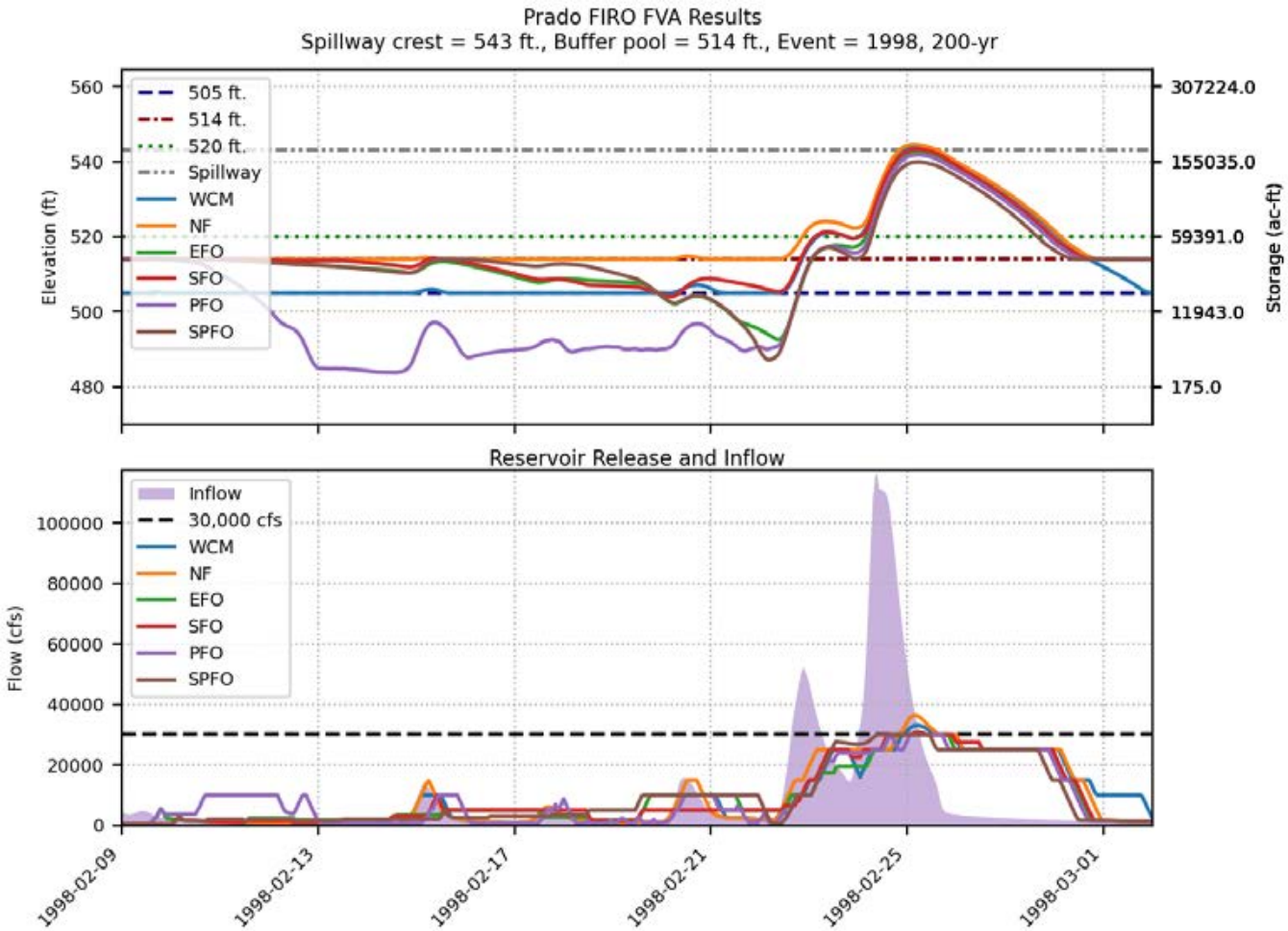
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 514 ft., Event = 1998, 200-yr
505 ft.
514 ft.
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Reservoir Release and Inflow
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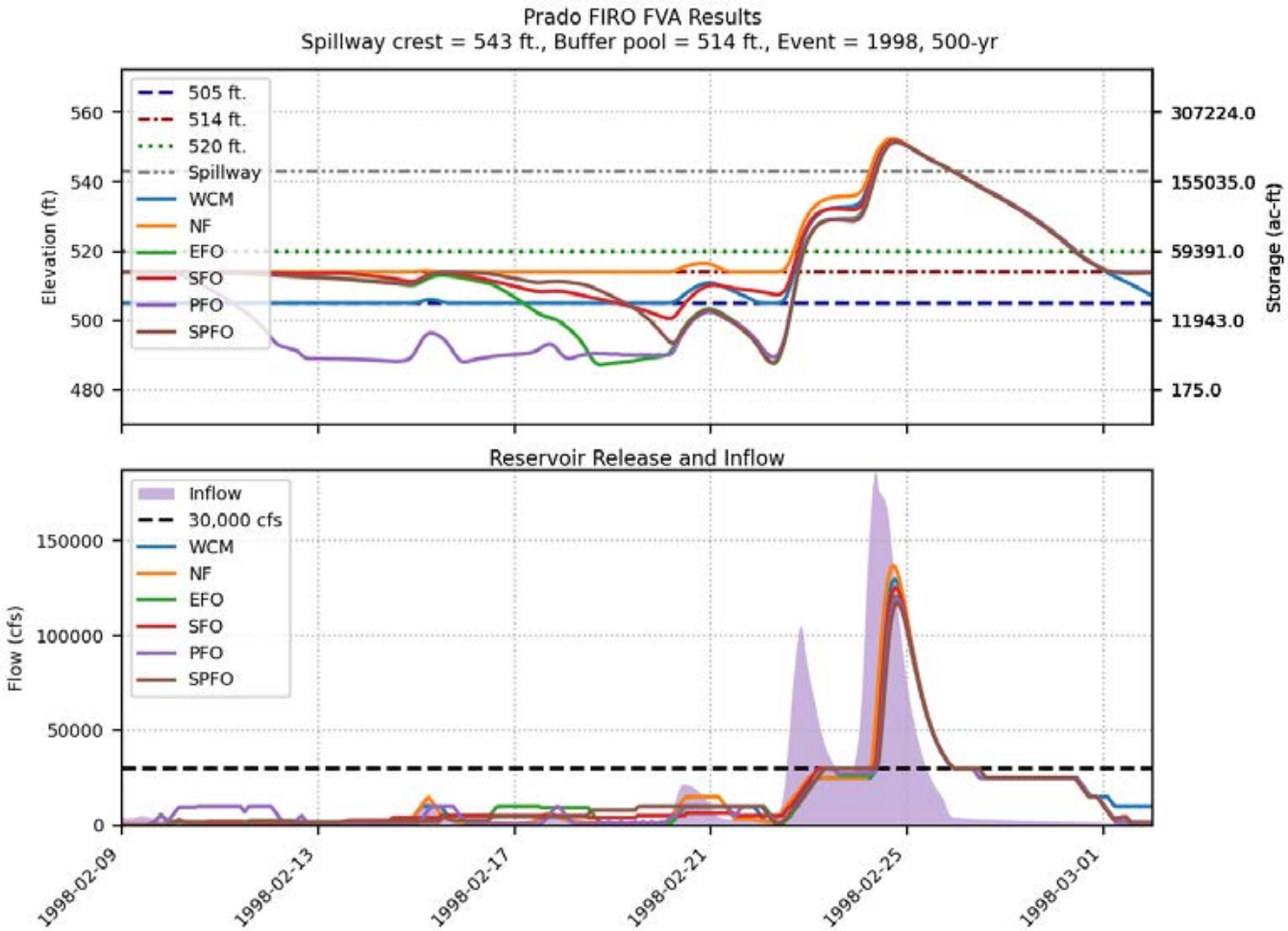
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 514 ft., Event = 1998, 500-yr
505 ft.
514 ft.
520 ft.
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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Flow (cfs)
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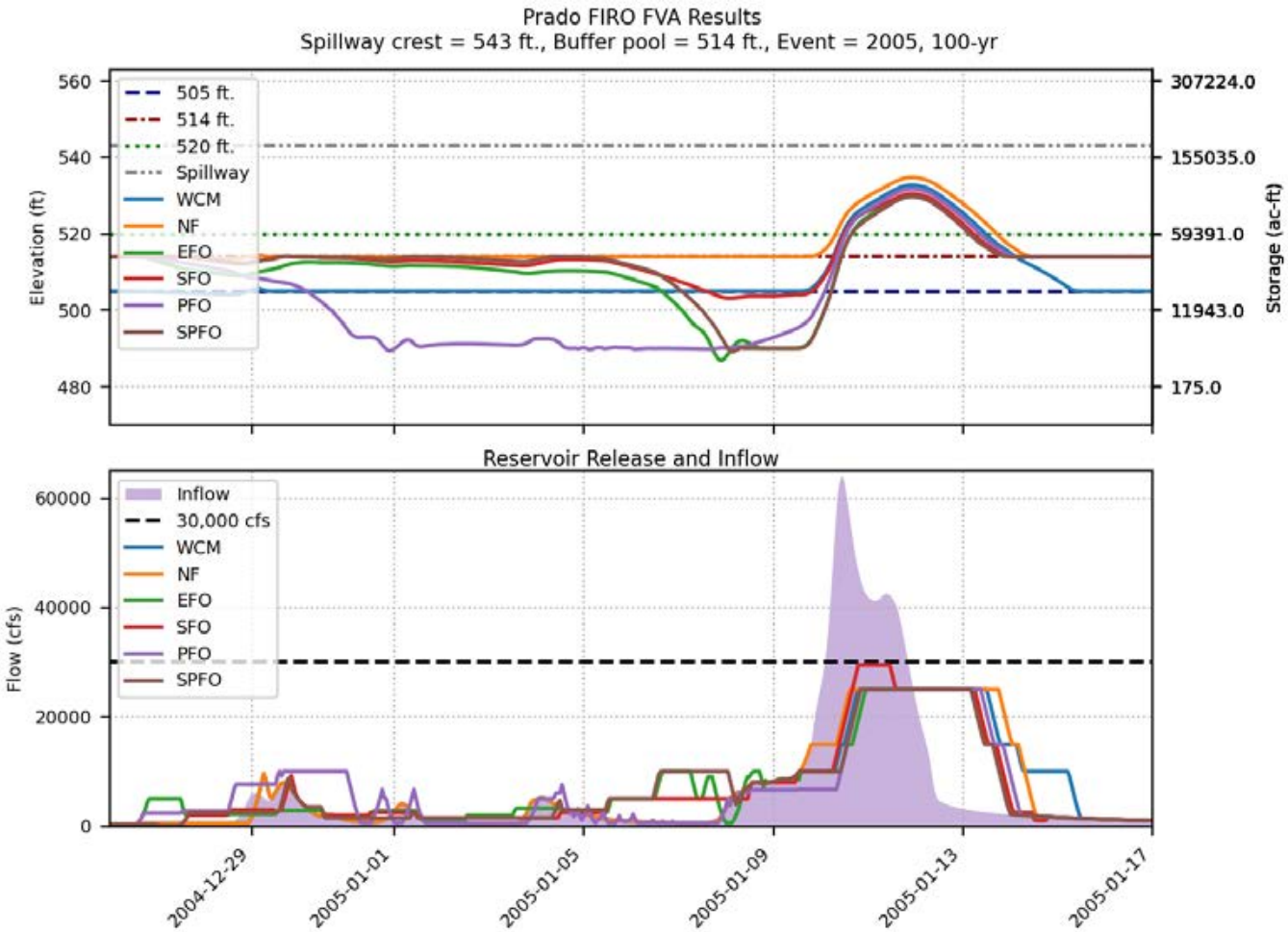
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 514 ft., Event = 2005, 100-yr
505 ft.
514 ft.
520 ft.
Spillway
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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SPFO
Flow (cfs)
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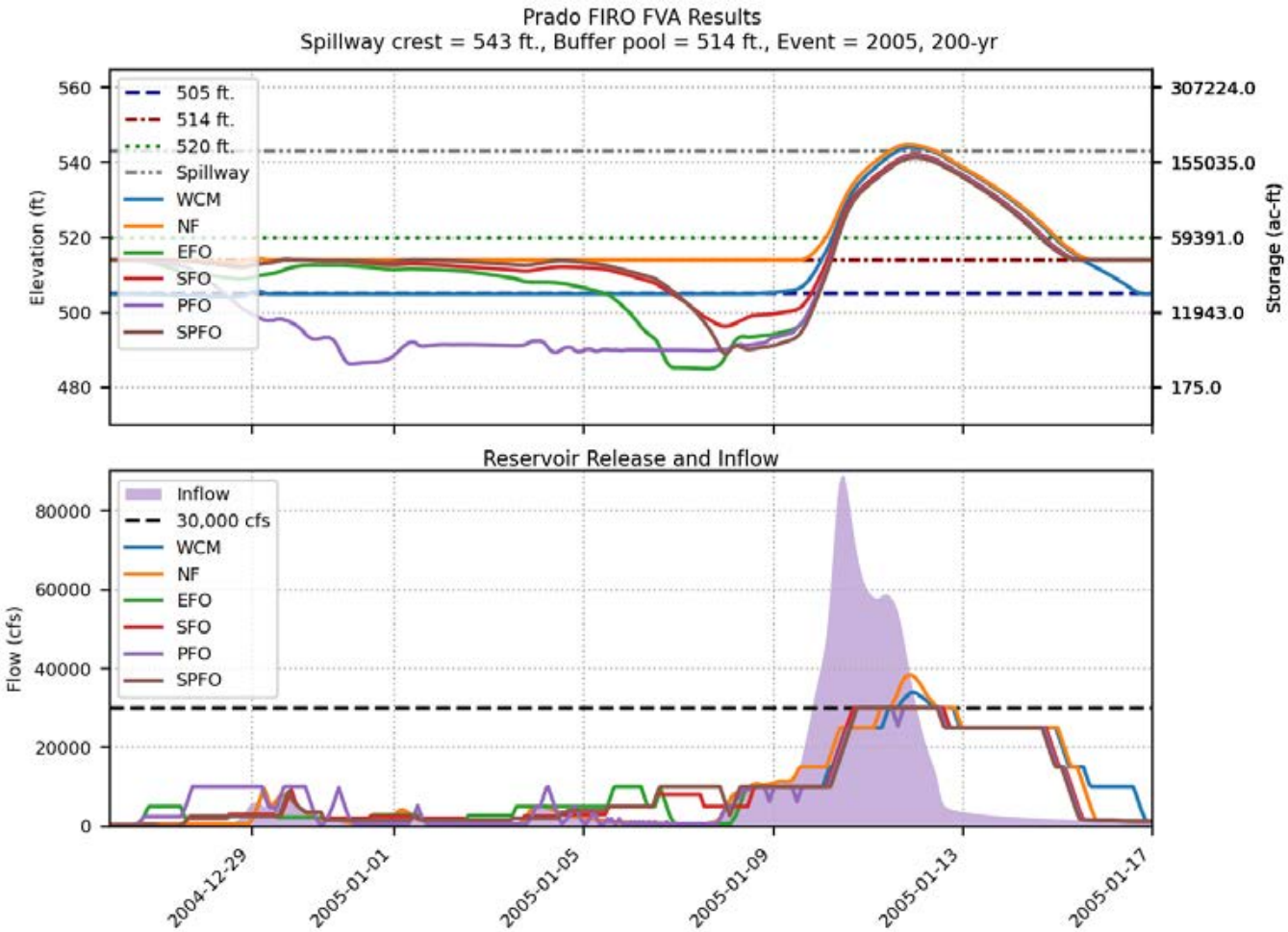
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 514 ft., Event = 2005, 200-yr
505 ft.
514 ft.
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Spillway
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
Inflow
30,000 cfs
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SPFO
Flow (cfs)
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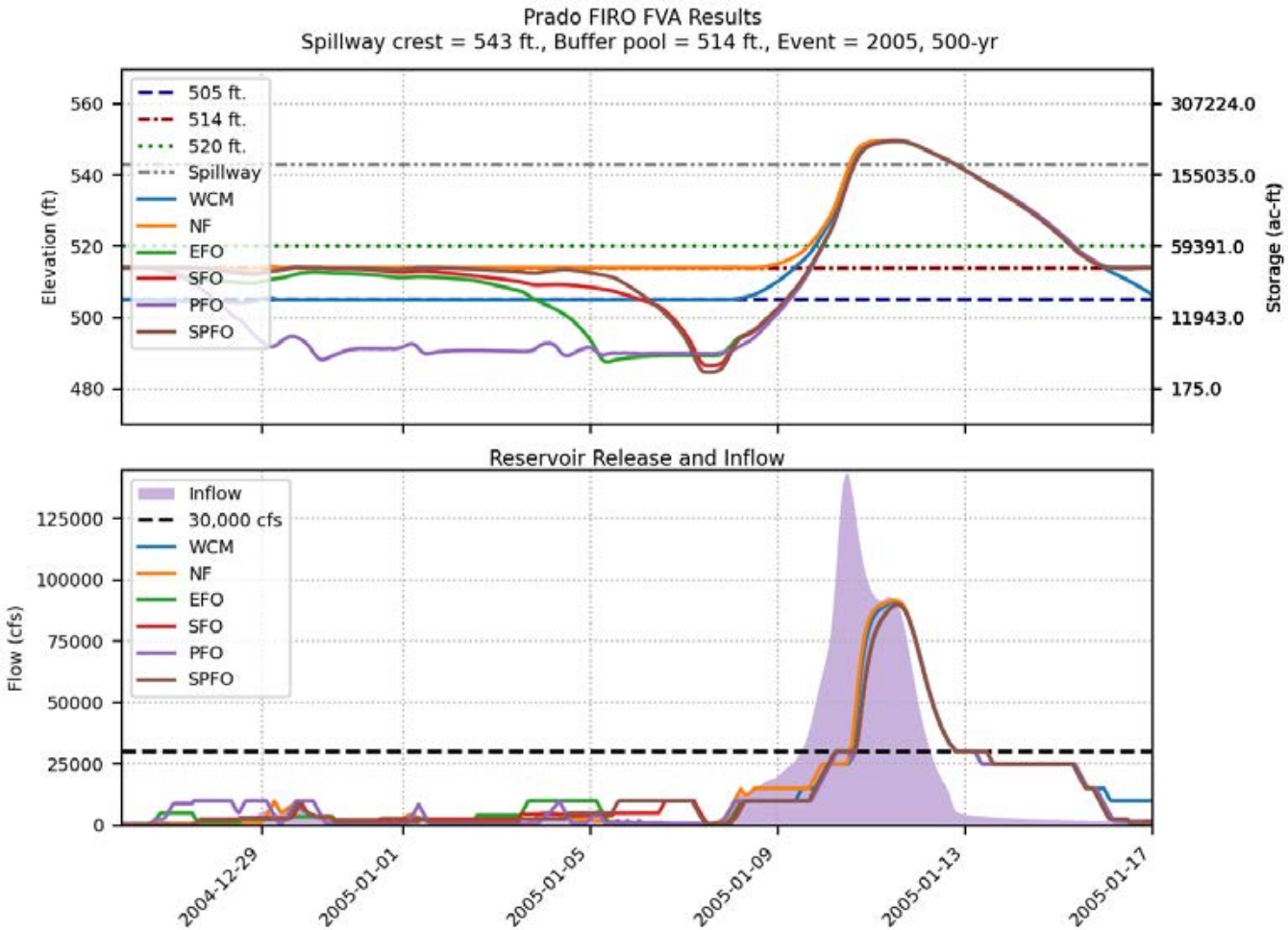
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 514 ft., Event = 2005, 500-yr
505 ft.
514 ft.
520 ft.
Spillway
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SPFO
Elevation (ft)
Storage (ac-ft)
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155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
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EFO
SFO
PFO
SPFO
Flow (cfs)
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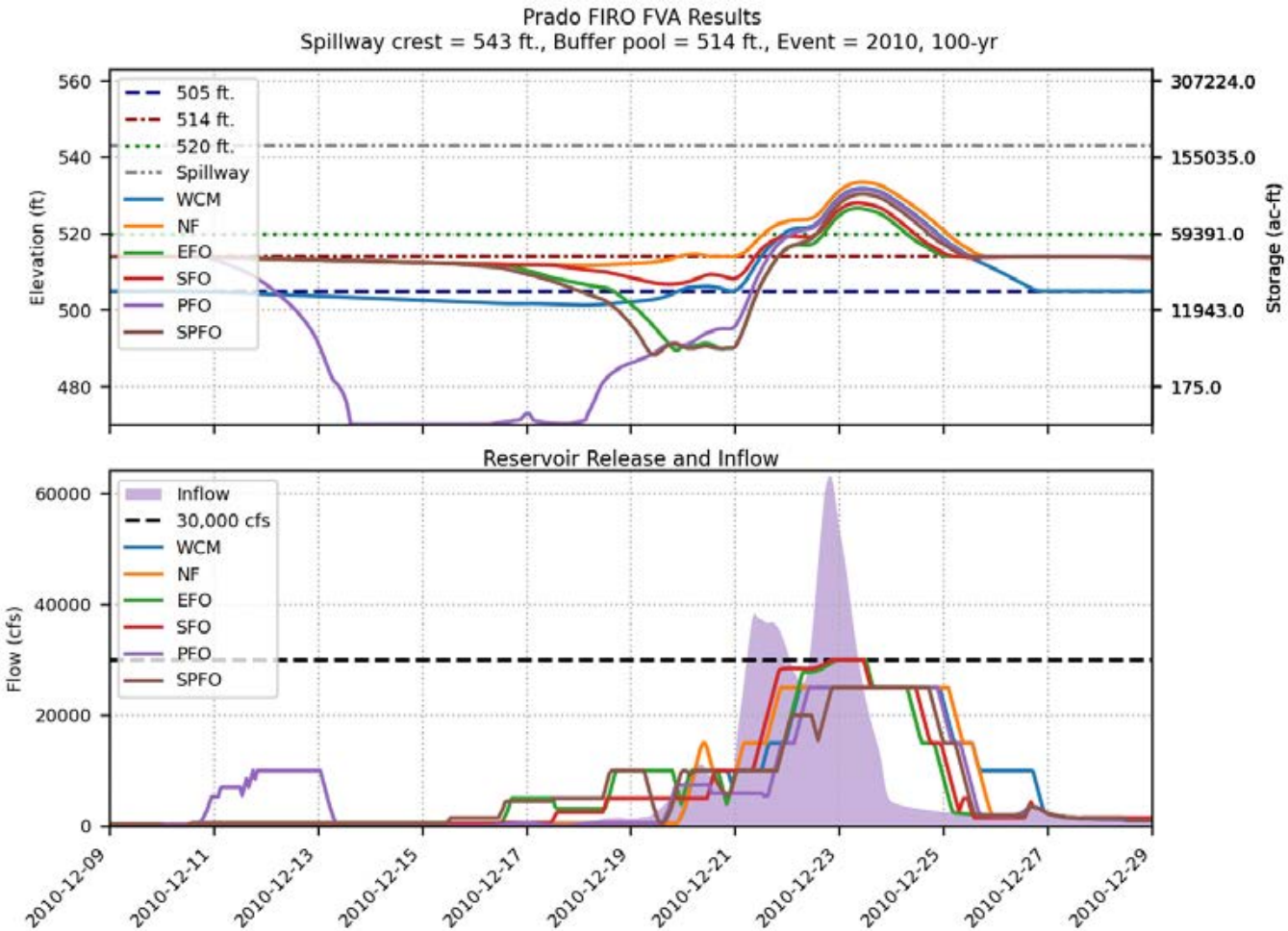
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 514 ft., Event = 2010, 100-yr
505 ft.
514 ft.
520 ft.
Spillway
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SPFO
Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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Flow (cfs)
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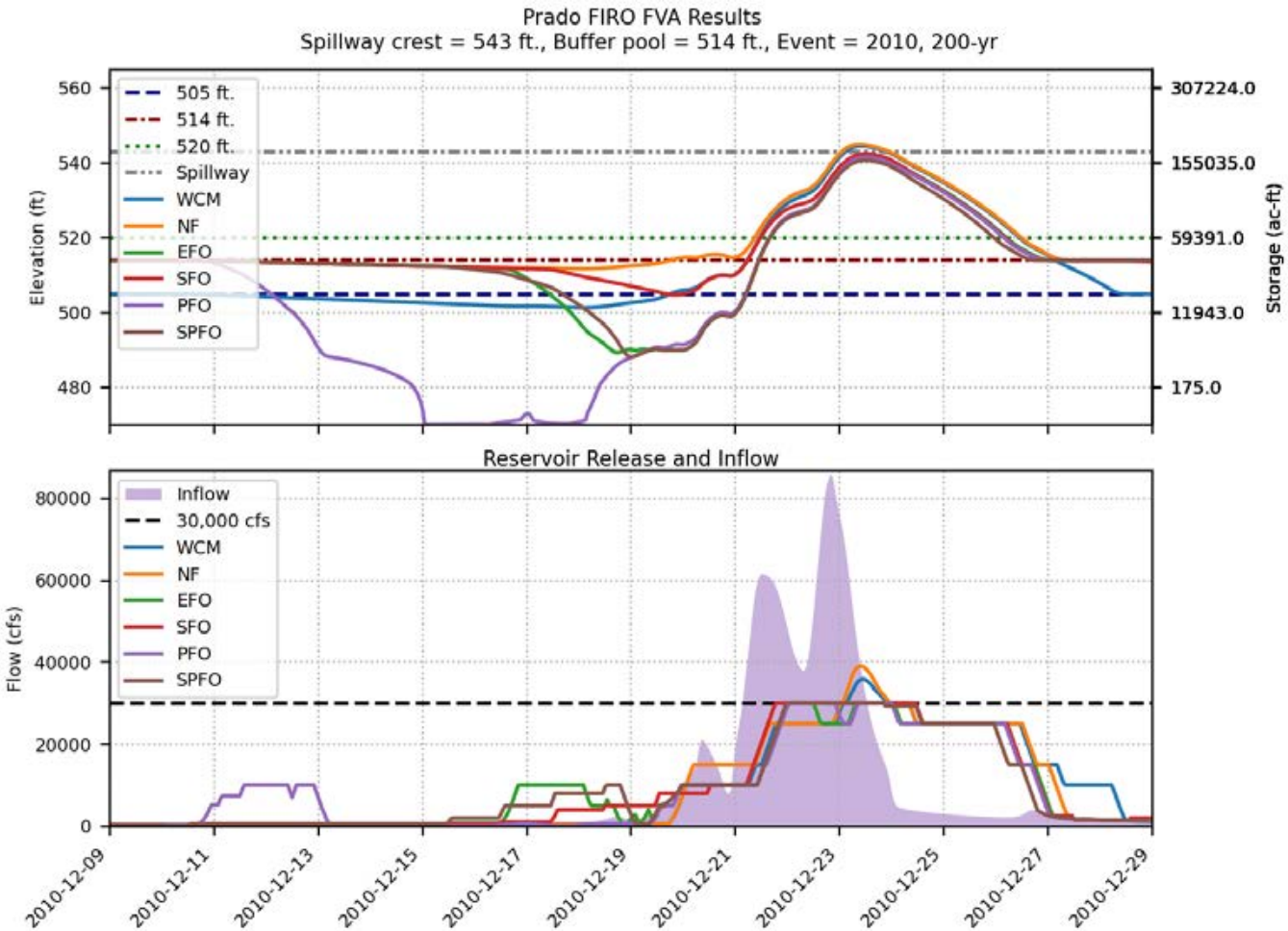
Prado FIRO FVA Results
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514 ft.
520 ft.
Spillway
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NF
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SPFO
Elevation (ft)
Storage (ac-ft)
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155035.0
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Reservoir Release and Inflow
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Flow (cfs)
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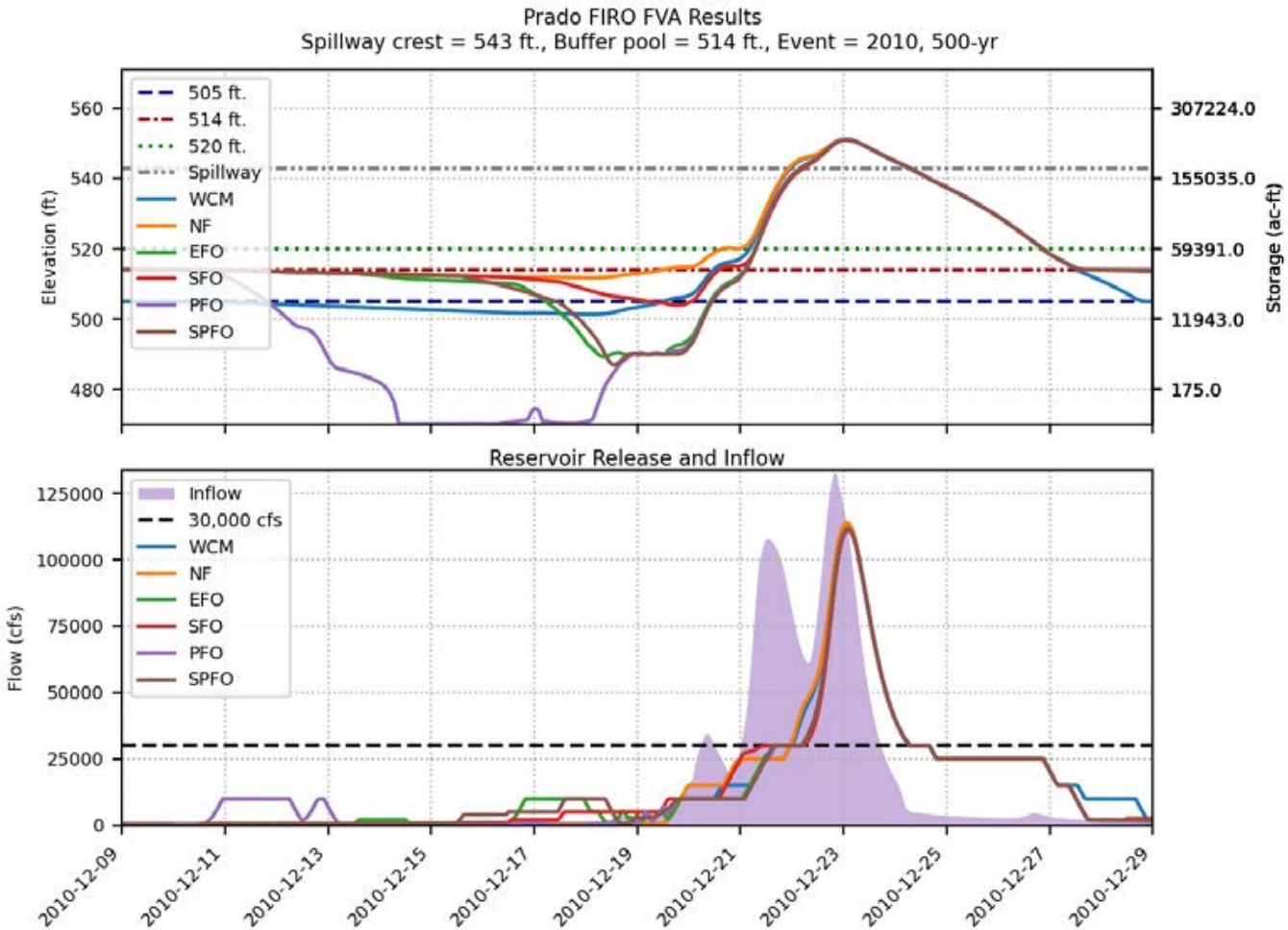
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 514 ft., Event = 2010, 500-yr
505 ft.
514 ft.
520 ft.
Spillway
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SPFO
Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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Flow (cfs)
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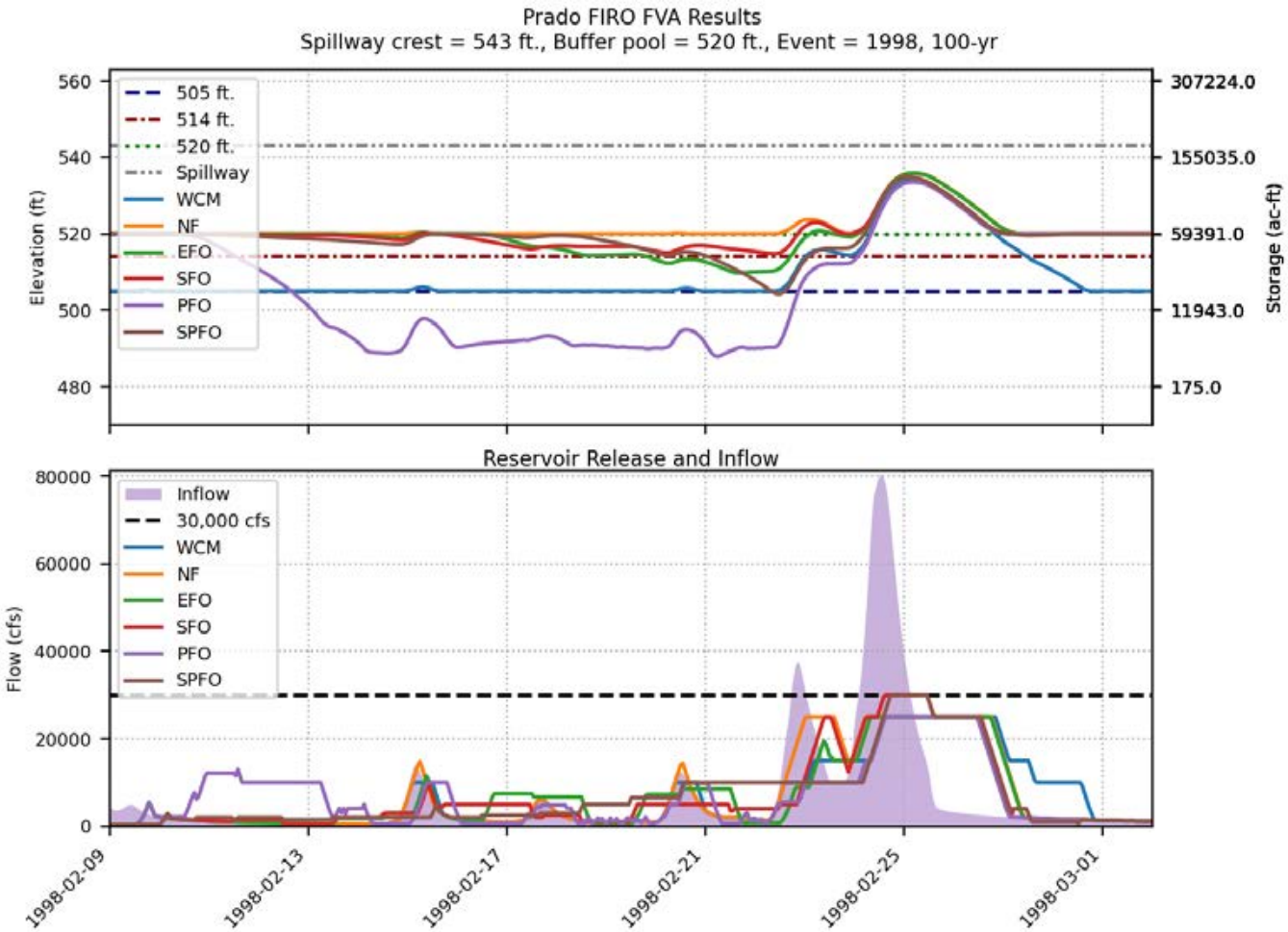
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 520 ft., Event = 1998, 100-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
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Reservoir Release and Inflow
Flow (cfs)
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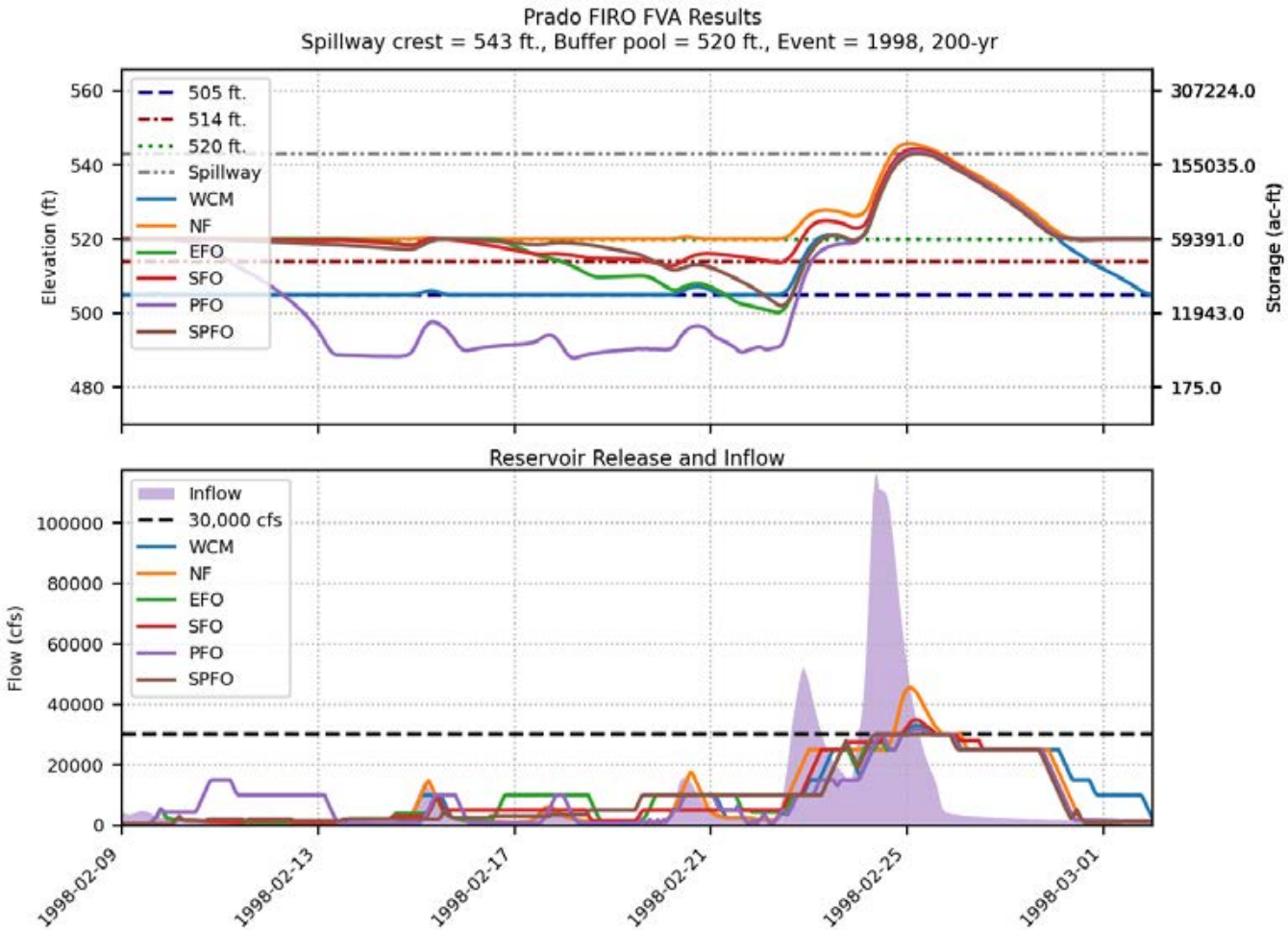
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 520 ft., Event = 1998, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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Flow (cfs)
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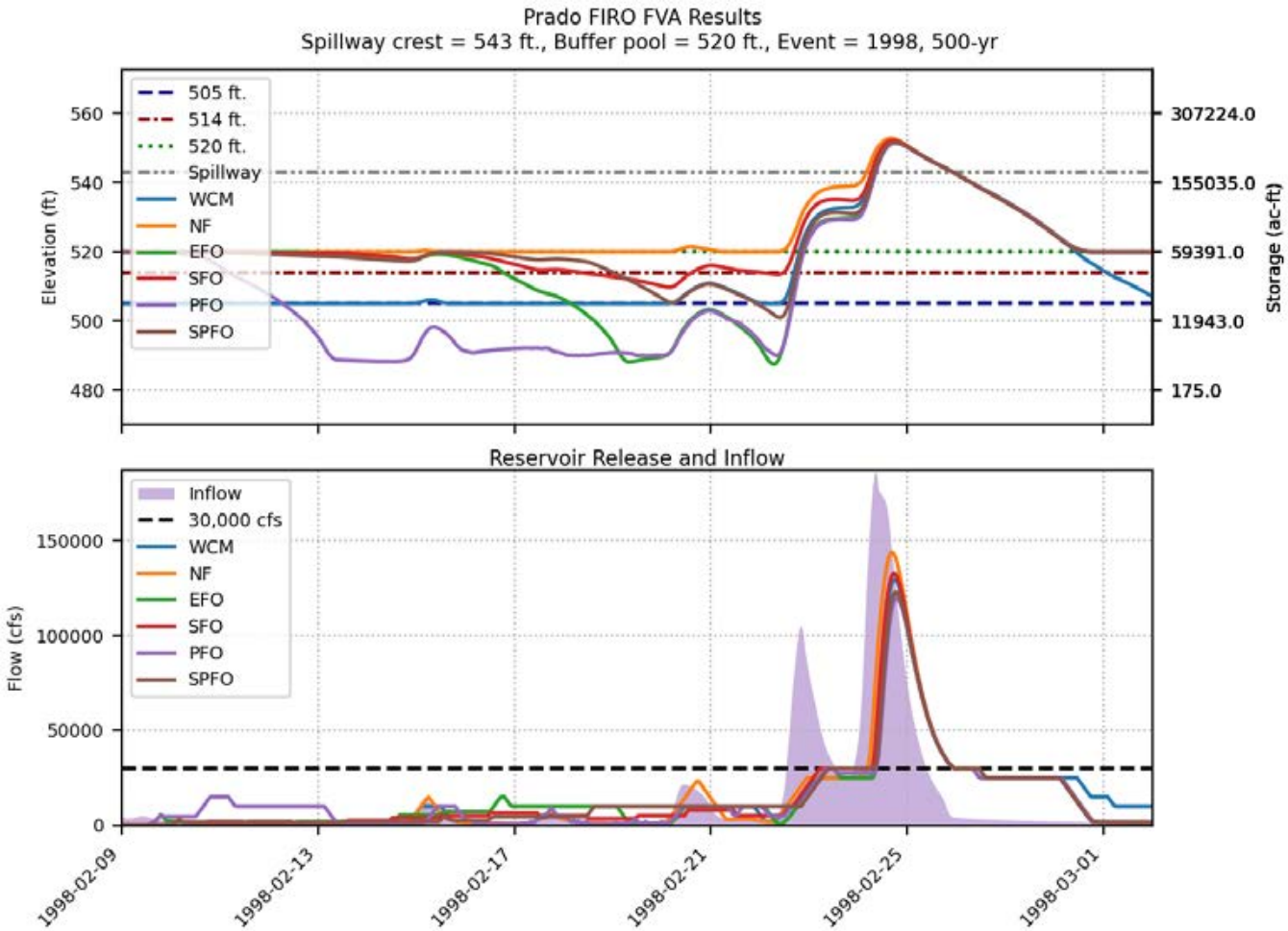
Prado FIRO FVA Results
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514 ft.
520 ft.
Spillway
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SPFO
Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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30,000 cfs
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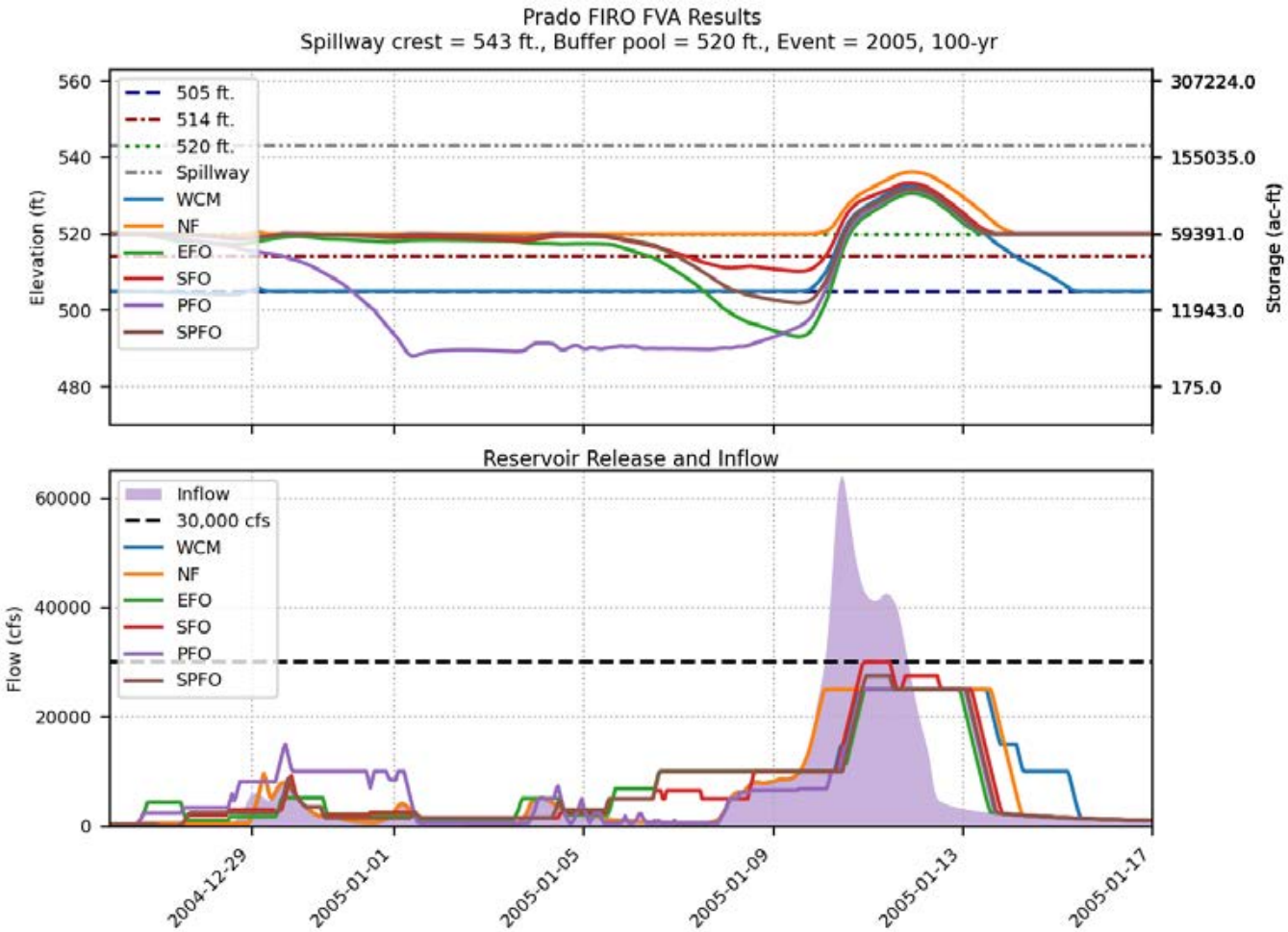
Prado FIRO FVA Results
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514 ft.
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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Flow (cfs)
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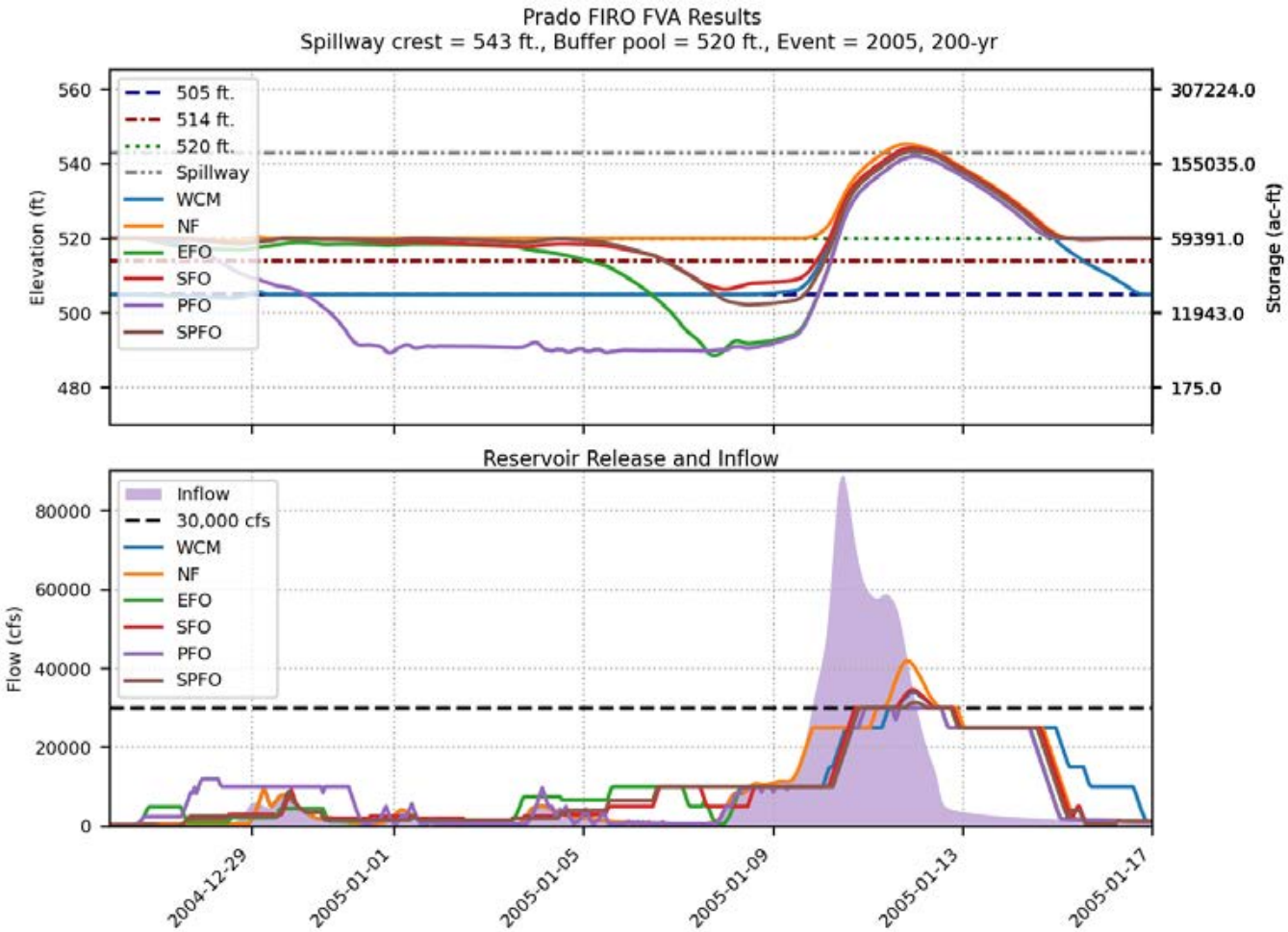
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 520 ft., Event = 2005, 200-yr
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Spillway
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SPFO
Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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Flow (cfs)
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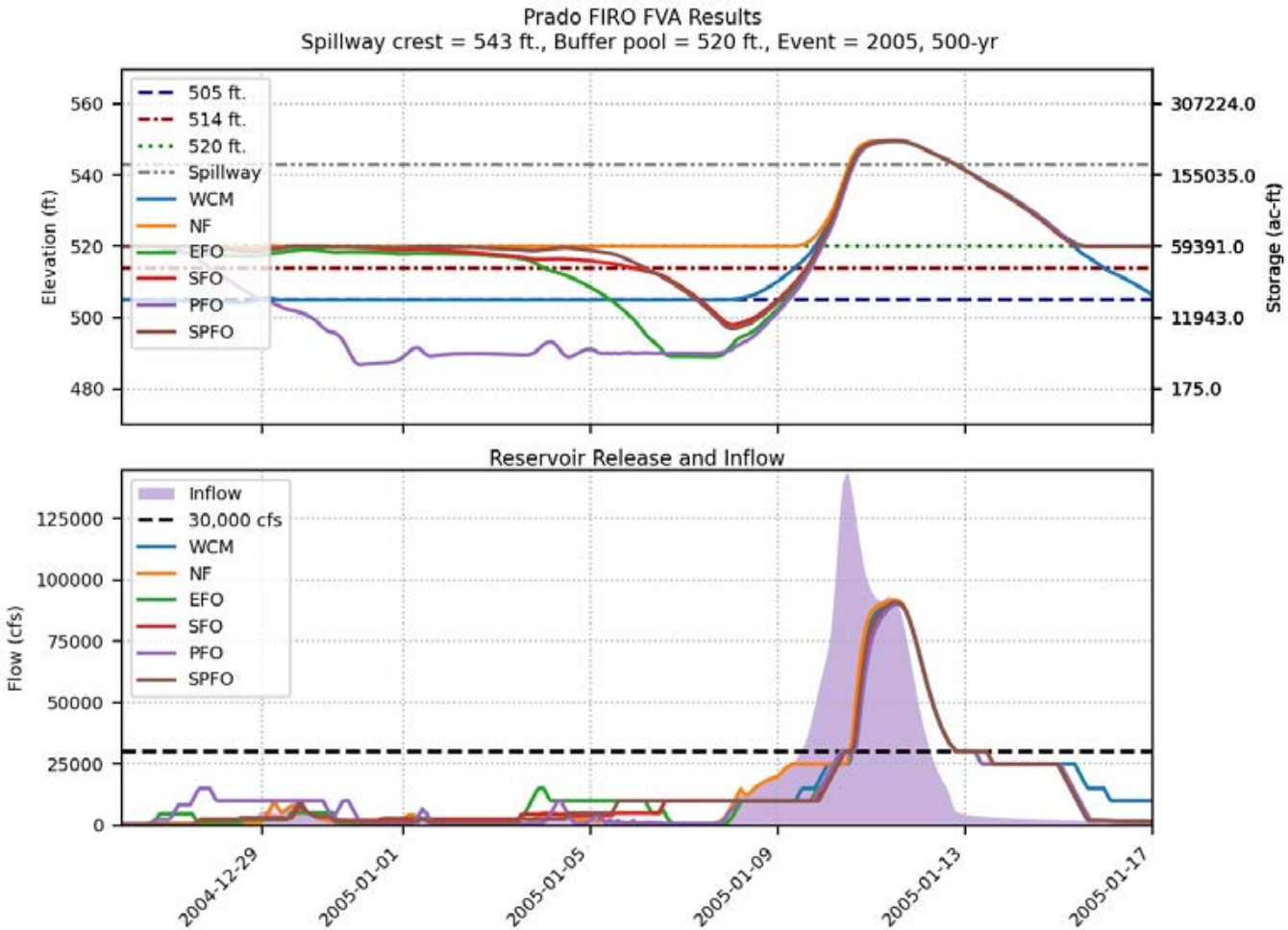
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 520 ft., Event = 2005, 500-yr
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514 ft.
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Storage (ac-ft)
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Reservoir Release and Inflow
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Flow (cfs)
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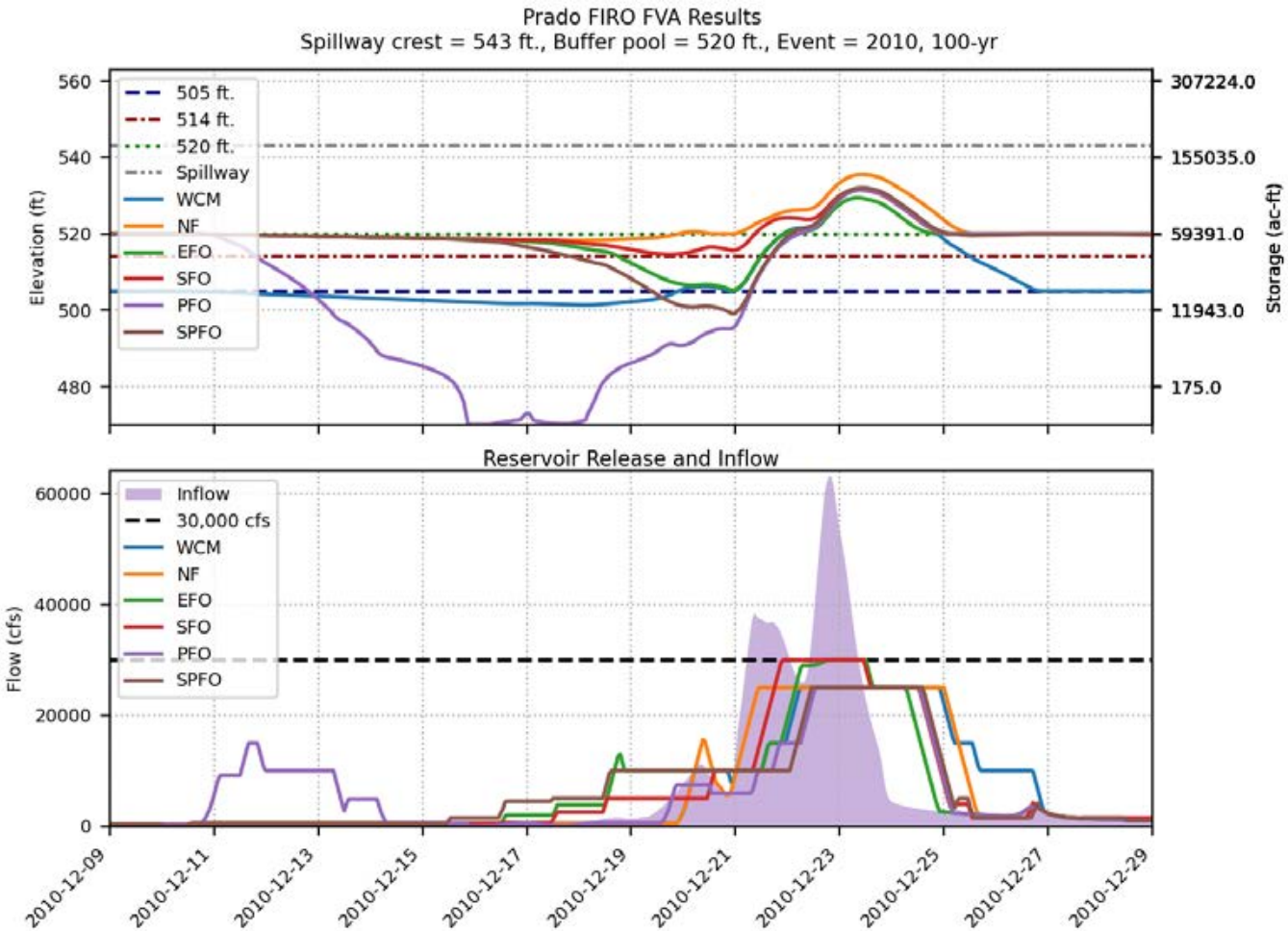
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 520 ft., Event = 2010, 100-yr
505 ft.
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Reservoir Release and Inflow
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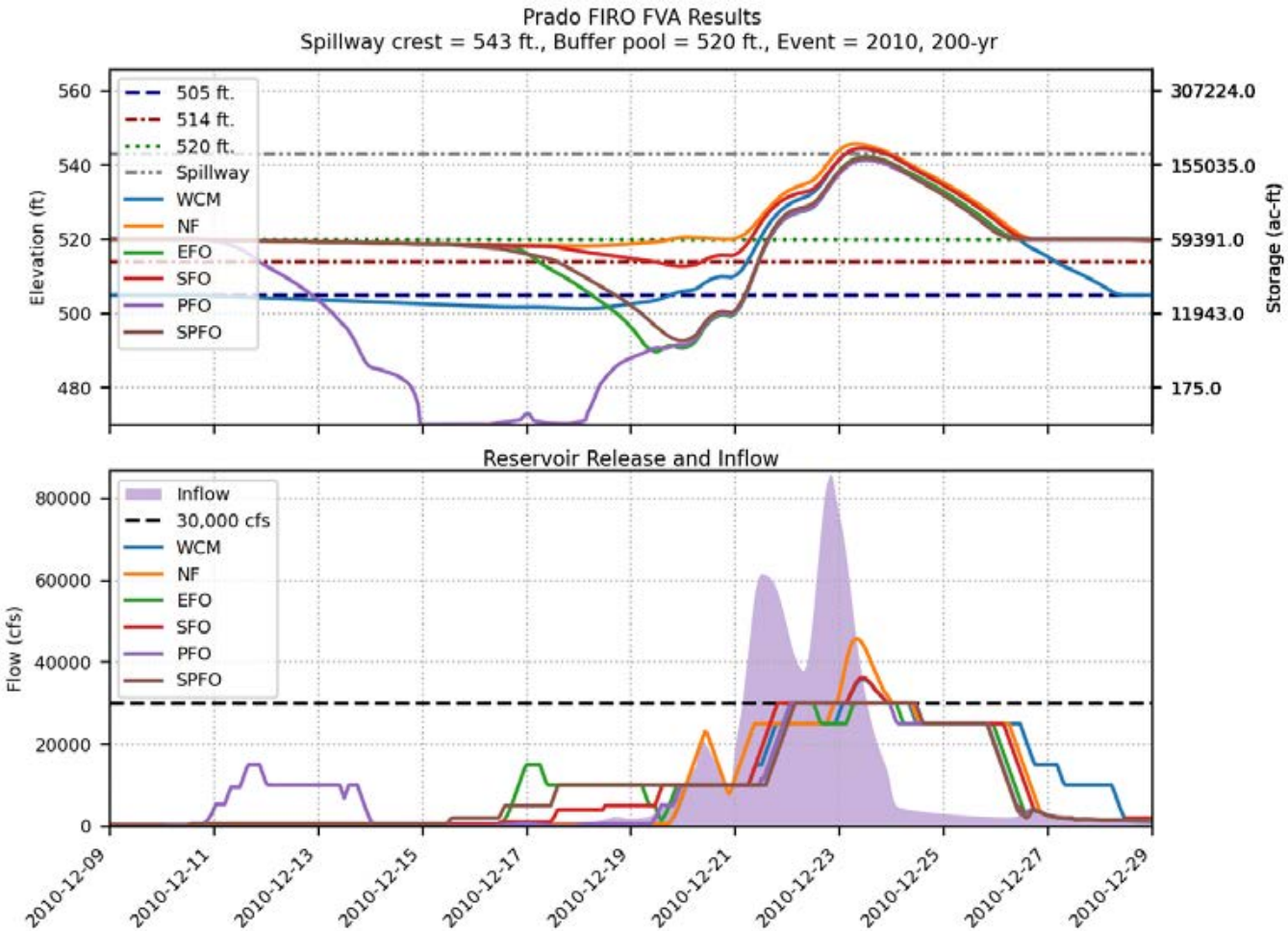
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 520 ft., Event = 2010, 200-yr
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520 ft.
Spillway
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SPFO
Elevation (ft)
Storage (ac-ft)
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175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
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SPFO
Flow (cfs)
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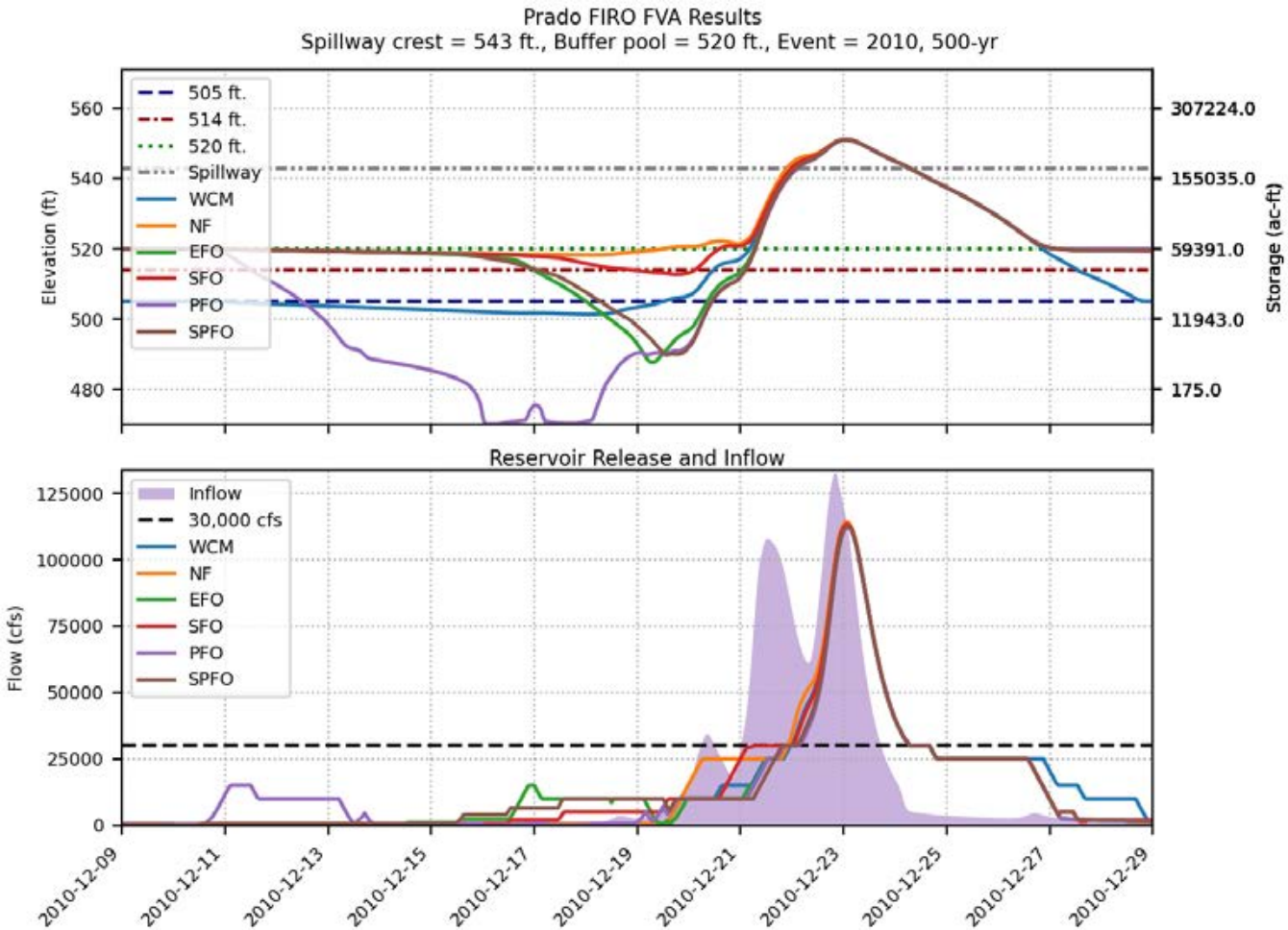
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 520 ft., Event = 2010, 500-yr
505 ft.
514 ft.
520 ft.
Spillway
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PFO
SPFO
Elevation (ft)
Storage (ac-ft)
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155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
Flow (cfs)
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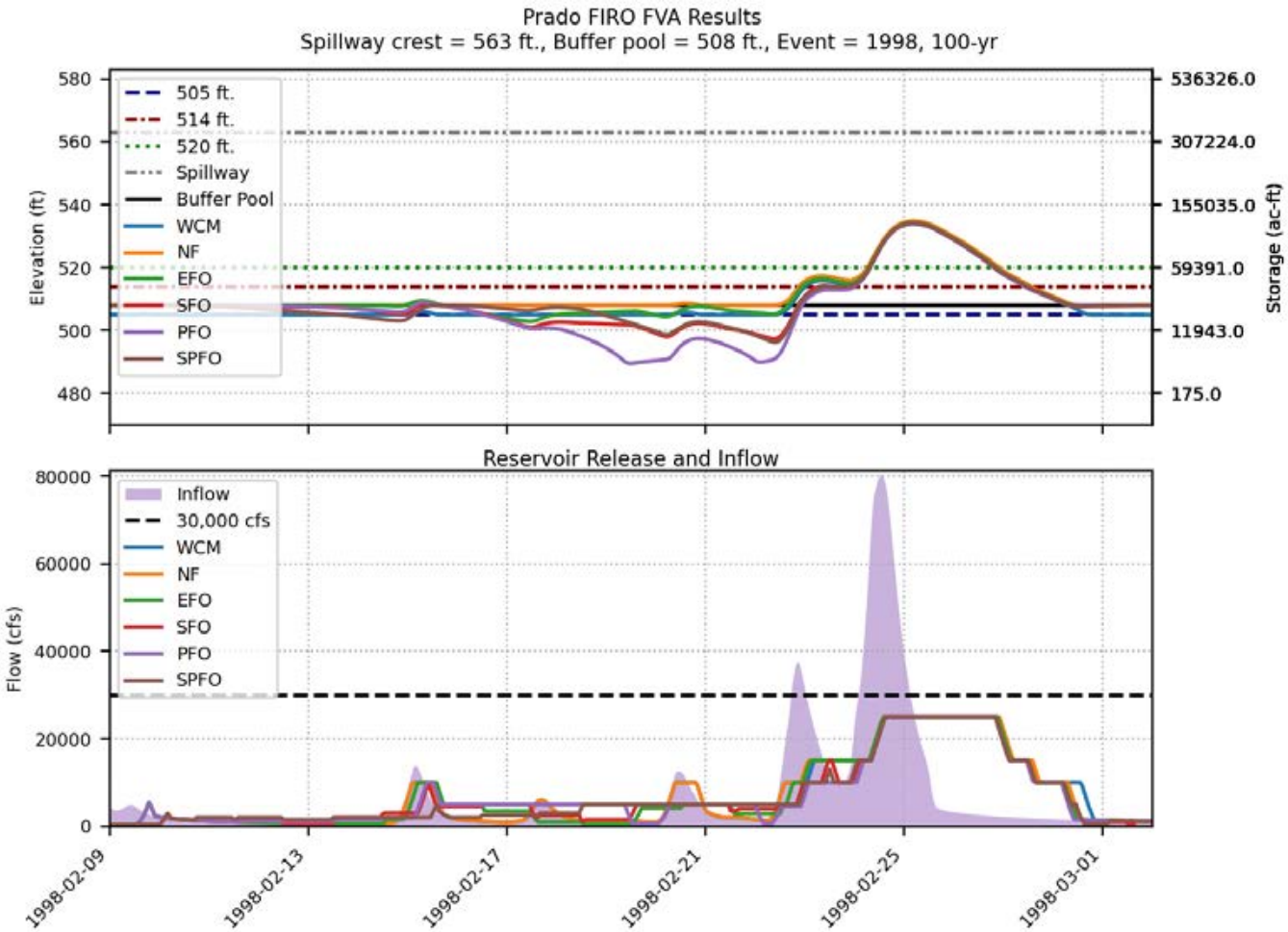
2010-12-29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Spillway crest = 563 ft., Buffer pool = 508 ft., Event = 1998, 100-yr
Elevation (ft)
Storage (ac-ft)
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514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
PFO
SPFO
580
560
540
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500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
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EFO
SFO
PFO
SPFO
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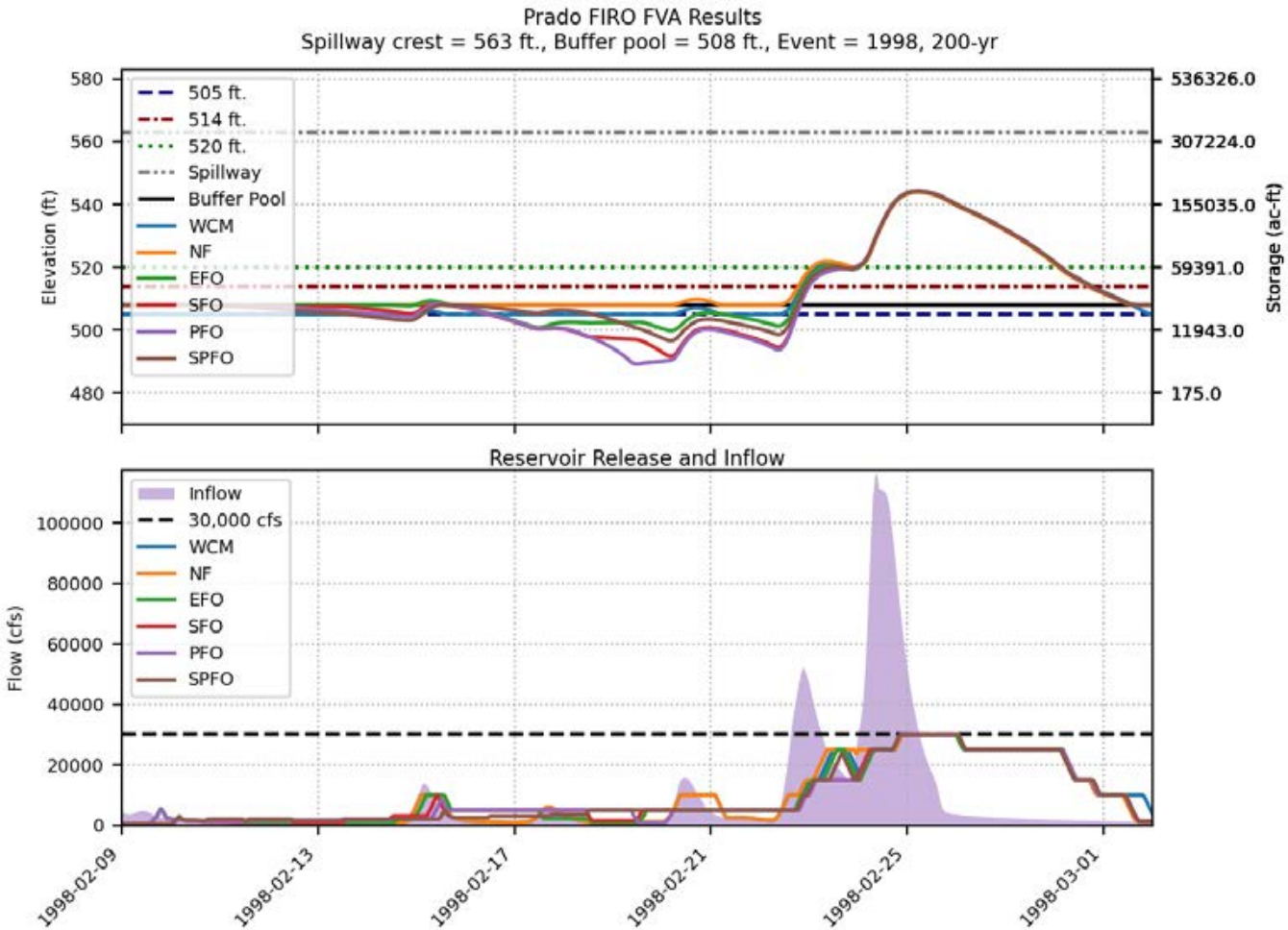
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 508 ft., Event = 1998, 200-yr
Elevation (ft)
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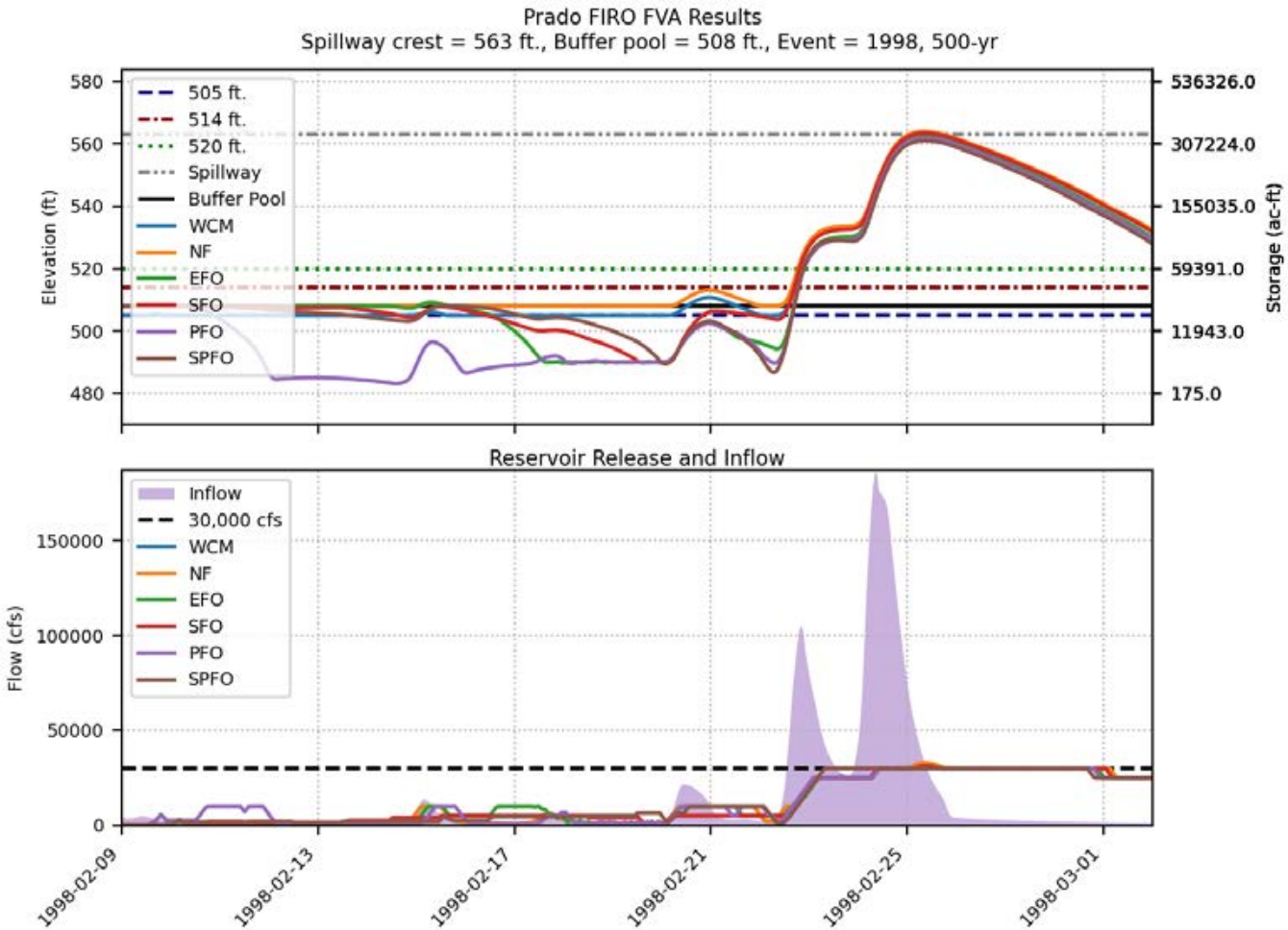
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 508 ft., Event = 1998, 500-yr
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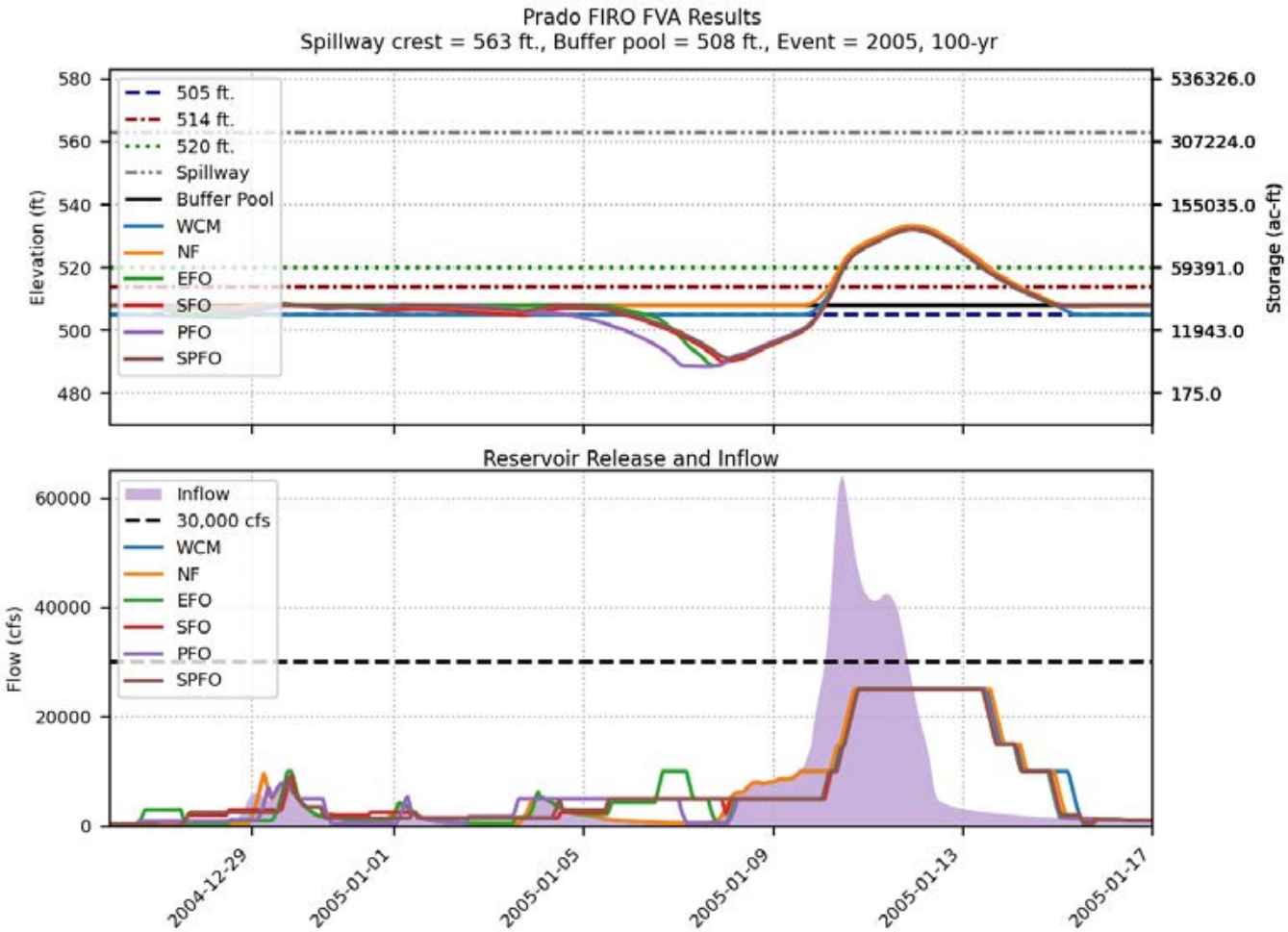
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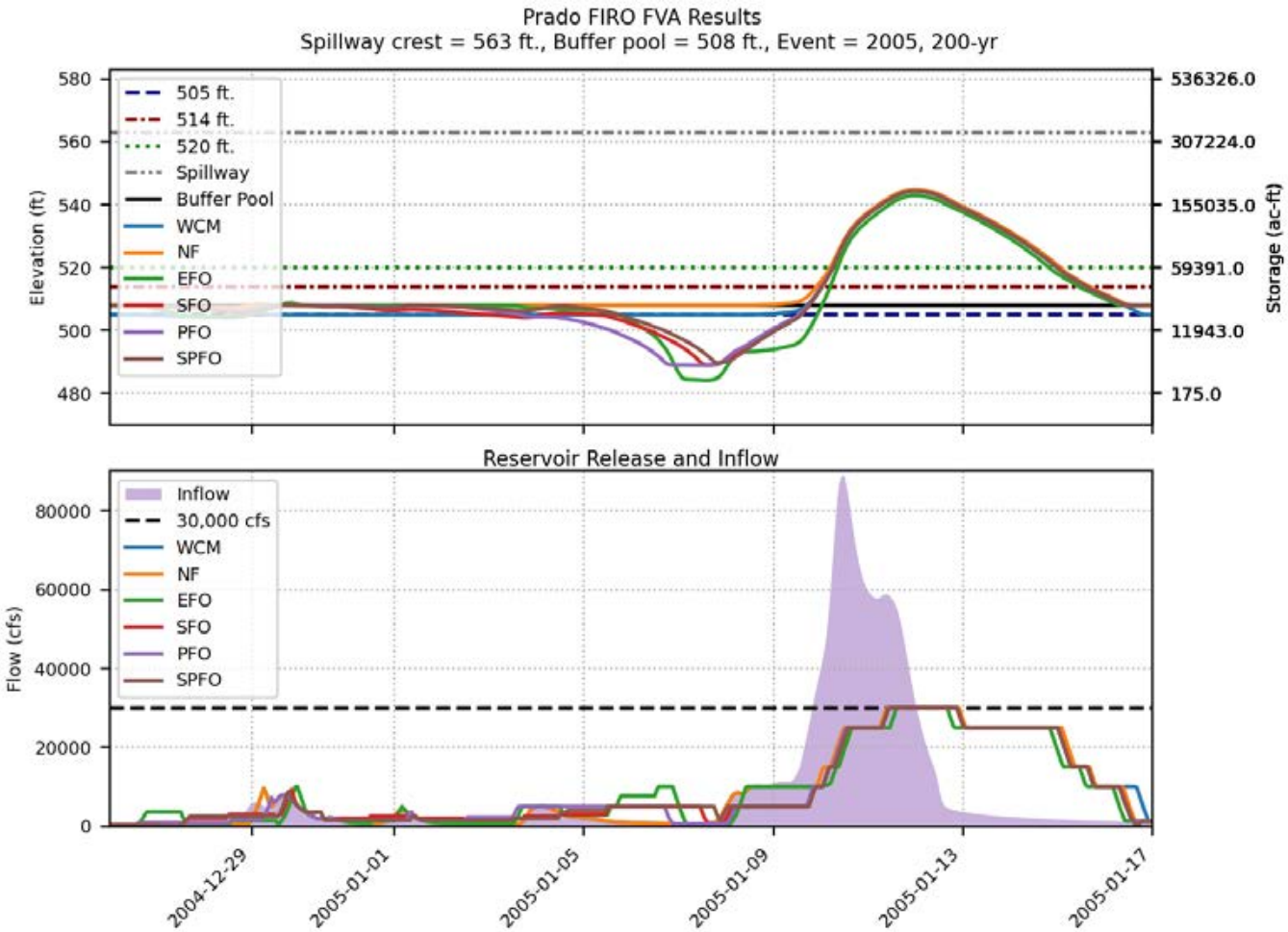
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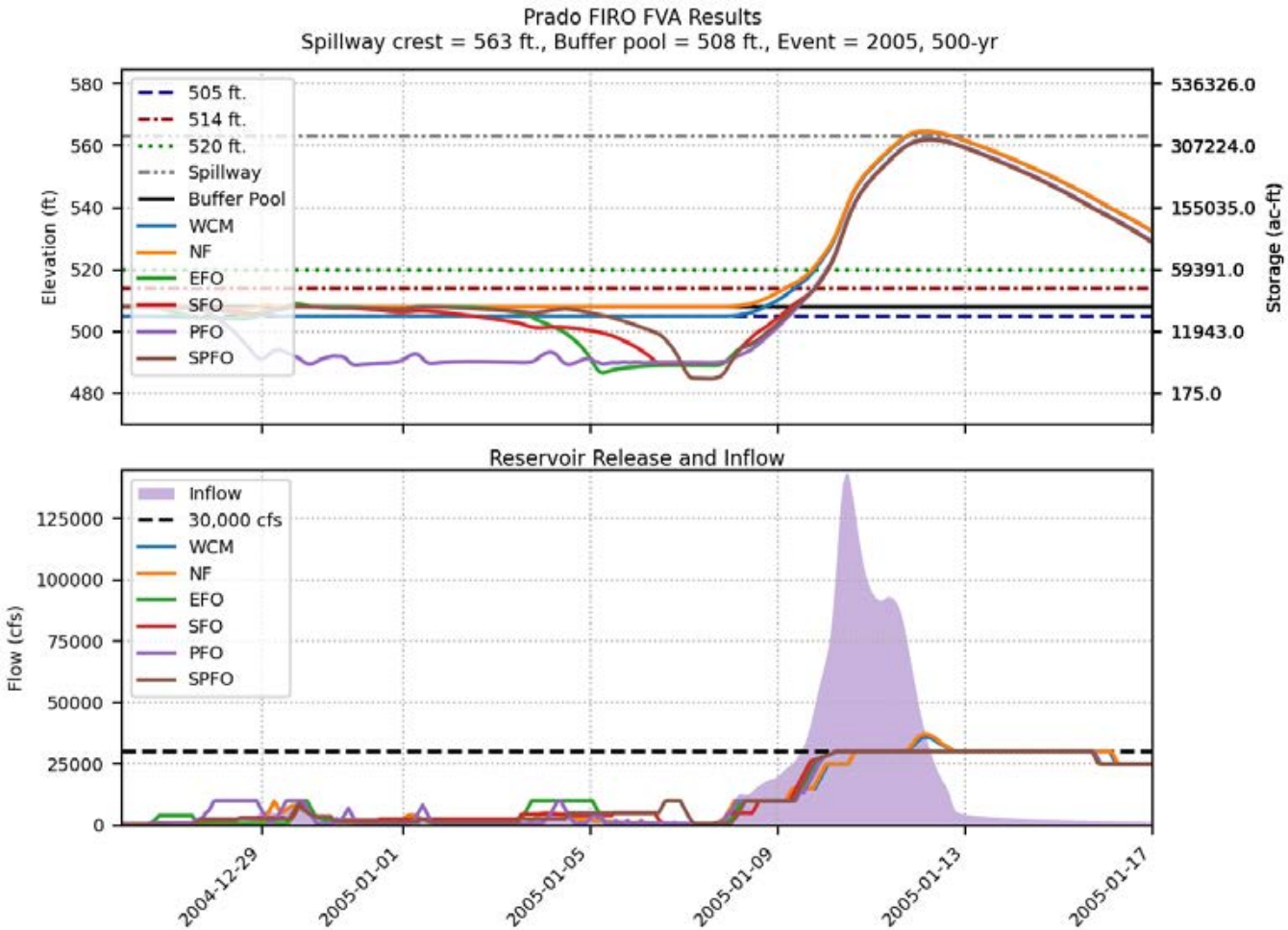
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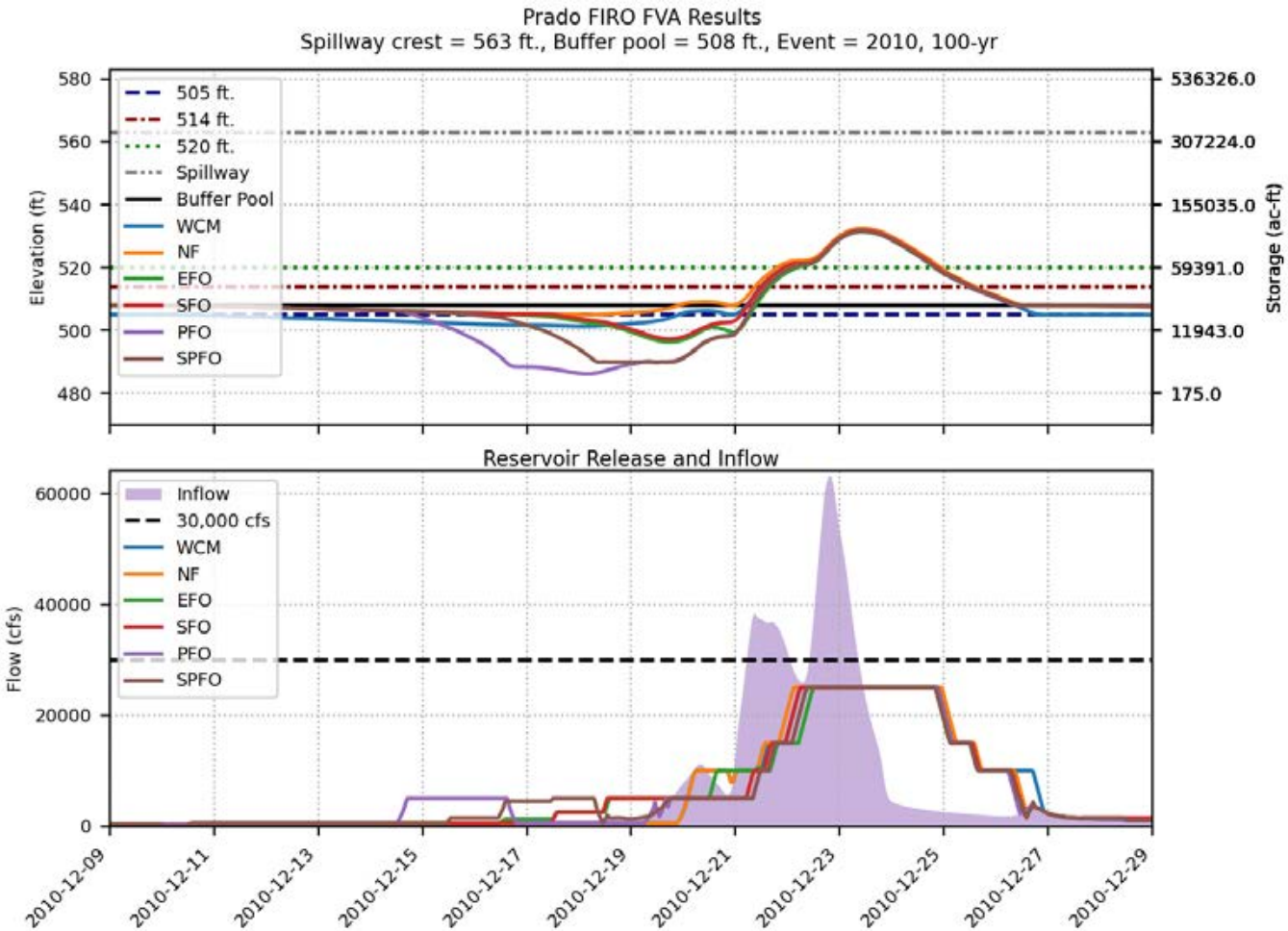
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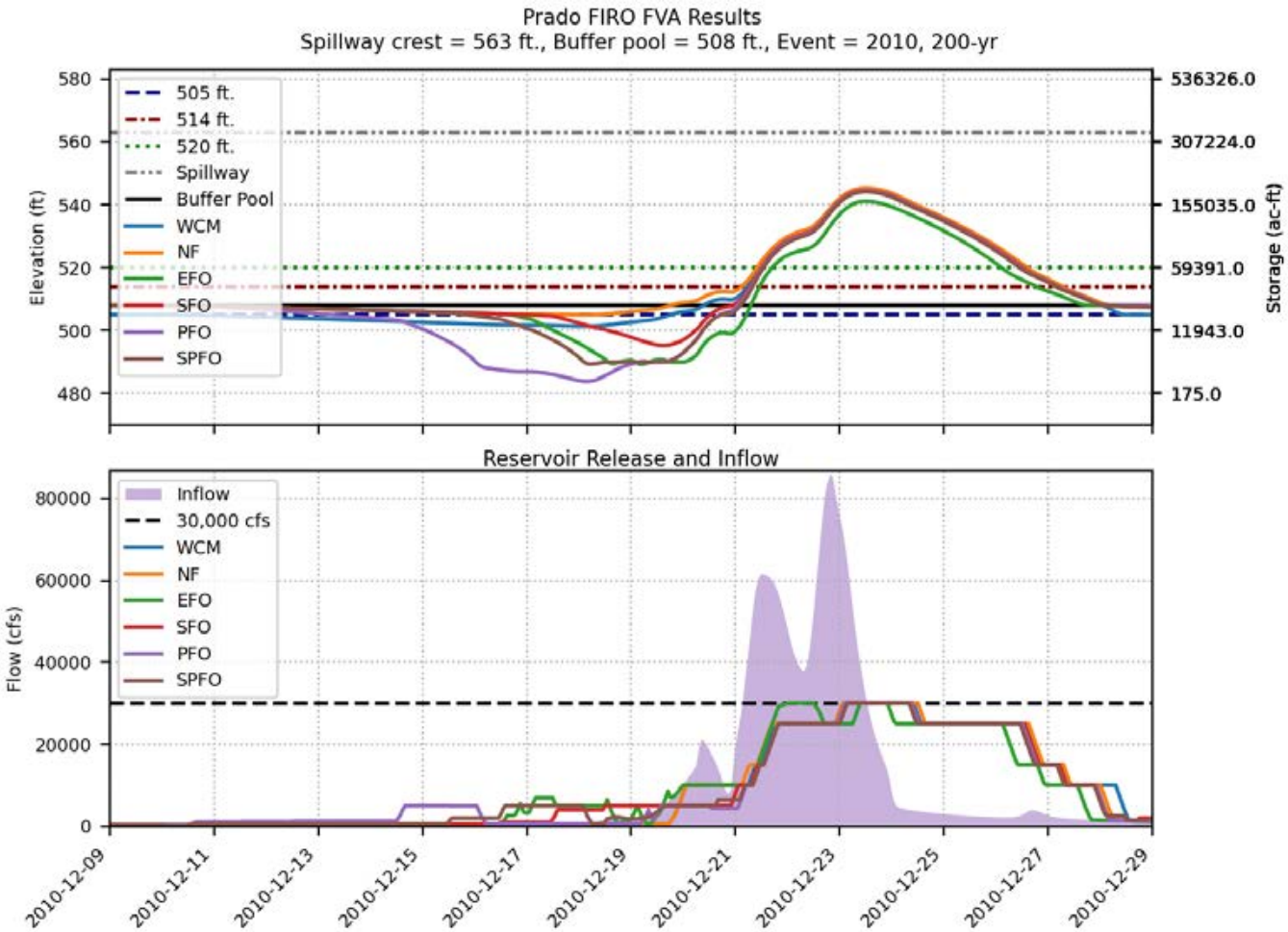
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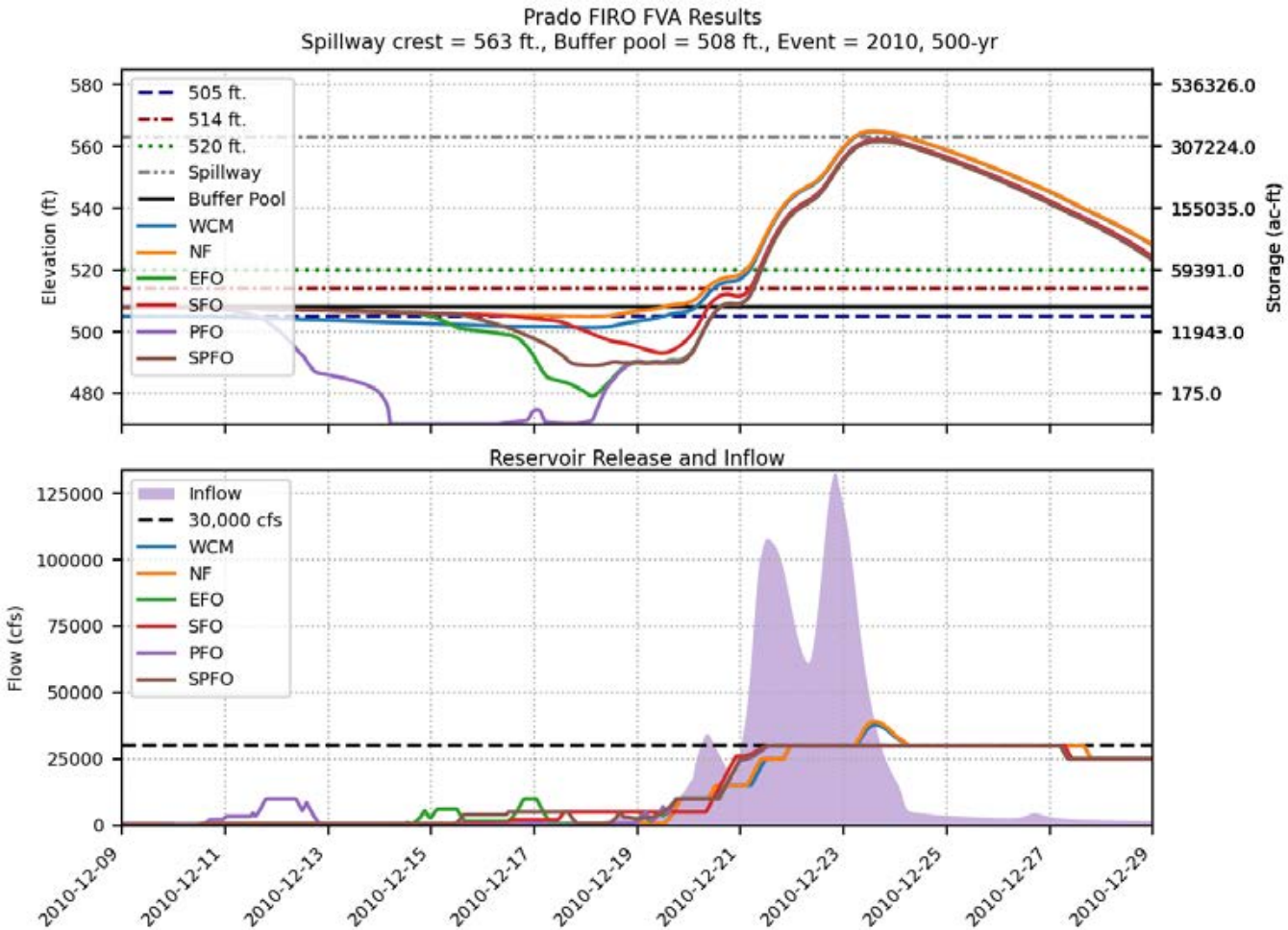
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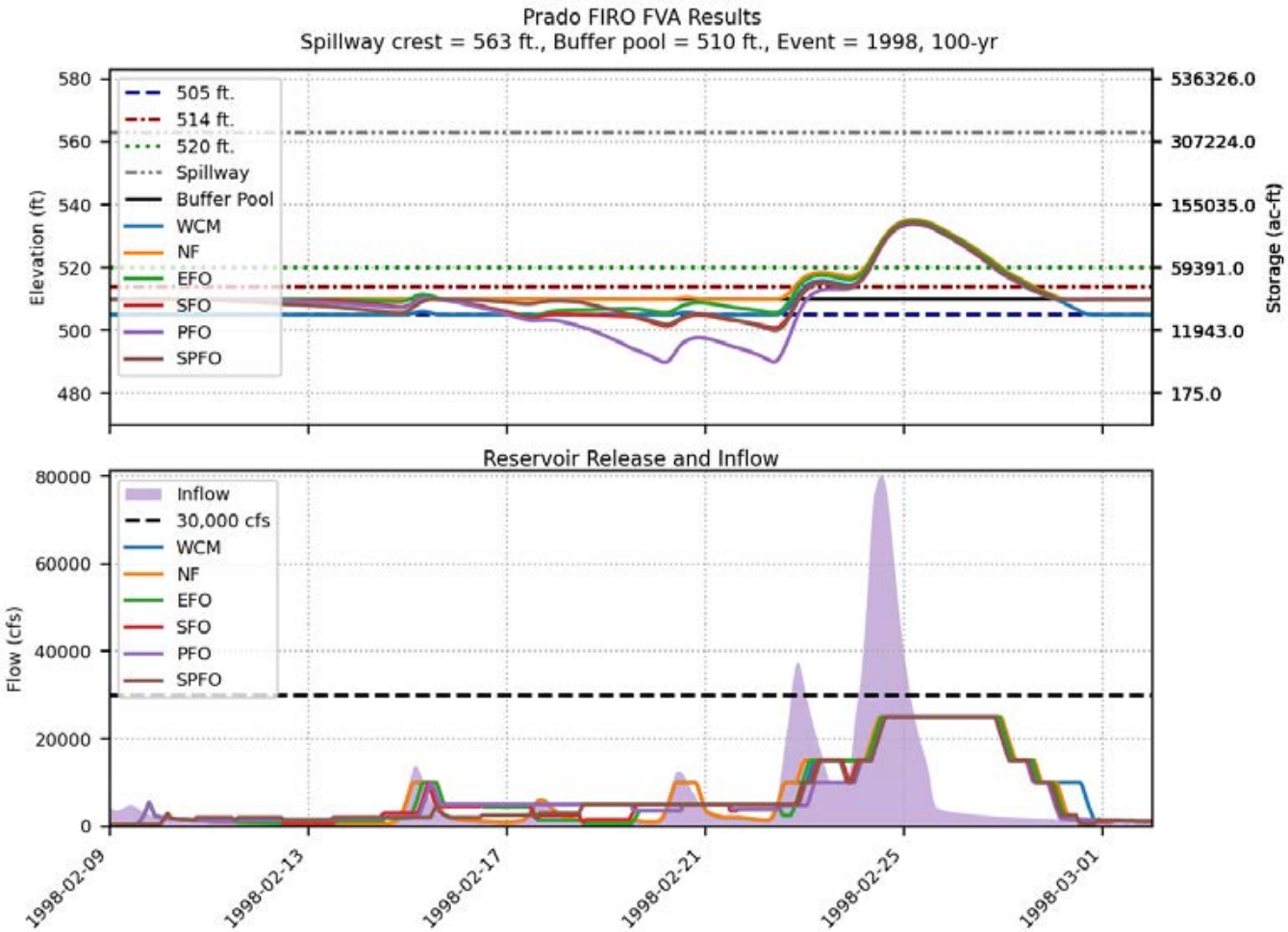
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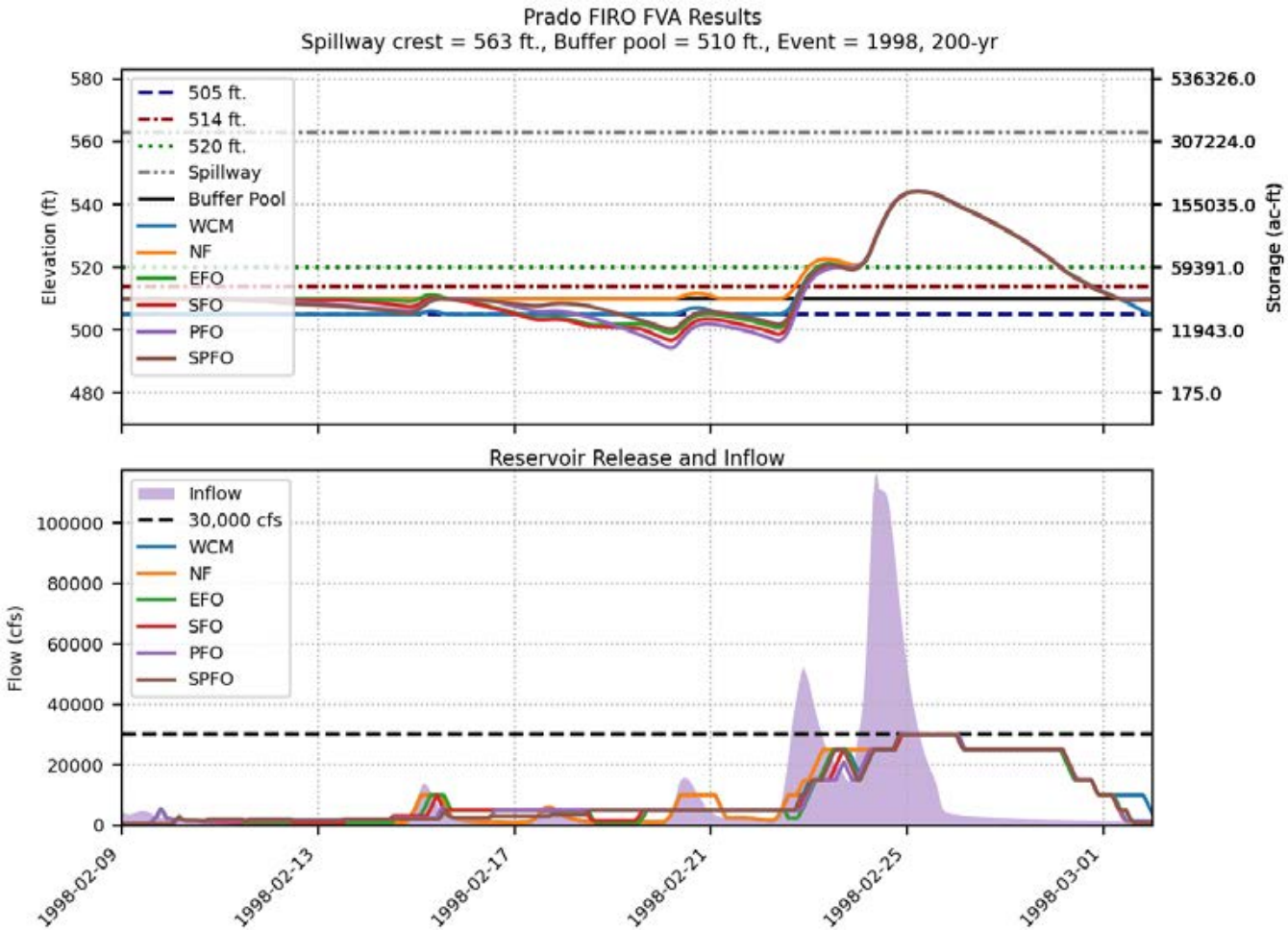
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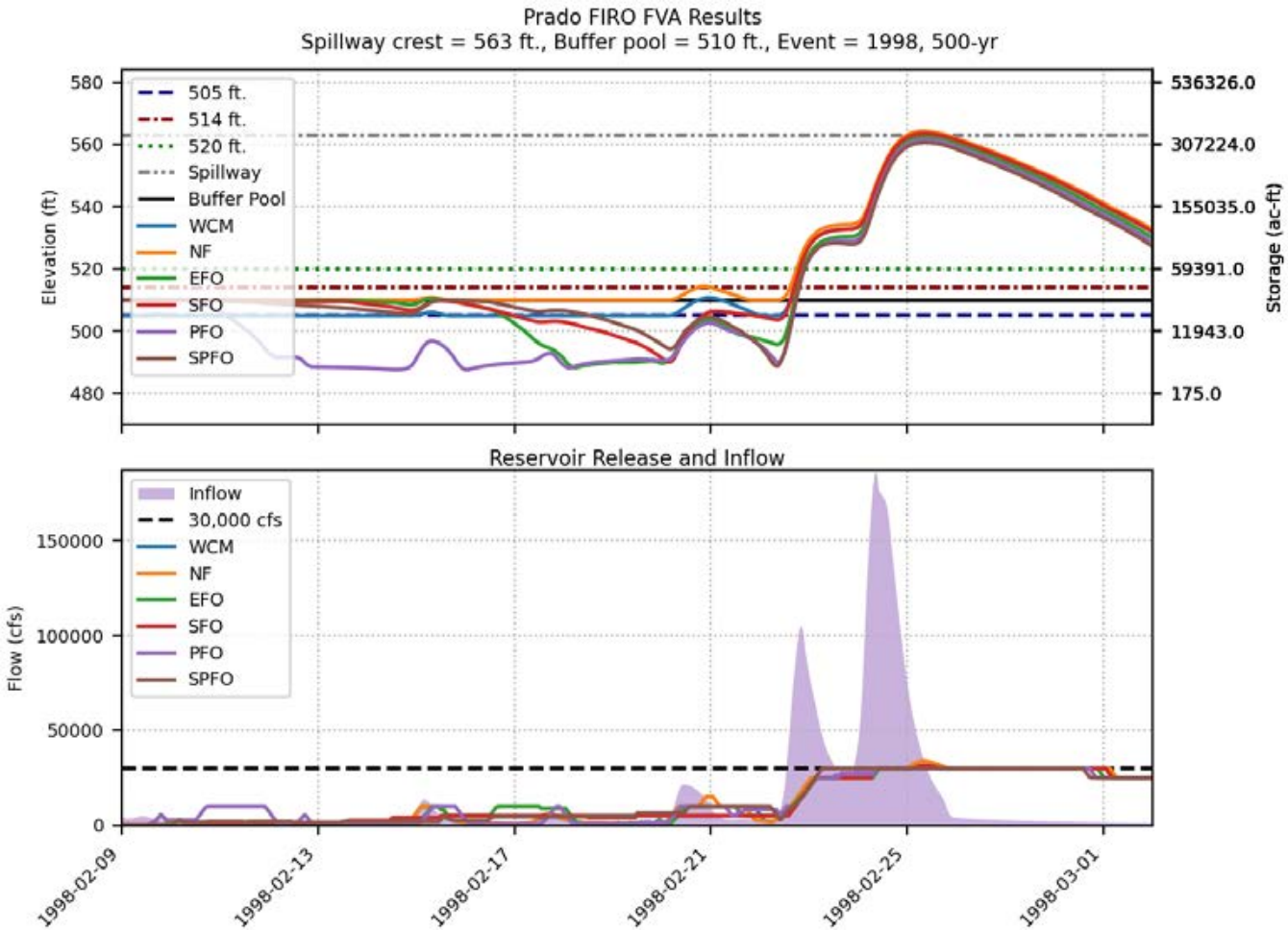
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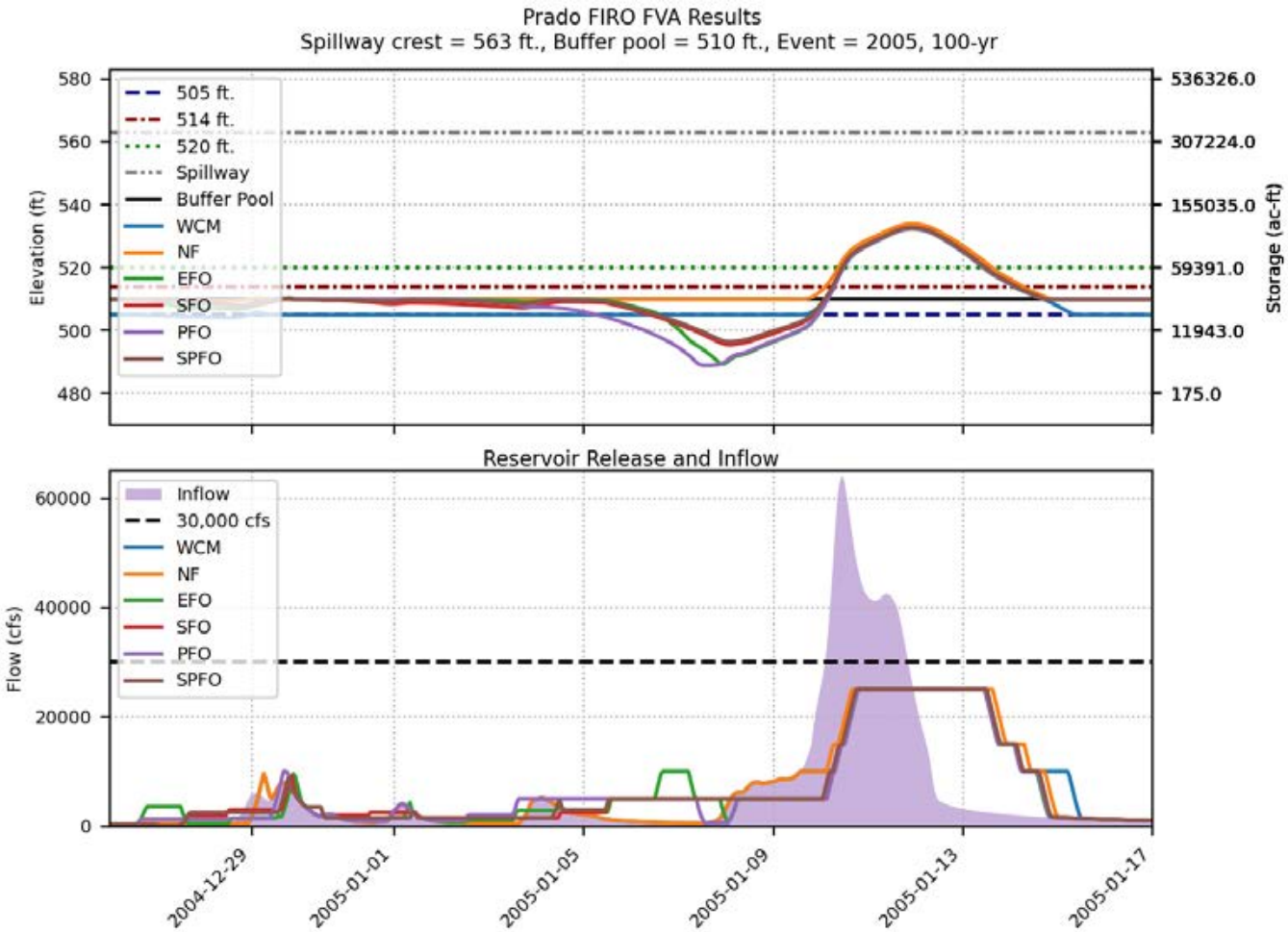
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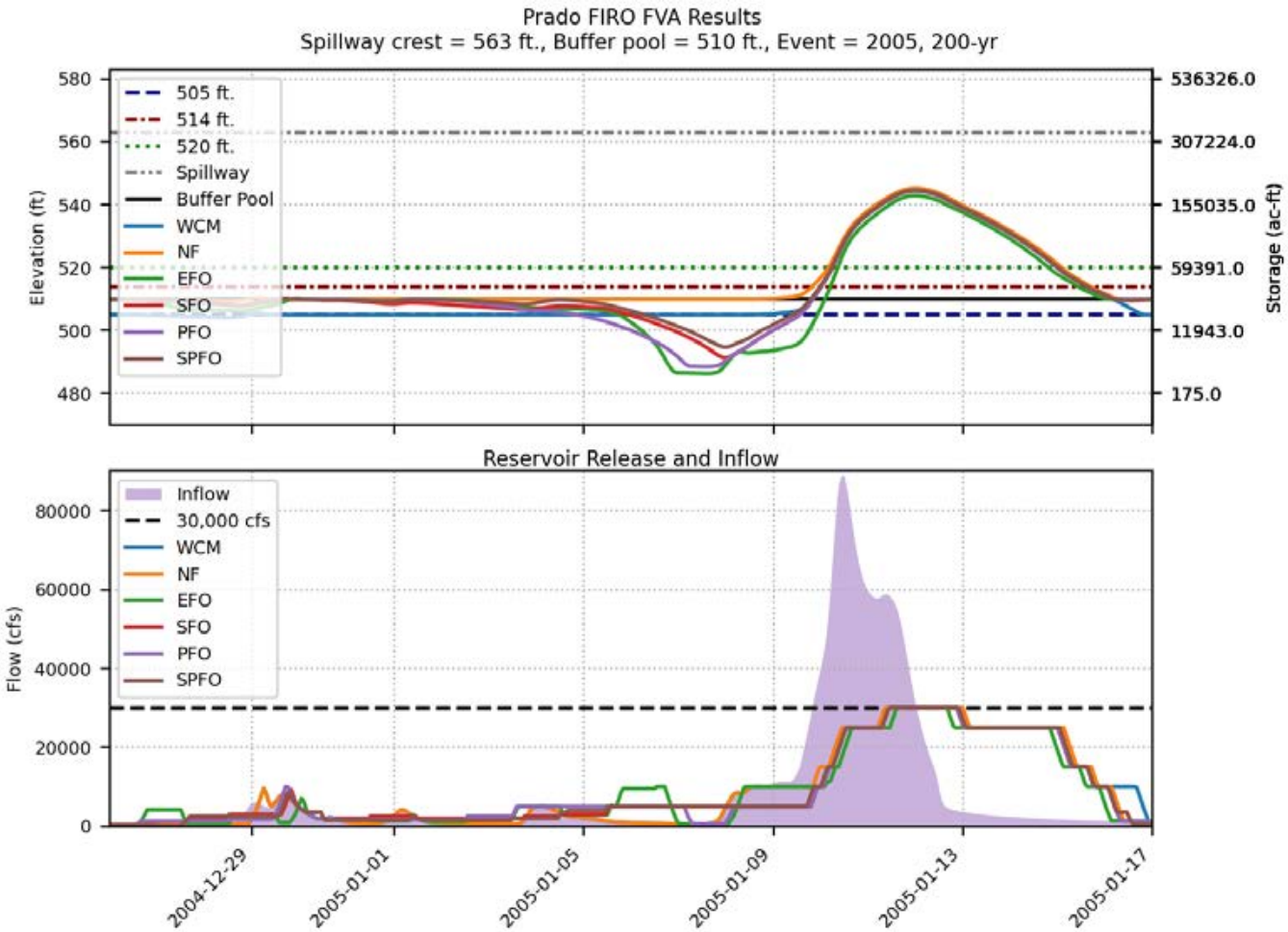
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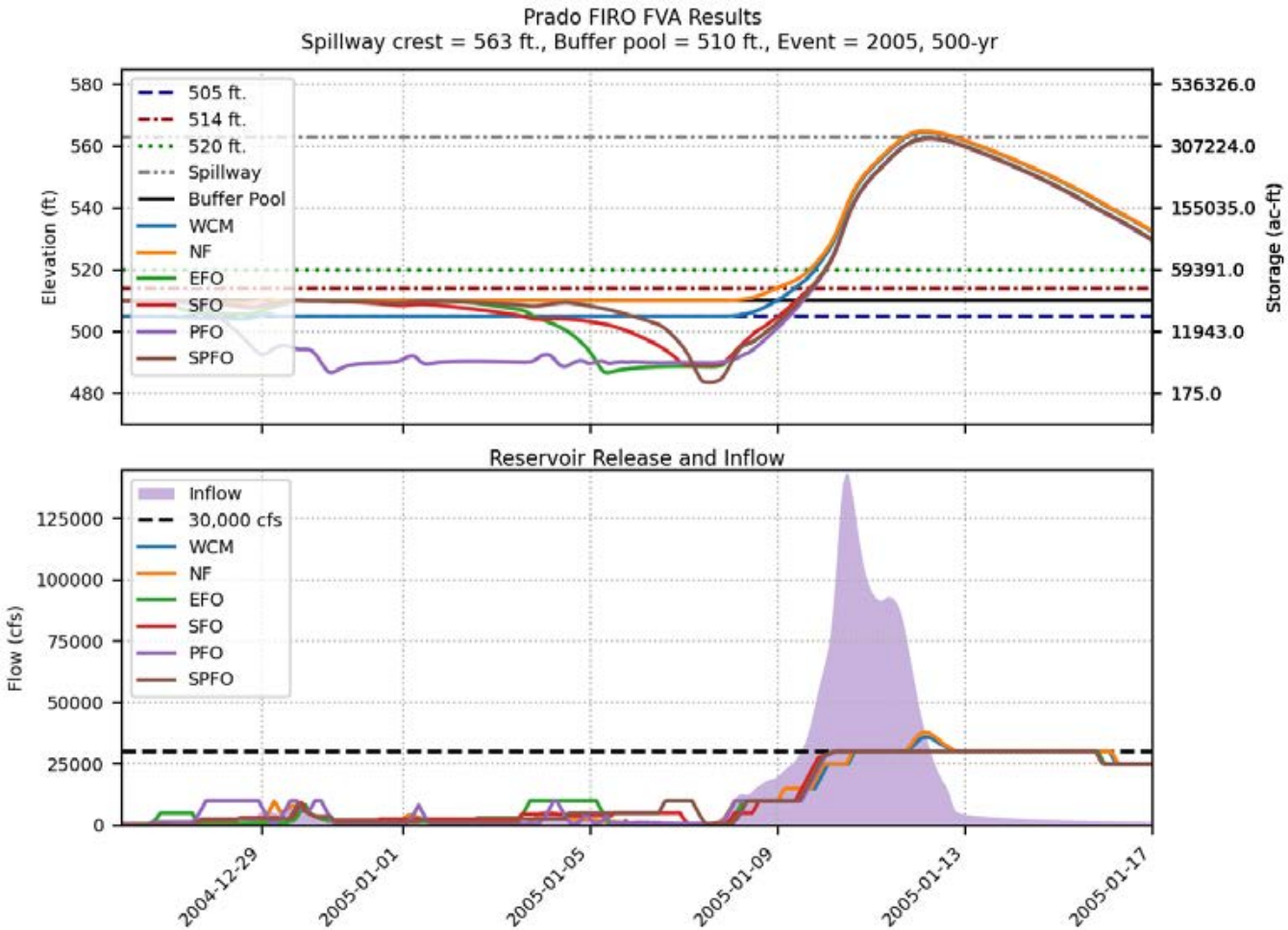
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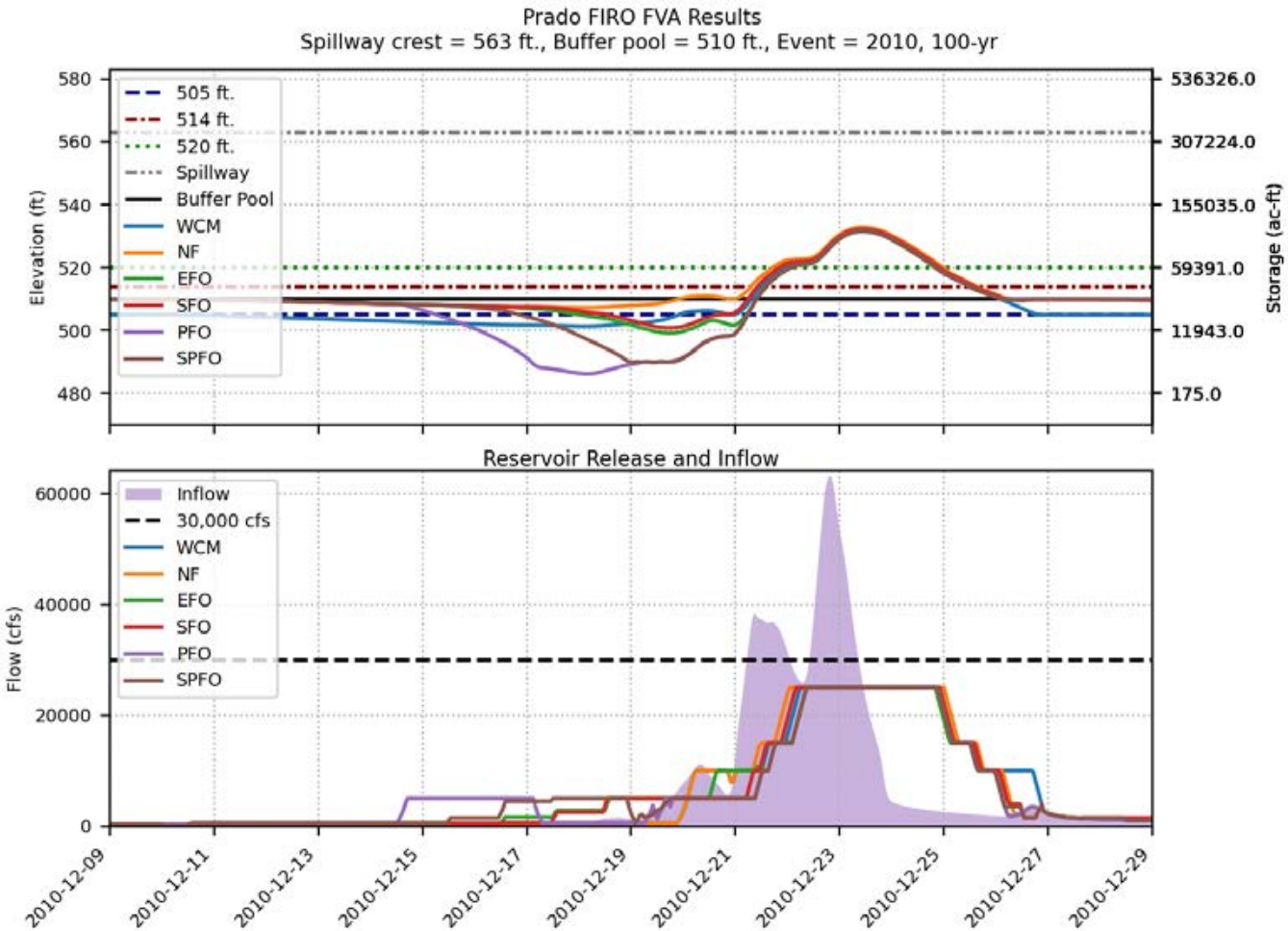
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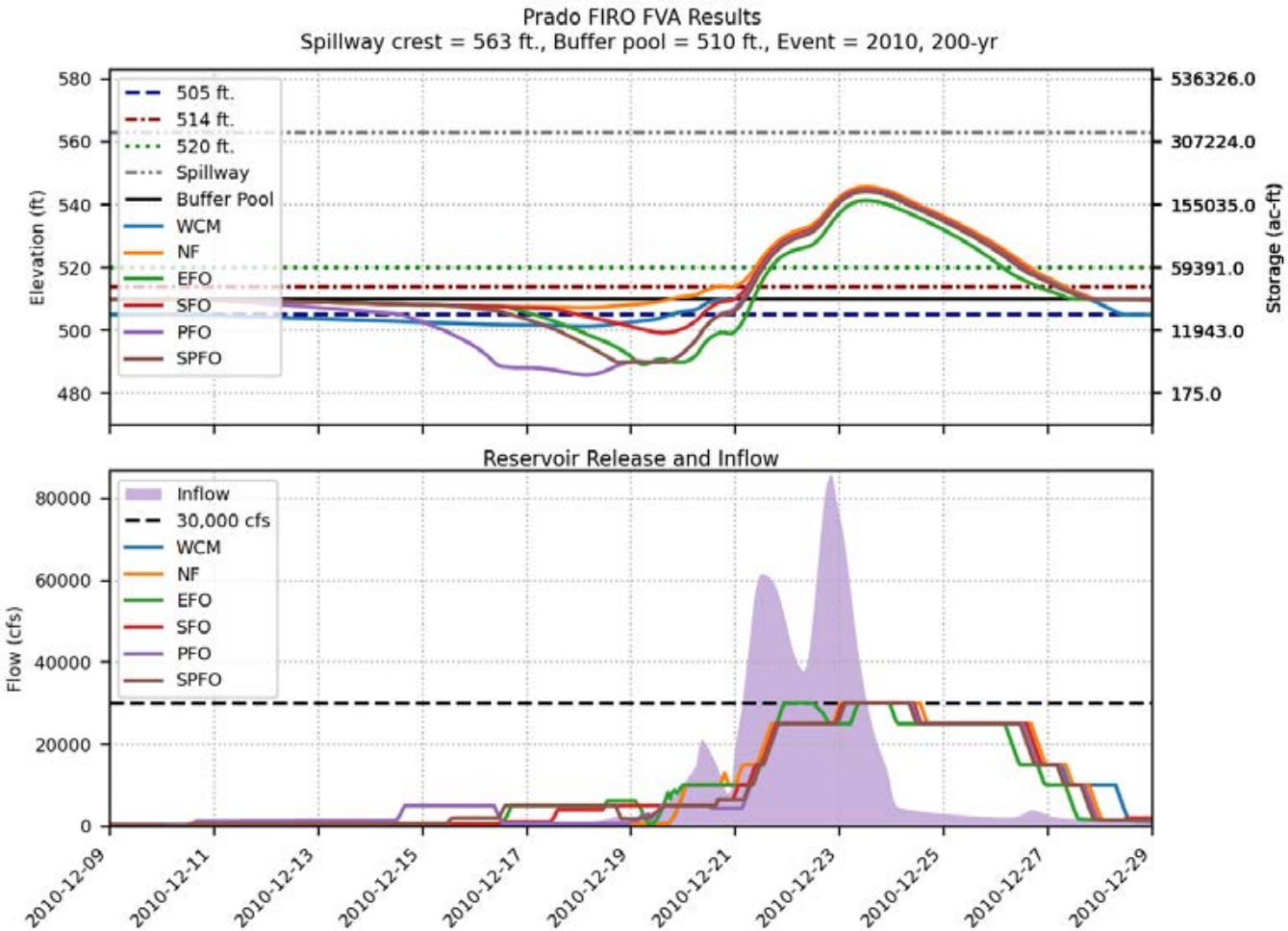
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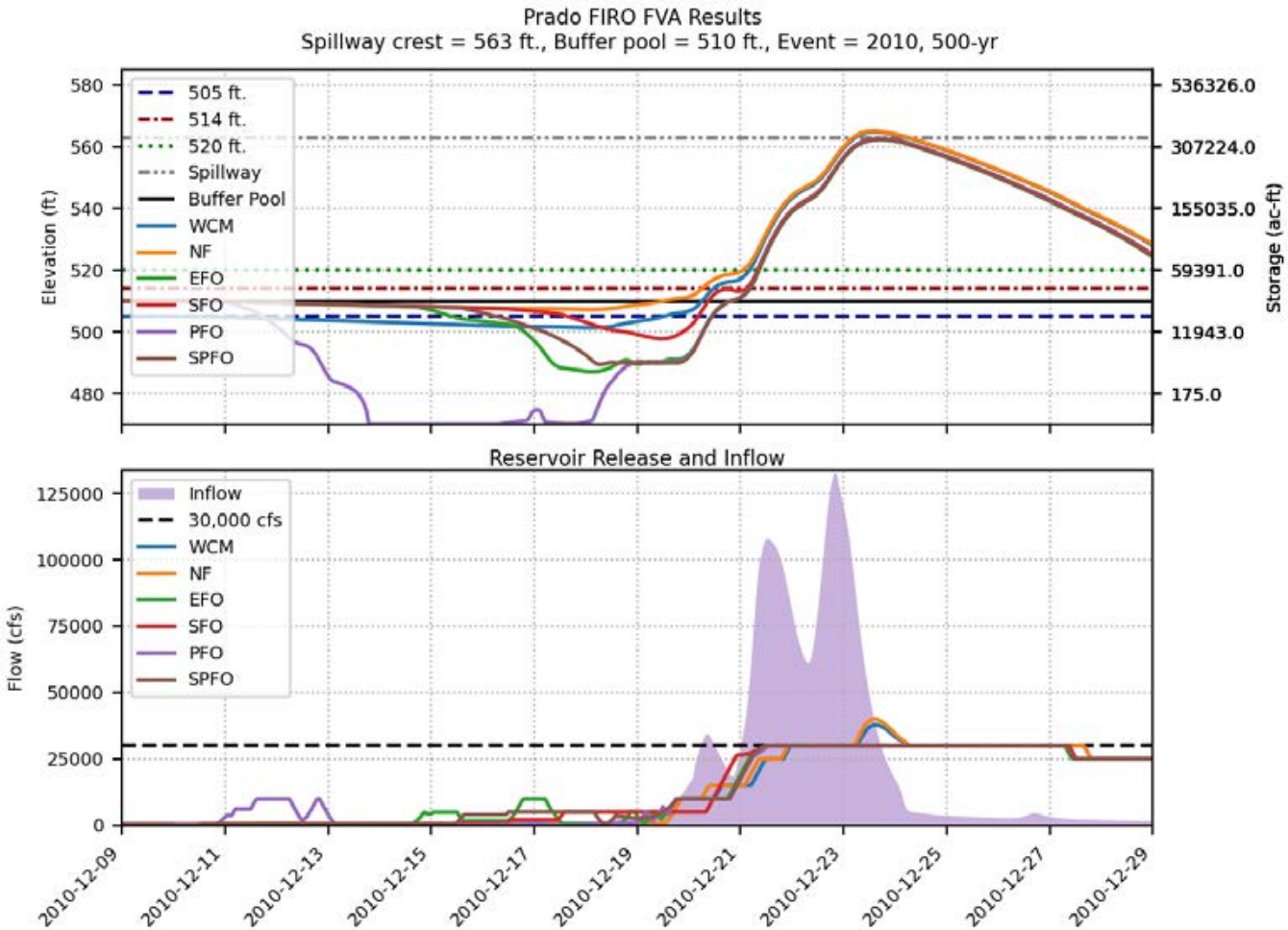
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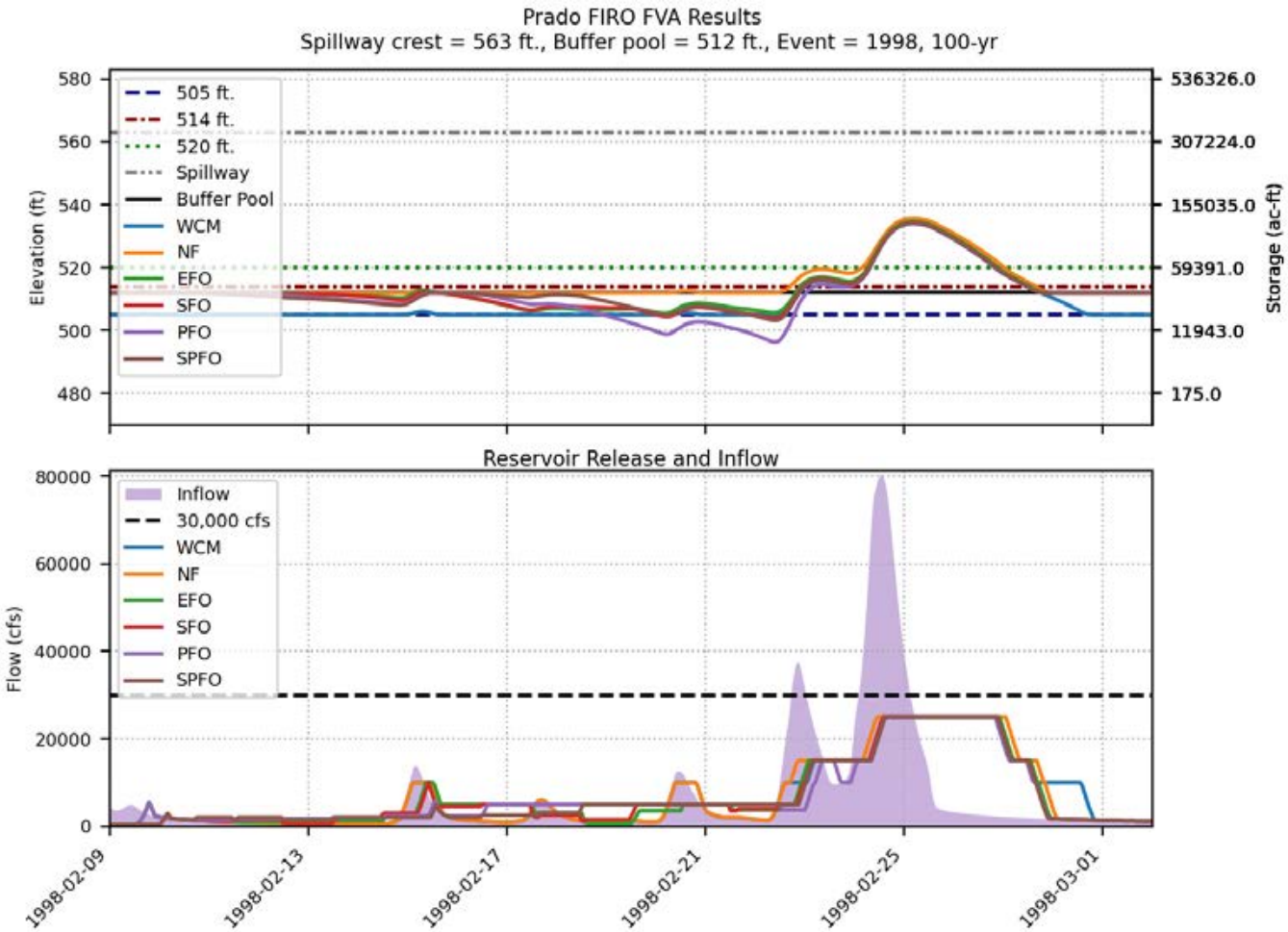
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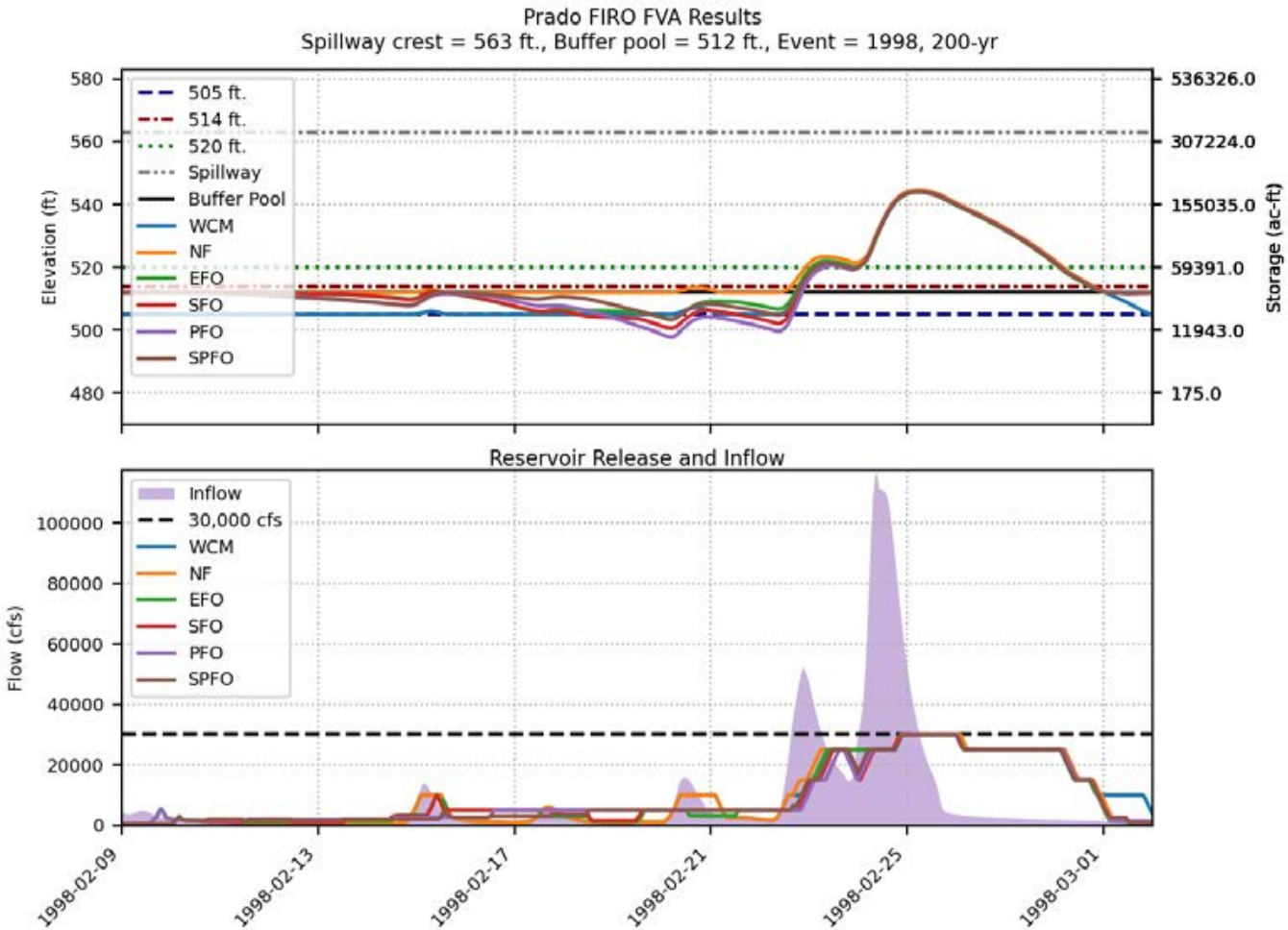
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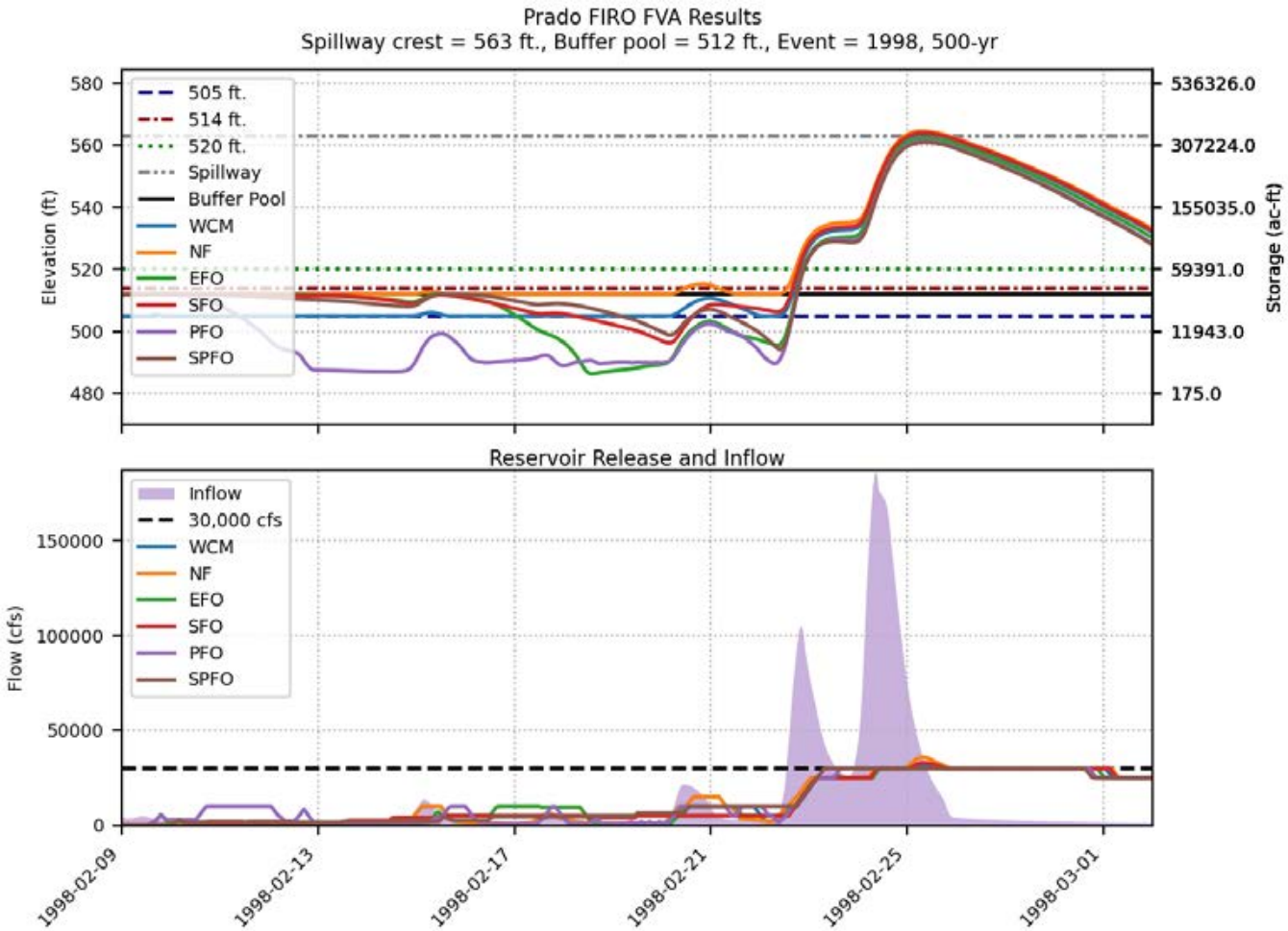
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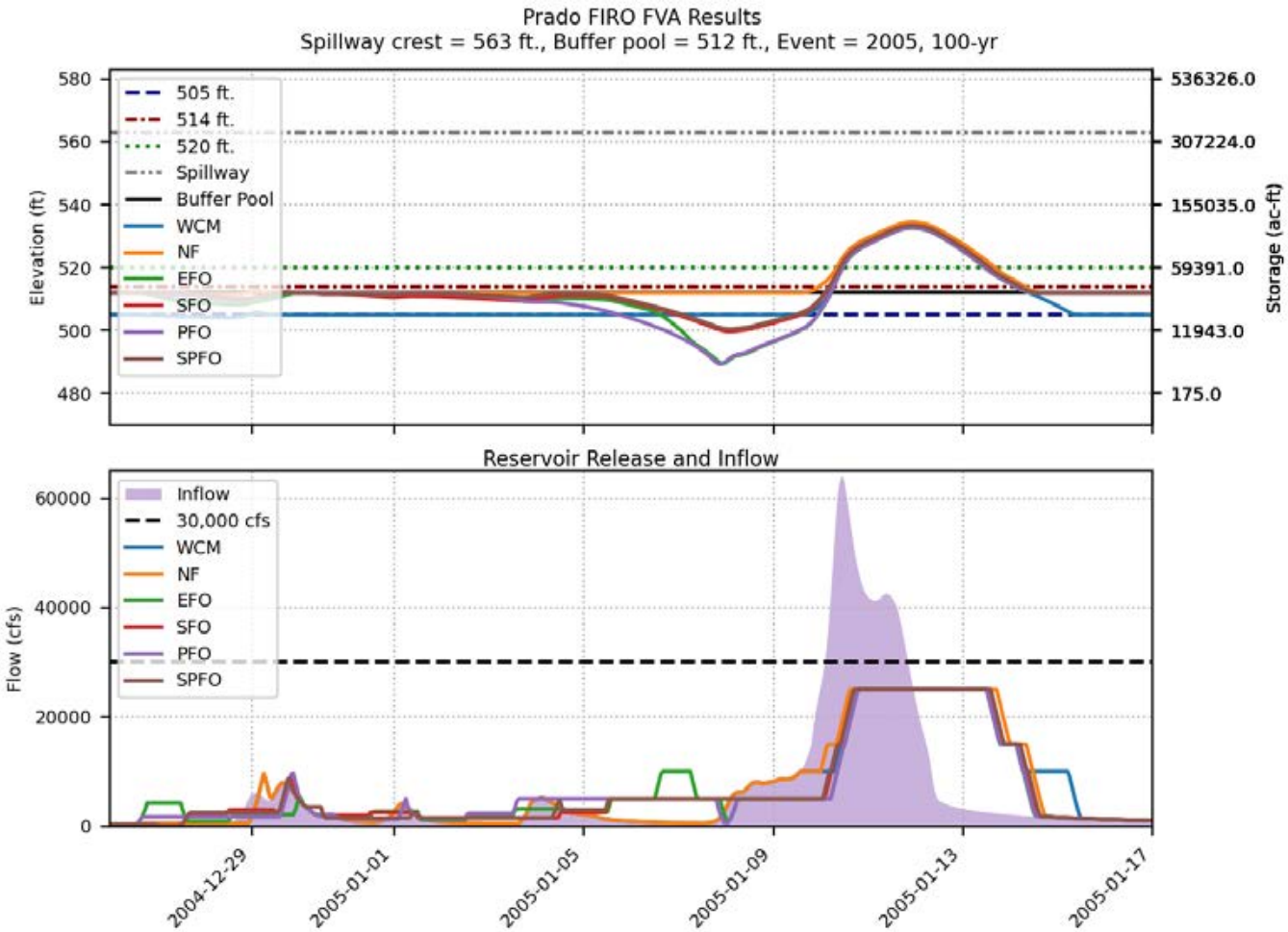
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 512 ft., Event = 2005, 100-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
PFO
SPFO
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
60000
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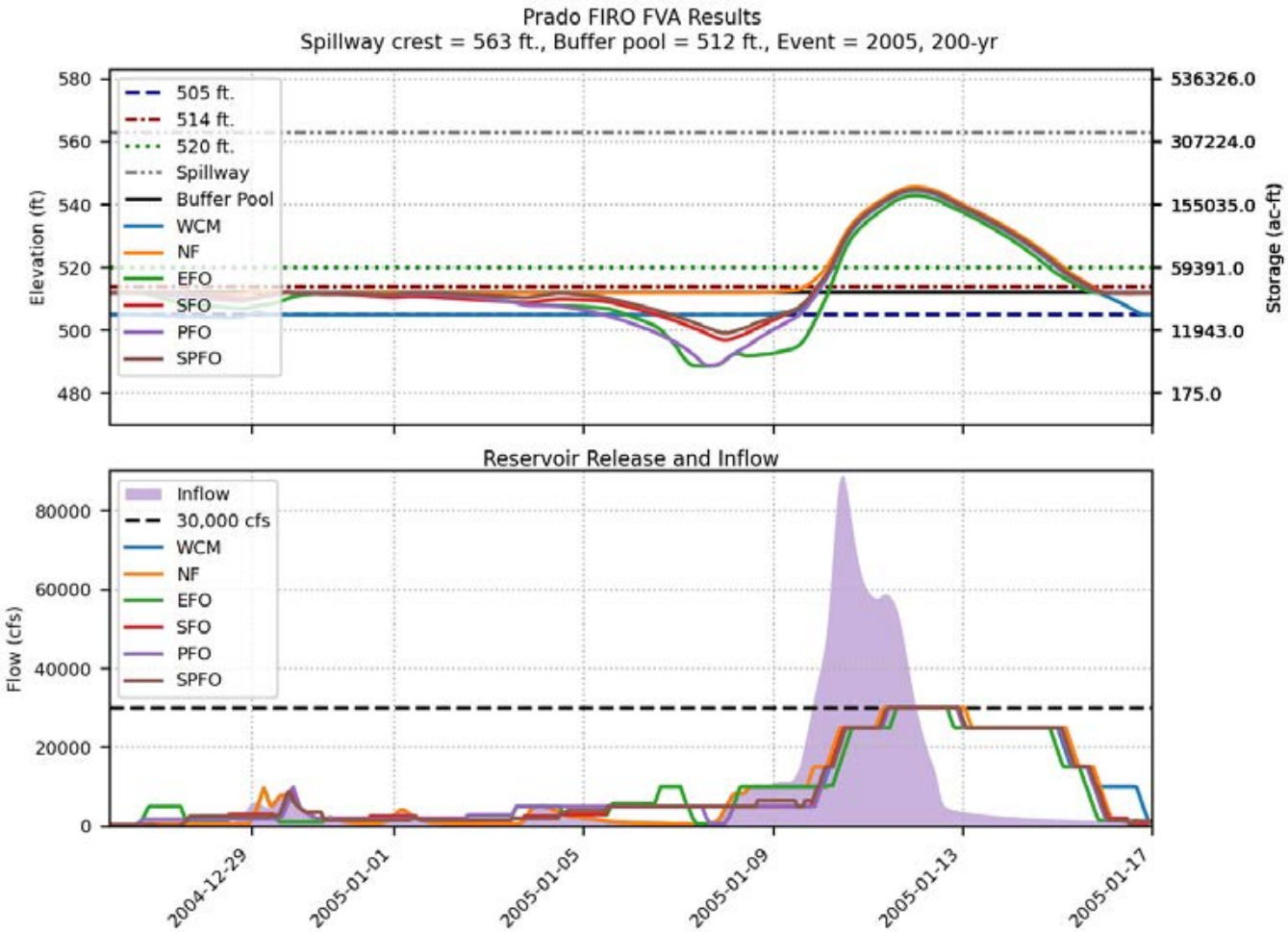
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 512 ft., Event = 2005, 200-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
PFO
SPFO
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
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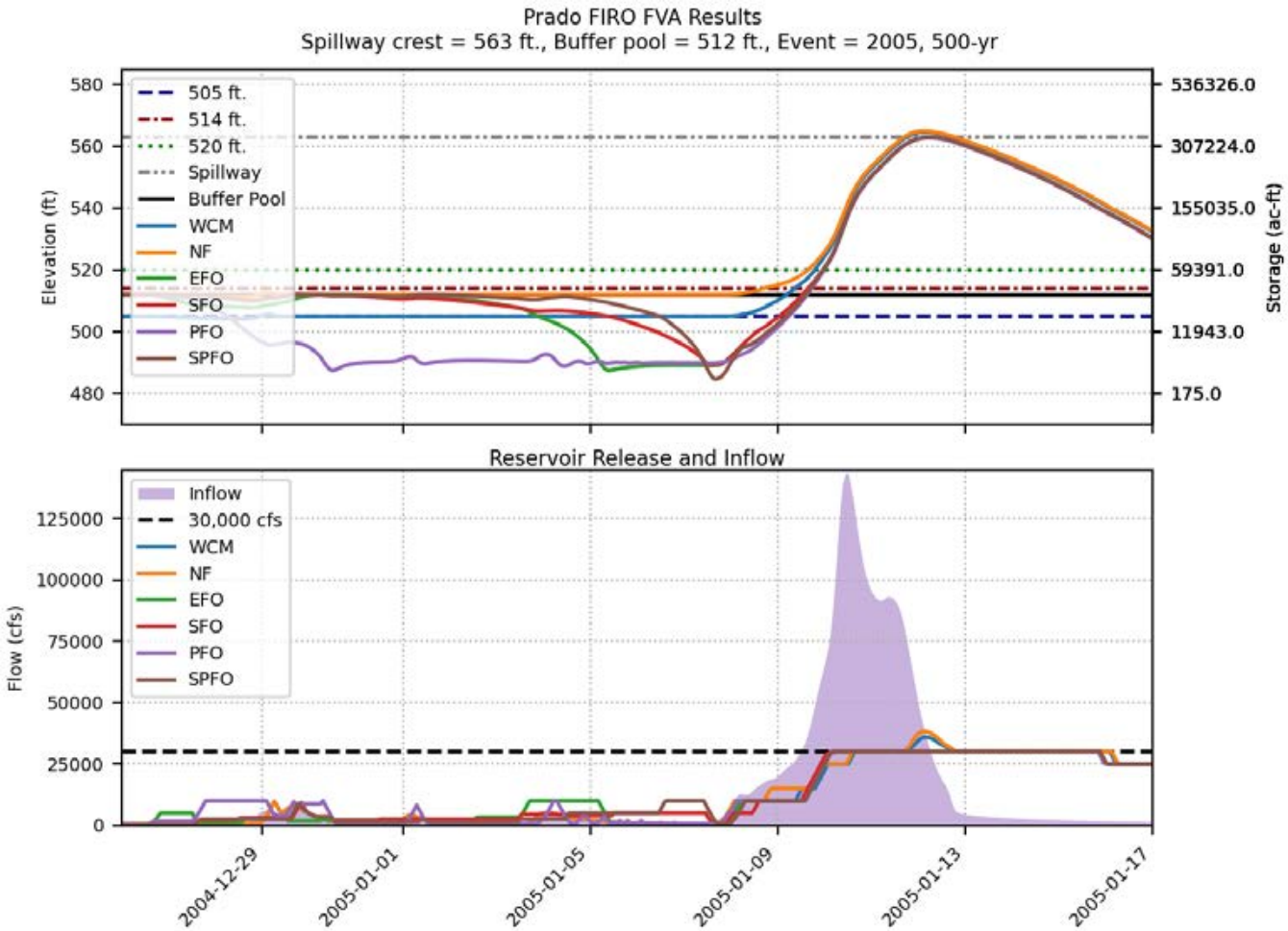
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 512 ft., Event = 2005, 500-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
PFO
SPFO
580
560
540
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500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
125000
100000
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2005-01-01
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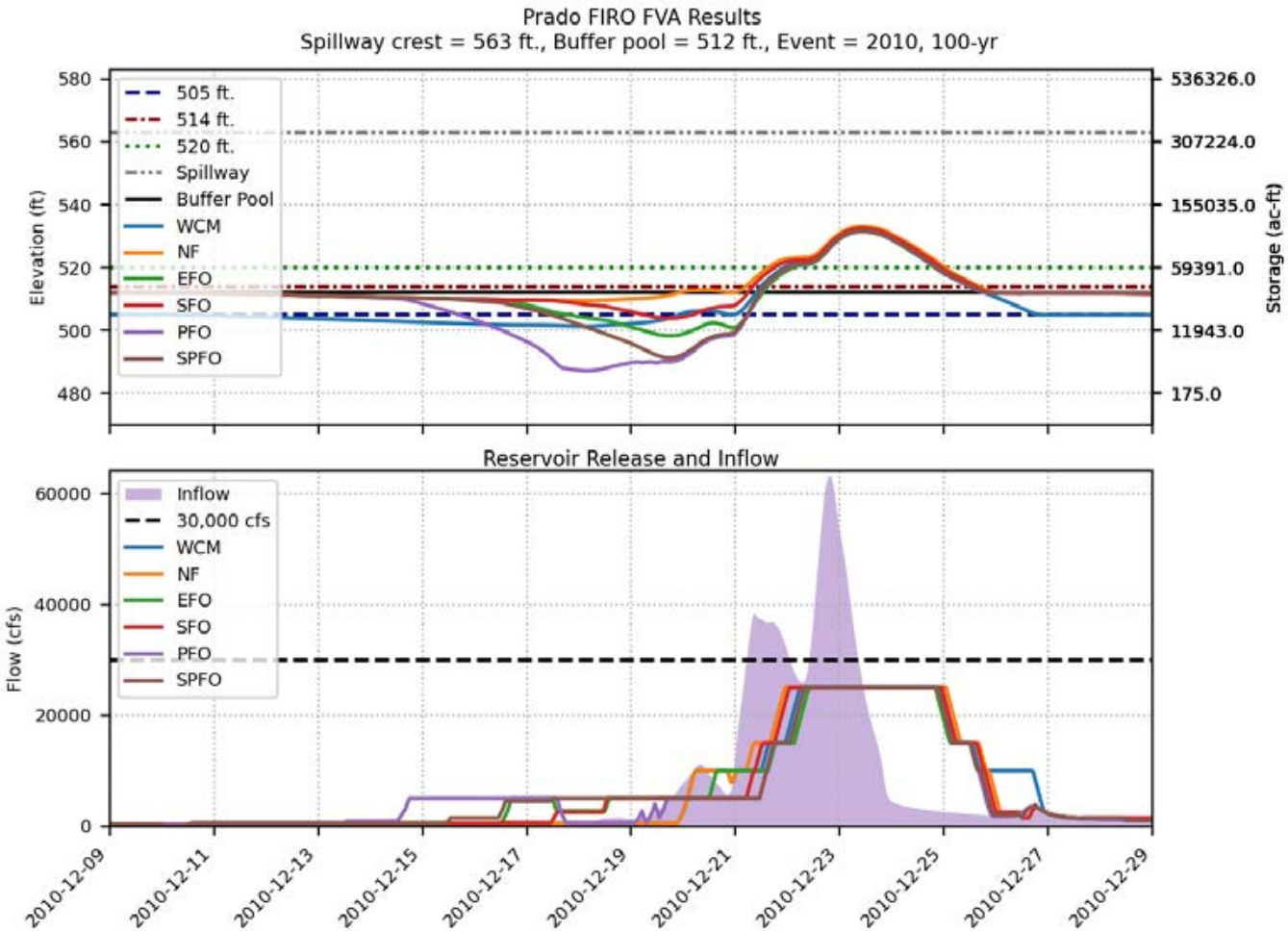
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 512 ft., Event = 2010, 100-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
PFO
SPFO
580
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480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
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EFO
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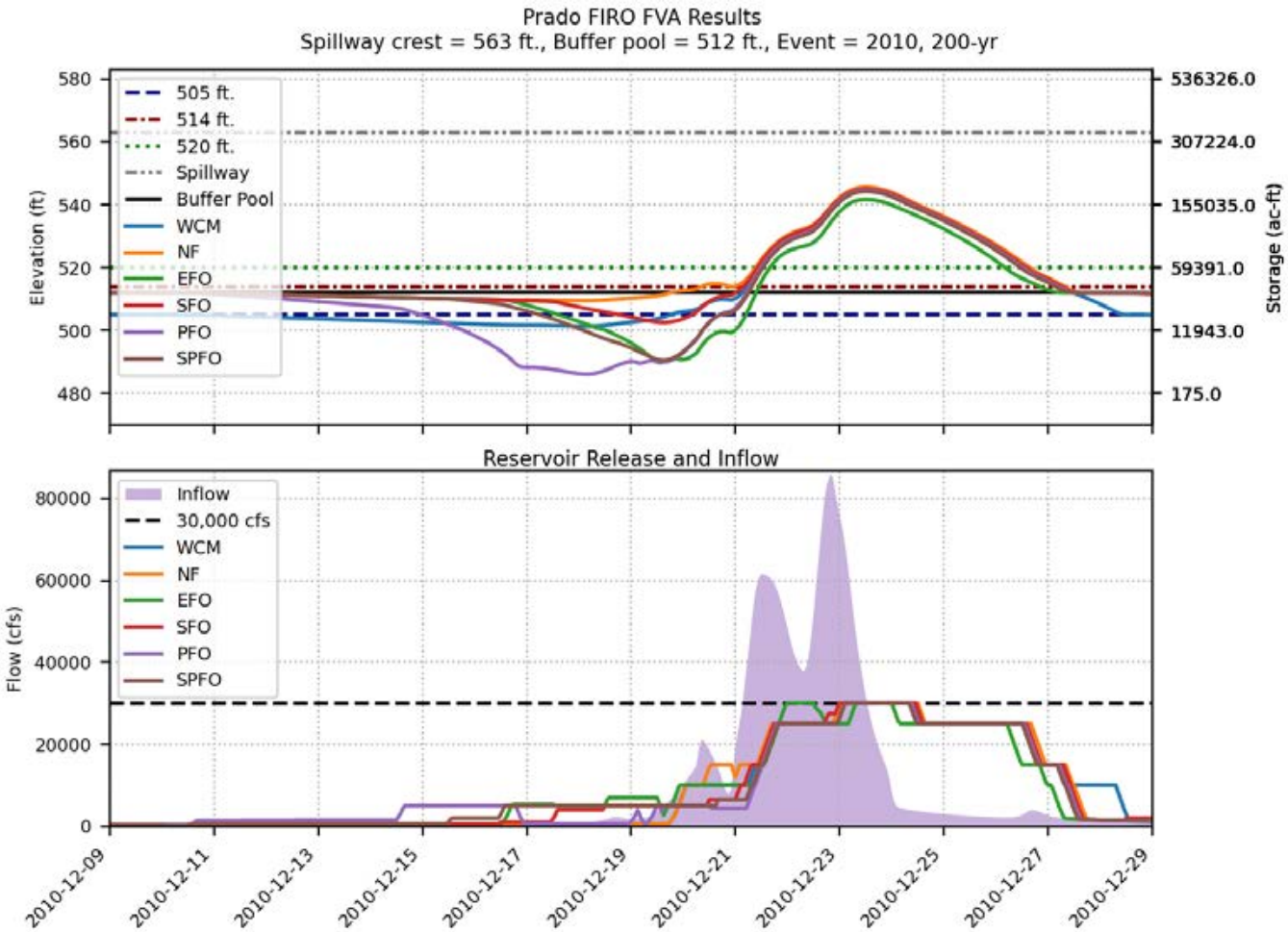
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 512 ft., Event = 2010, 200-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
PFO
SPFO
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536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
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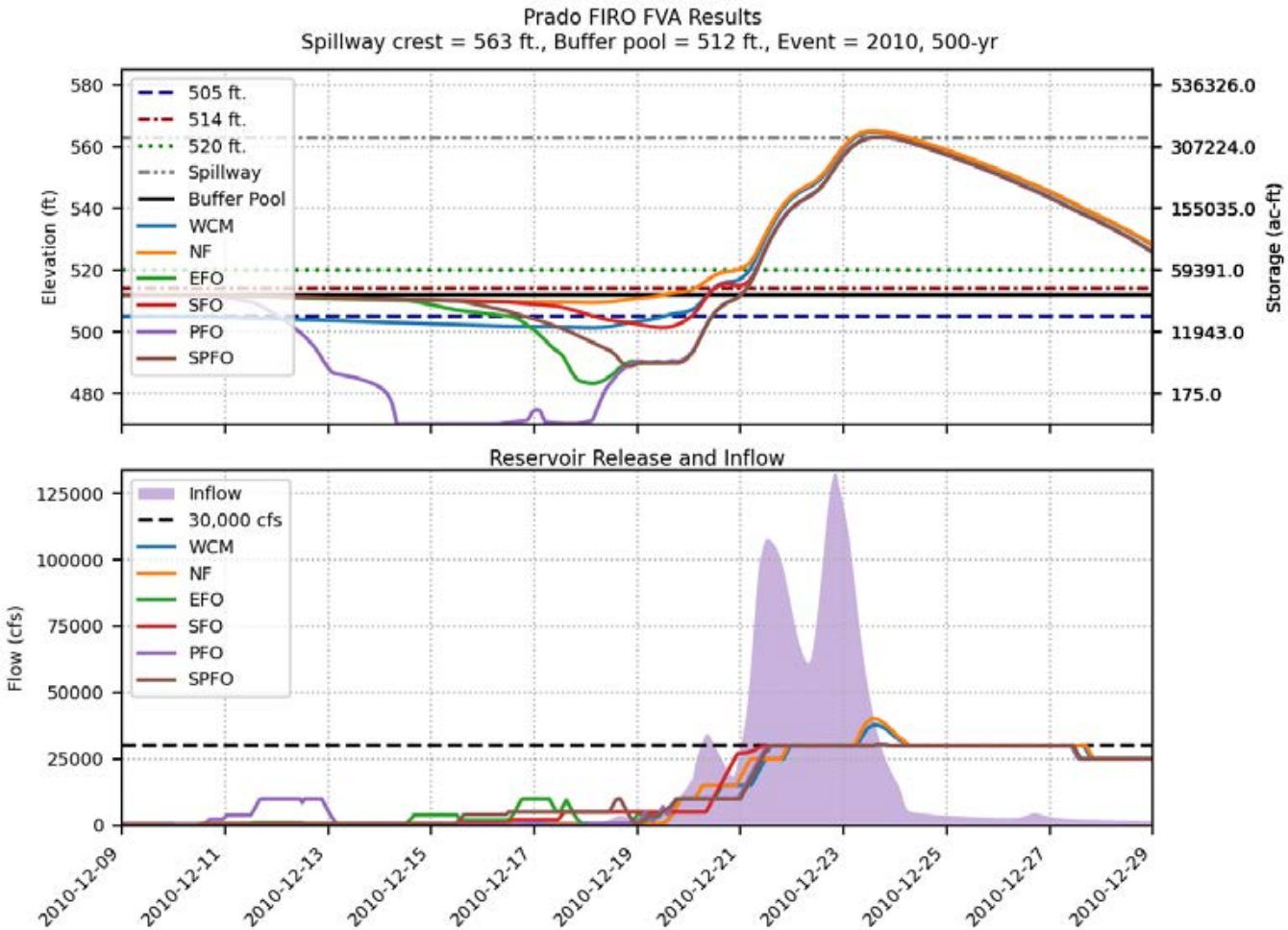
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 512 ft., Event = 2010, 500-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
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307224.0
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Reservoir Release and Inflow
Flow (cfs)
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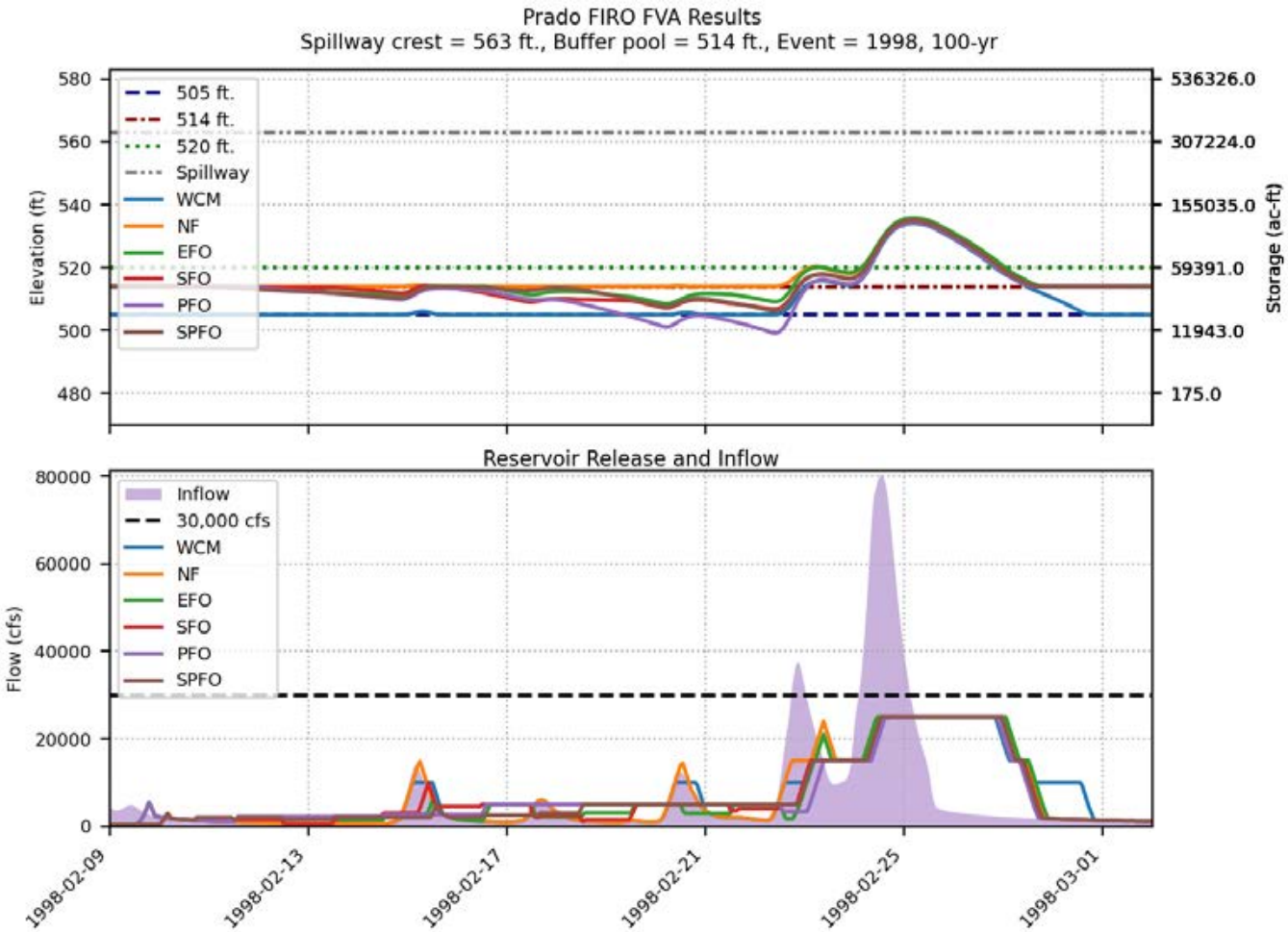
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 514 ft., Event = 1998, 100-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
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Reservoir Release and Inflow
Flow (cfs)
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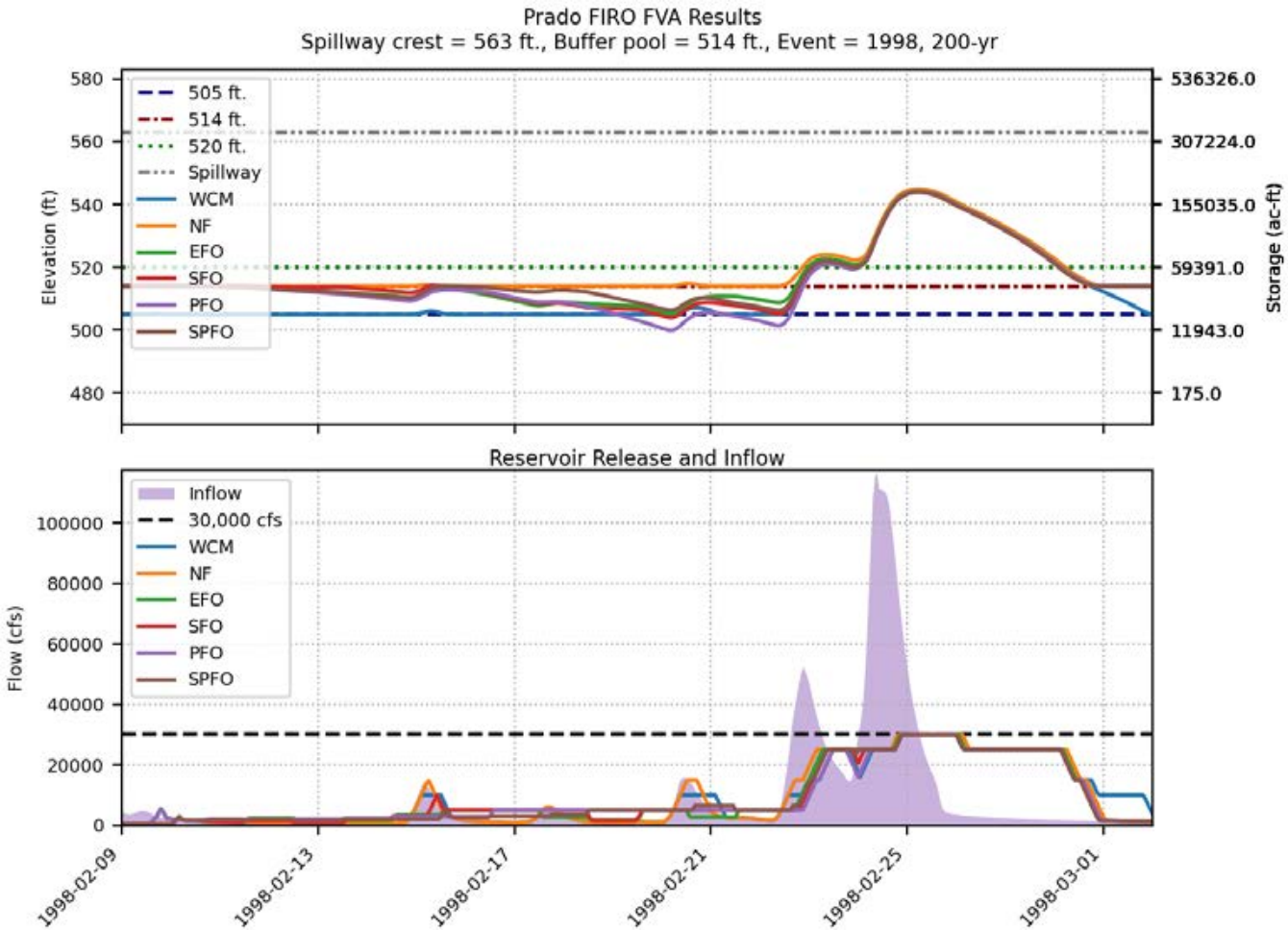
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 514 ft., Event = 1998, 200-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
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Reservoir Release and Inflow
Flow (cfs)
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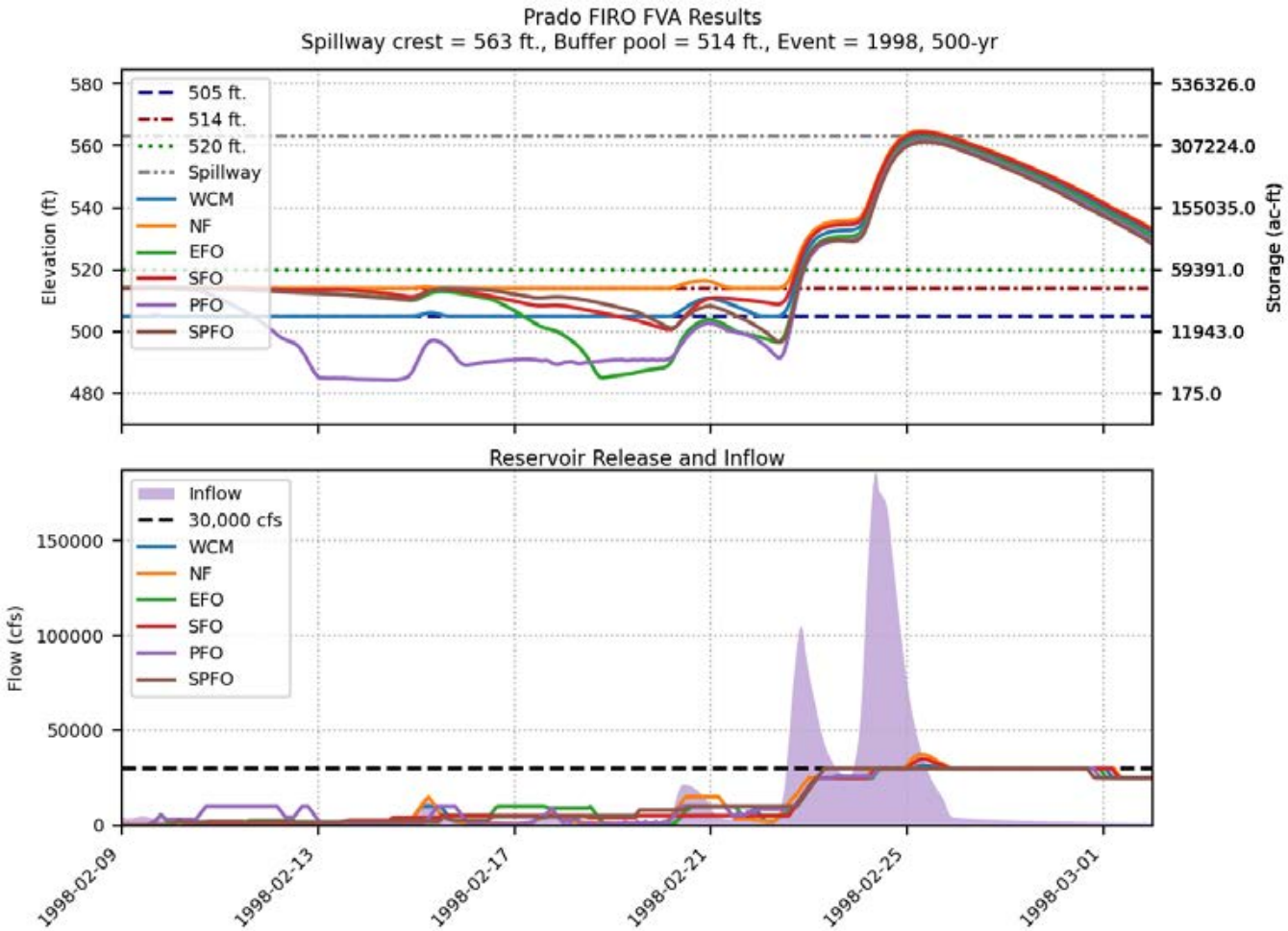
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 514 ft., Event = 1998, 500-yr
505 ft.
514 ft.
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Elevation (ft)
Storage (ac-ft)
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Flow (cfs)
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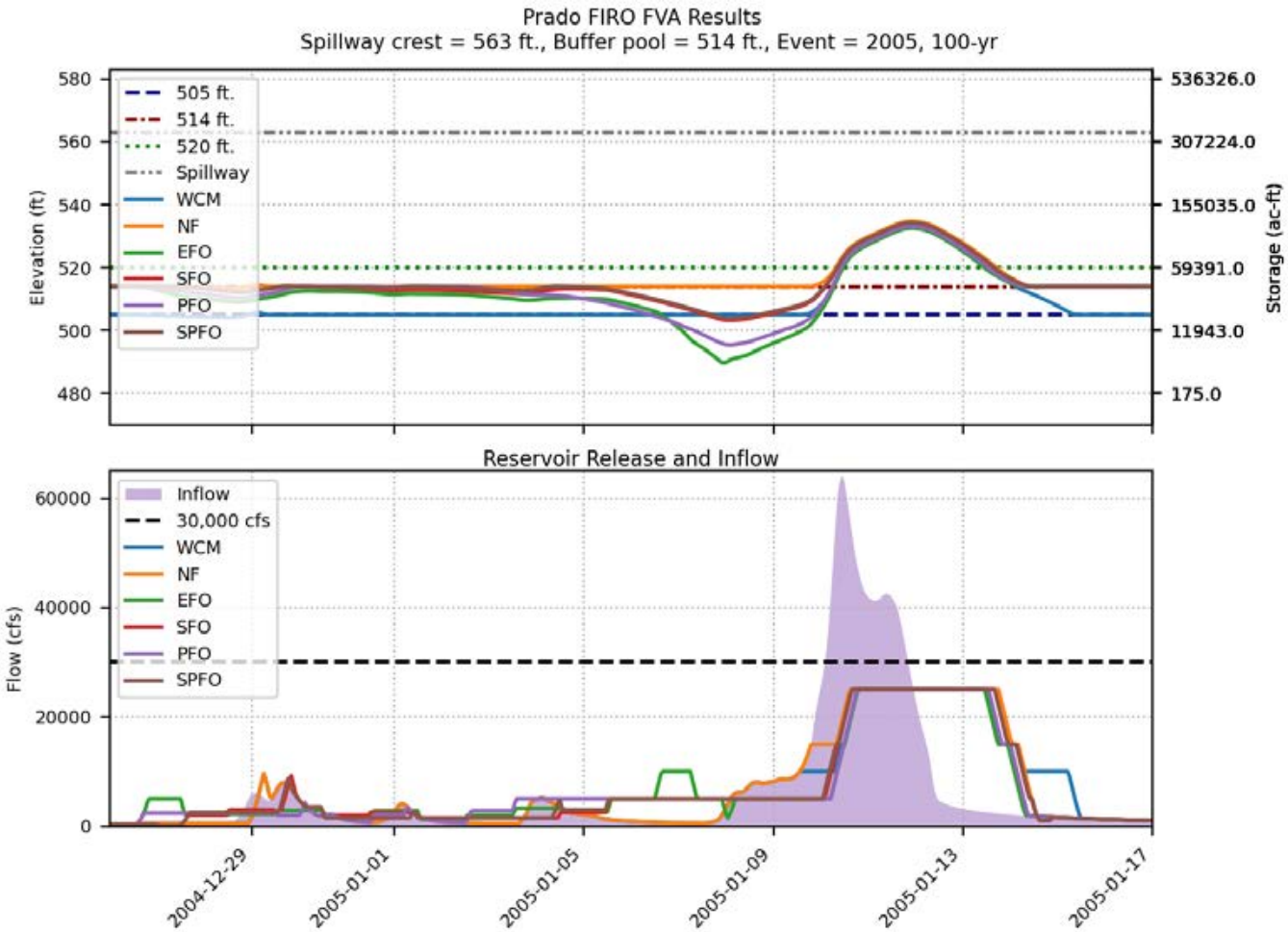
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 514 ft., Event = 2005, 100-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
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520 ft.
Spillway
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Reservoir Release and Inflow
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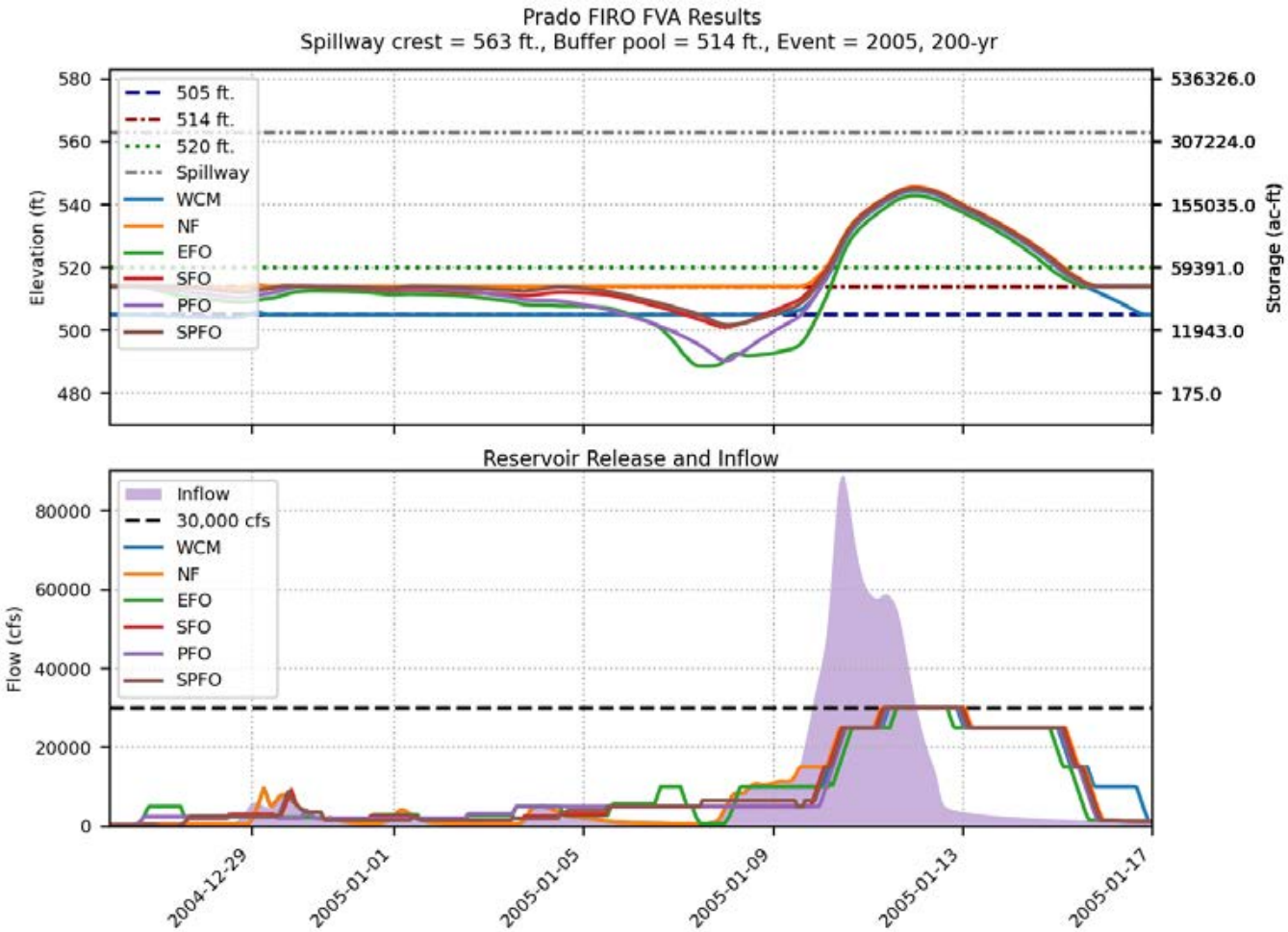
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 514 ft., Event = 2005, 200-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
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520 ft.
Spillway
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Reservoir Release and Inflow
Flow (cfs)
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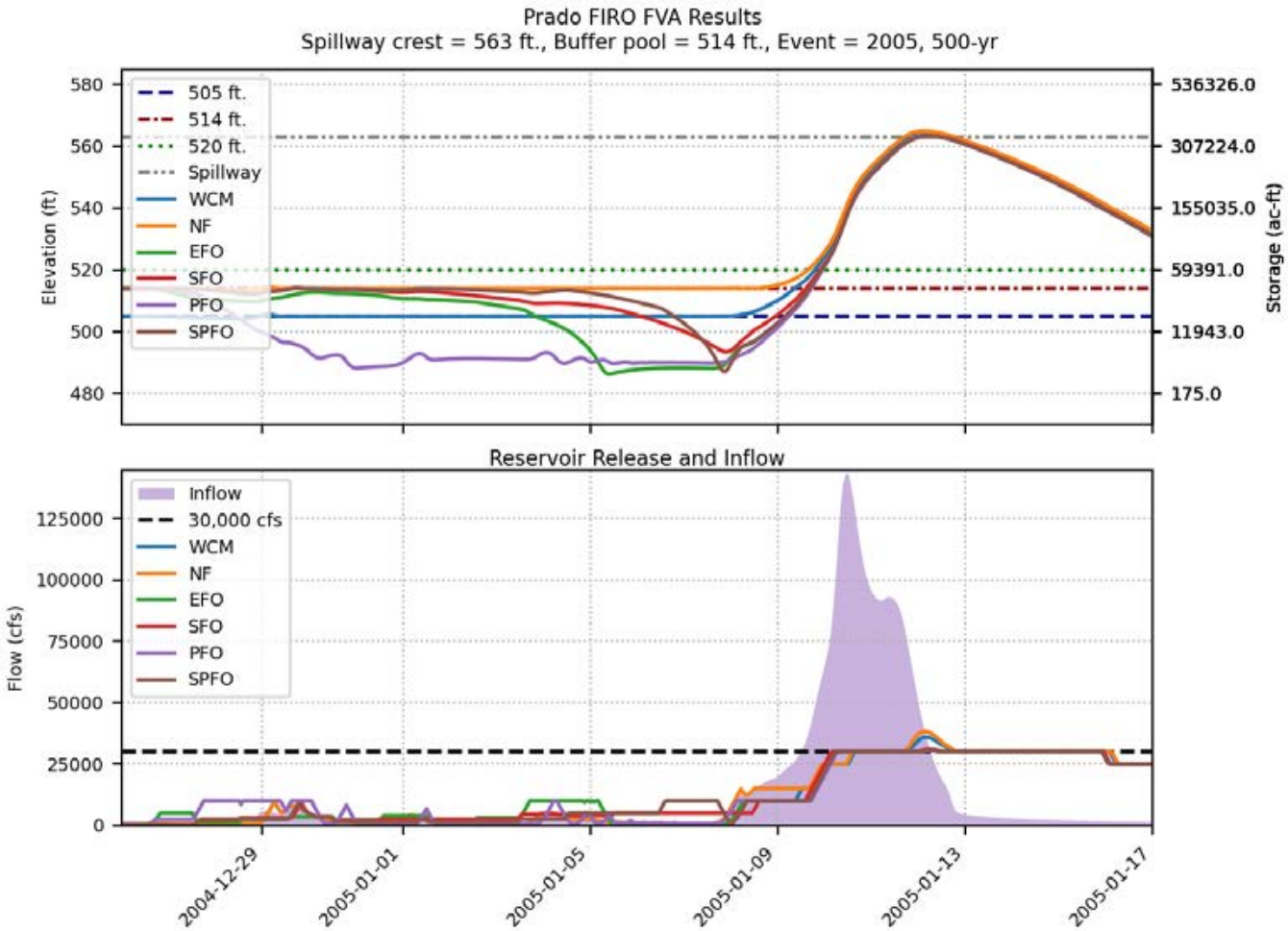
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 514 ft., Event = 2005, 500-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
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11943.0
175.0
Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
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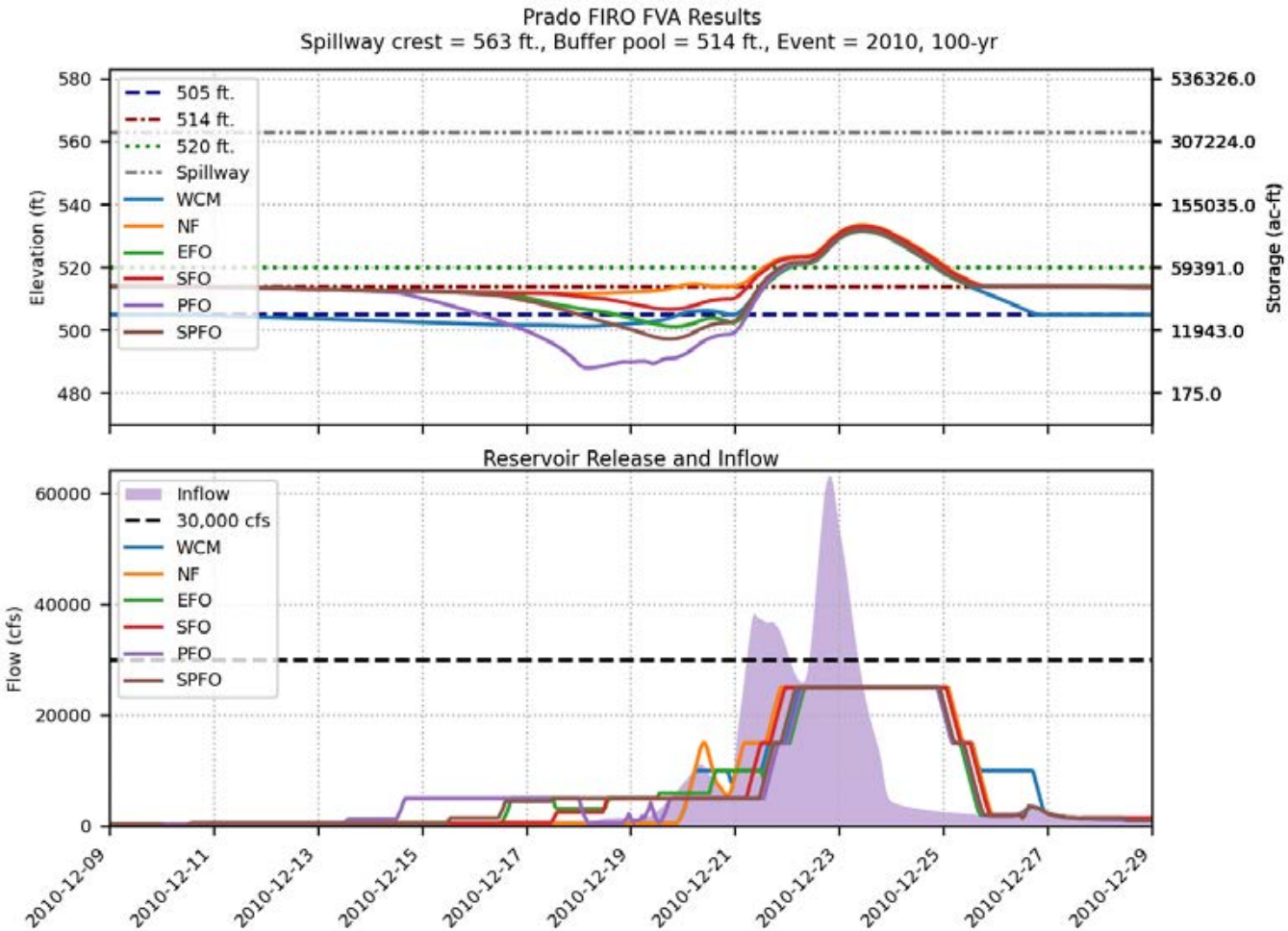
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 514 ft., Event = 2010, 100-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
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155035.0
59391.0
11943.0
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Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
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2010-12-09
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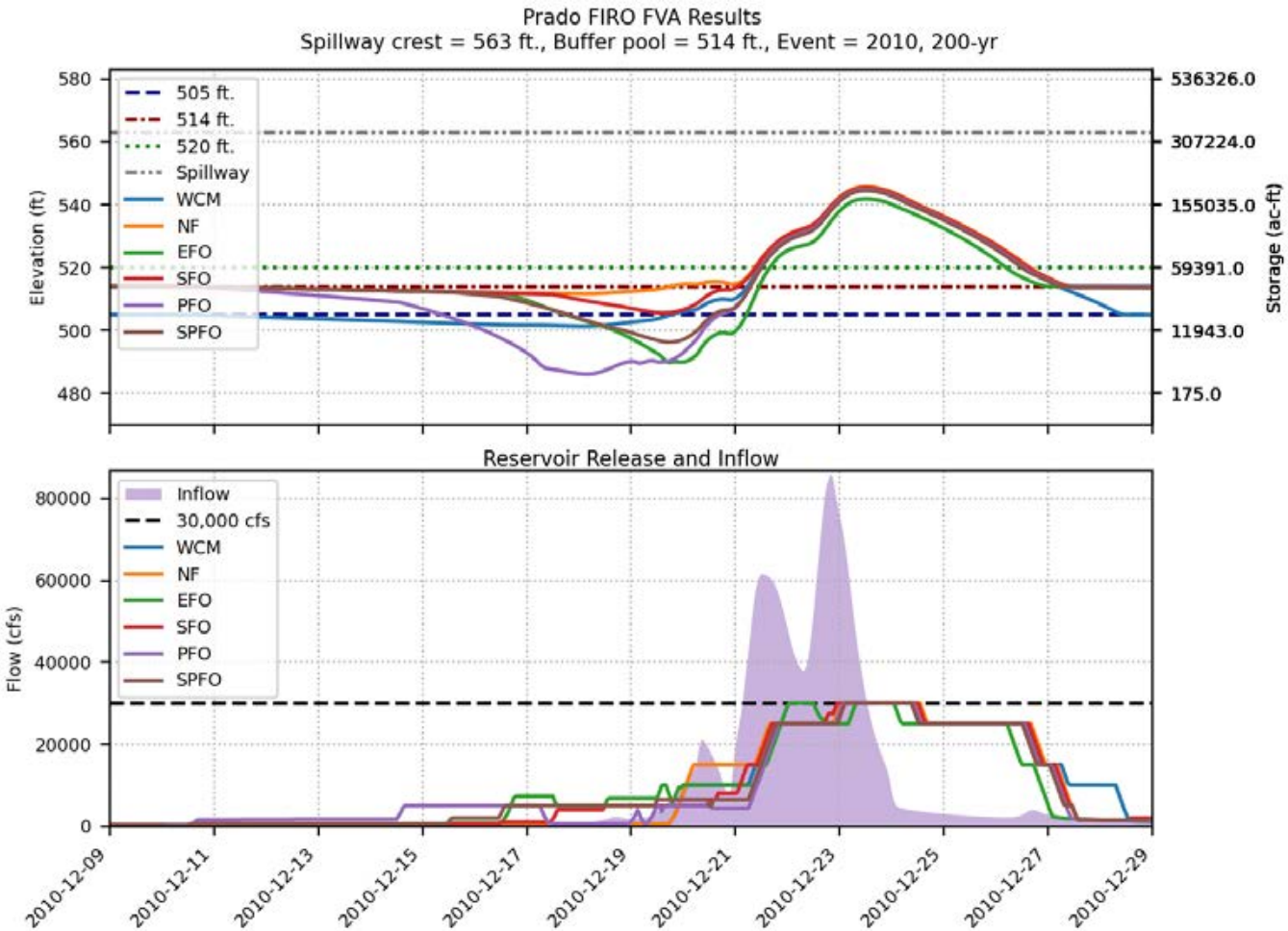
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 514 ft., Event = 2010, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
PFO
SPFO
Elevation (ft)
Storage (ac-ft)
580
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540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
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Reservoir Release and Inflow
Inflow
30,000 cfs
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EFO
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SPFO
Flow (cfs)
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2010-12-09
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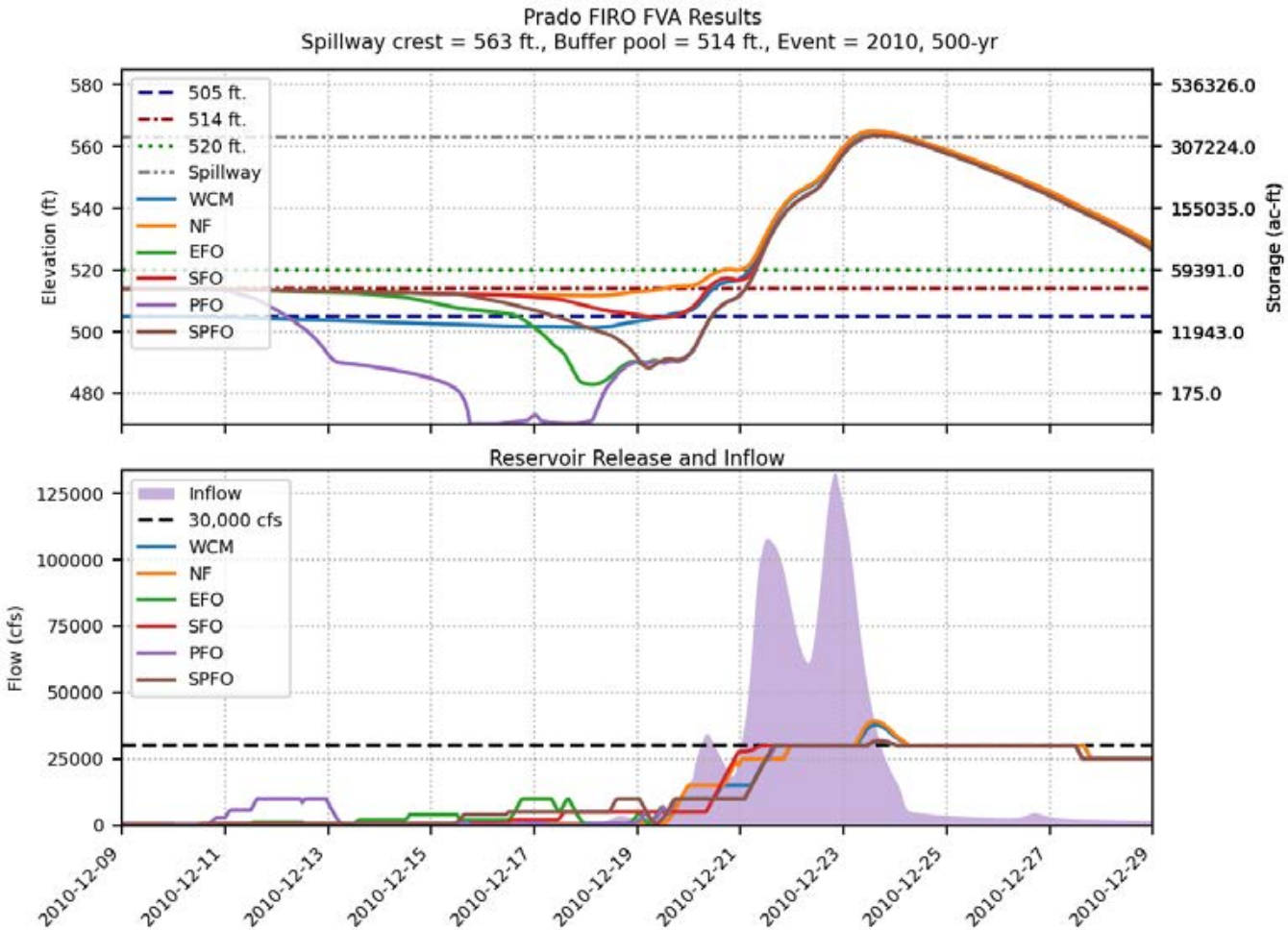
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 514 ft., Event = 2010, 500-yr
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514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
PFO
SPFO
Elevation (ft)
Storage (ac-ft)
580
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540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
Flow (cfs)
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100000
75000
50000
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2010-12-09
2010-12-11
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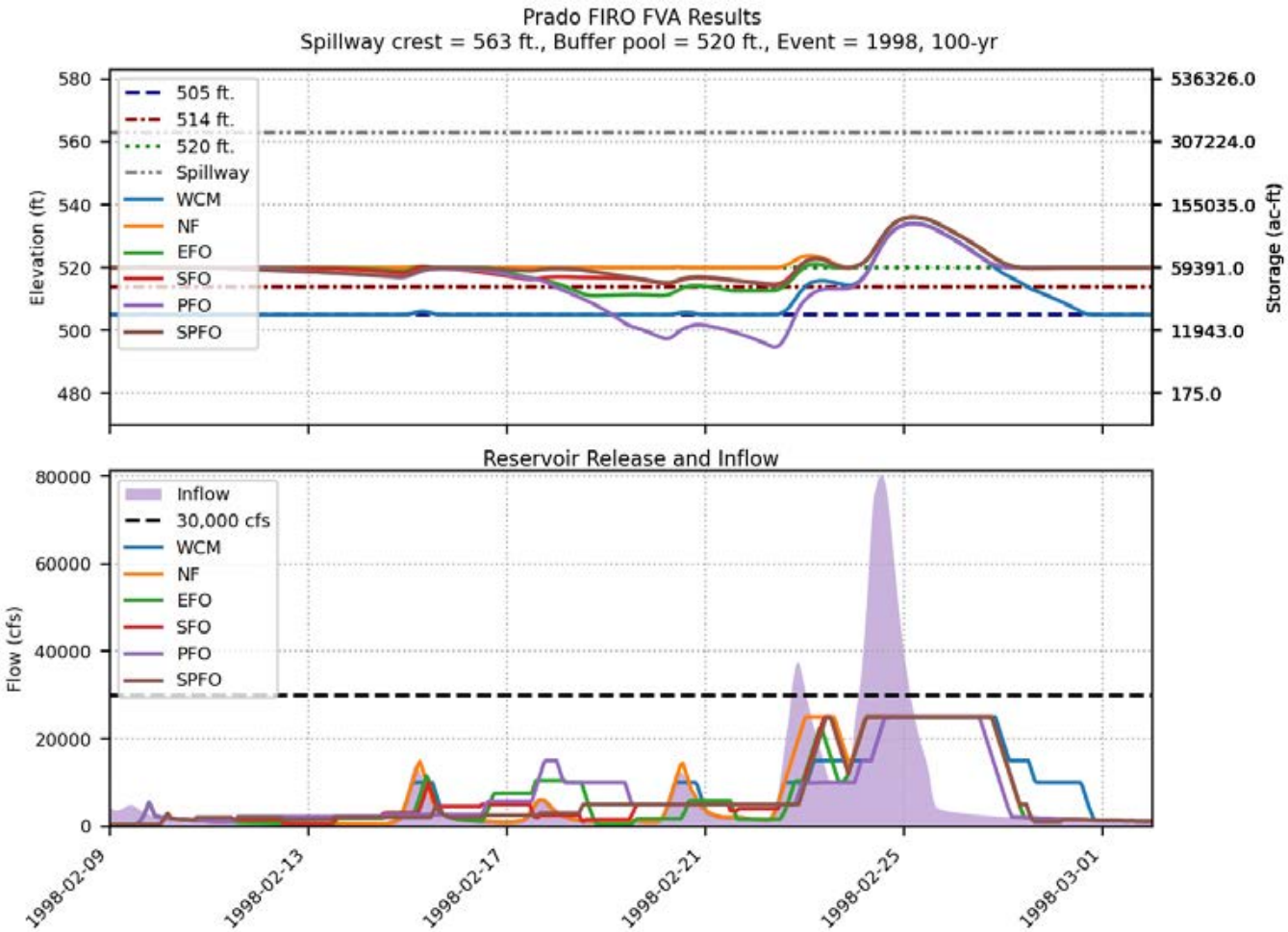
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 520 ft., Event = 1998, 100-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
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536326.0
307224.0
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Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
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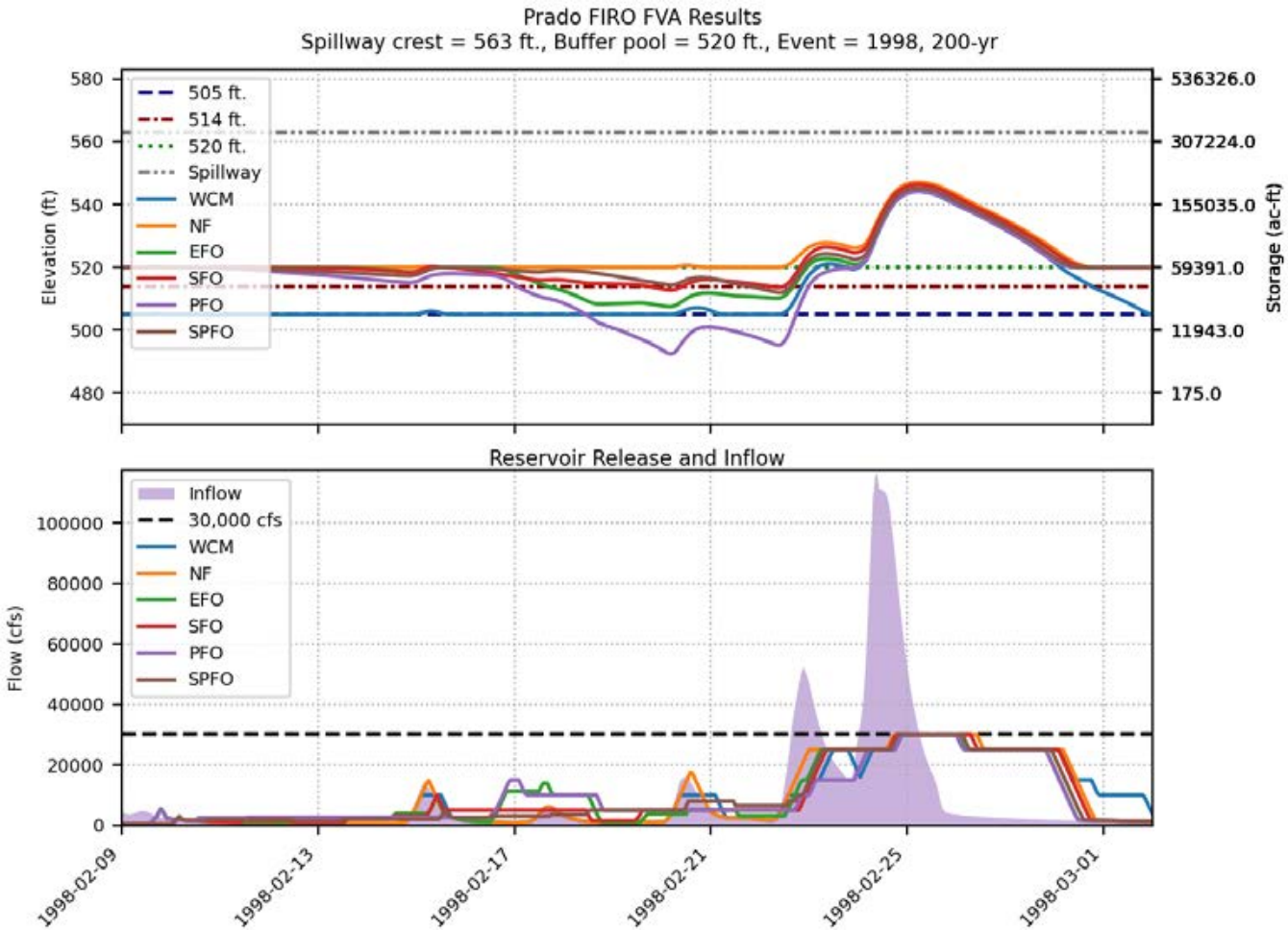
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 520 ft., Event = 1998, 200-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
WCM
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EFO
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155035.0
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11943.0
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Reservoir Release and Inflow
Flow (cfs)
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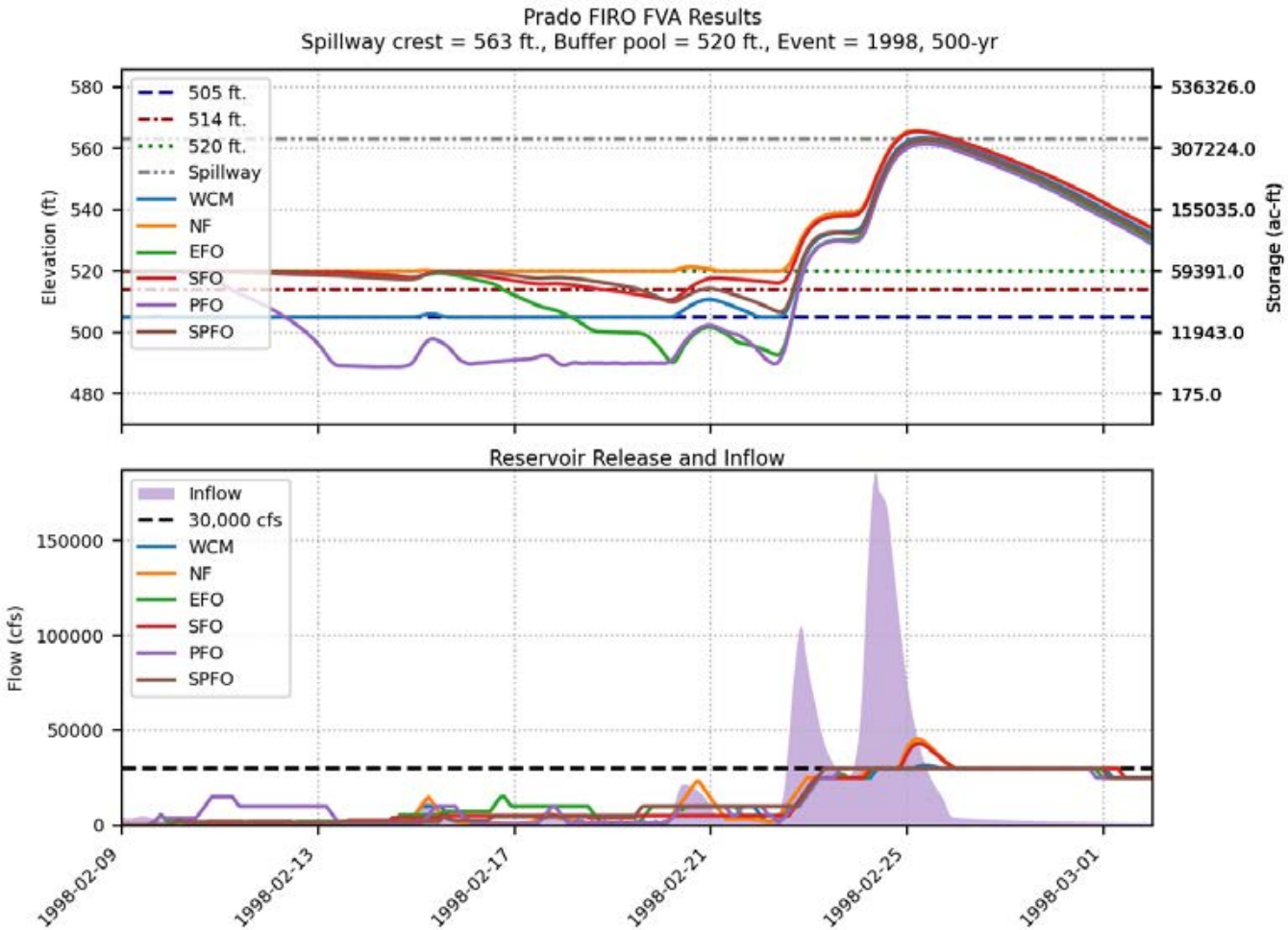
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 520 ft., Event = 1998, 500-yr
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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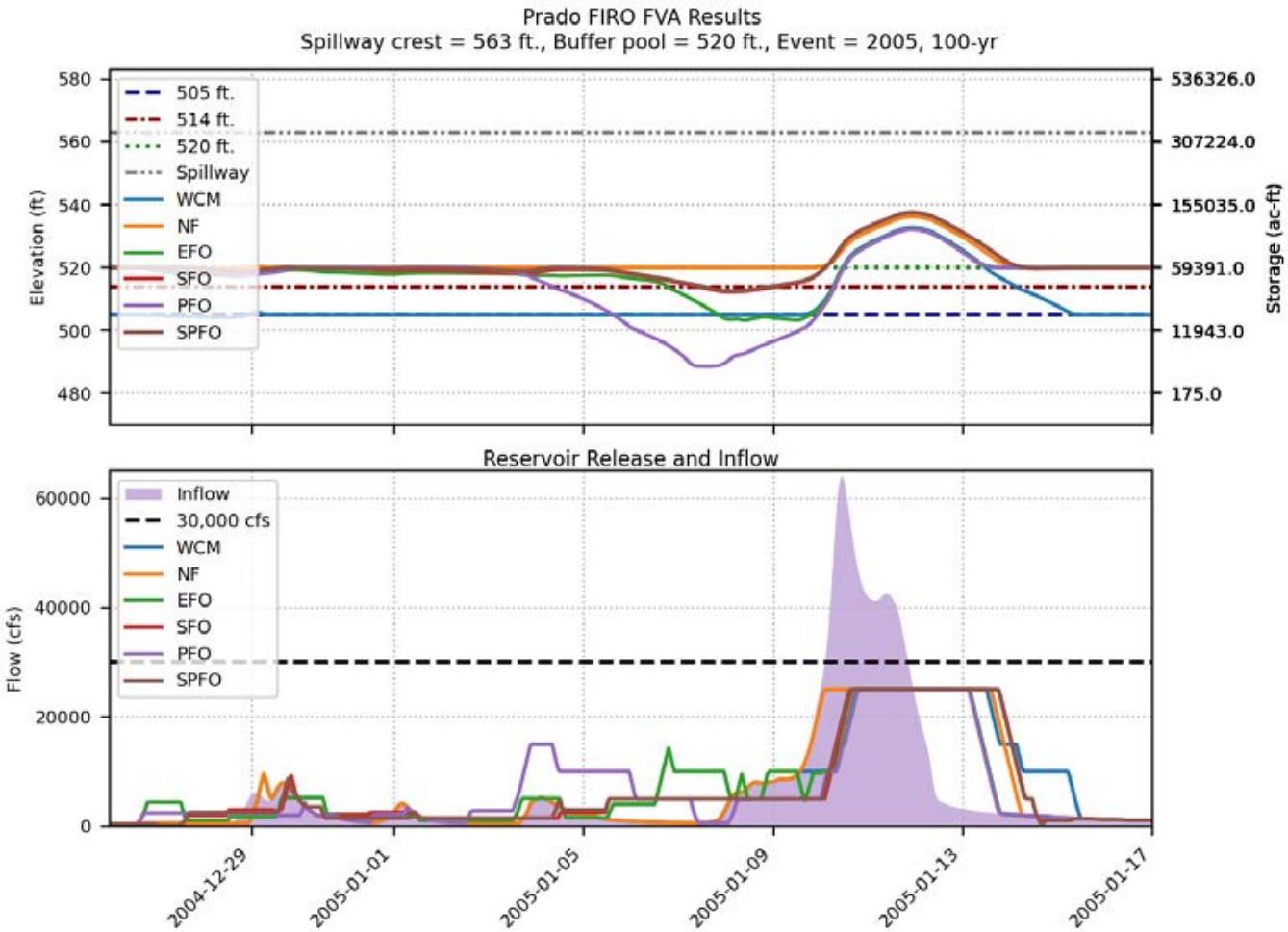
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 520 ft., Event = 2005, 100-yr
Elevation (ft)
Storage (ac-ft)
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514 ft.
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Reservoir Release and Inflow
Flow (cfs)
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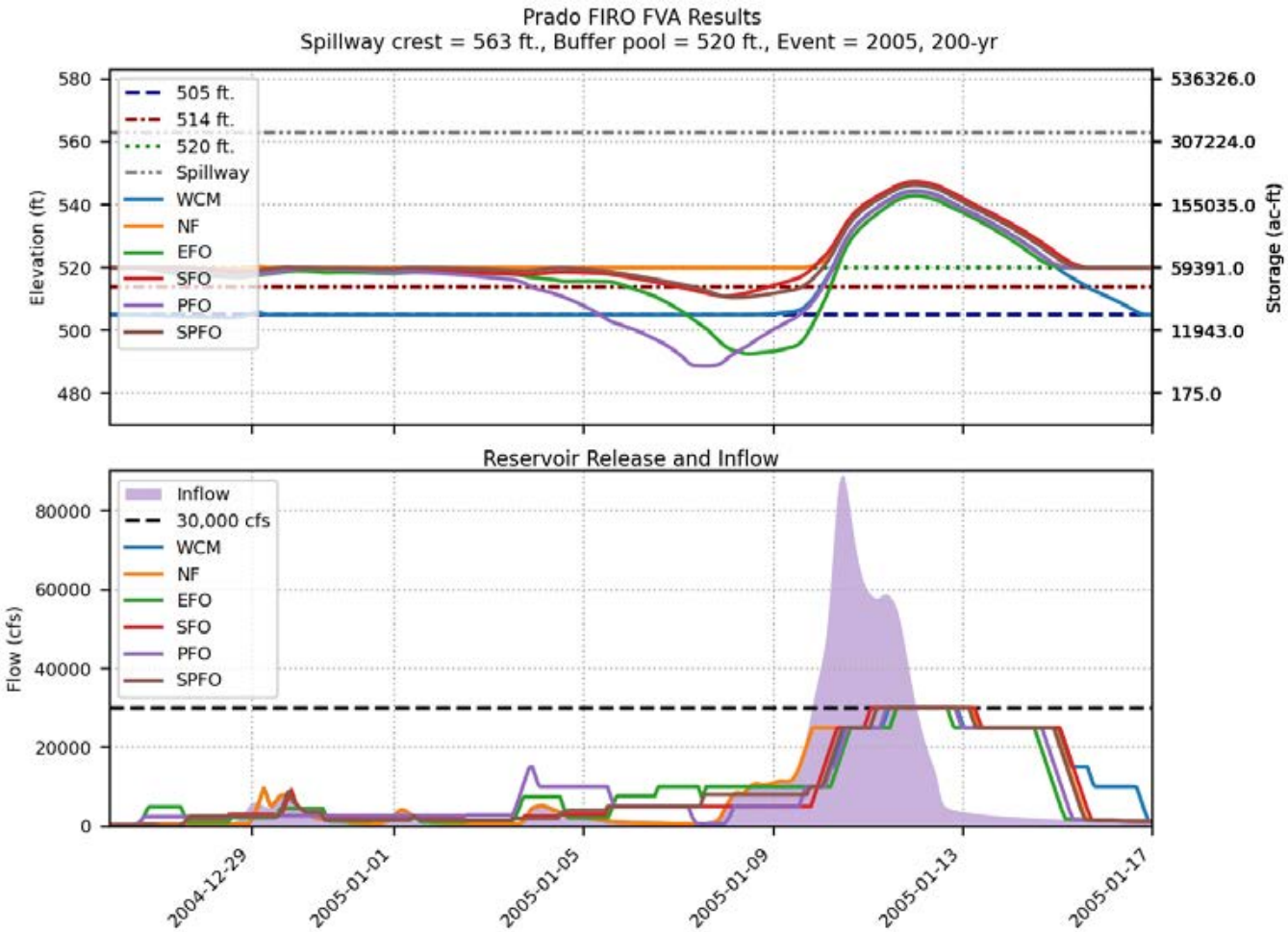
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 520 ft., Event = 2005, 200-yr
Elevation (ft)
Storage (ac-ft)
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514 ft.
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Spillway
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Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
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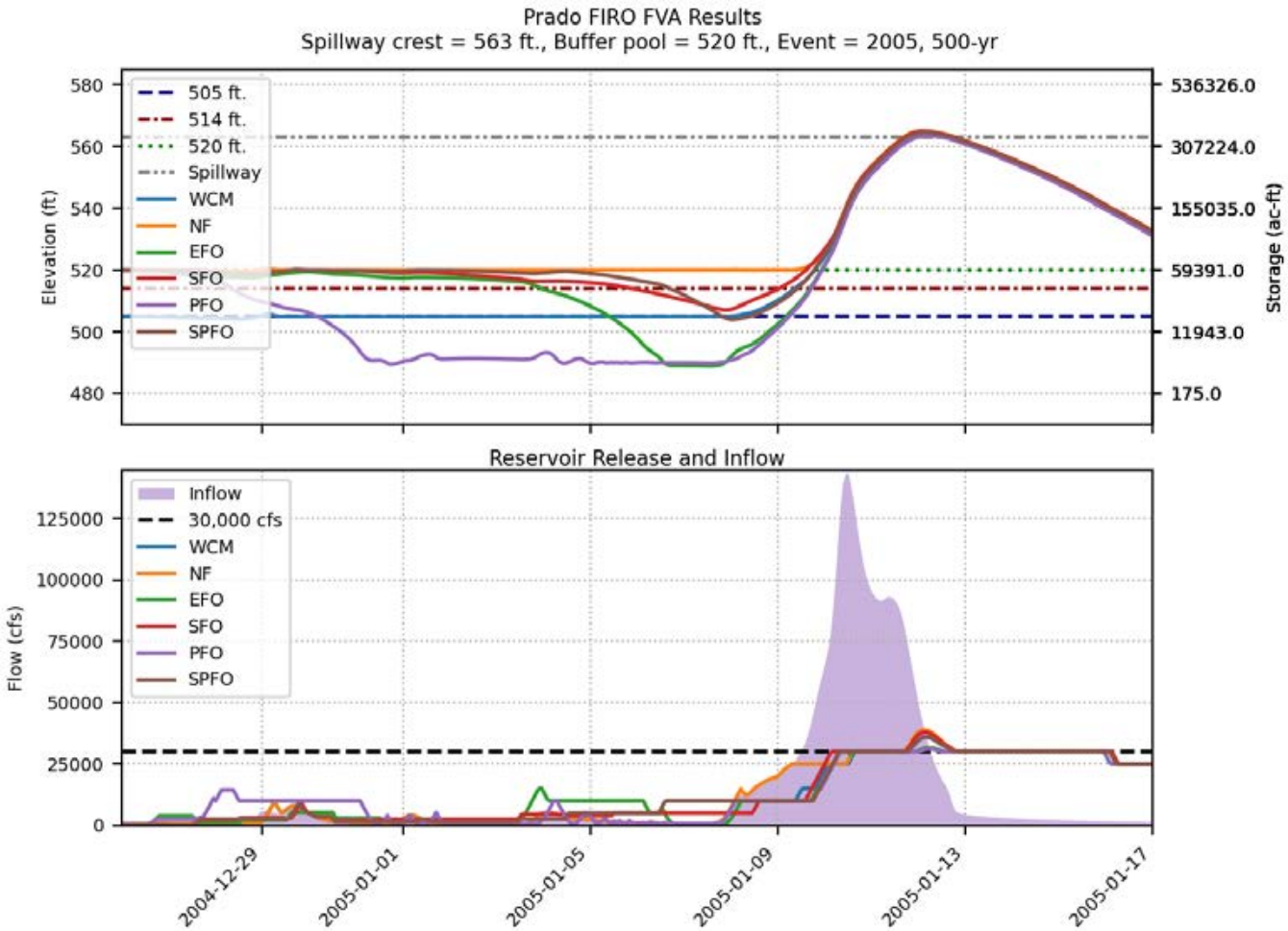
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 520 ft., Event = 2005, 500-yr
Elevation (ft)
Storage (ac-ft)
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514 ft.
520 ft.
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Reservoir Release and Inflow
Flow (cfs)
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2004-12-29
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2005-01-09
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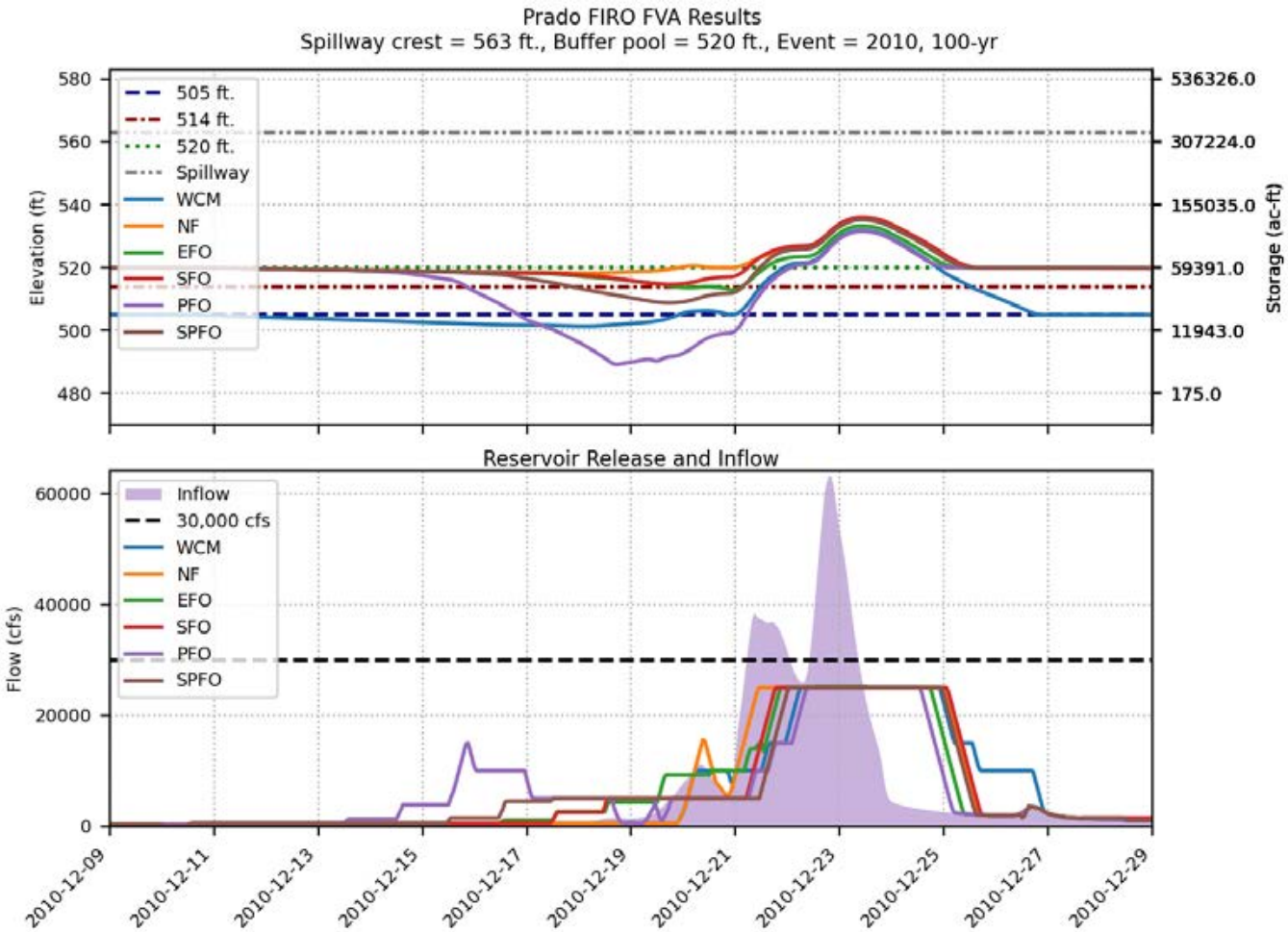
2005-01-17


Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 520 ft., Event = 2010, 100-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
PFO
SPFO
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
60000
40000
20000
0
2010-12-09
2010-12-11
2010-12-13
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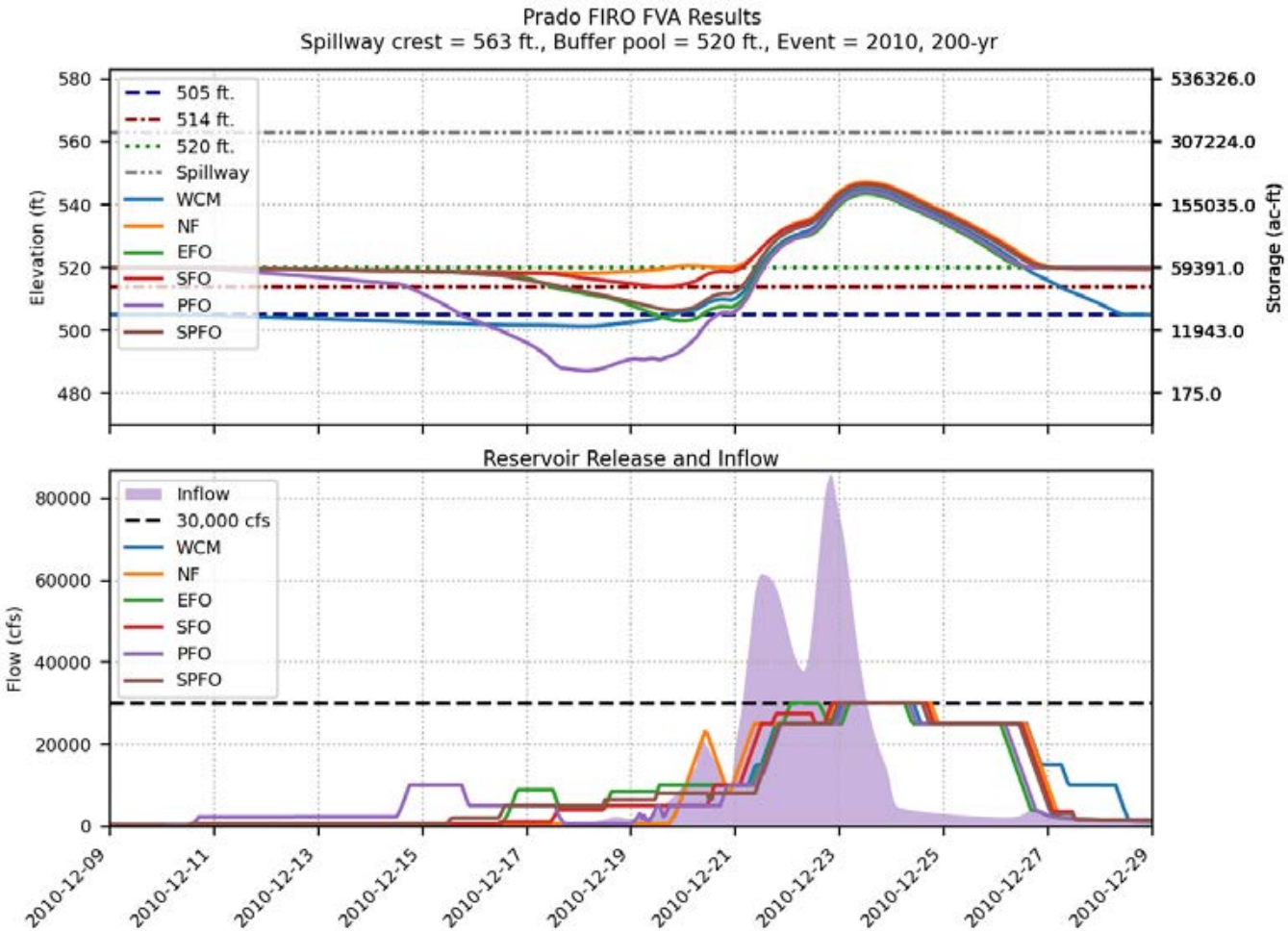
2010-12-29


Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 520 ft., Event = 2010, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
PFO
SPFO
Elevation (ft)
Storage (ac-ft)
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
Flow (cfs)
80000
60000
40000
20000
0
2010-12-09
2010-12-11
2010-12-13
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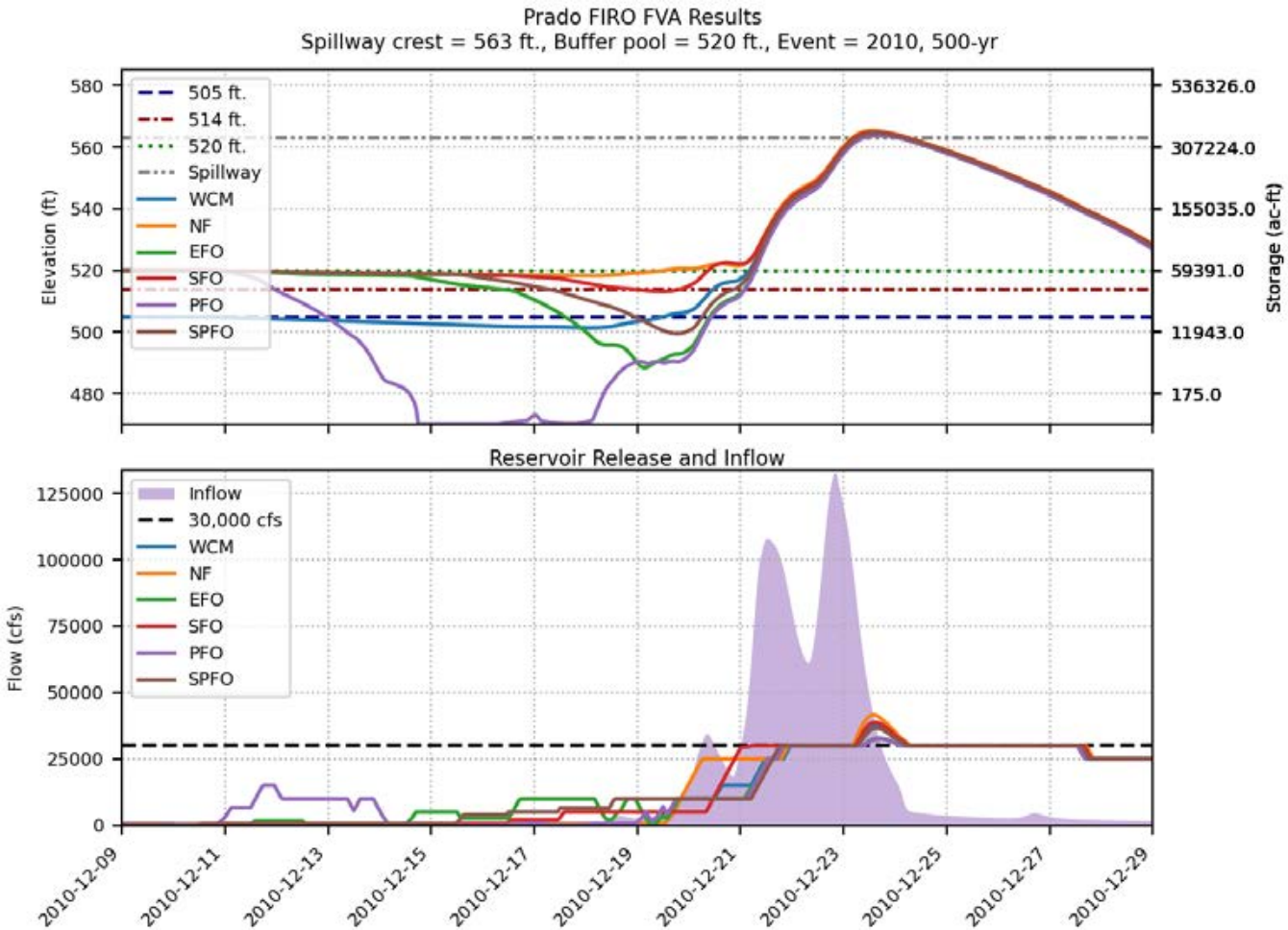
Prado FIRO FVA Results
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505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
PFO
SPFO
Elevation (ft)
Storage (ac-ft)
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
PFO
SPFO
Flow (cfs)
125000
100000
75000
50000
25000
0
2010-12-09
2010-12-11
2010-12-13
2010-12-15
2010-12-17
2010-12-19
2010-12-21
2010-12-23
2010-12-25
2010-12-27
2010-12-29

Scaled Hindcast Events (No PF)

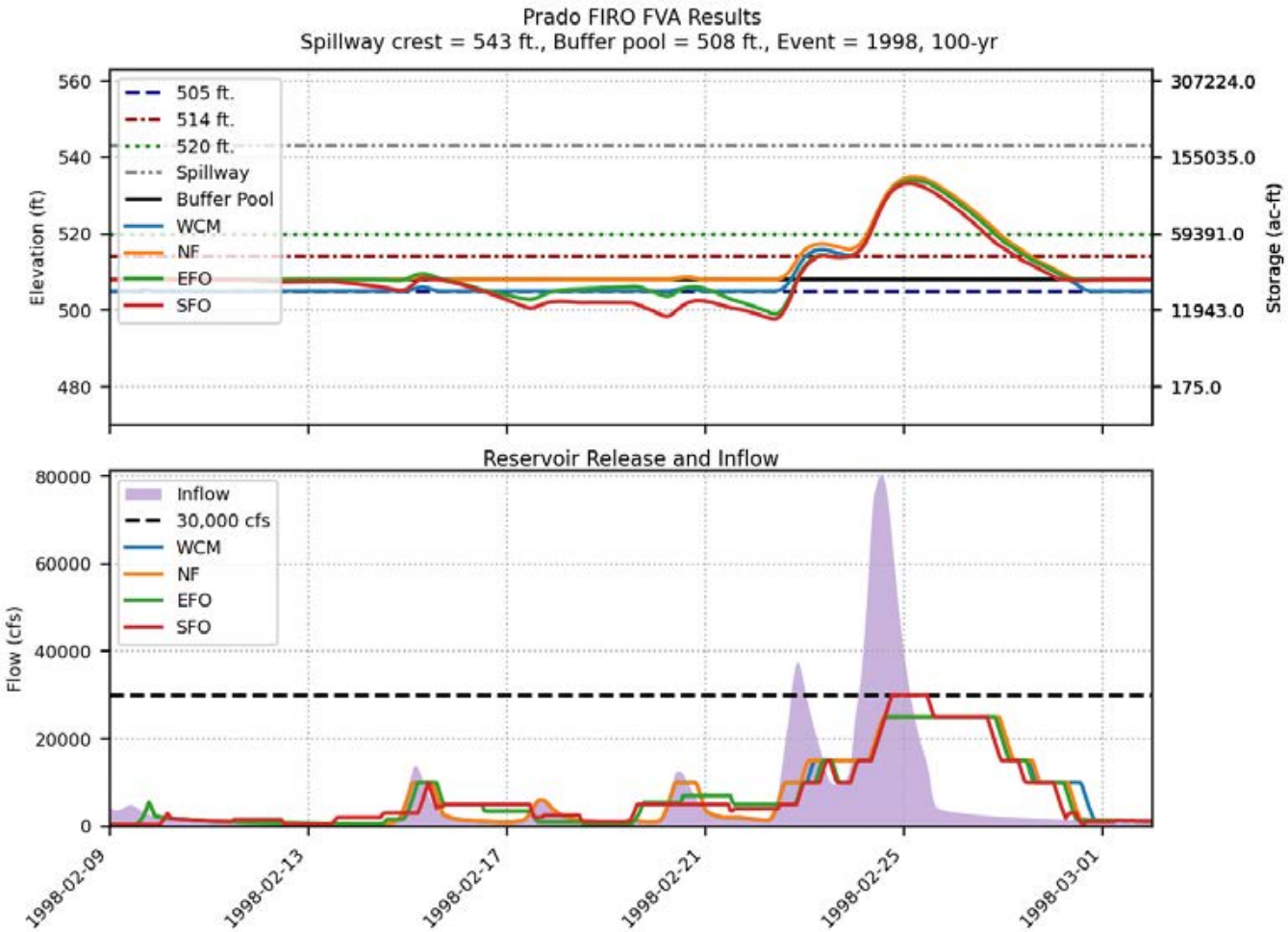
- Upper panel – Reservoir elevation/storage
- Lower panel – Reservoir inflow and release

- February 1998
- January 2006
- December 2010

- Scaled to 100-y, 200-yr, 500-yr 3-day inflow volume

Scaled Hindcast Events (No PF)

- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’, 510’, 512’, 514’, 520’
- WCP alternatives in legend
  - WCM is 505’ Buffer Pool
  - Perfect Forecast alternatives omitted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Spillway crest = 543 ft., Buffer pool = 508 ft., Event = 1998, 100-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
80000
60000
40000
20000
0
1998-02-09
1998-02-13
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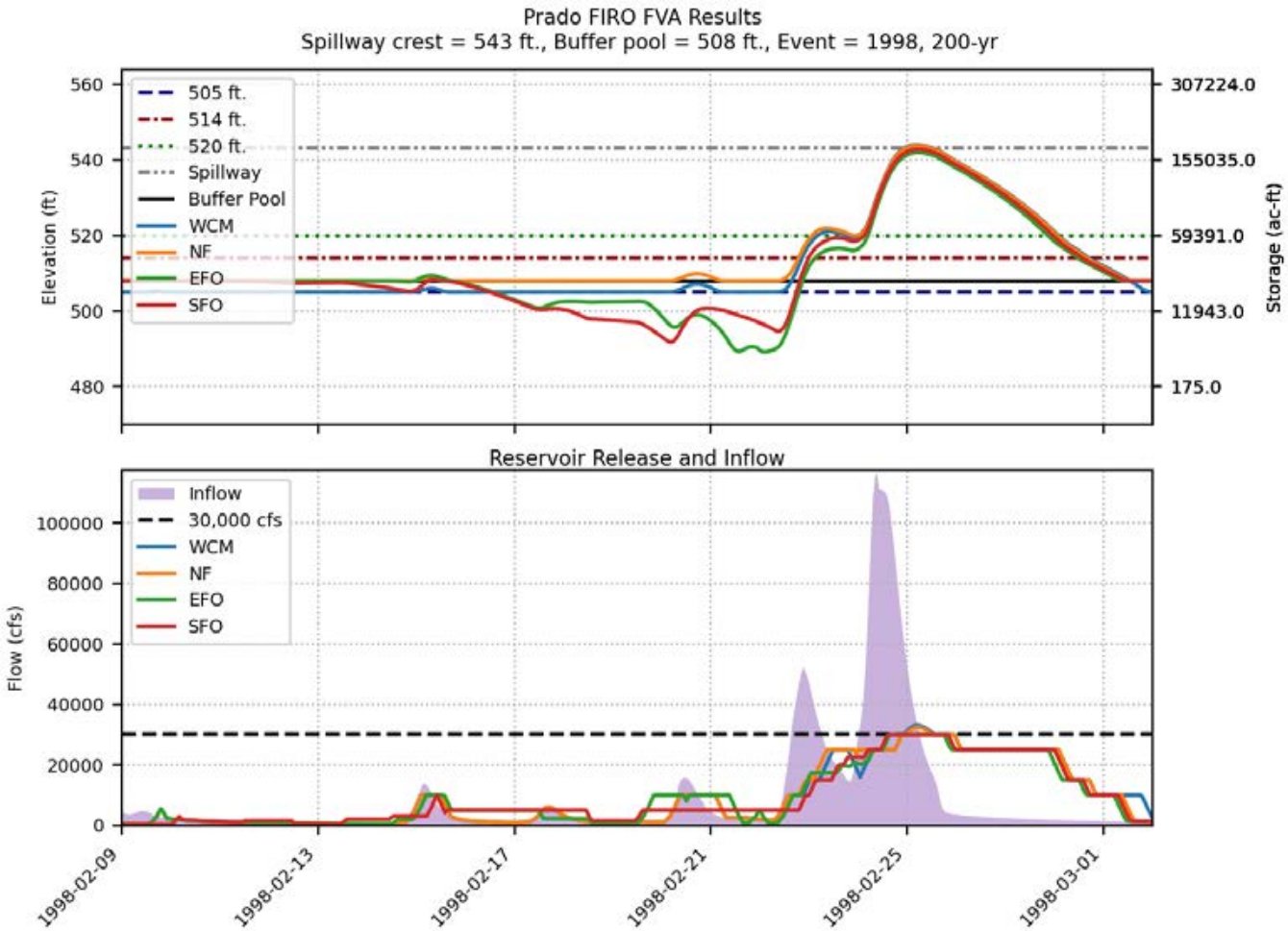
1998-02-21
1998-02-25
1998-03-01


Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 508 ft., Event = 1998, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
100000
80000
60000
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1998-02-21
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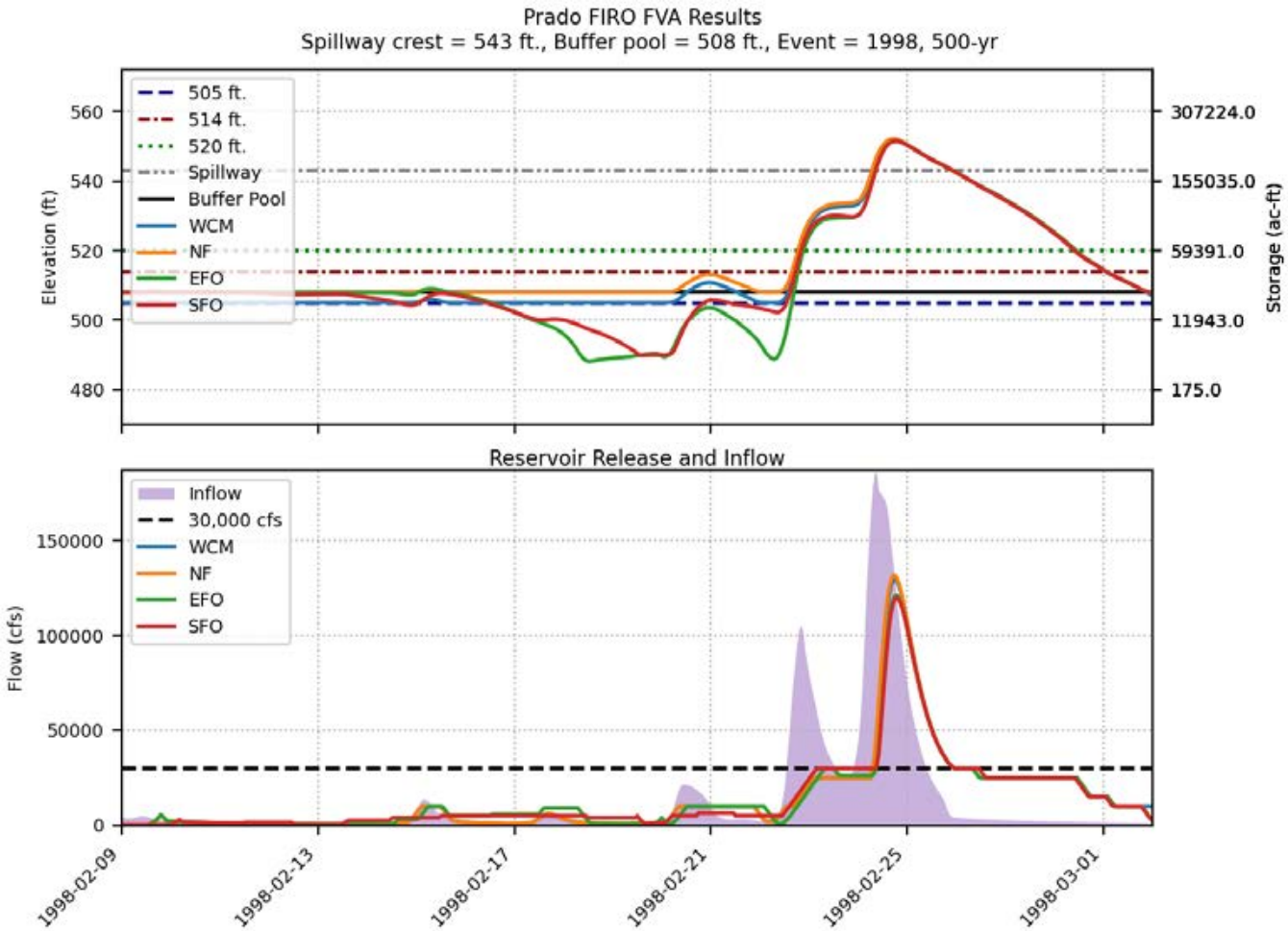
1998-03-01


Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 508 ft., Event = 1998, 500-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
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540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
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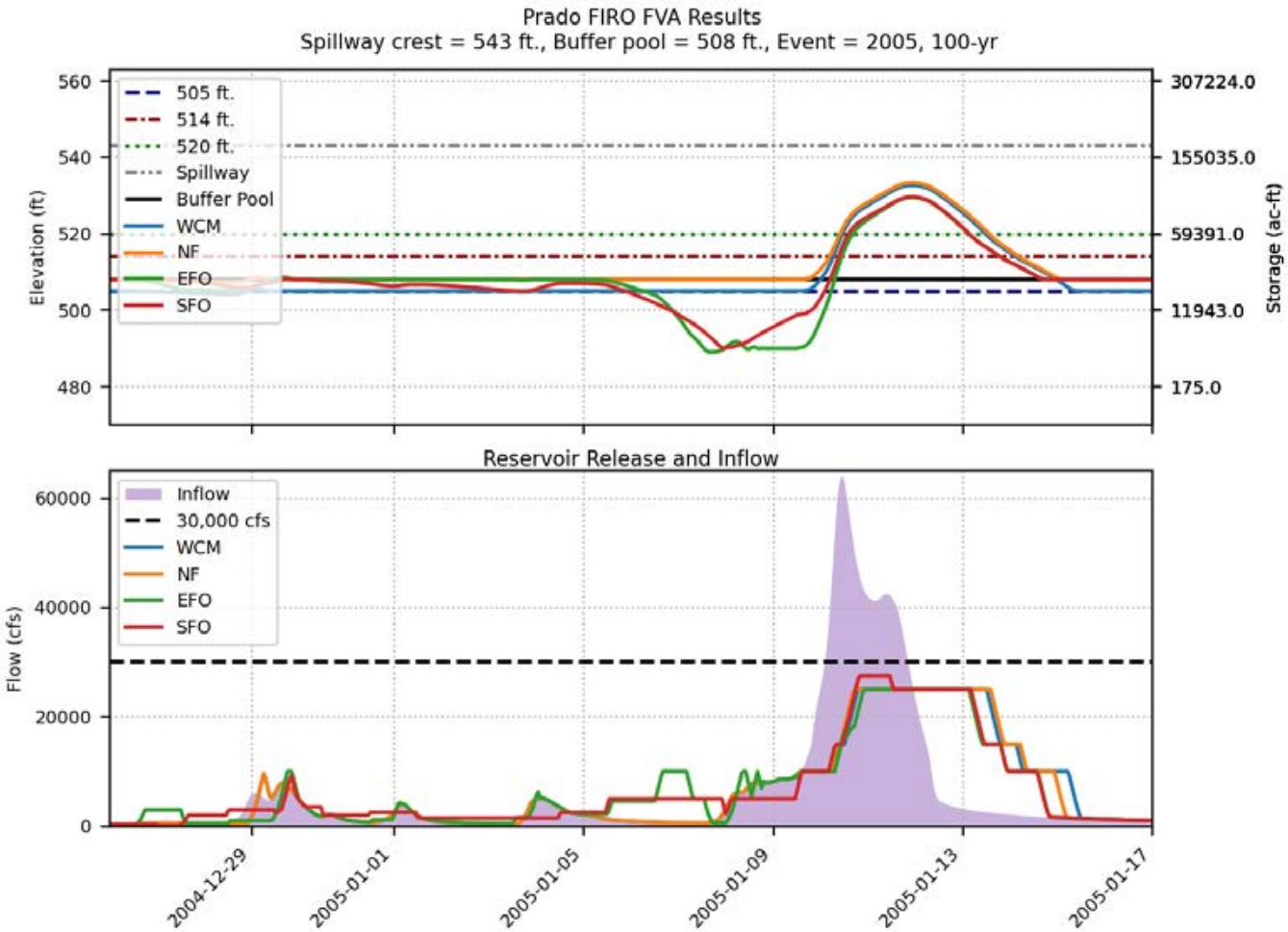
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 508 ft., Event = 2005, 100-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
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20000
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2004-12-29
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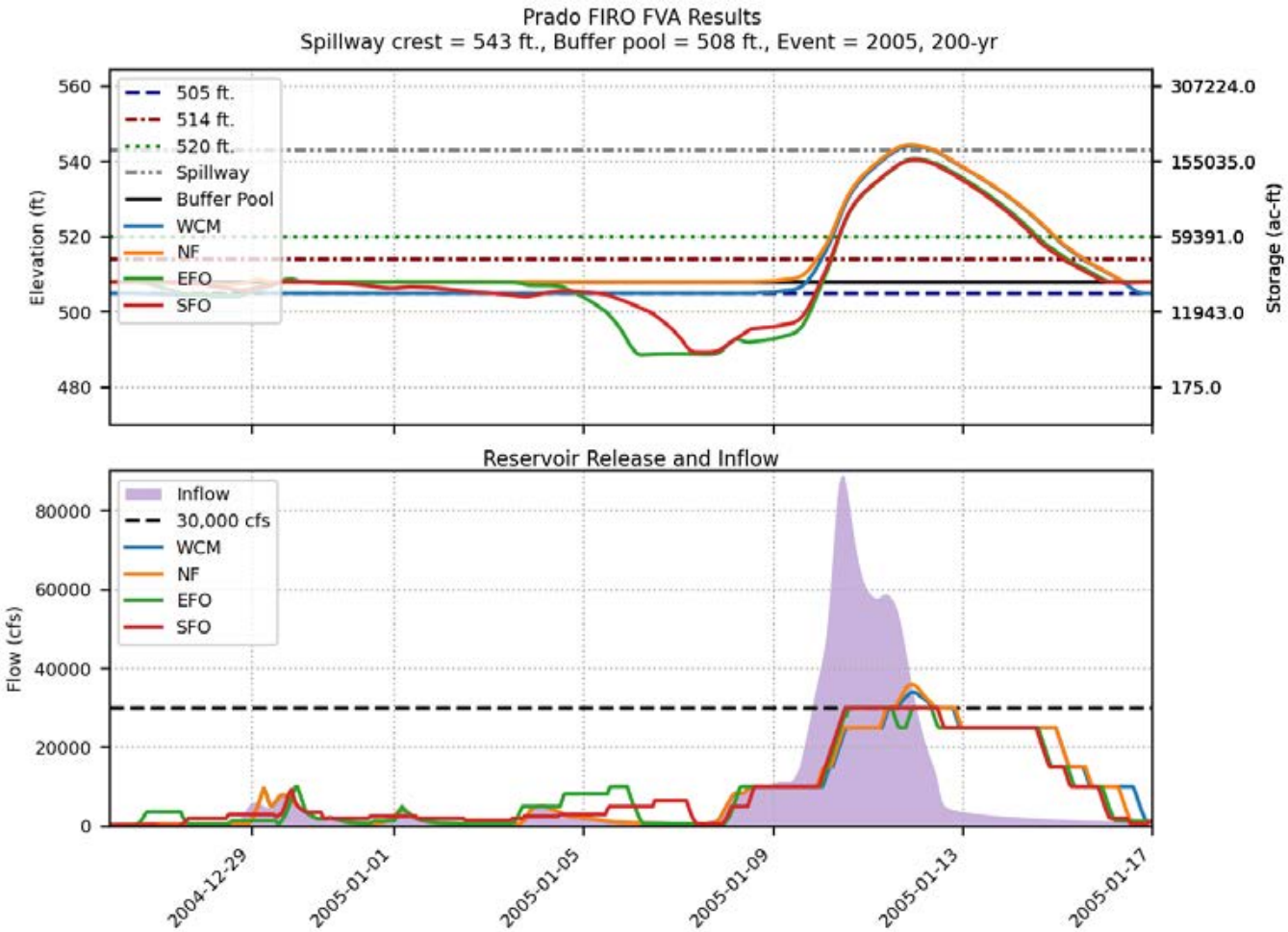
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514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
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540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
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EFO
SFO
Flow (cfs)
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2004-12-29
2005-01-01
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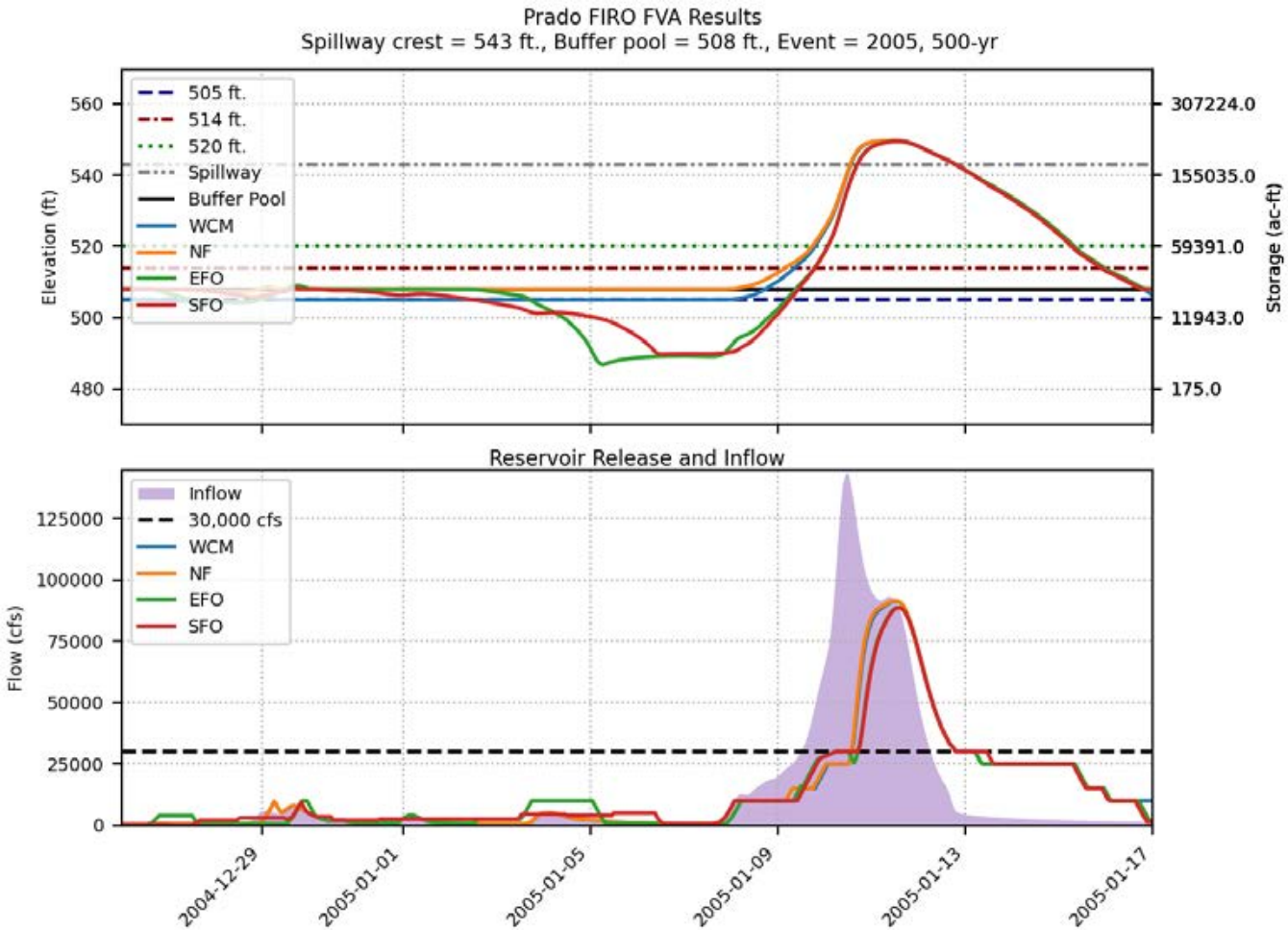
2005-01-13
2005-01-17


Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 508 ft., Event = 2005, 500-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
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EFO
SFO
Flow (cfs)
125000
100000
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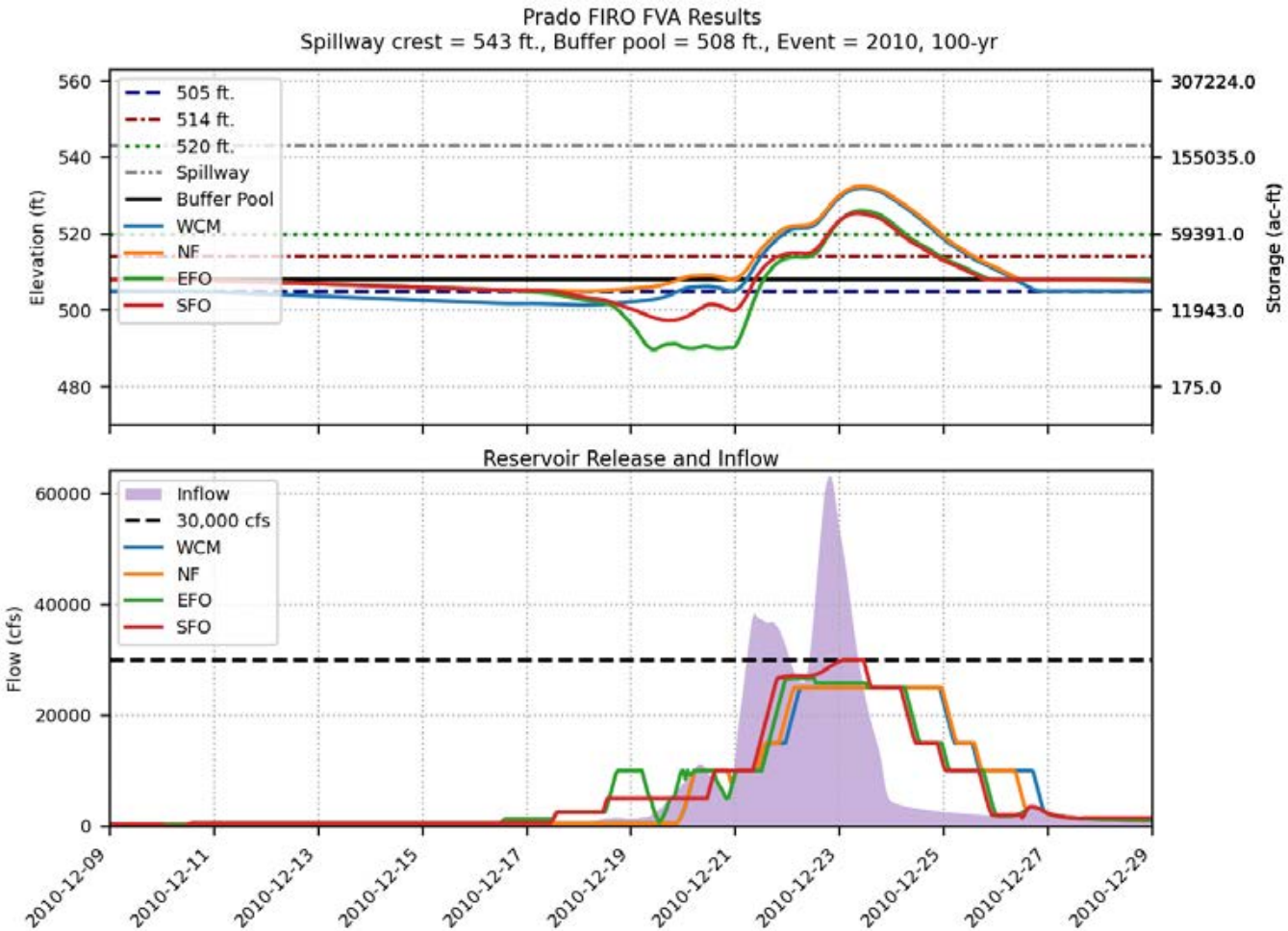
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Spillway crest = 543 ft., Buffer pool = 508 ft., Event = 2010, 100-yr
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514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
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540
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500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
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EFO
SFO
Flow (cfs)
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2010-12-09
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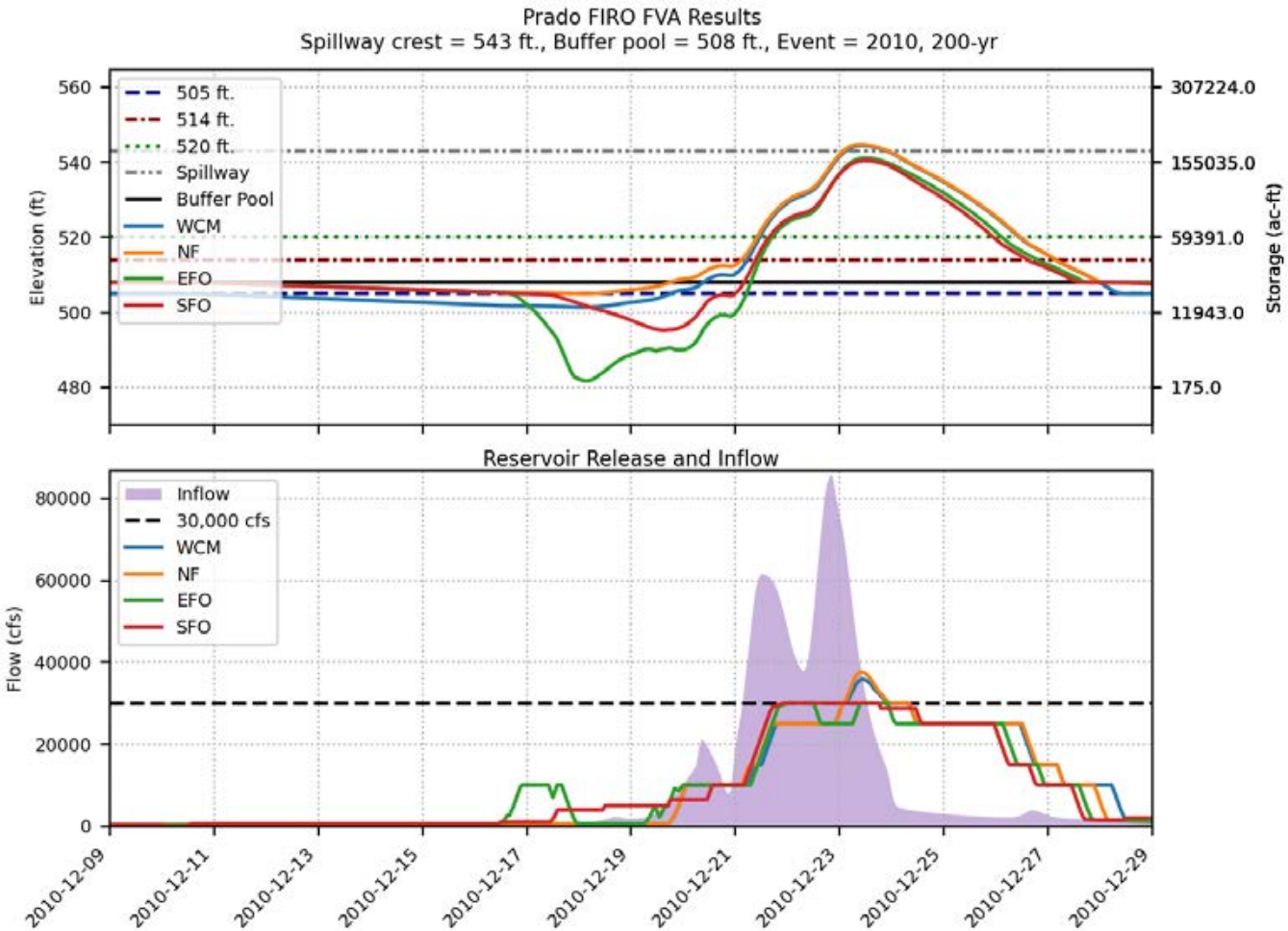
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 508 ft., Event = 2010, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
80000
60000
40000
20000
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2010-12-09
2010-12-11
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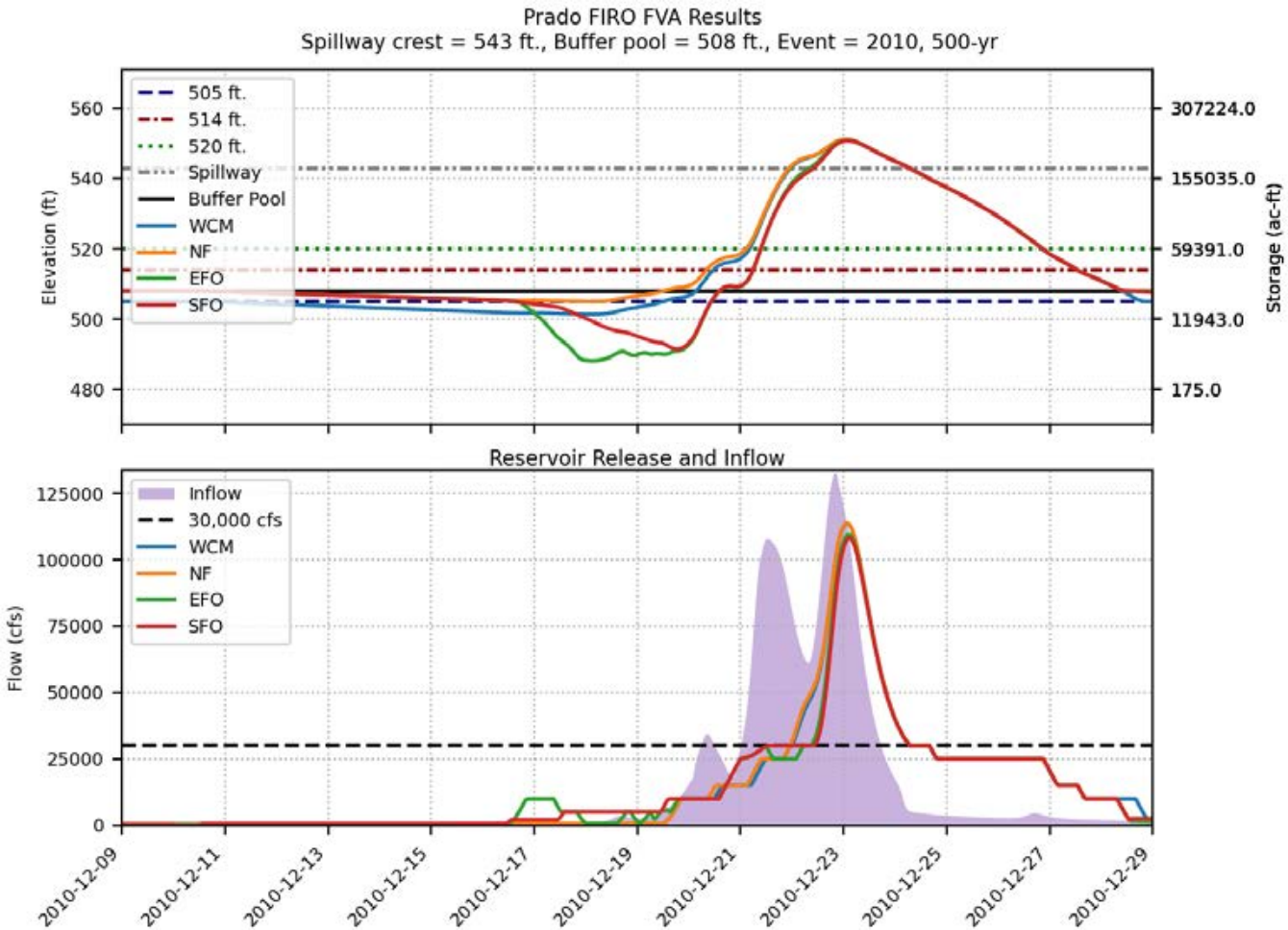
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 508 ft., Event = 2010, 500-yr
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514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
125000
100000
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50000
25000
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2010-12-09
2010-12-11
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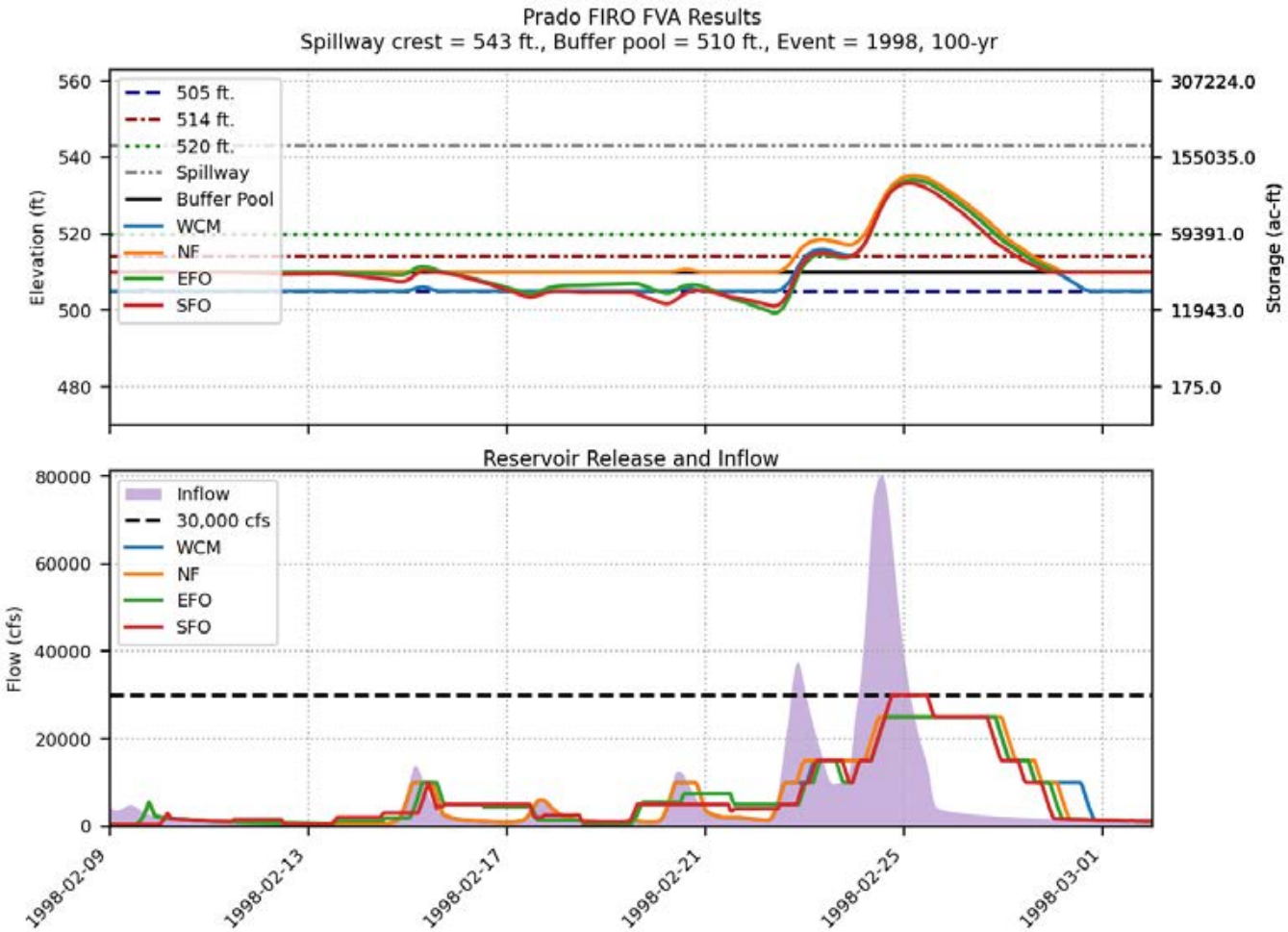
Prado FIRO FVA Results
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514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
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Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
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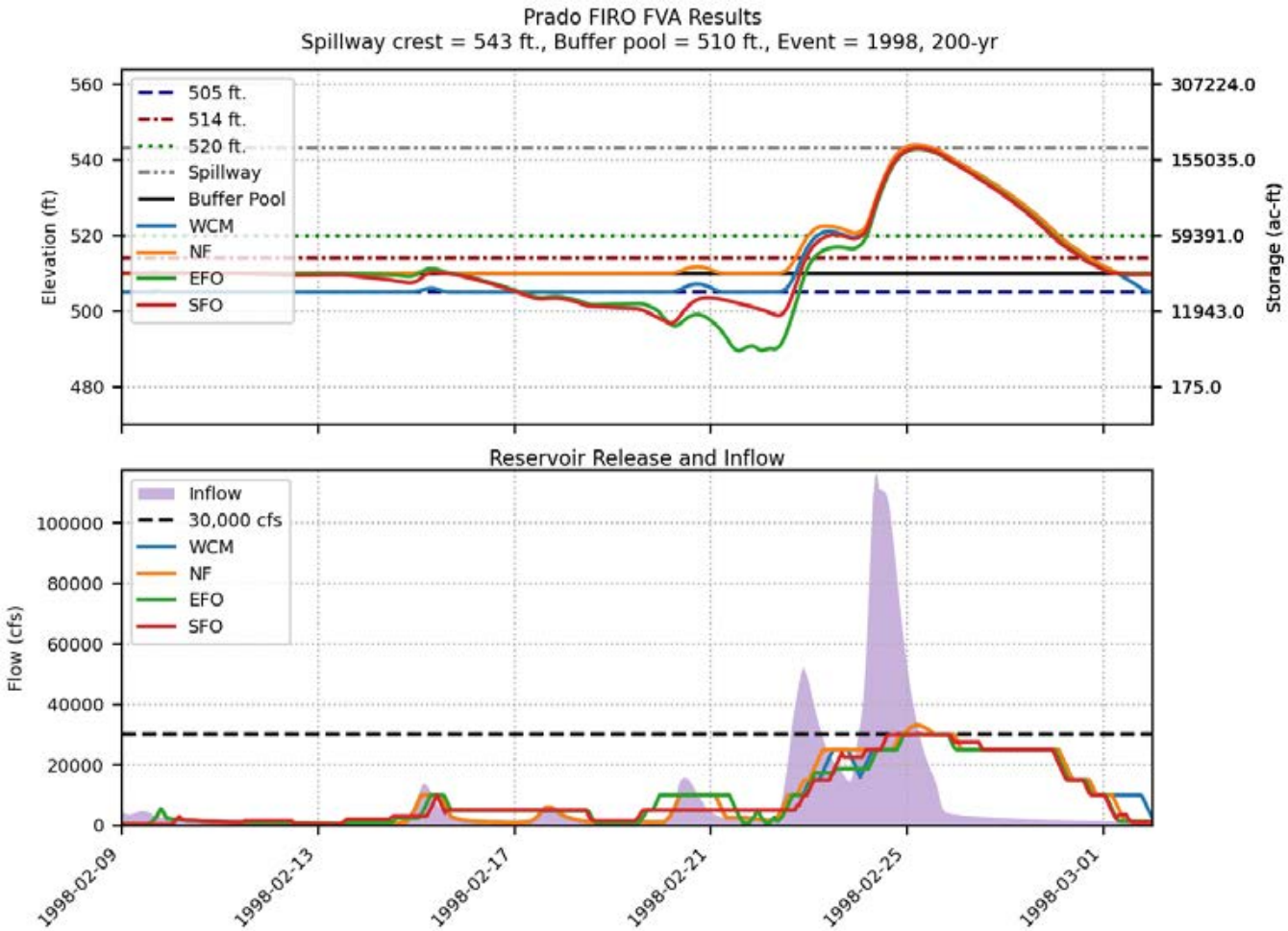
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 510 ft., Event = 1998, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
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Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
100000
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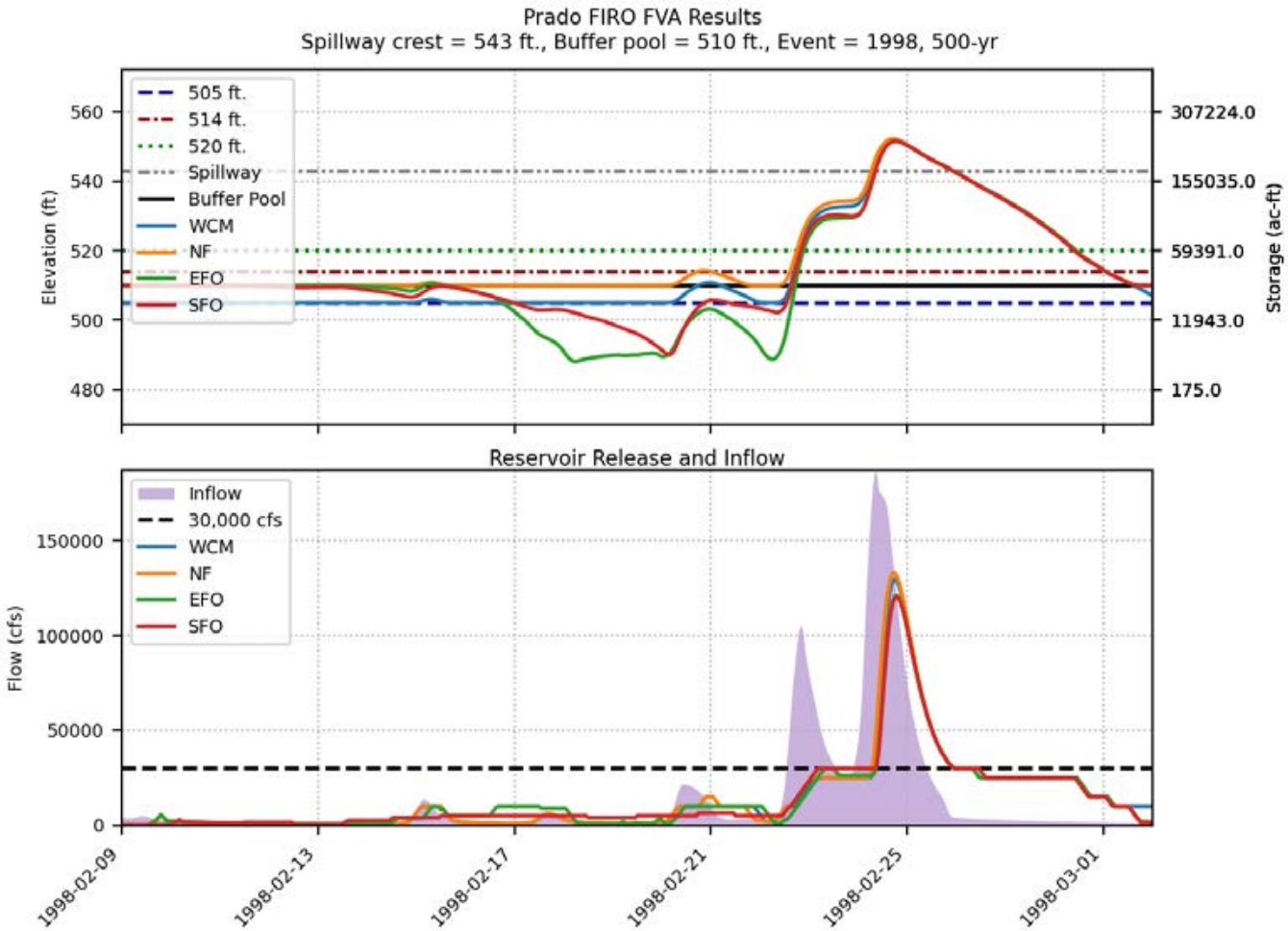
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 510 ft., Event = 1998, 500-yr
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514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
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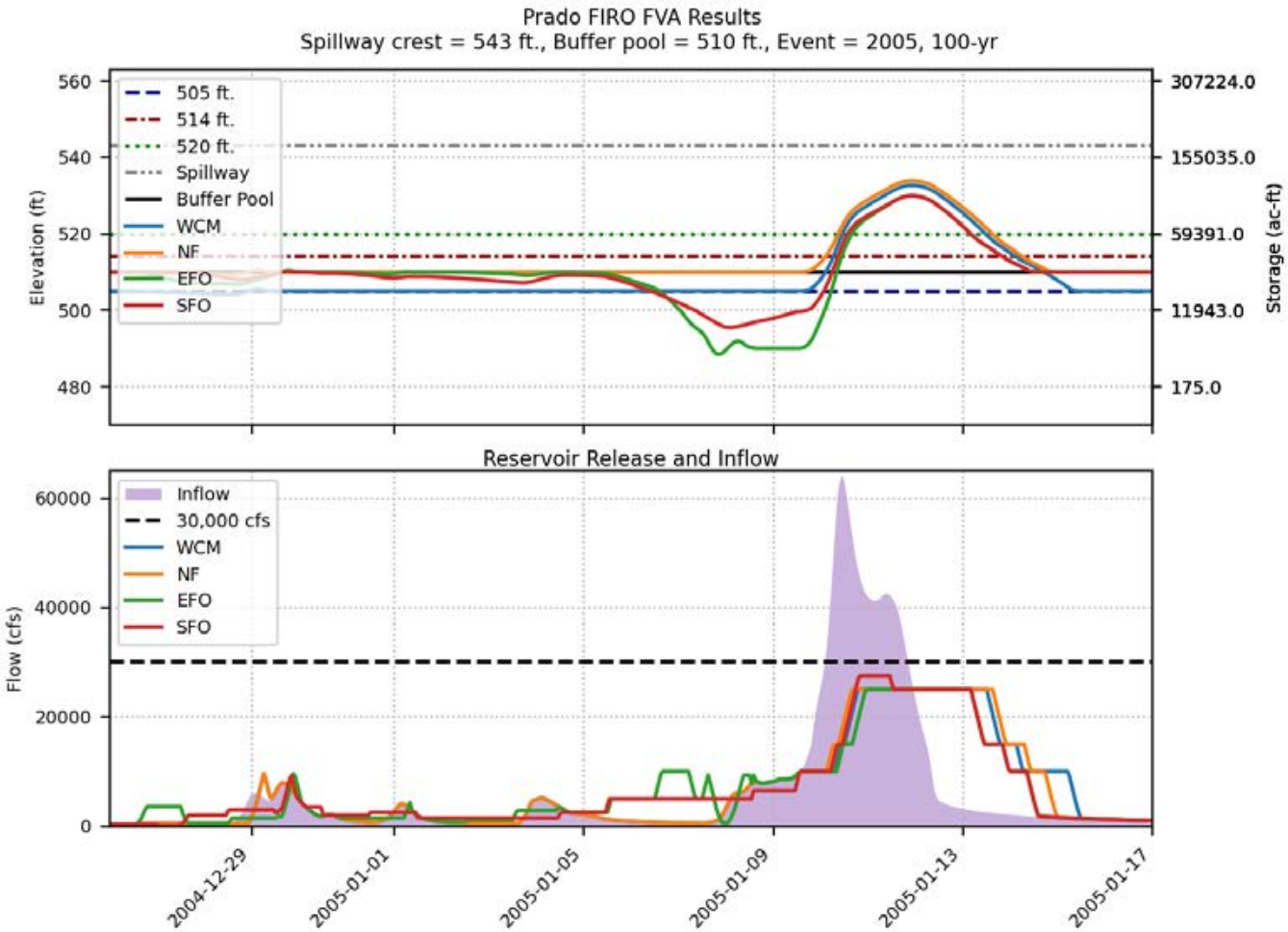
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 510 ft., Event = 2005, 100-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
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Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
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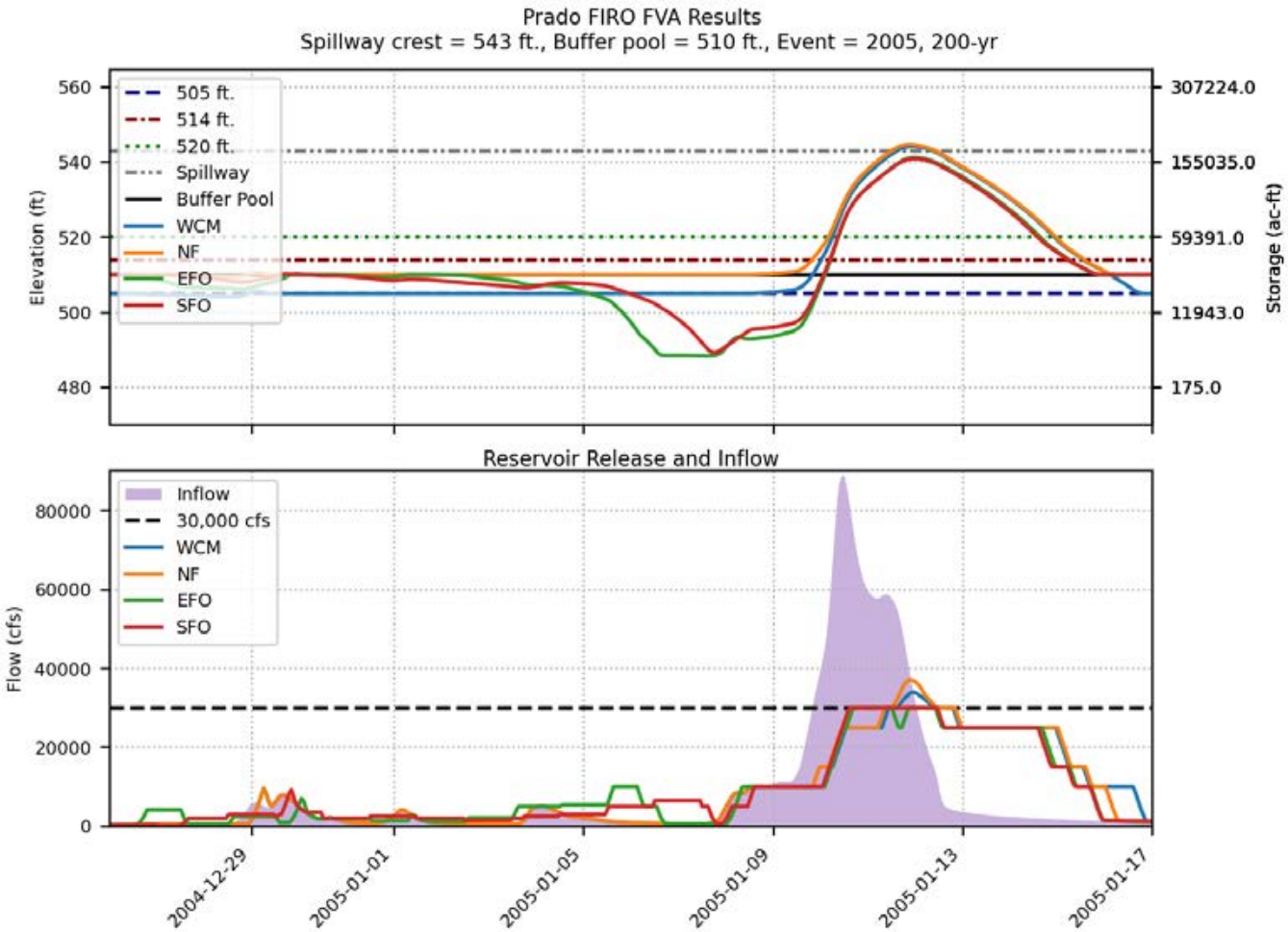
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 510 ft., Event = 2005, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
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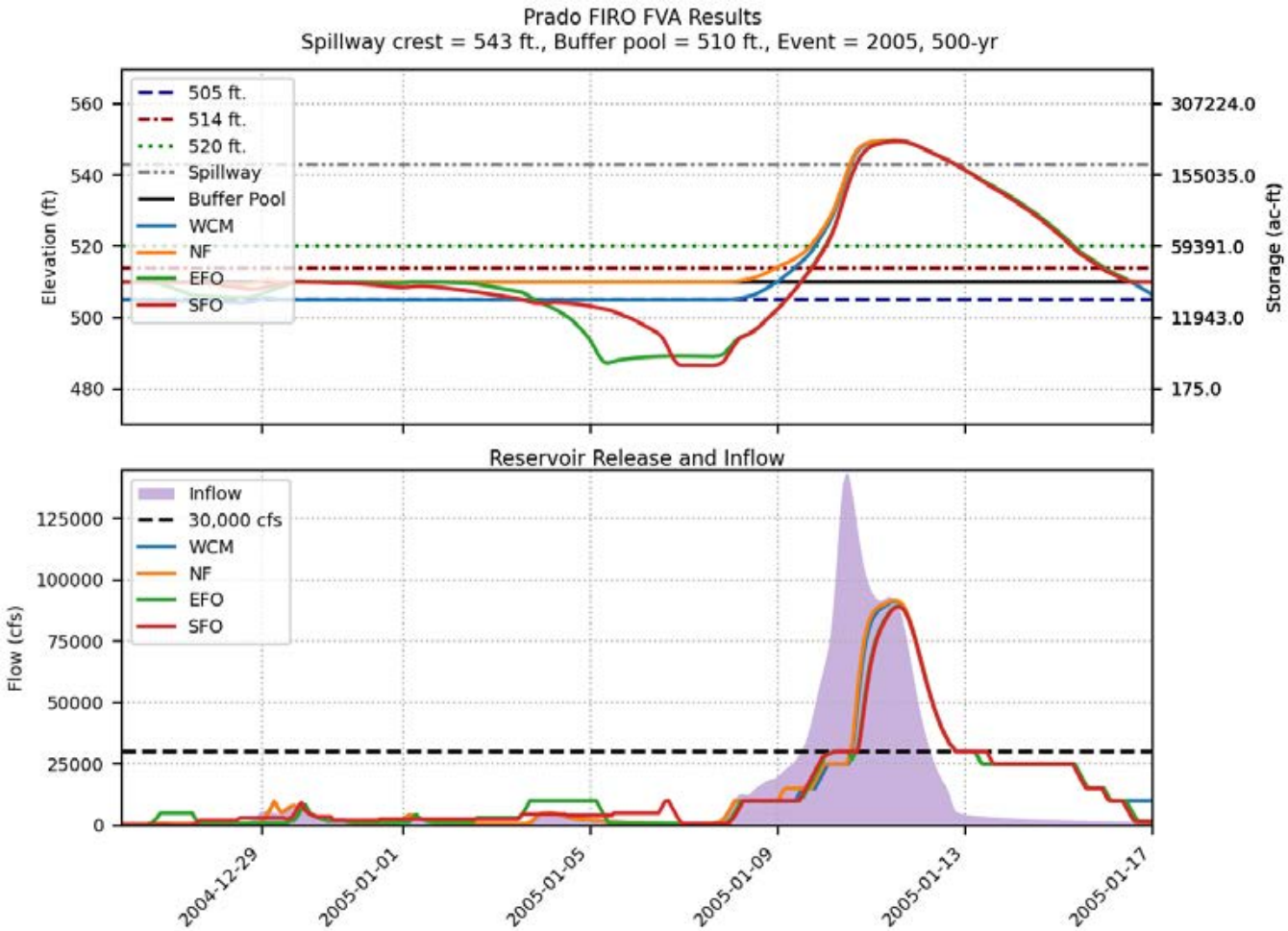
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 510 ft., Event = 2005, 500-yr
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514 ft.
520 ft.
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Buffer Pool
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540
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Reservoir Release and Inflow
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30,000 cfs
WCM
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EFO
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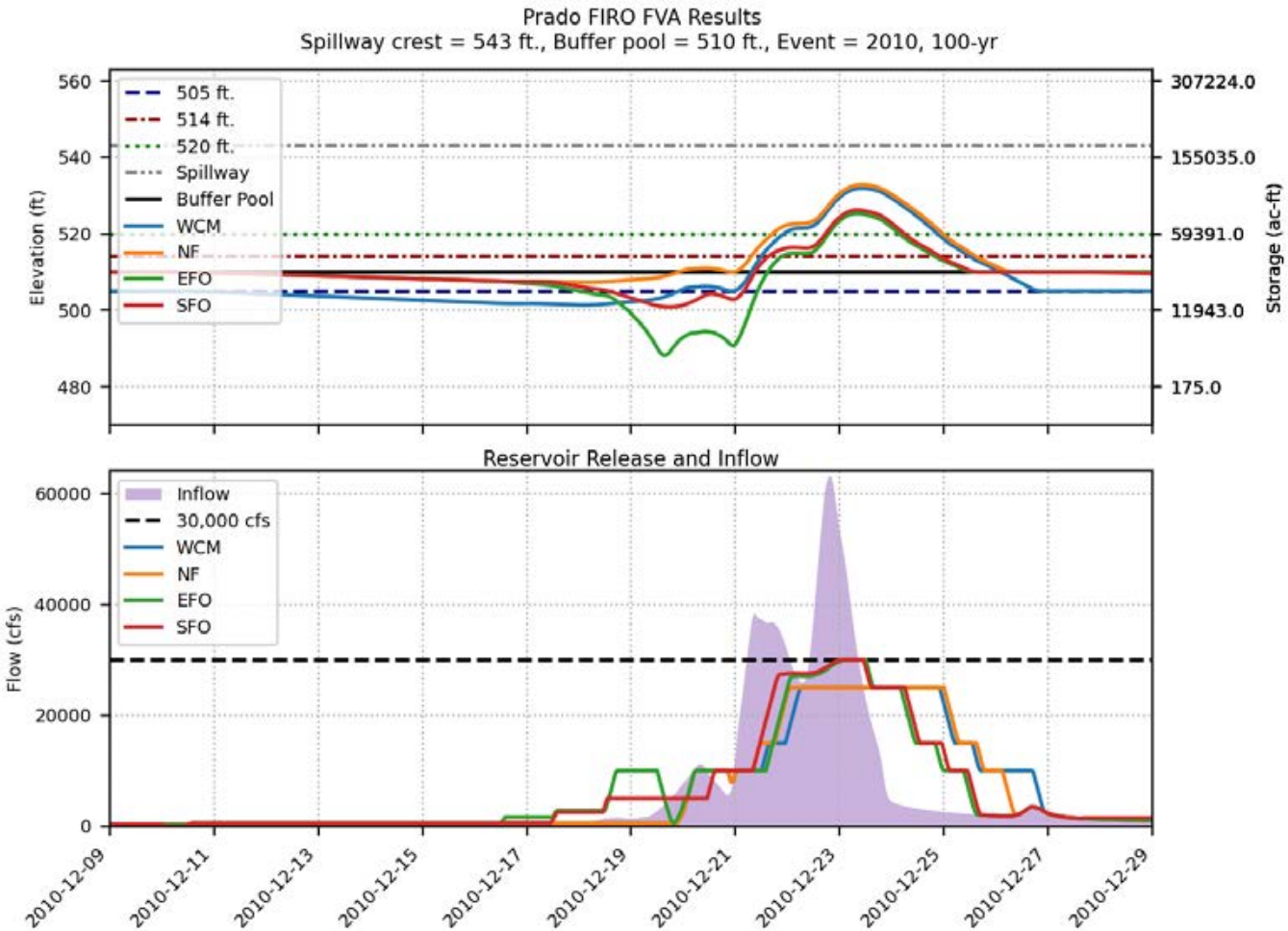
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 510 ft., Event = 2010, 100-yr
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514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
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Elevation (ft)
Storage (ac-ft)
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307224.0
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Reservoir Release and Inflow
Inflow
30,000 cfs
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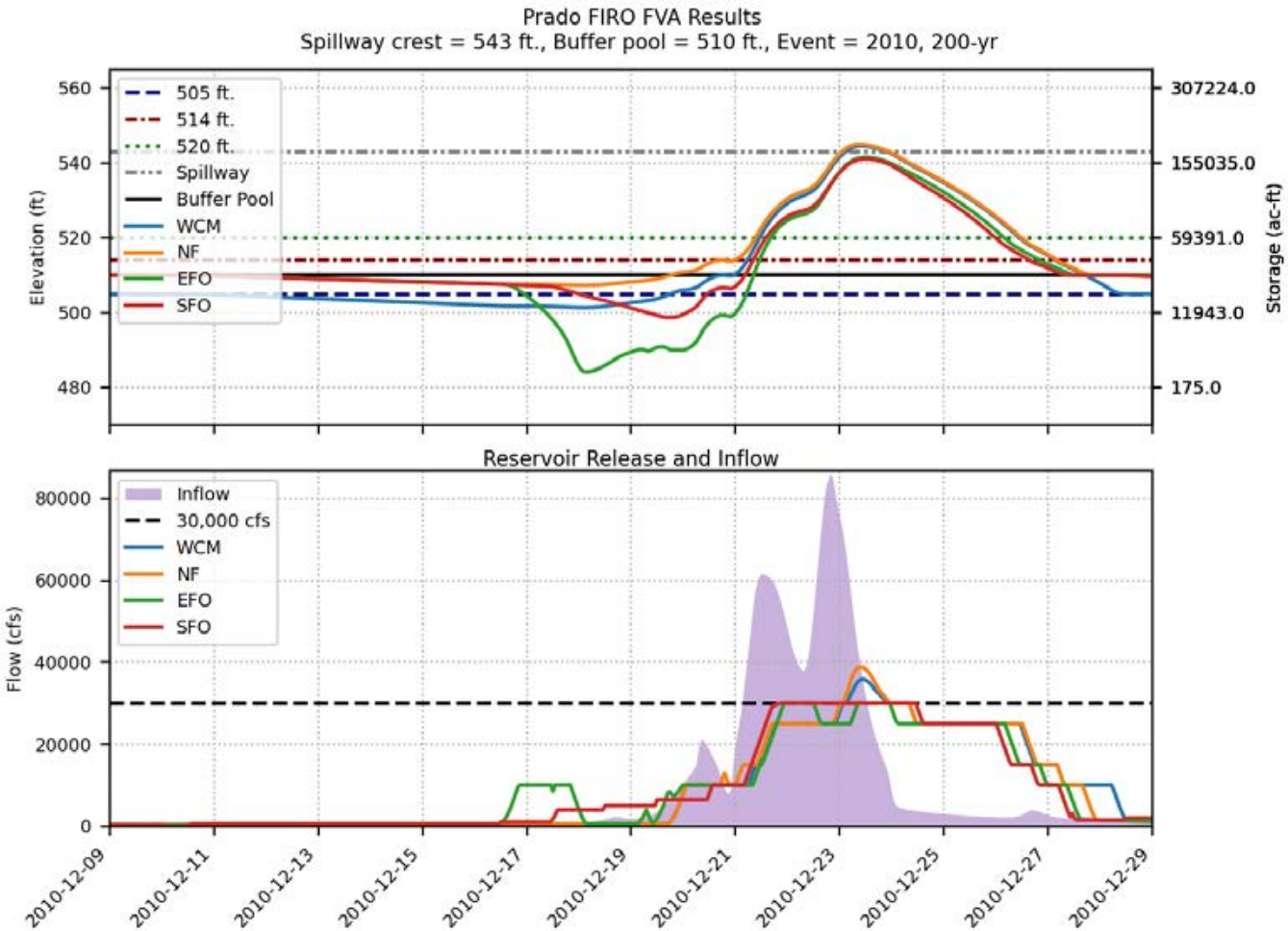
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 510 ft., Event = 2010, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
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540
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480
307224.0
155035.0
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Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
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Flow (cfs)
80000
60000
40000
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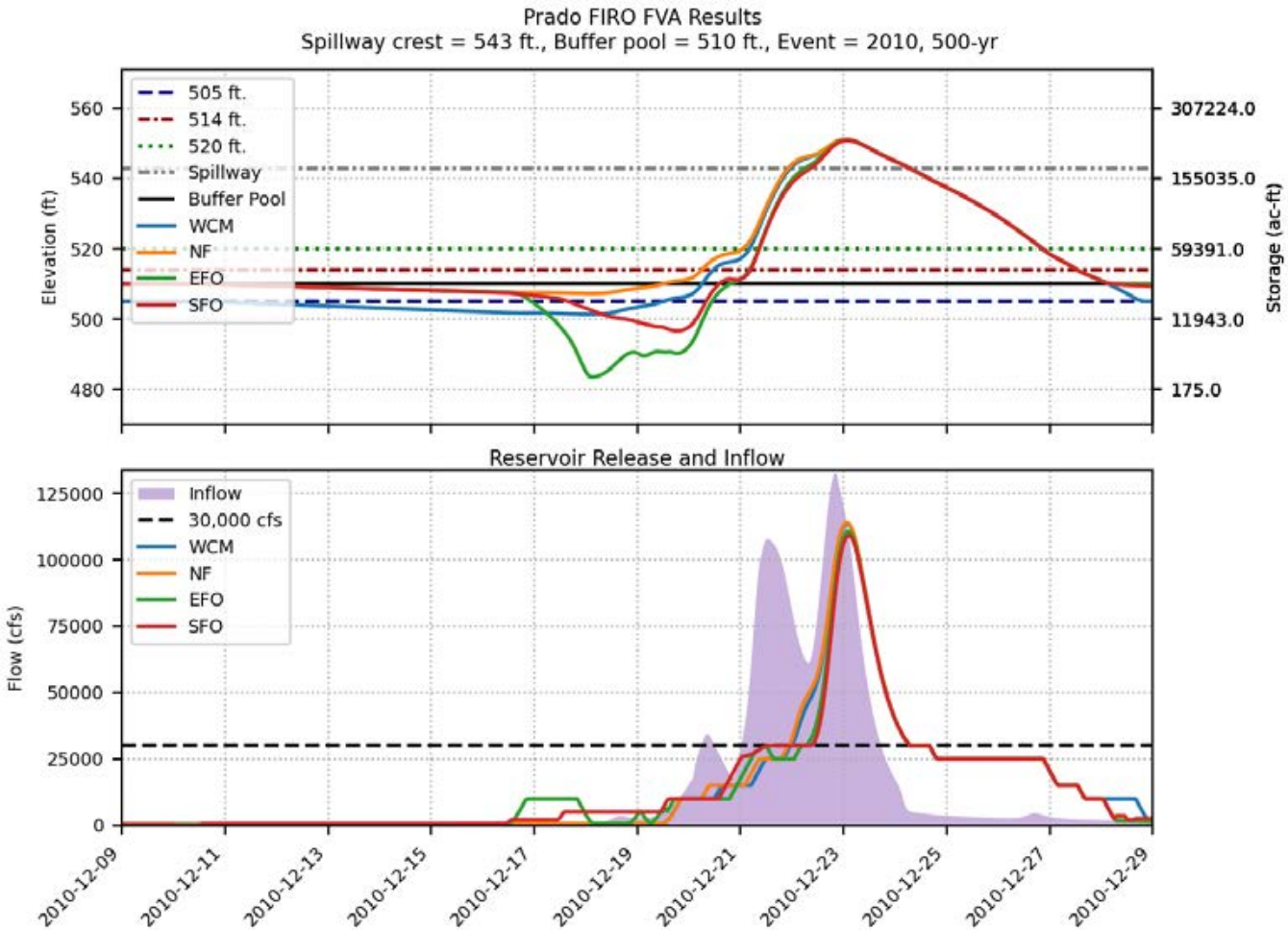
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 510 ft., Event = 2010, 500-yr
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Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
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155035.0
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Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
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100000
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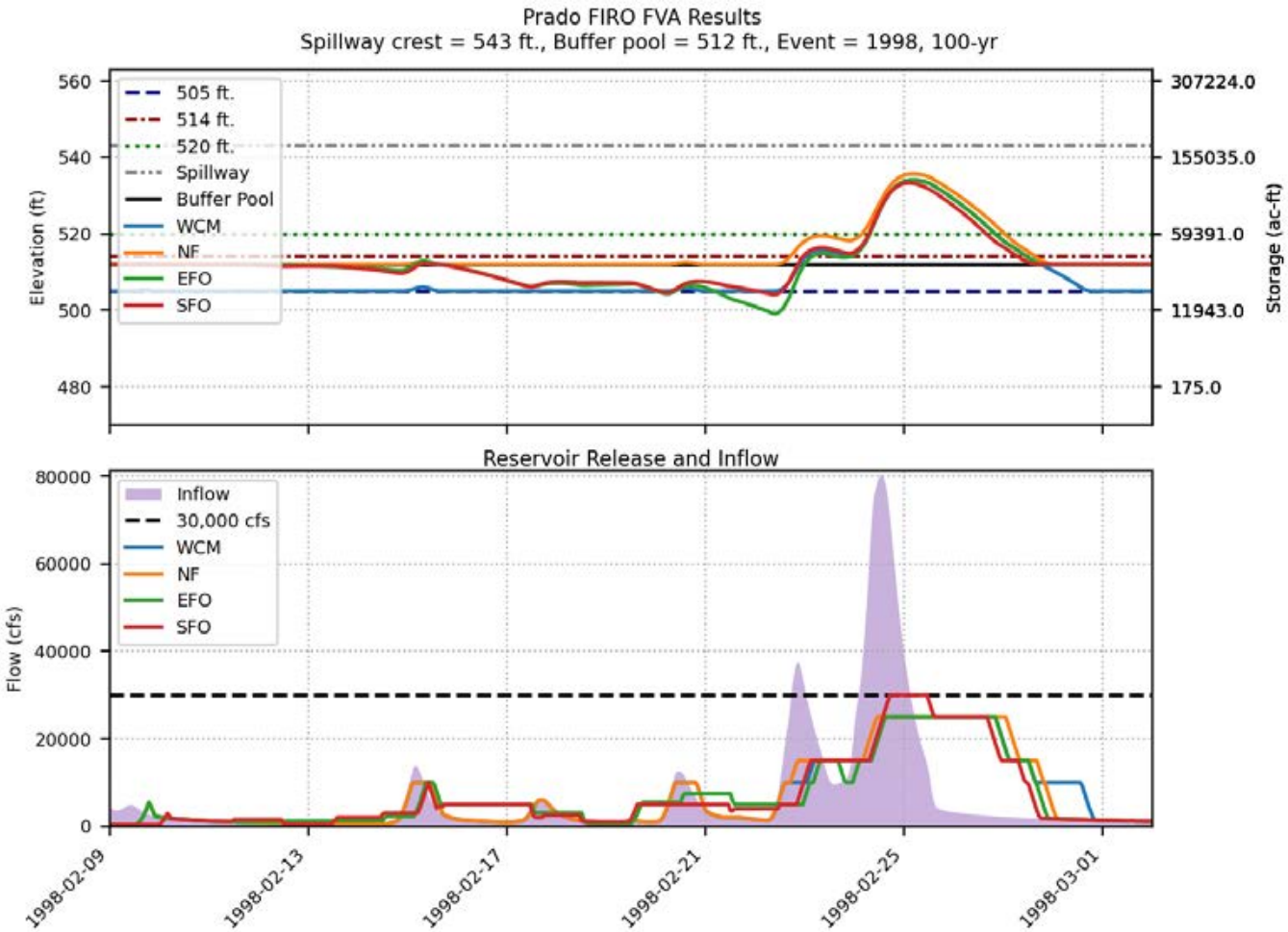
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 512 ft., Event = 1998, 100-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
80000
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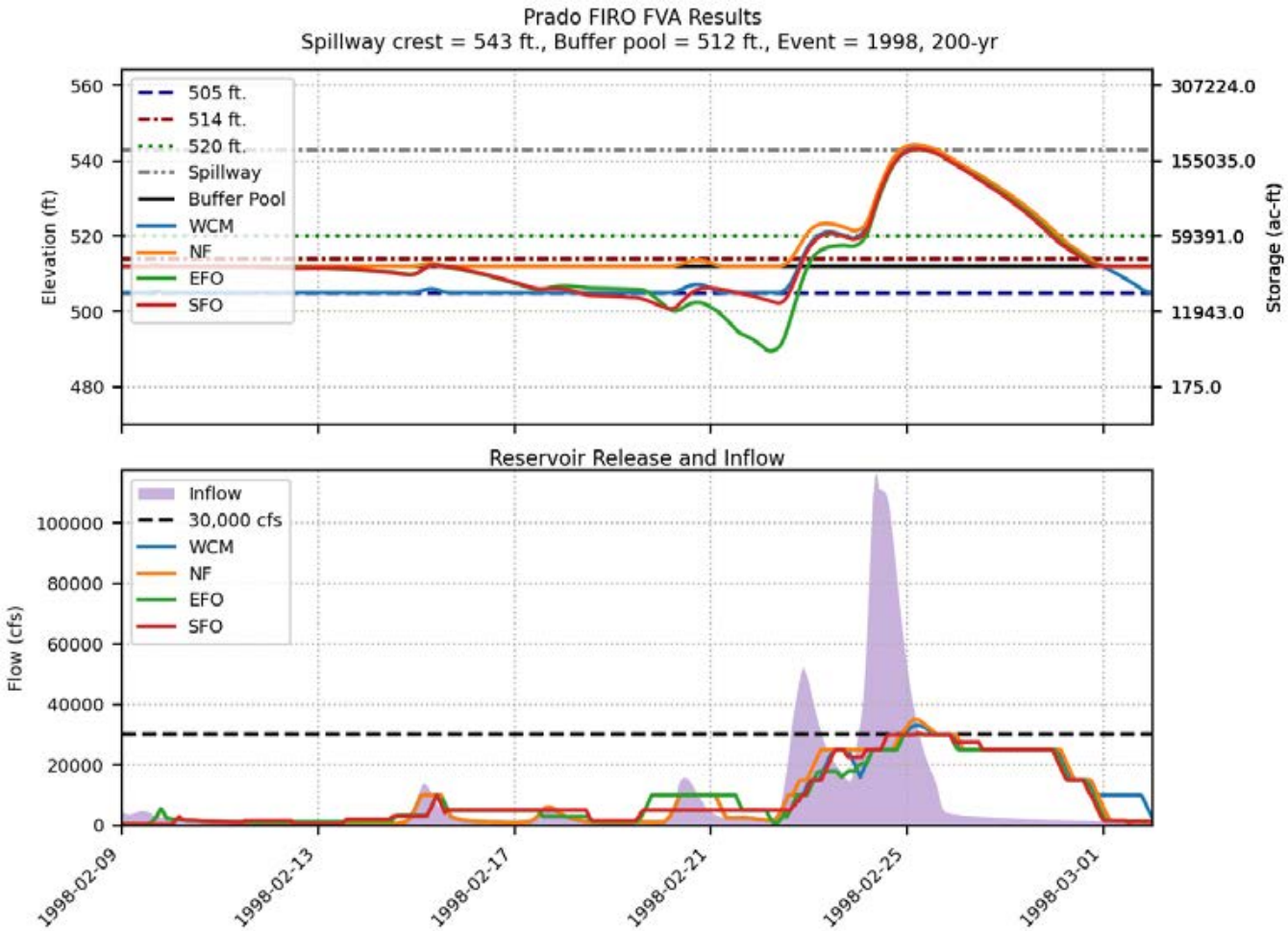
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 512 ft., Event = 1998, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
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500
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307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
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EFO
SFO
Flow (cfs)
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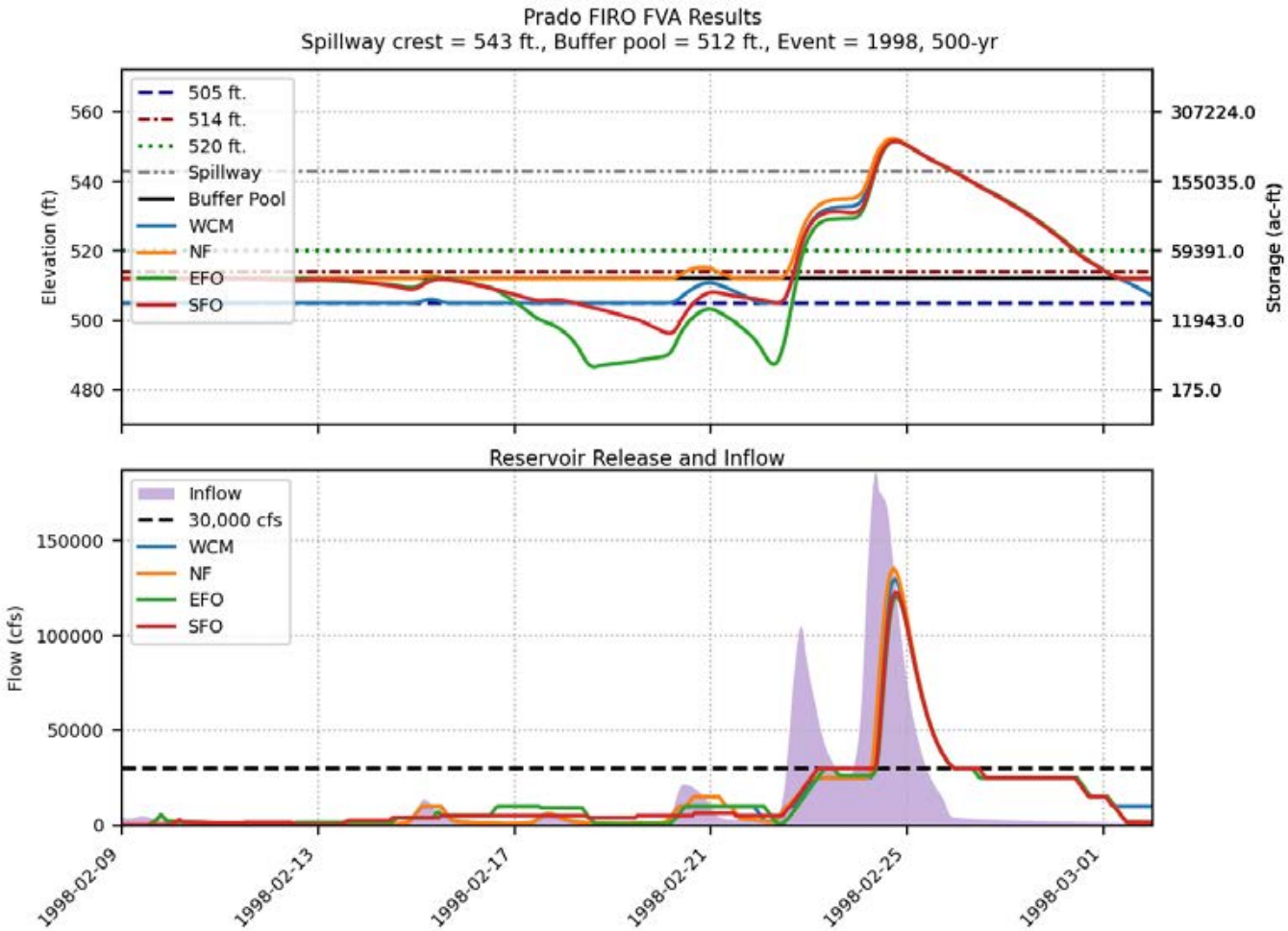
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 512 ft., Event = 1998, 500-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
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SFO
Elevation (ft)
Storage (ac-ft)
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307224.0
155035.0
59391.0
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175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
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SFO
Flow (cfs)
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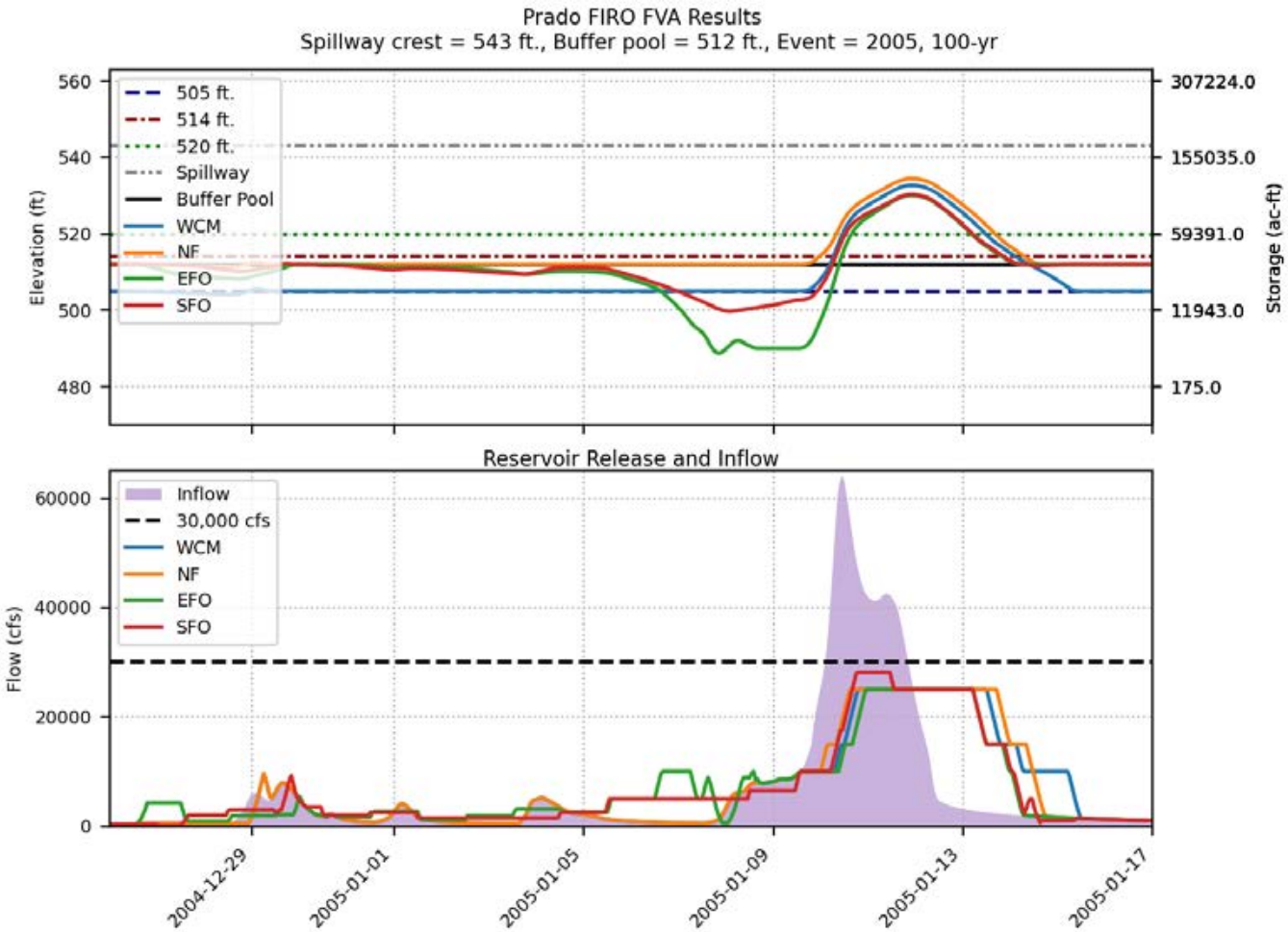
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 512 ft., Event = 2005, 100-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
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307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
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EFO
SFO
Flow (cfs)
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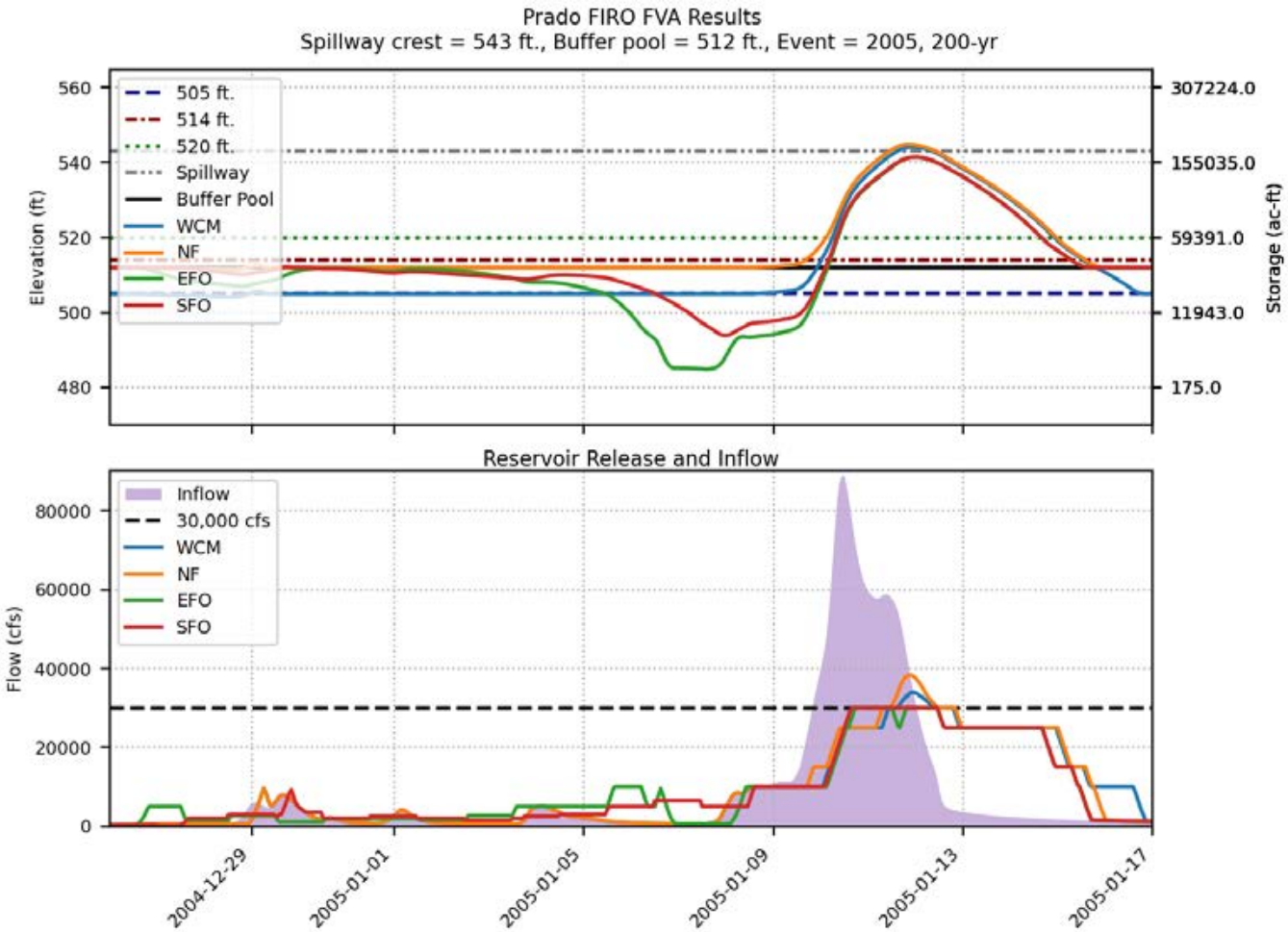
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 512 ft., Event = 2005, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
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EFO
SFO
Elevation (ft)
Storage (ac-ft)
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307224.0
155035.0
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11943.0
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Reservoir Release and Inflow
Inflow
30,000 cfs
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SFO
Flow (cfs)
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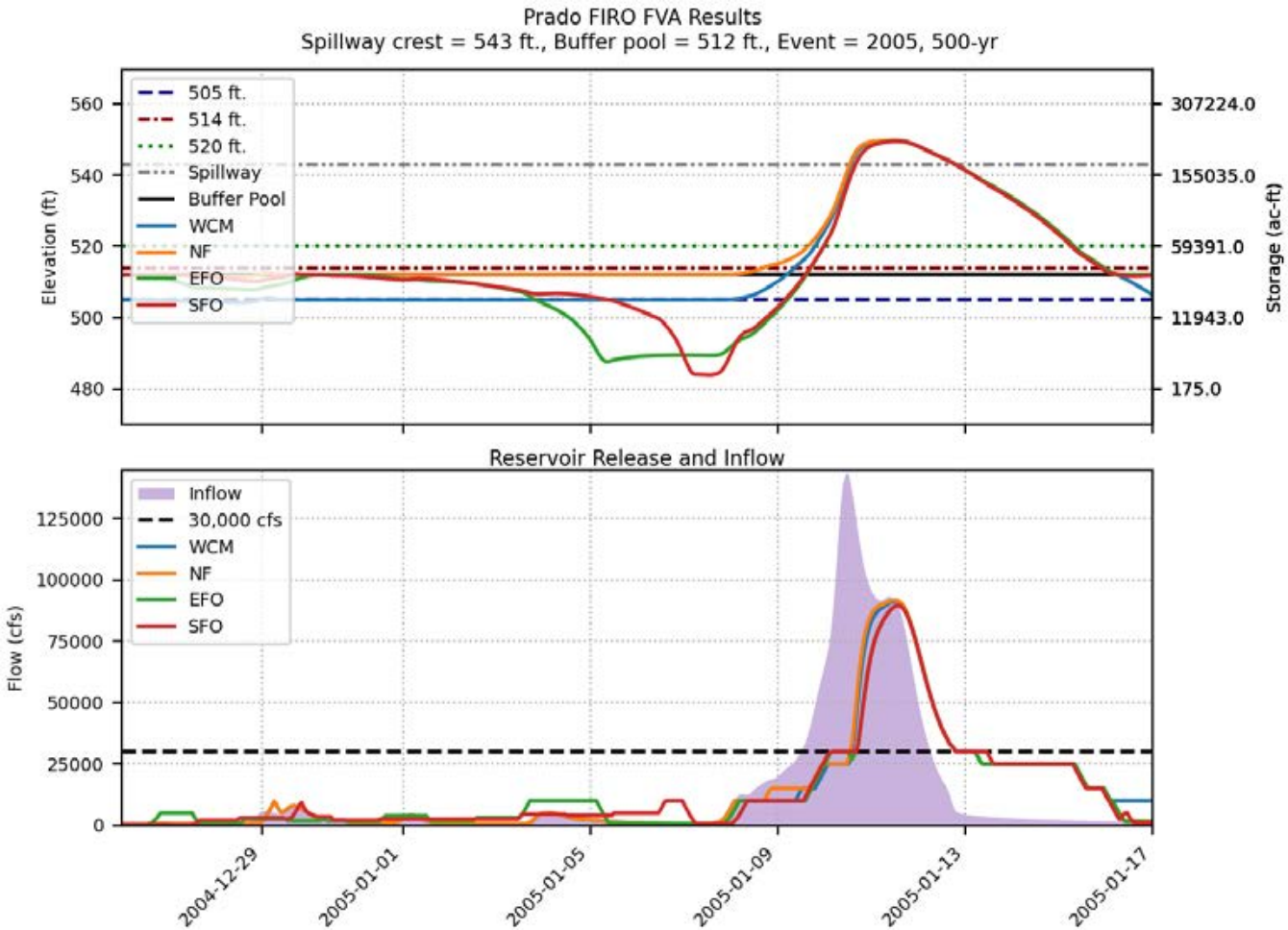
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 512 ft., Event = 2005, 500-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
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SFO
Elevation (ft)
Storage (ac-ft)
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307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
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EFO
SFO
Flow (cfs)
125000
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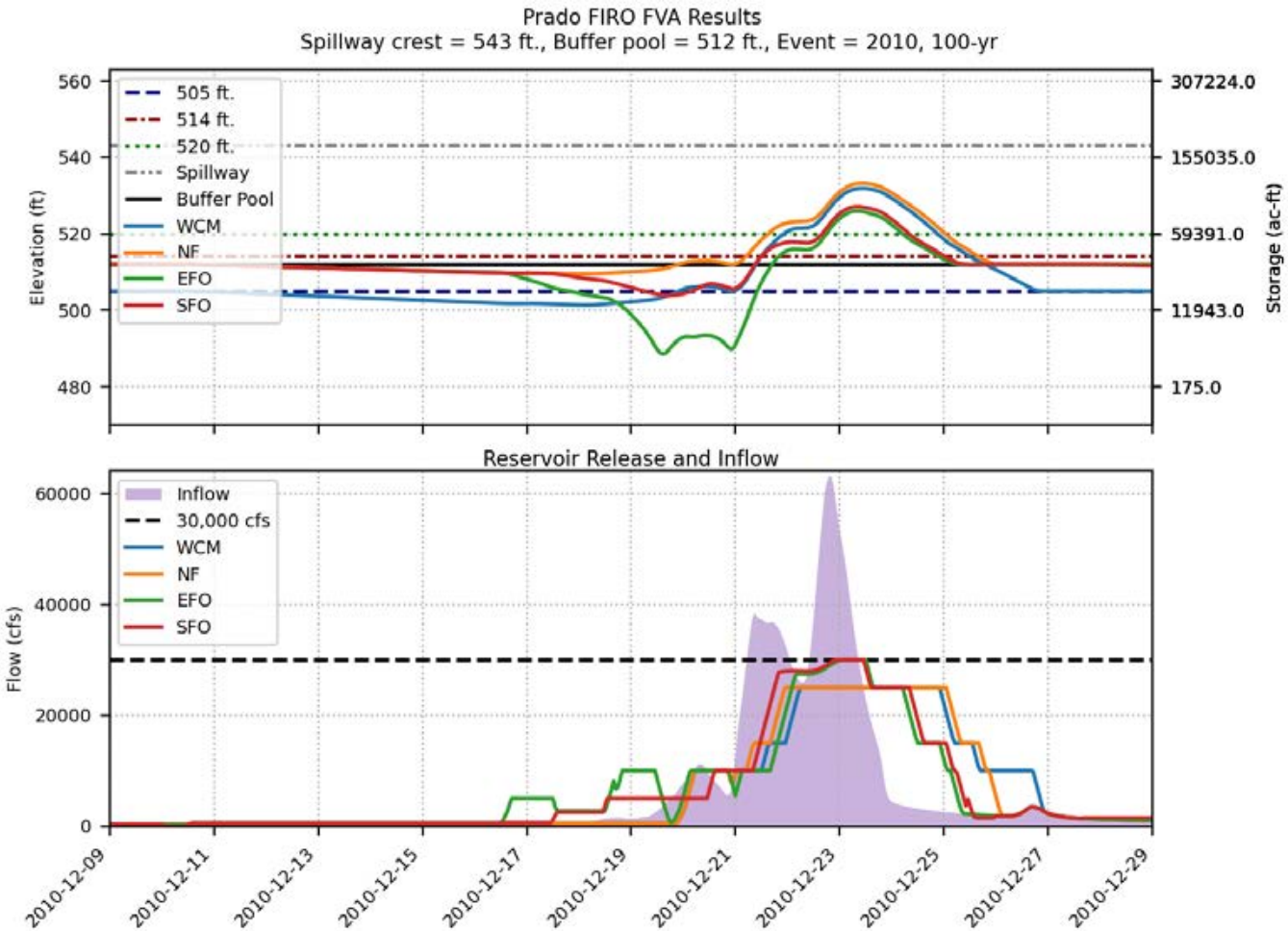
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Spillway crest = 543 ft., Buffer pool = 512 ft., Event = 2010, 100-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
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307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
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Flow (cfs)
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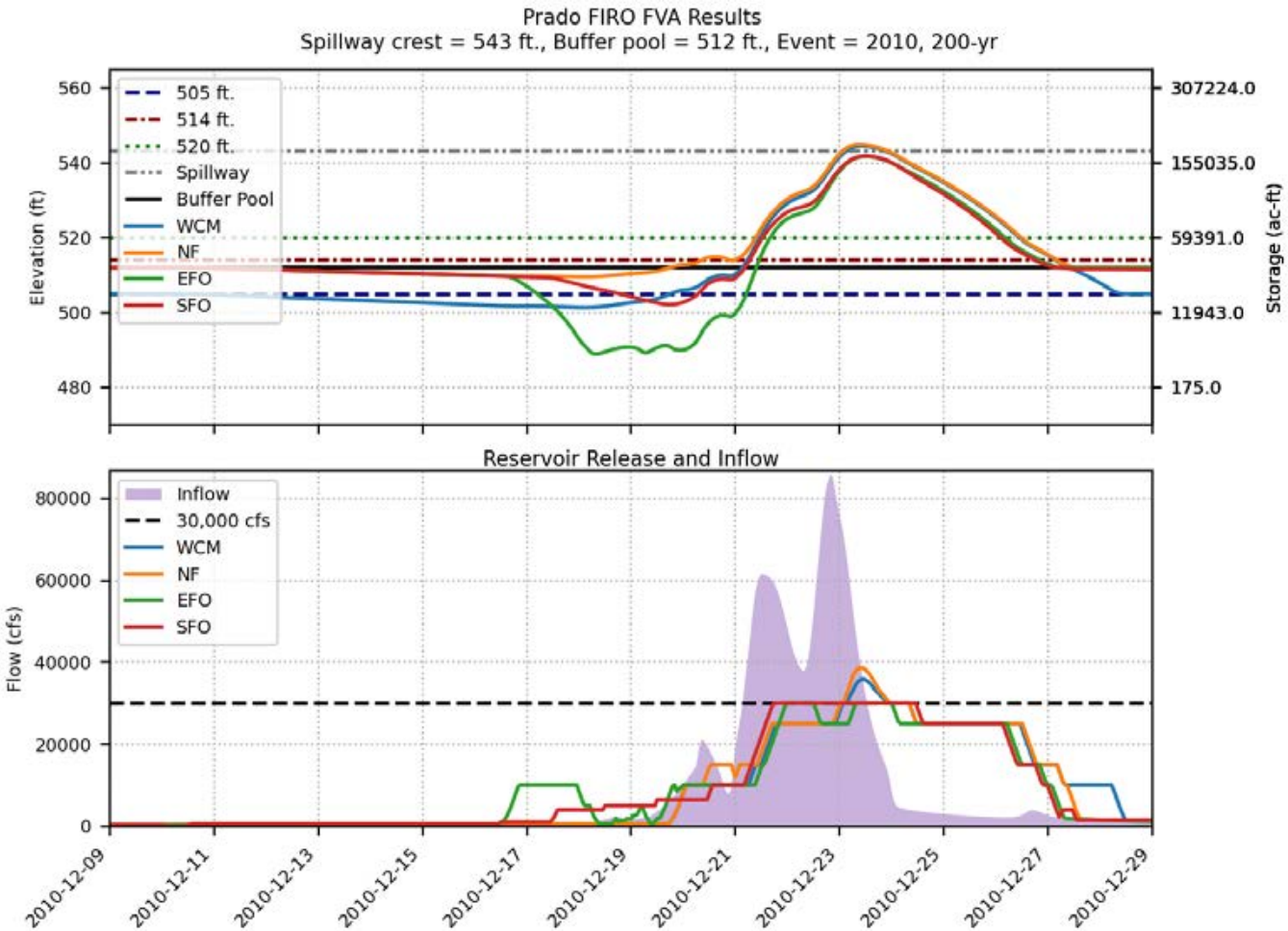
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 512 ft., Event = 2010, 200-yr
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514 ft.
520 ft.
Spillway
Buffer Pool
WCM
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SFO
Elevation (ft)
Storage (ac-ft)
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307224.0
155035.0
59391.0
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Reservoir Release and Inflow
Inflow
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Flow (cfs)
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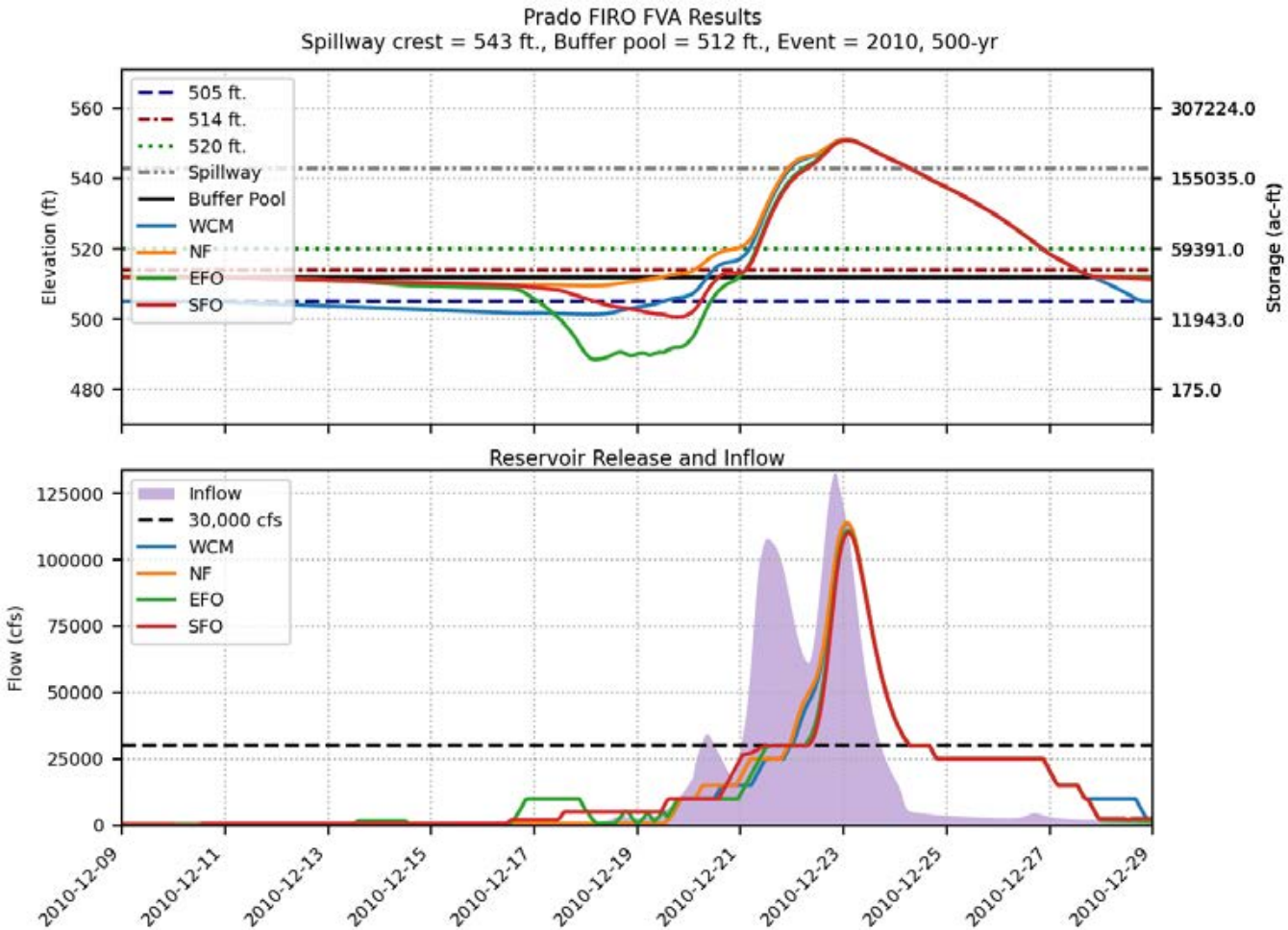
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 512 ft., Event = 2010, 500-yr
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514 ft.
520 ft.
Spillway
Buffer Pool
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SFO
Elevation (ft)
Storage (ac-ft)
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155035.0
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11943.0
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Reservoir Release and Inflow
Inflow
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SFO
Flow (cfs)
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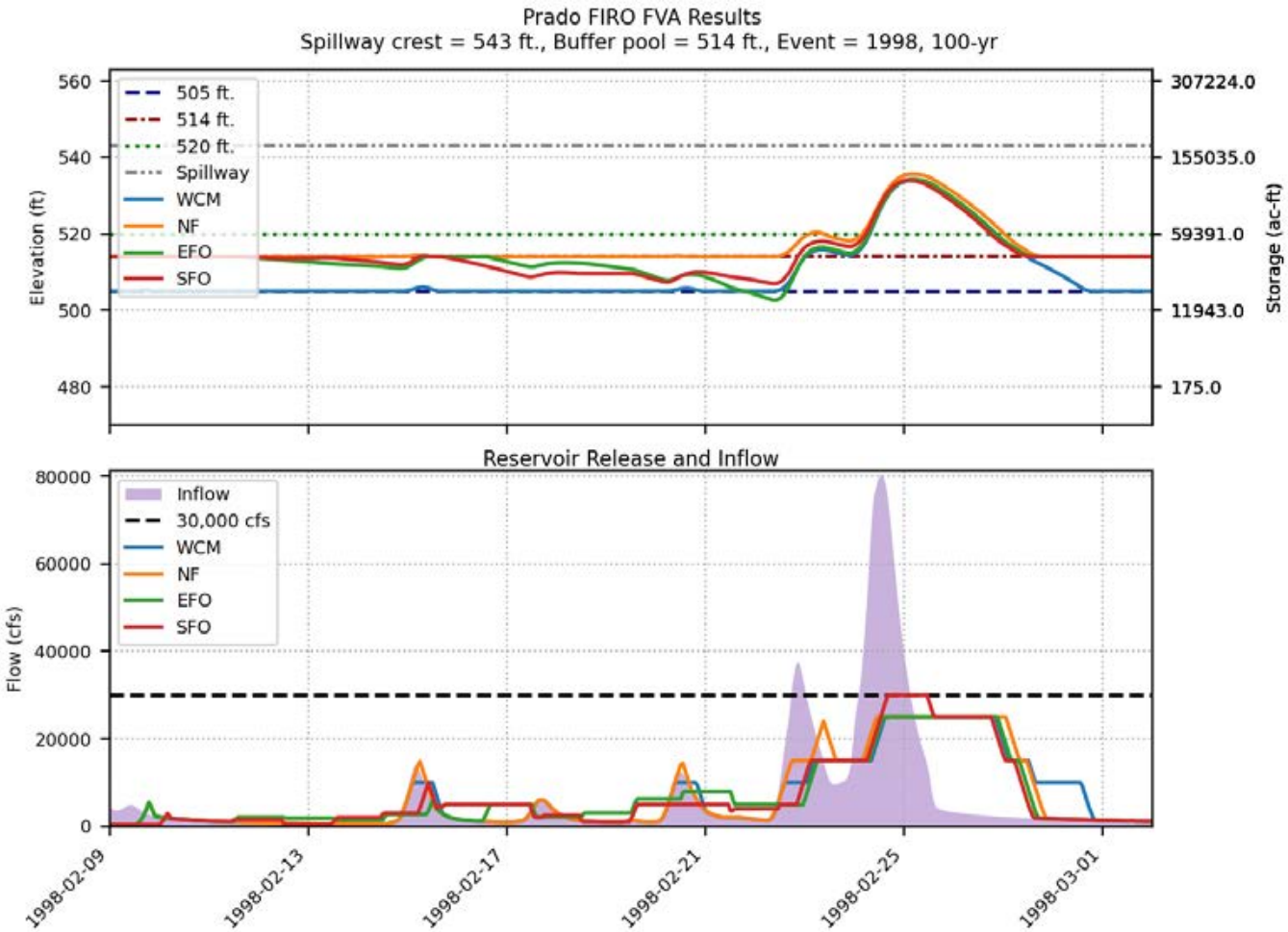
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Spillway crest = 543 ft., Buffer pool = 514 ft., Event = 1998, 100-yr
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514 ft.
520 ft.
Spillway
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
Inflow
30,000 cfs
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Flow (cfs)
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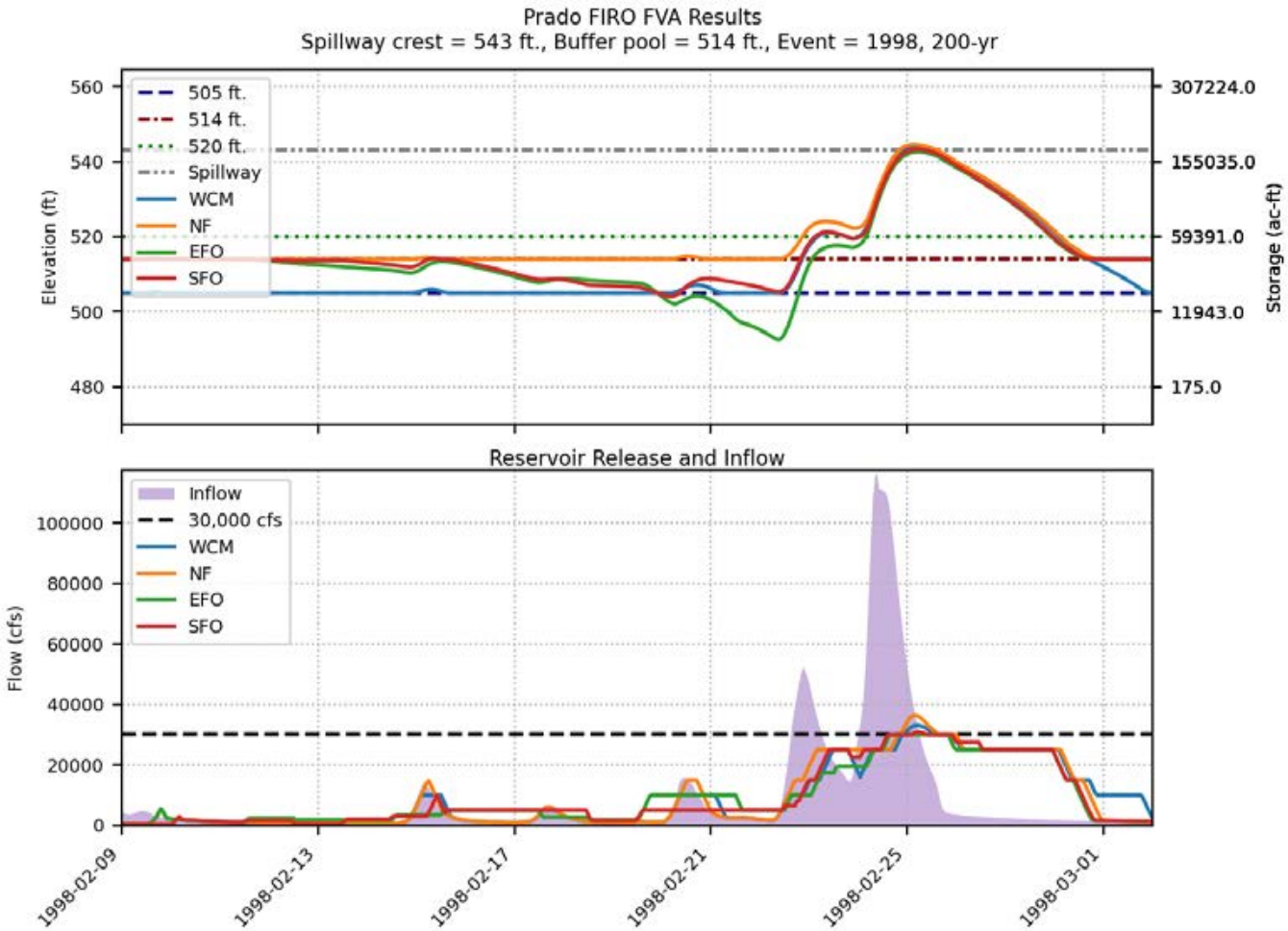
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Spillway crest = 543 ft., Buffer pool = 514 ft., Event = 1998, 200-yr
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520 ft.
Spillway
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NF
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SFO
Elevation (ft)
Storage (ac-ft)
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155035.0
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11943.0
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Reservoir Release and Inflow
Inflow
30,000 cfs
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EFO
SFO
Flow (cfs)
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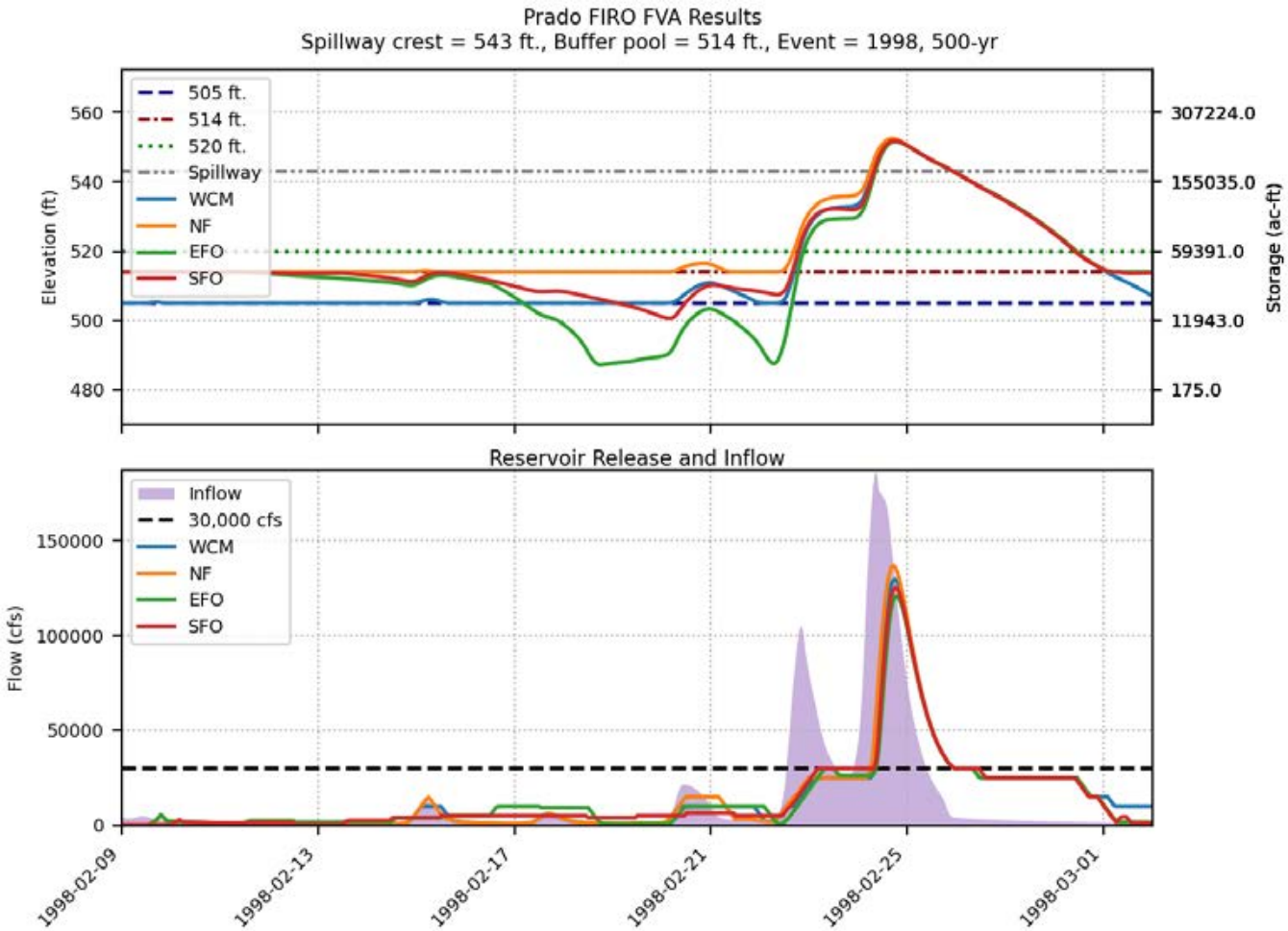
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 514 ft., Event = 1998, 500-yr
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514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
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500
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307224.0
155035.0
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11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
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EFO
SFO
Flow (cfs)
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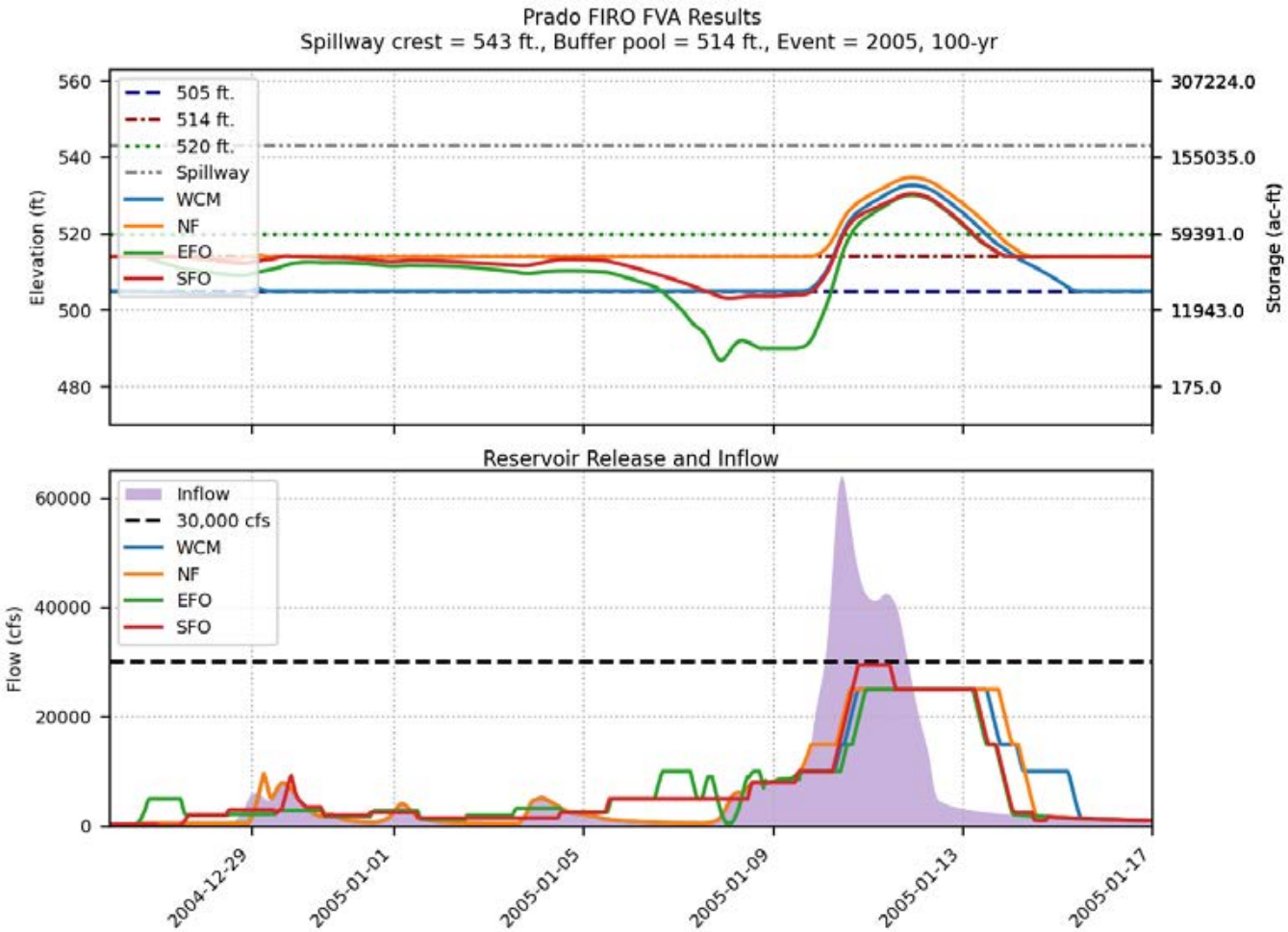
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 514 ft., Event = 2005, 100-yr
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514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
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520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
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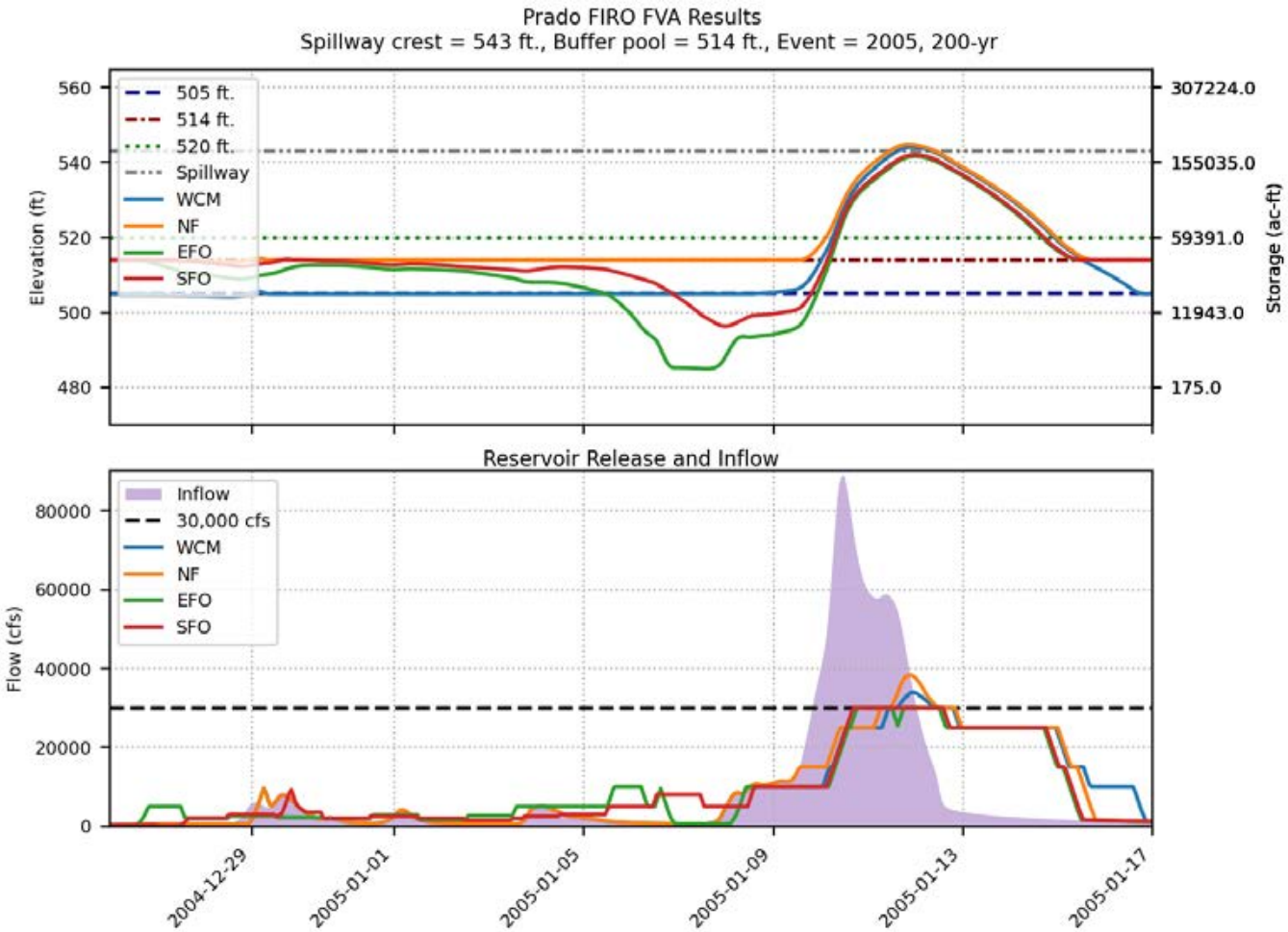
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514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
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500
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307224.0
155035.0
59391.0
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Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
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EFO
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Flow (cfs)
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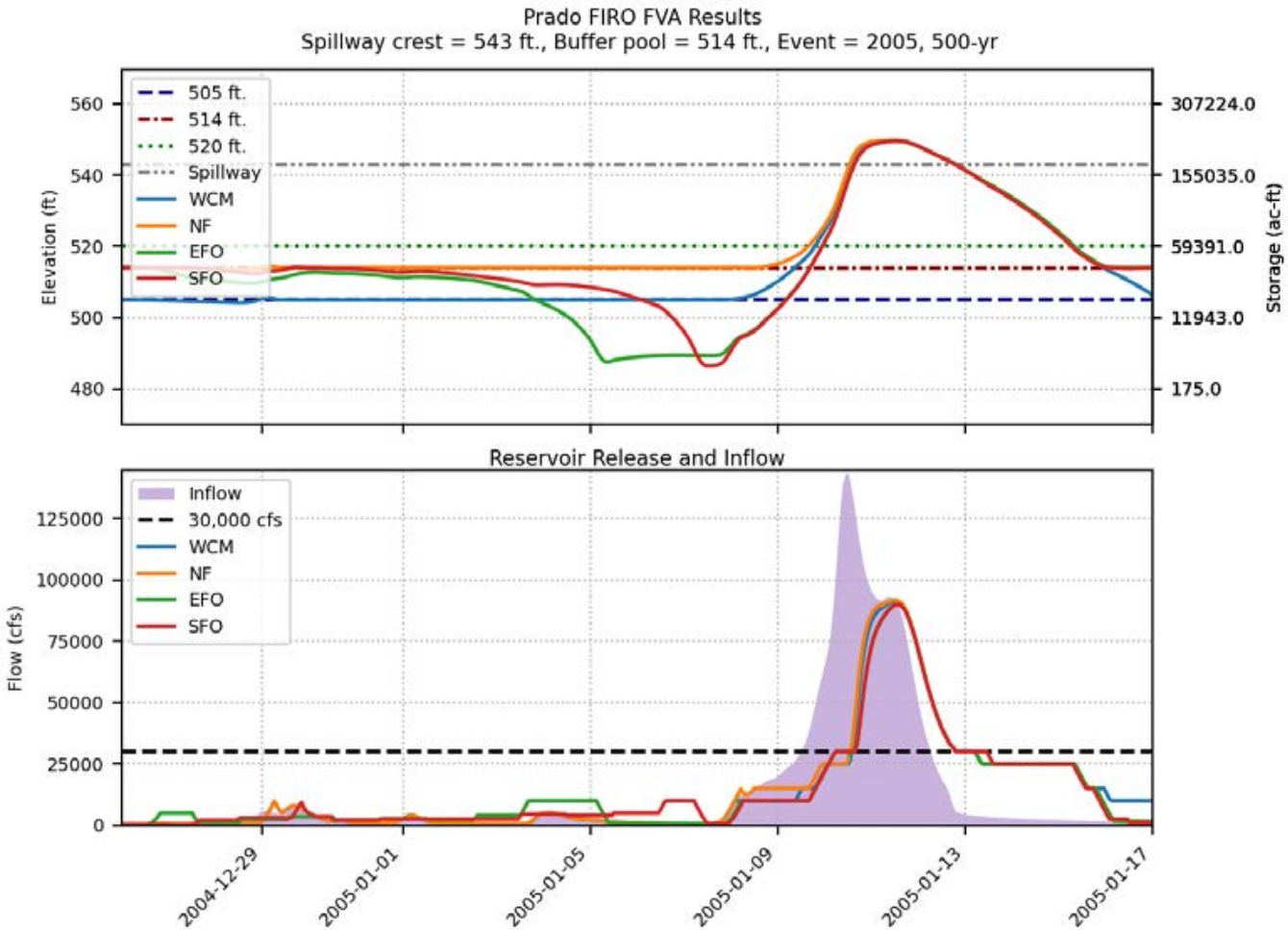
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Spillway
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
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520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
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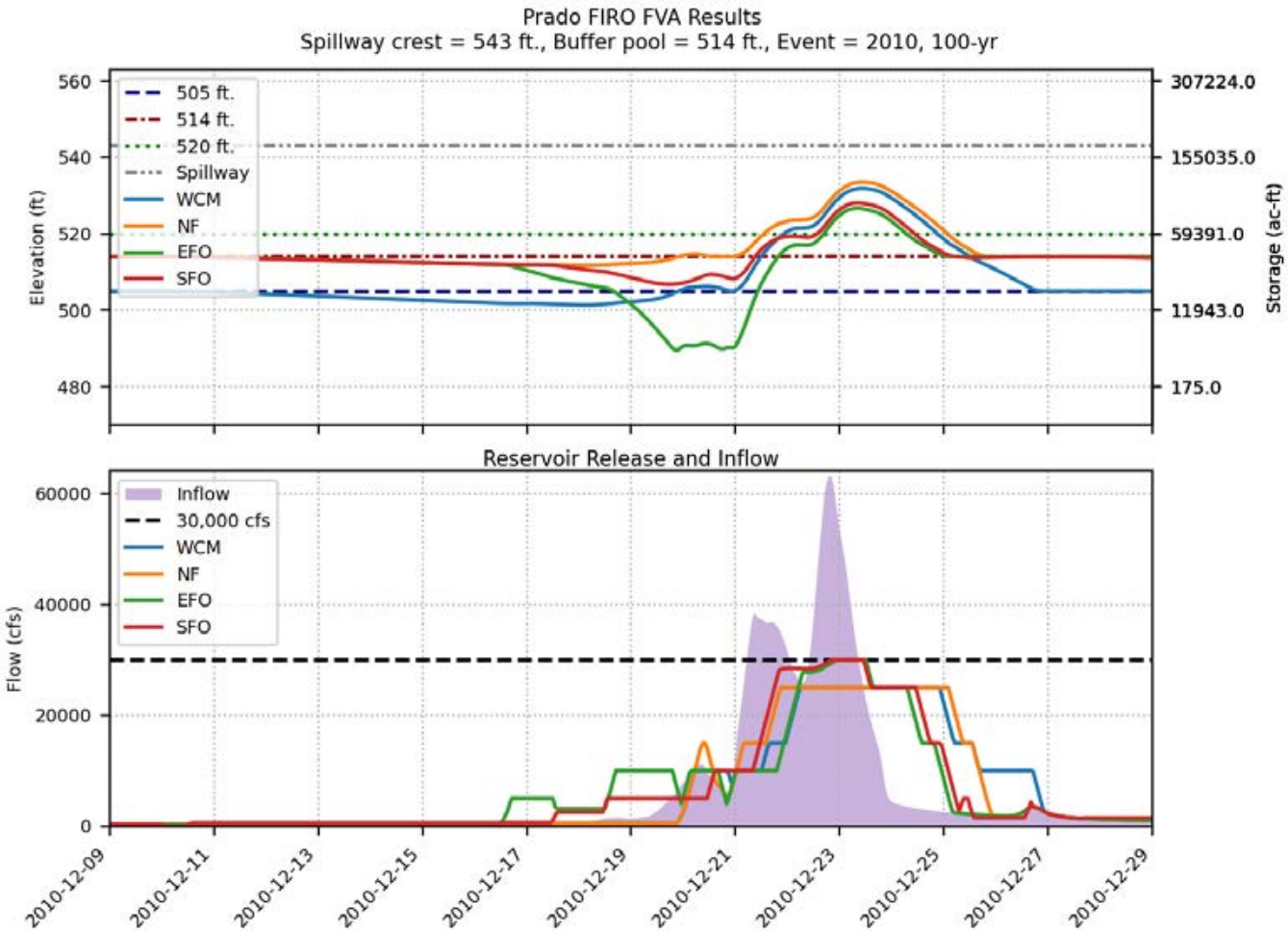
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520 ft.
Spillway
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
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500
480
307224.0
155035.0
59391.0
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175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
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EFO
SFO
Flow (cfs)
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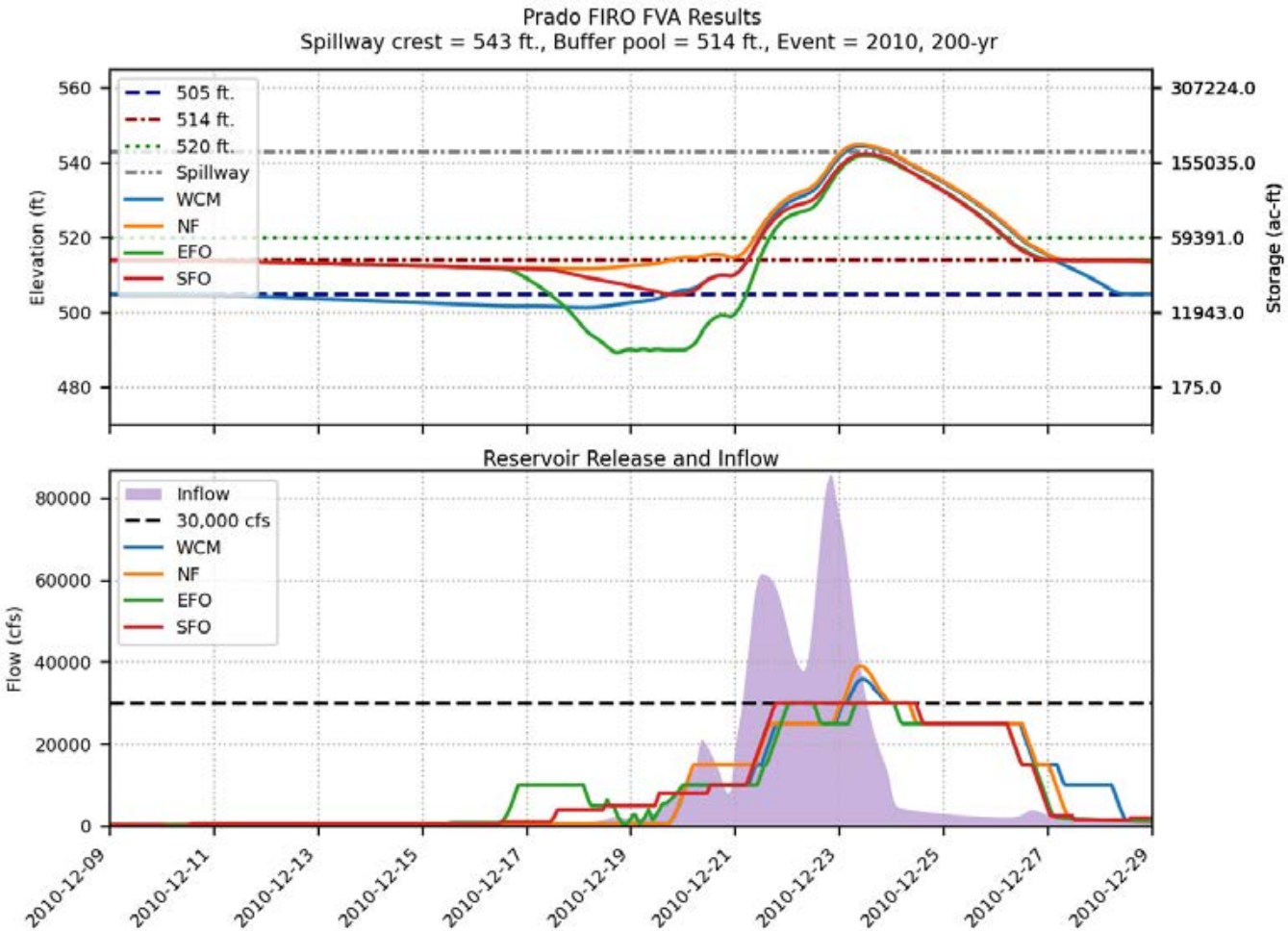
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 514 ft., Event = 2010, 200-yr
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514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
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520
500
480
307224.0
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11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
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EFO
SFO
Flow (cfs)
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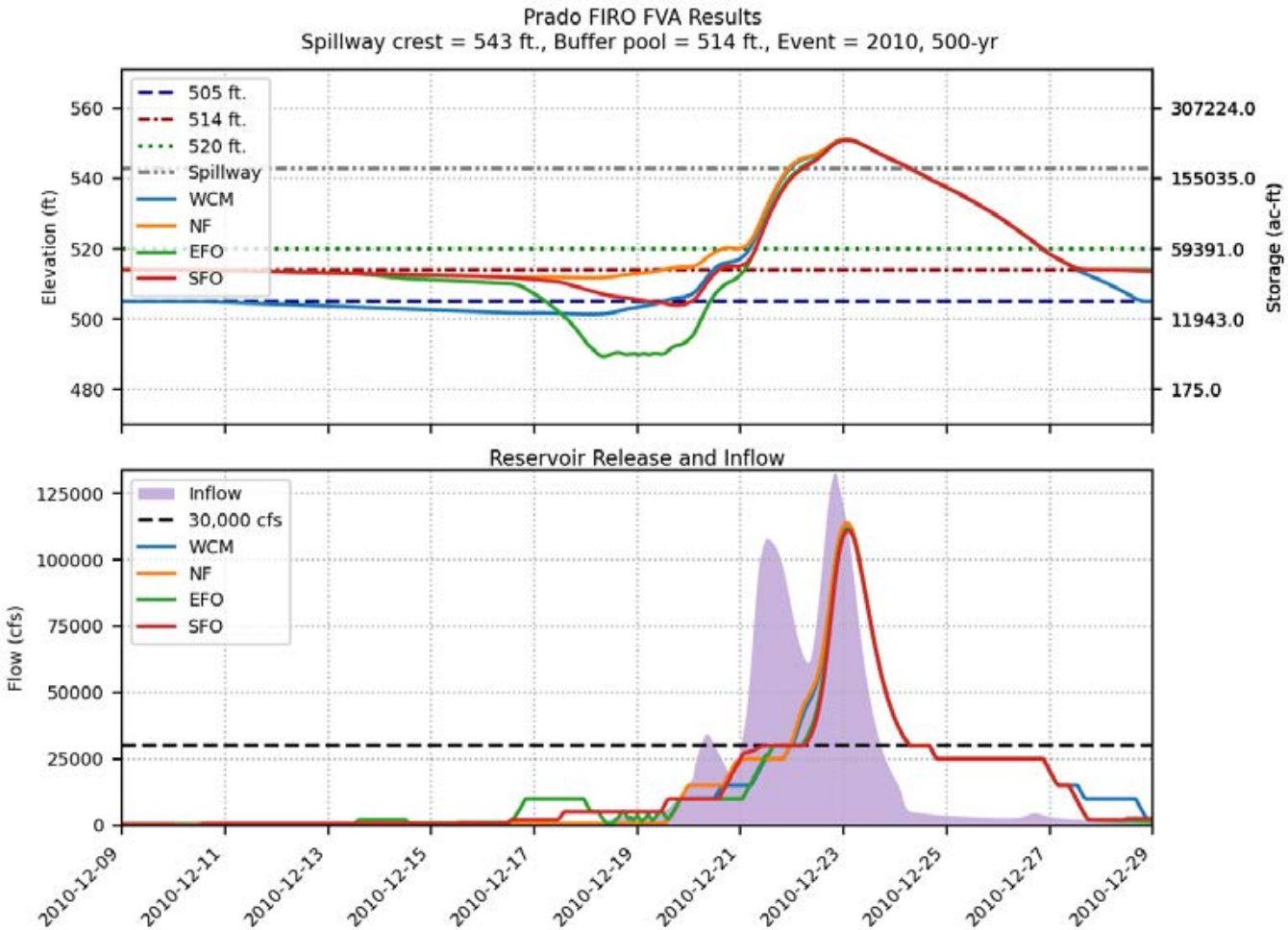
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 514 ft., Event = 2010, 500-yr
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Spillway
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
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520
500
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155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
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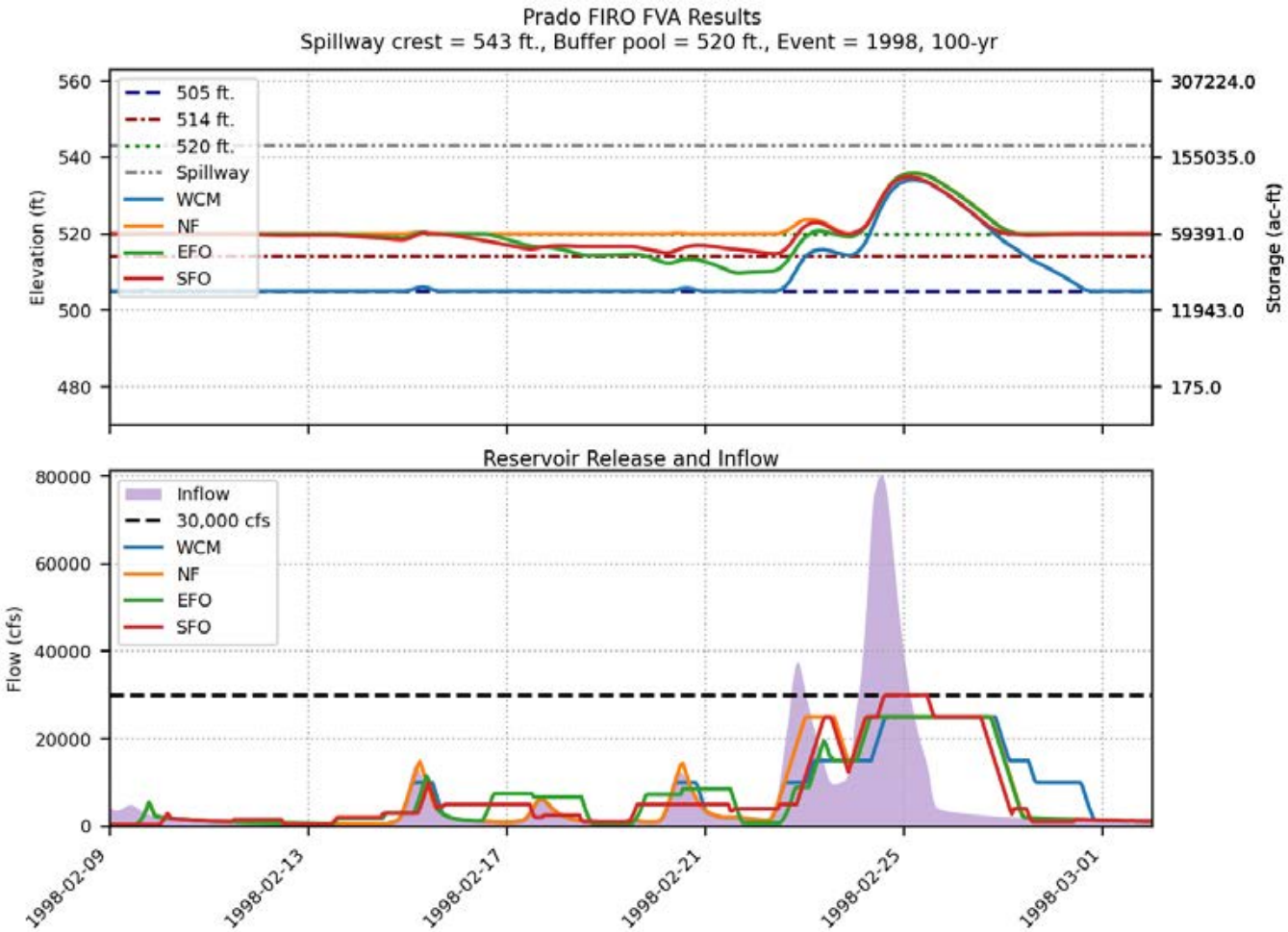
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WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
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520
500
480
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155035.0
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Reservoir Release and Inflow
Inflow
30,000 cfs
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Flow (cfs)
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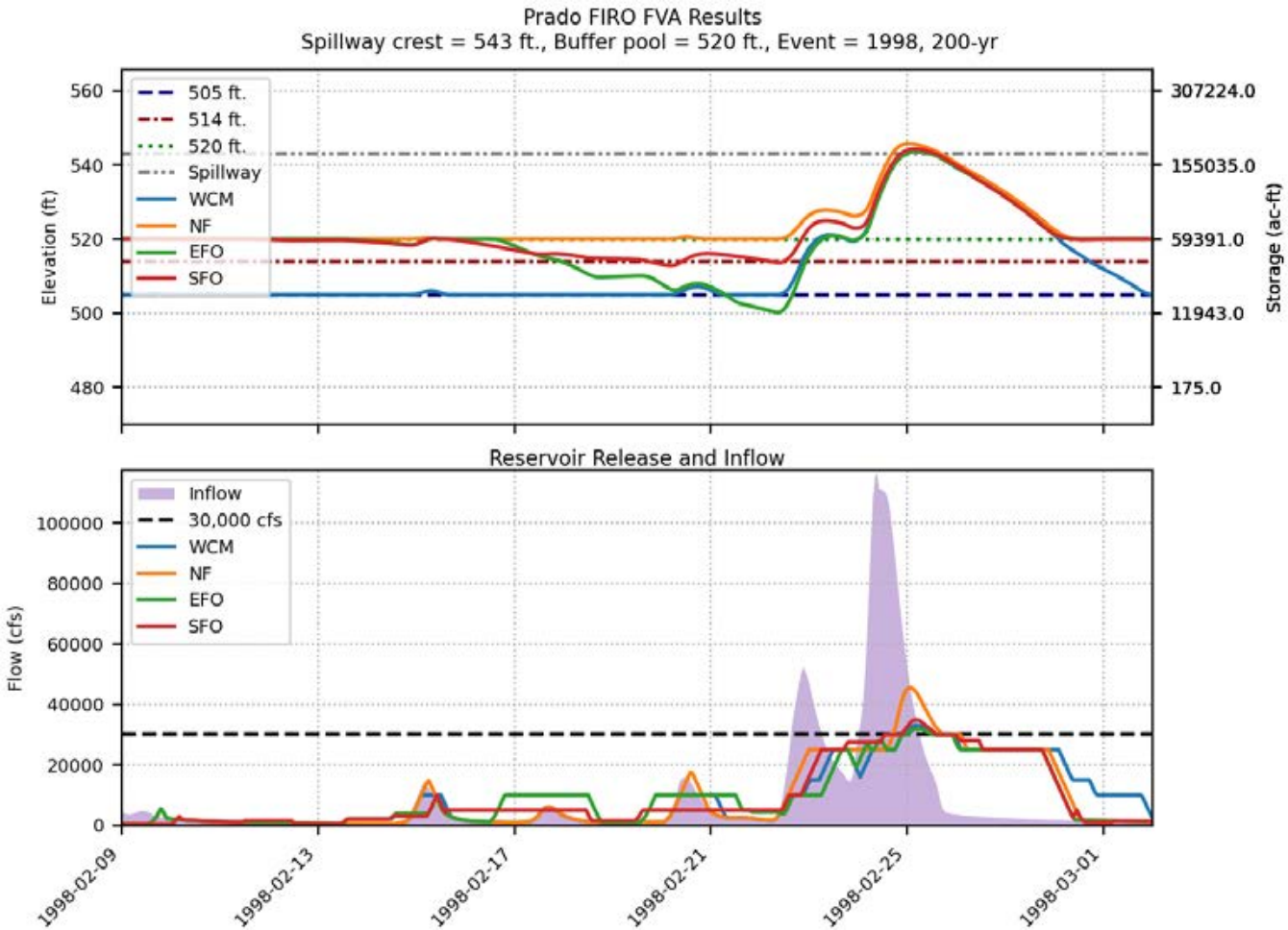
Prado FIRO FVA Results
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514 ft.
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Spillway
WCM
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EFO
SFO
Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
Inflow
30,000 cfs
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Flow (cfs)
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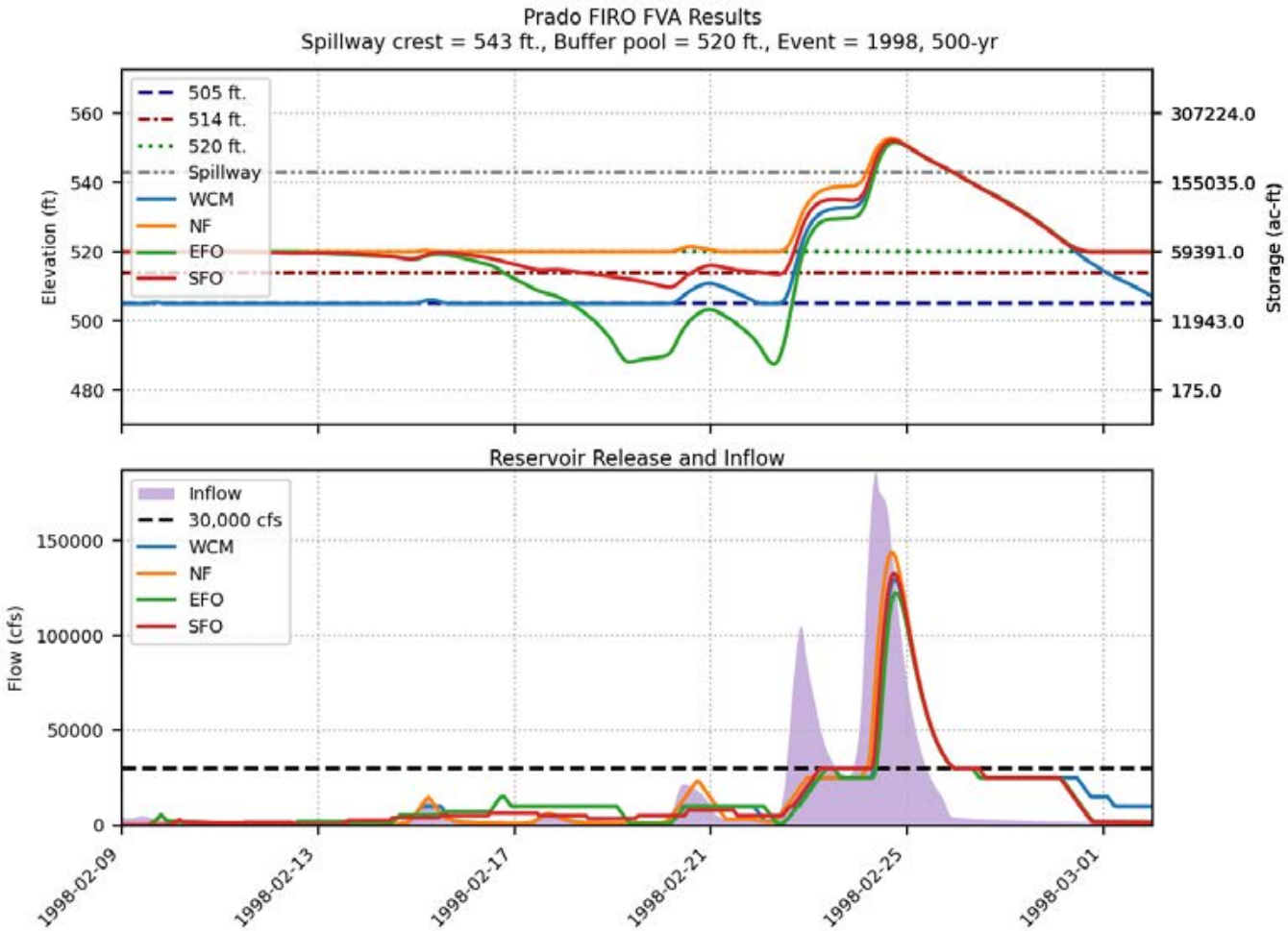
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514 ft.
520 ft.
Spillway
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Elevation (ft)
Storage (ac-ft)
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307224.0
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Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
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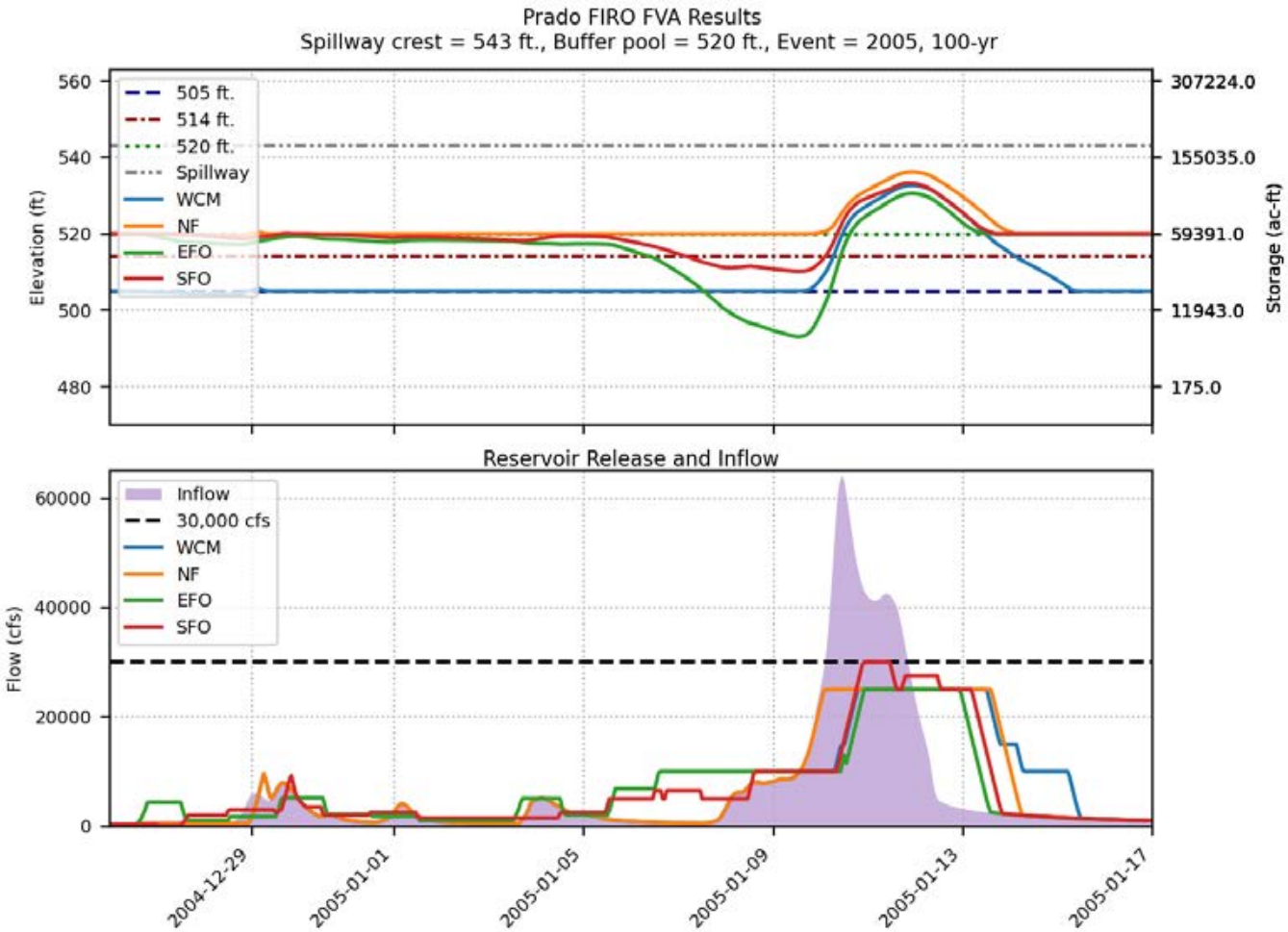
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 520 ft., Event = 2005, 100-yr
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514 ft.
520 ft.
Spillway
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Elevation (ft)
Storage (ac-ft)
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307224.0
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Reservoir Release and Inflow
Inflow
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Flow (cfs)
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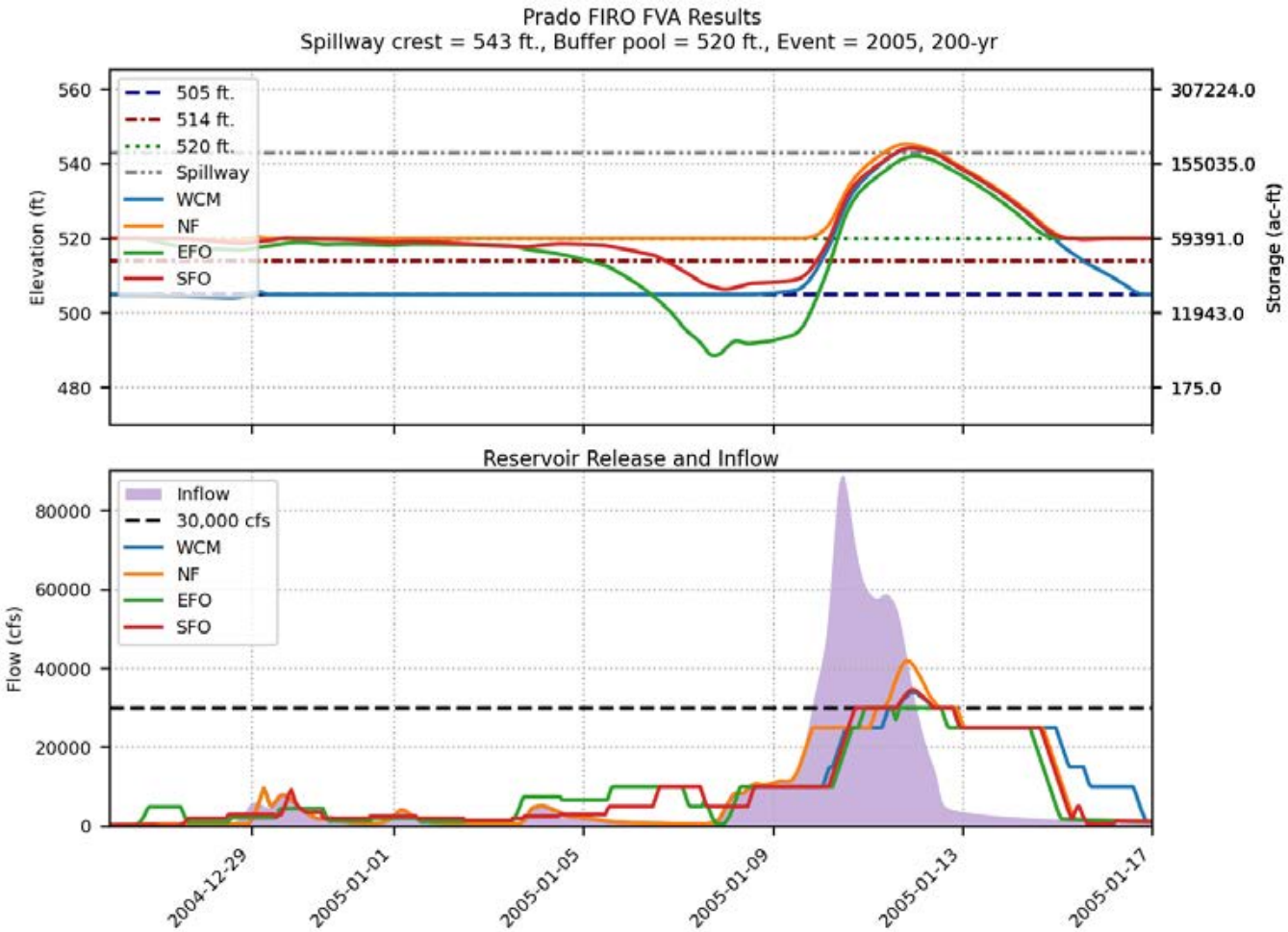
2005-01-17


Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 520 ft., Event = 2005, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
80000
60000
40000
20000
0
2004-12-29
2005-01-01
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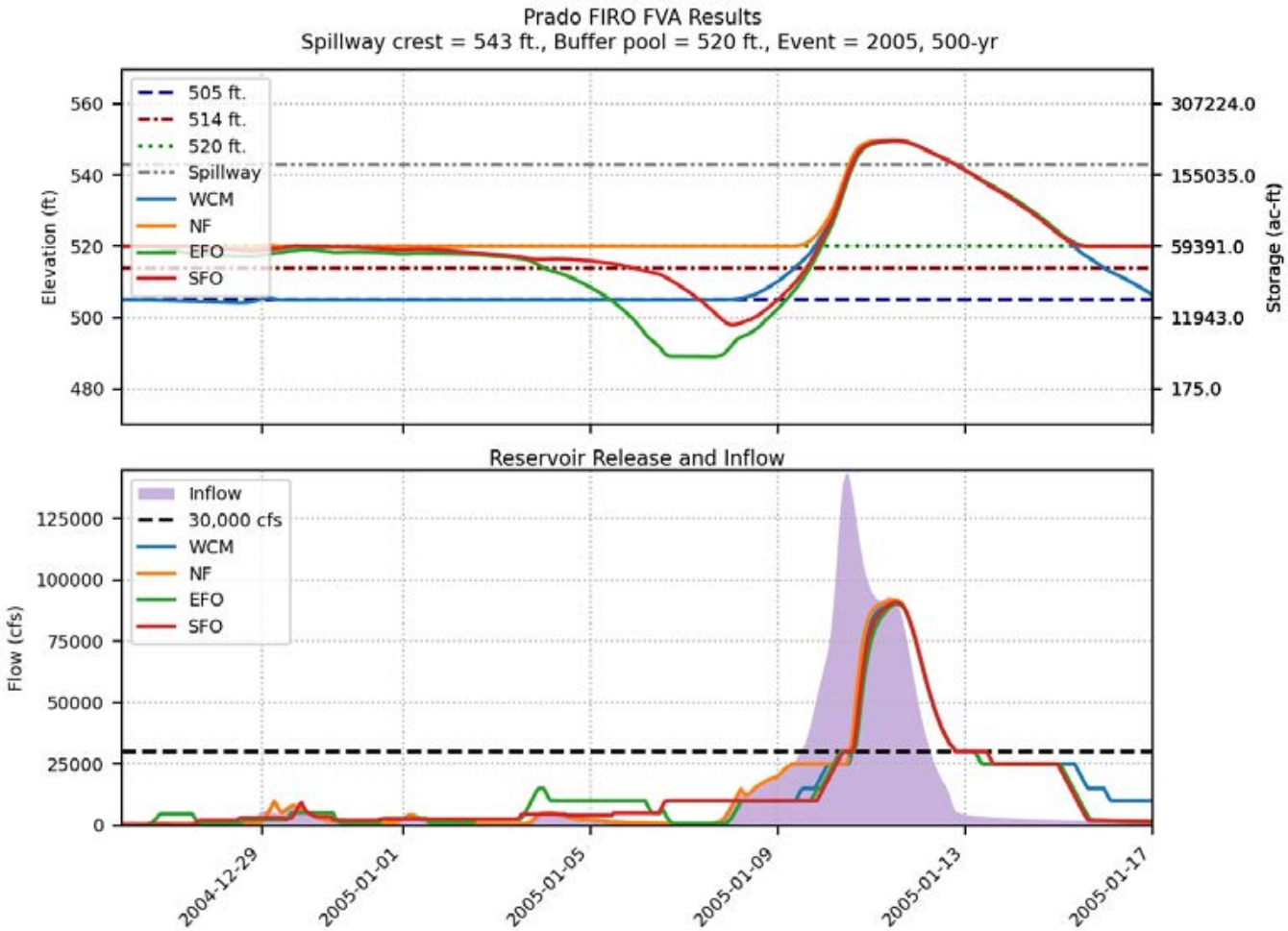
2005-01-09
2005-01-13
2005-01-17


Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 520 ft., Event = 2005, 500-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
125000
100000
75000
50000
25000
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2004-12-29
2005-01-01
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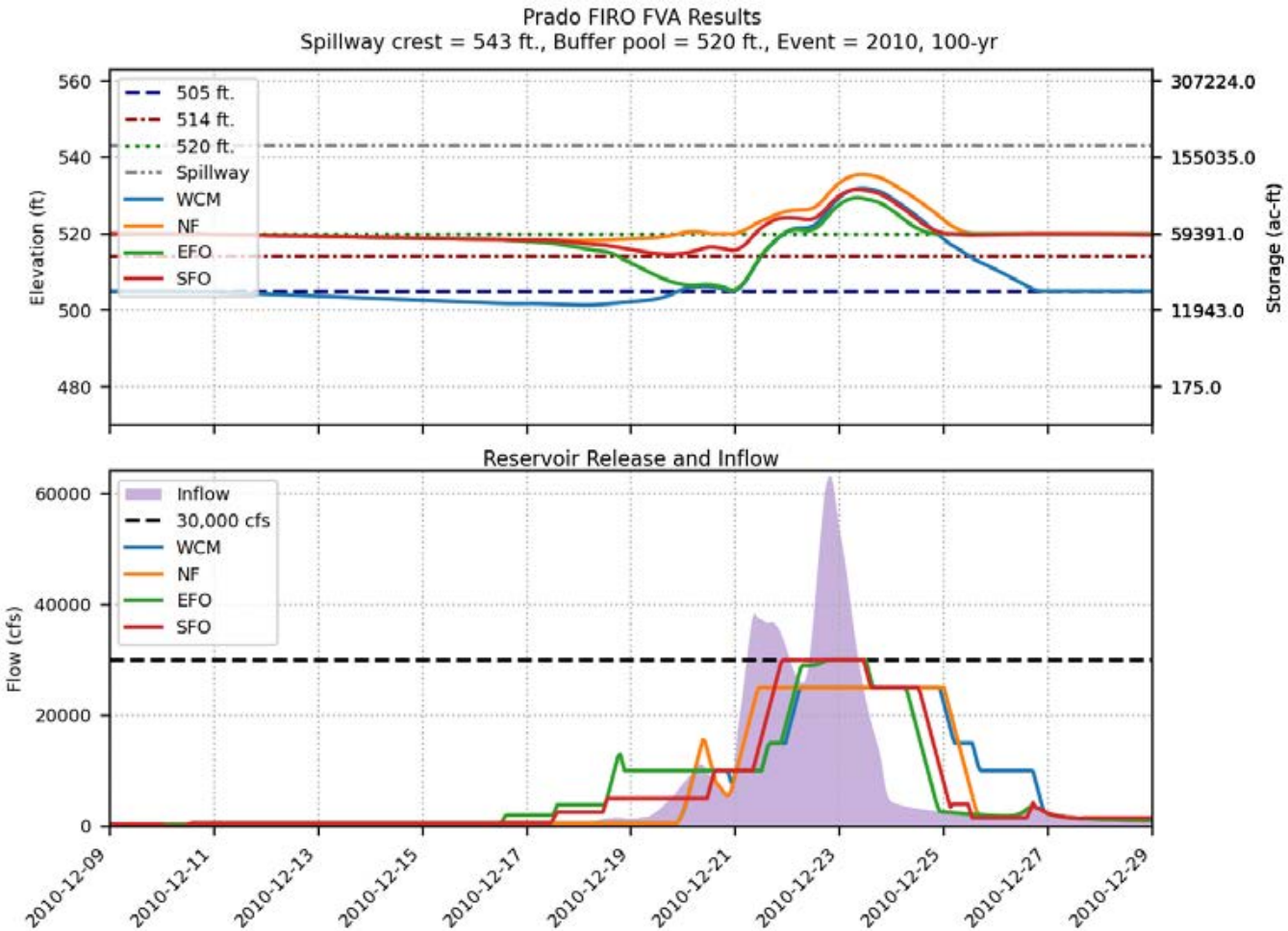
2005-01-09
2005-01-13
2005-01-17


Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 520 ft., Event = 2010, 100-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
60000
40000
20000
0
2010-12-09
2010-12-11
2010-12-13
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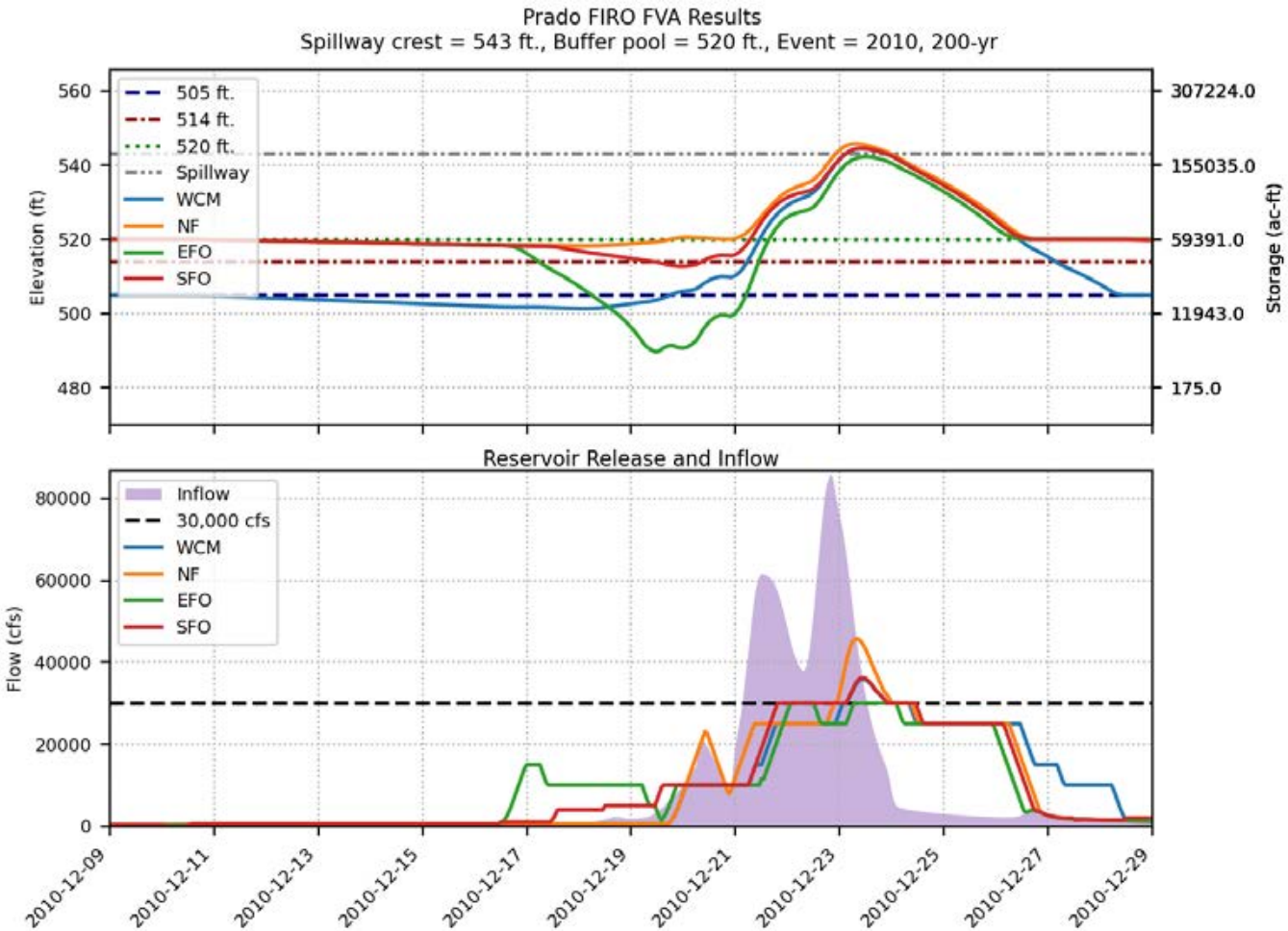
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 520 ft., Event = 2010, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
80000
60000
40000
20000
0
2010-12-09
2010-12-11
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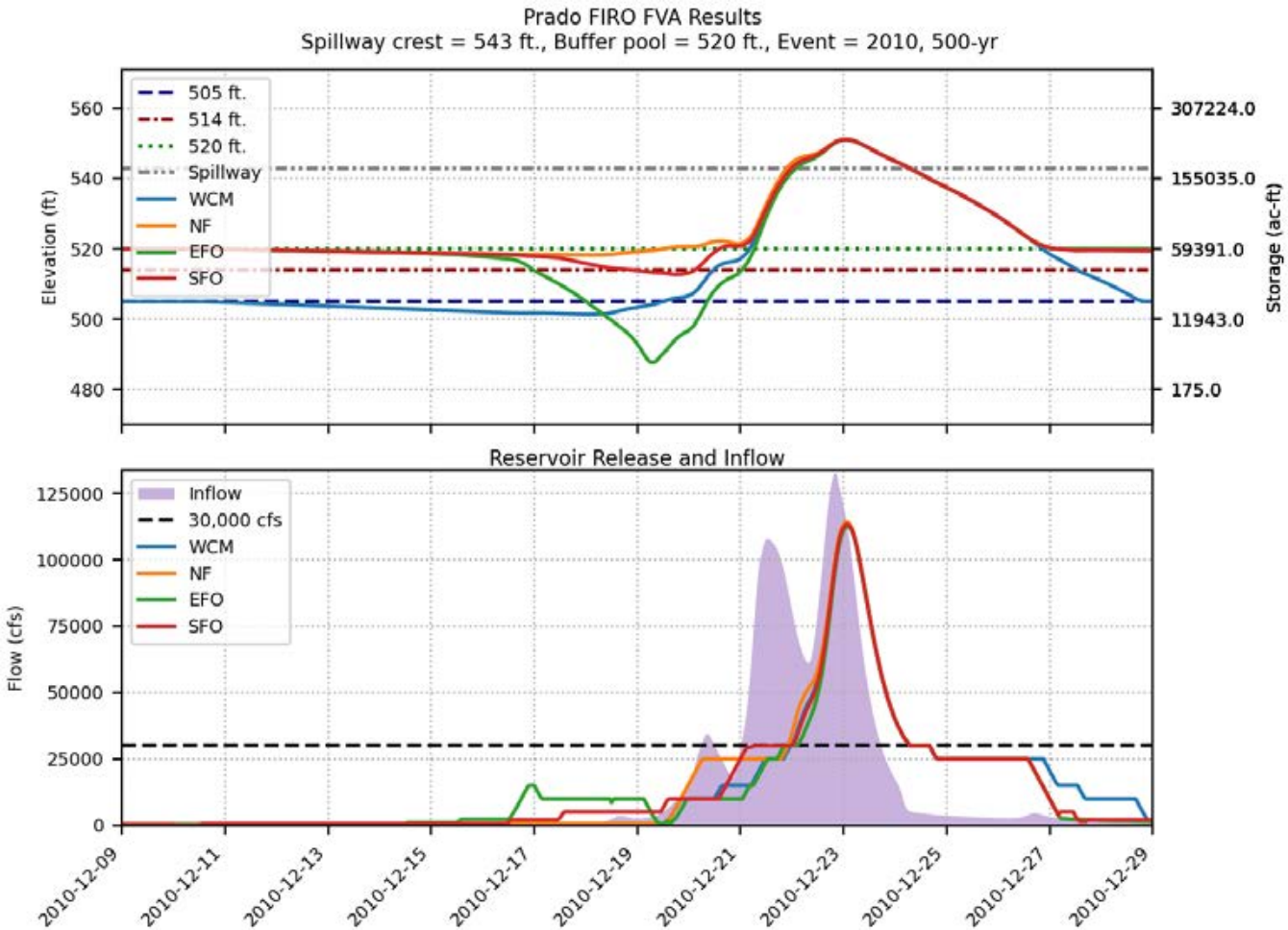
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 520 ft., Event = 2010, 500-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
125000
100000
75000
50000
25000
0
2010-12-09
2010-12-11
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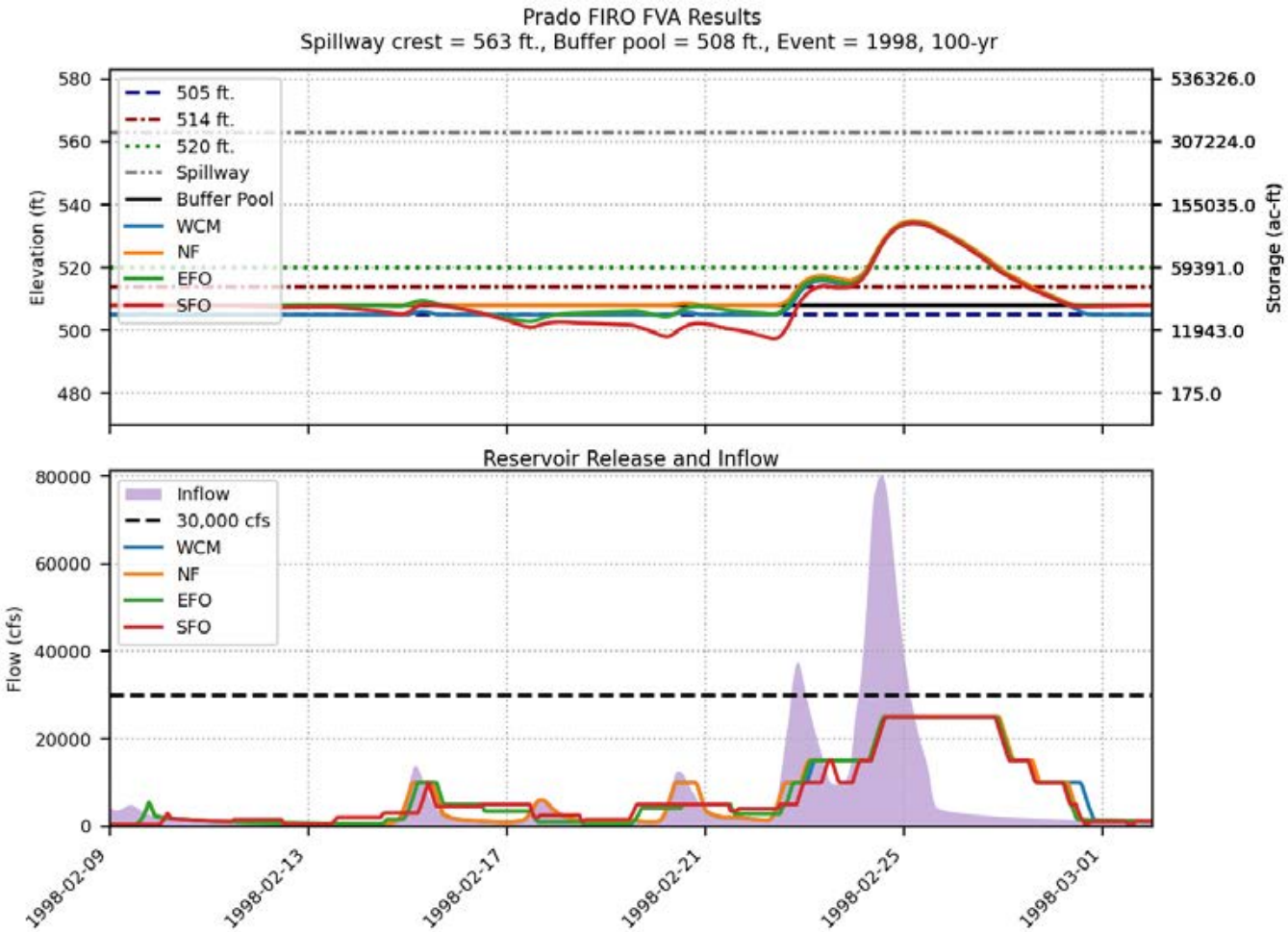
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 508 ft., Event = 1998, 100-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
80000
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40000
20000
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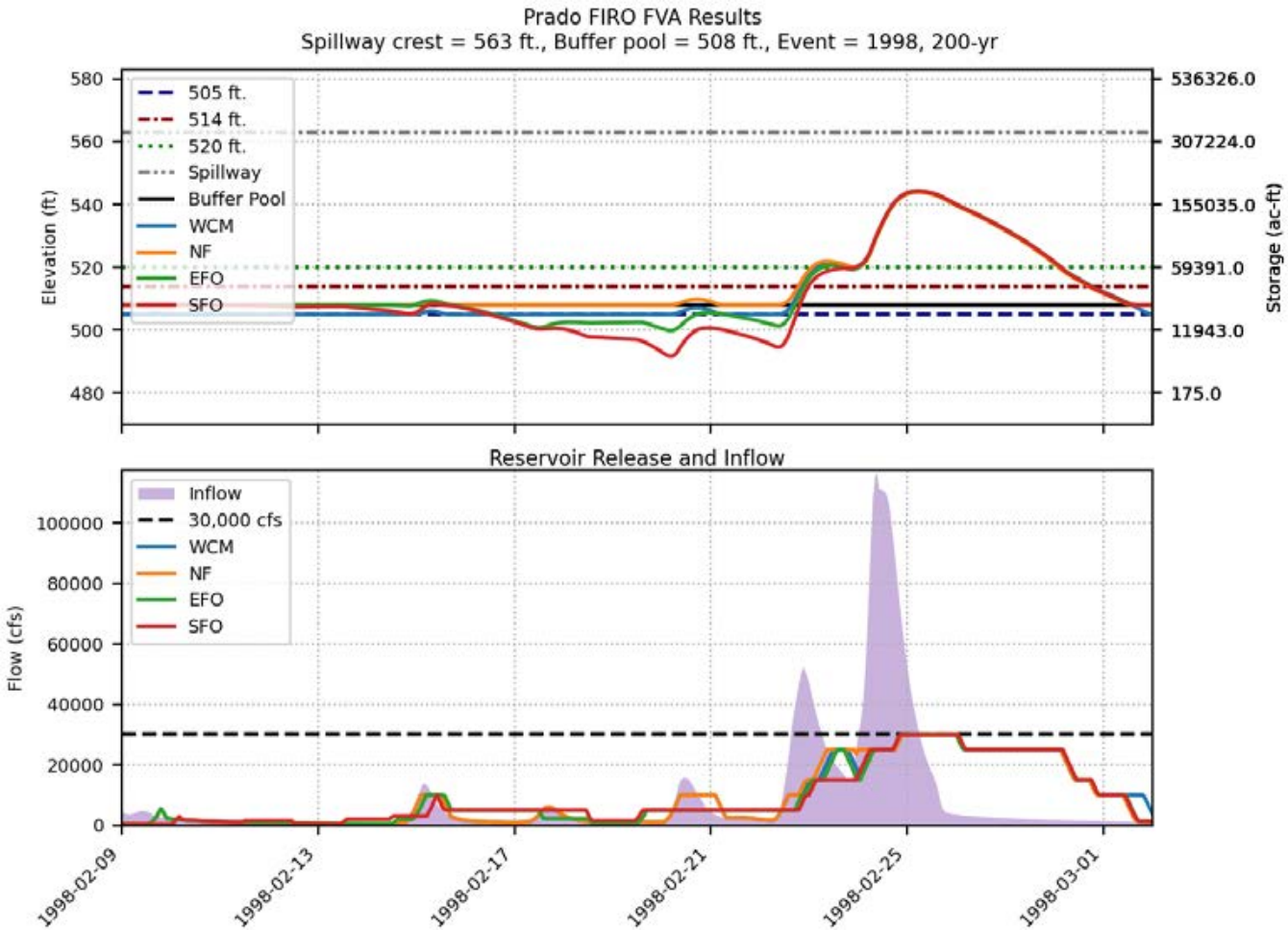
1998-02-25
1998-03-01


Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 508 ft., Event = 1998, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
100000
80000
60000
40000
20000
0
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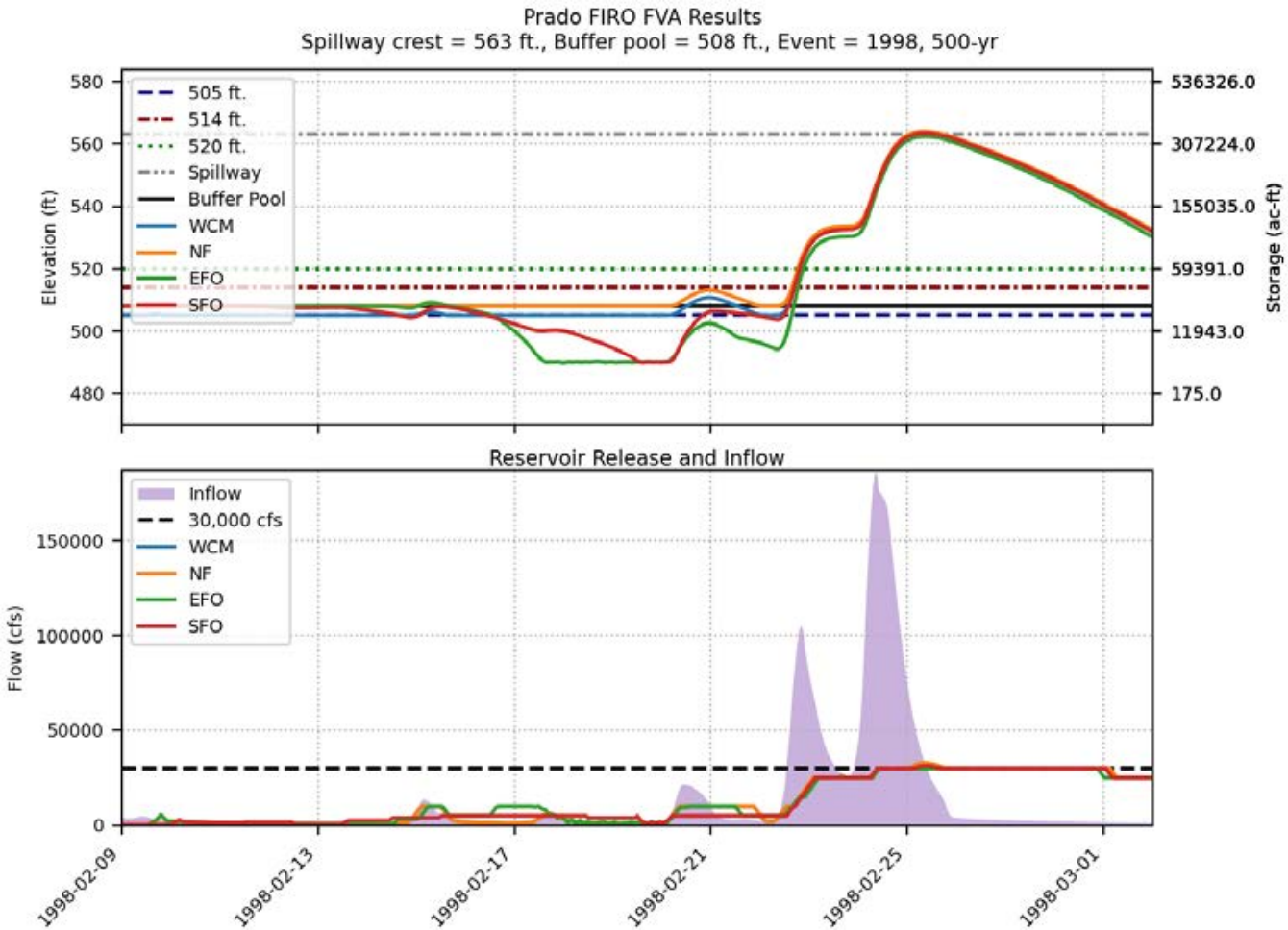
1998-02-25
1998-03-01


Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 508 ft., Event = 1998, 500-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
150000
100000
50000
0
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1998-02-13
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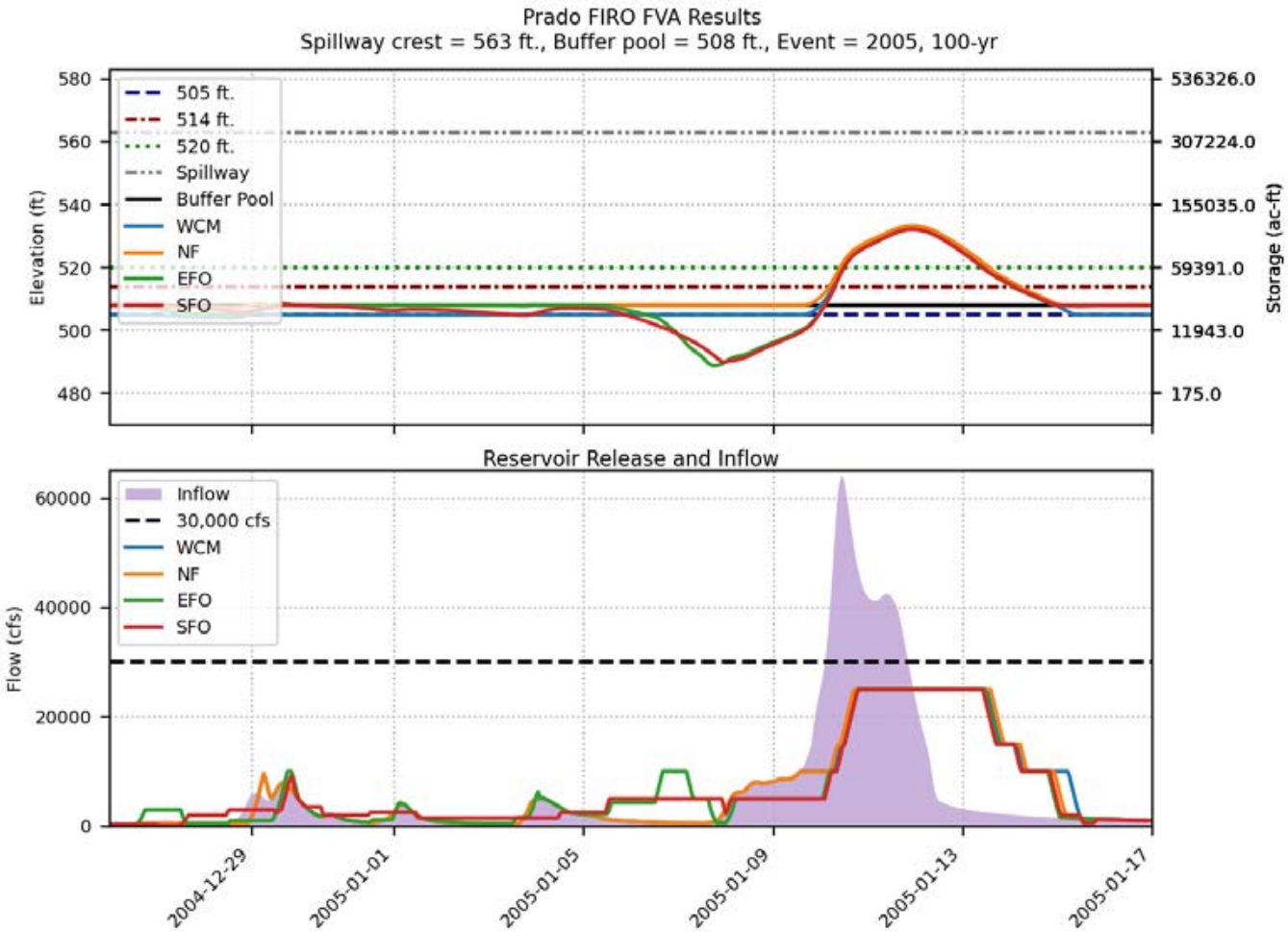
1998-02-21
1998-02-25
1998-03-01


Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 508 ft., Event = 2005, 100-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
60000
40000
20000
0
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2005-01-01
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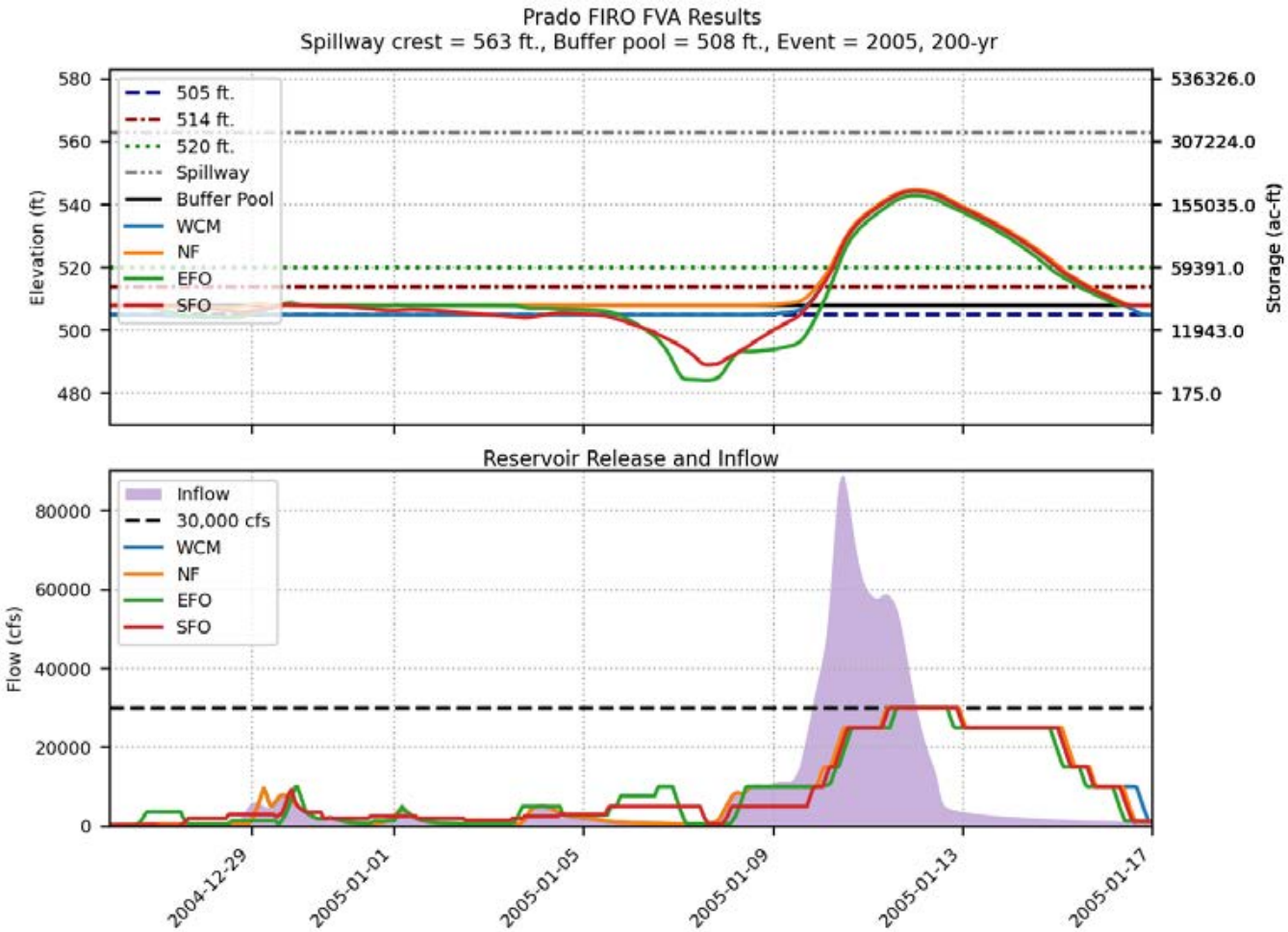
2005-01-17


Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 508 ft., Event = 2005, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
80000
60000
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0
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2005-01-01
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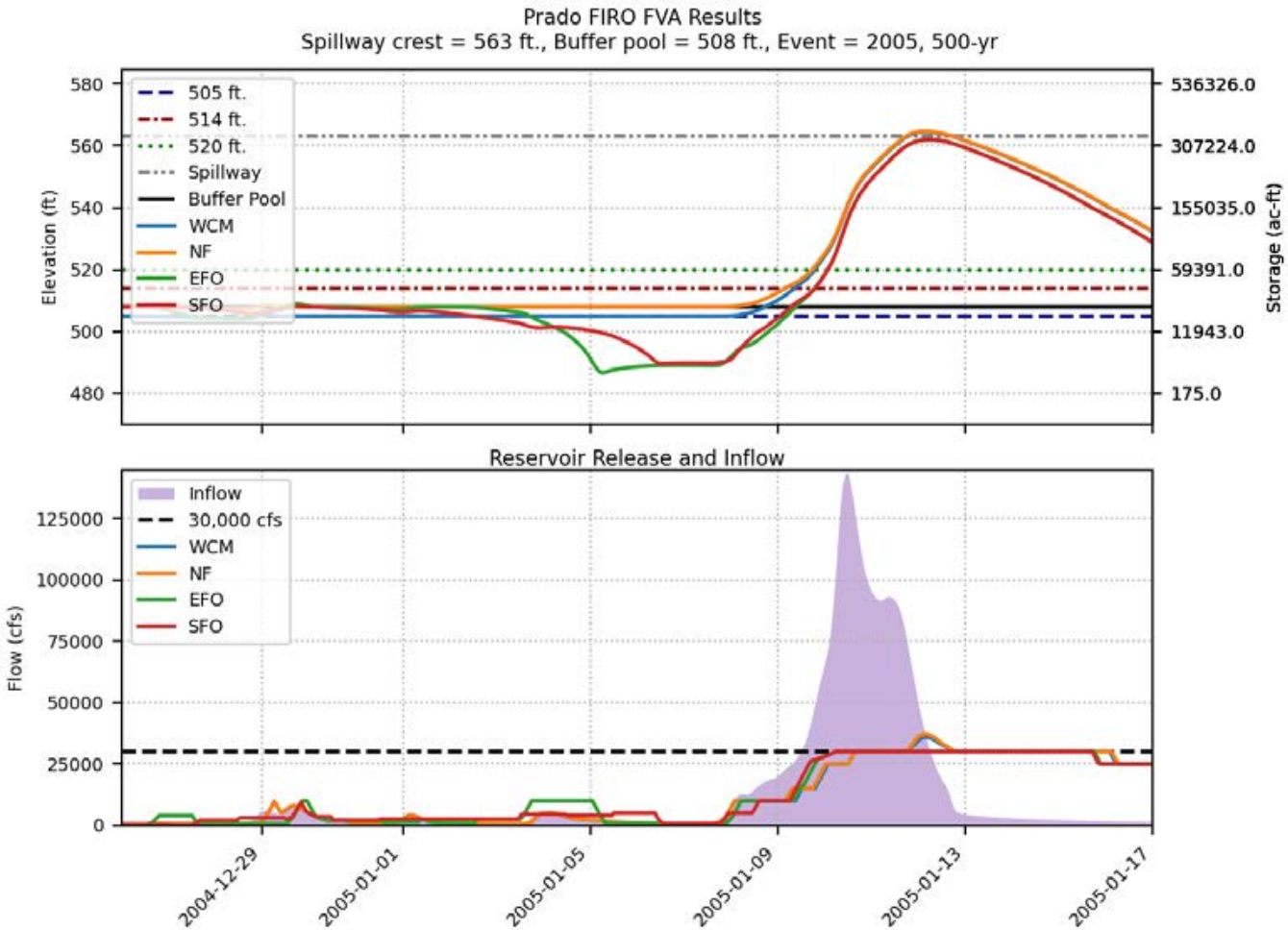
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 508 ft., Event = 2005, 500-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
125000
100000
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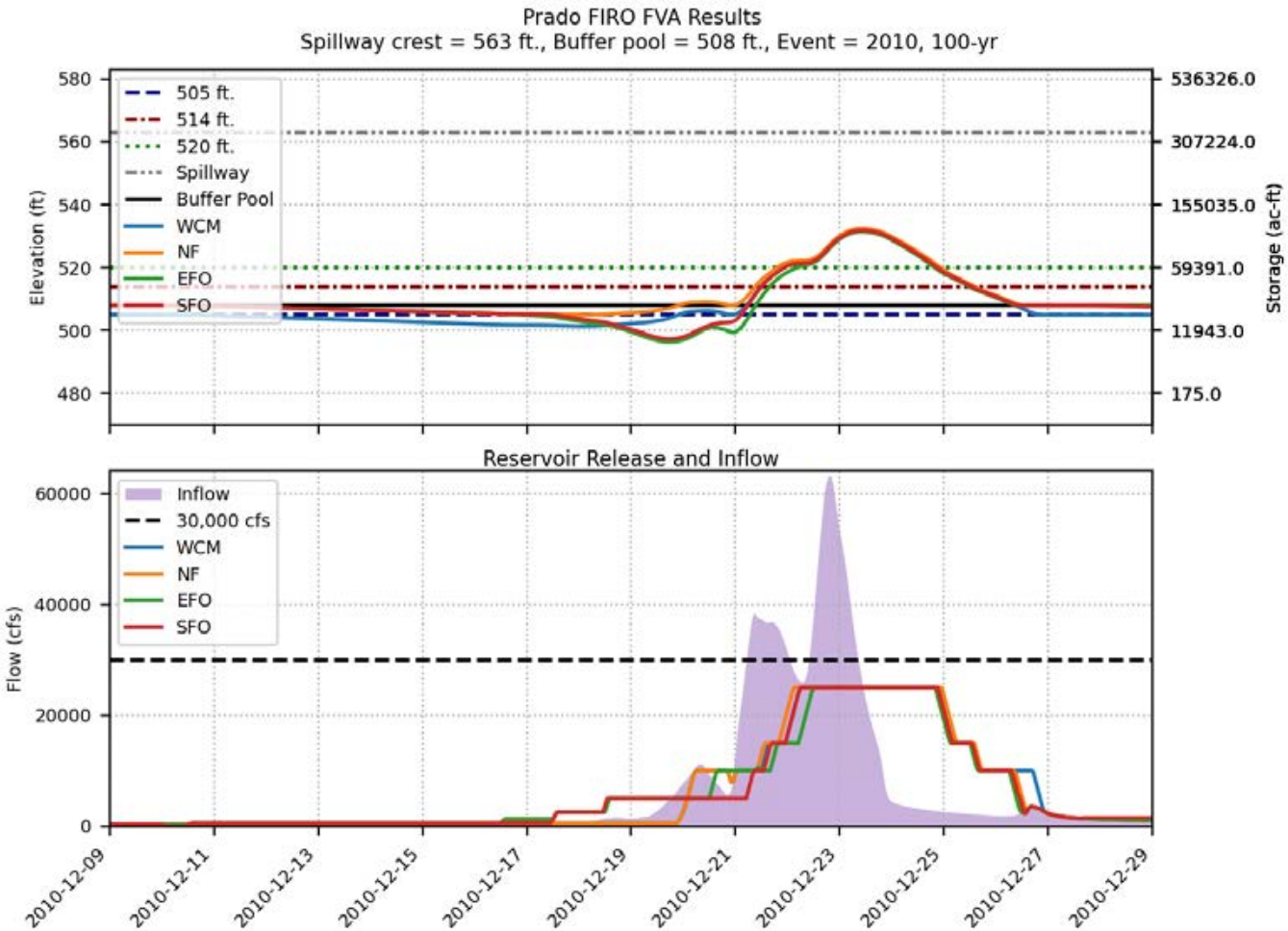
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 508 ft., Event = 2010, 100-yr
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514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
60000
40000
20000
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2010-12-09
2010-12-11
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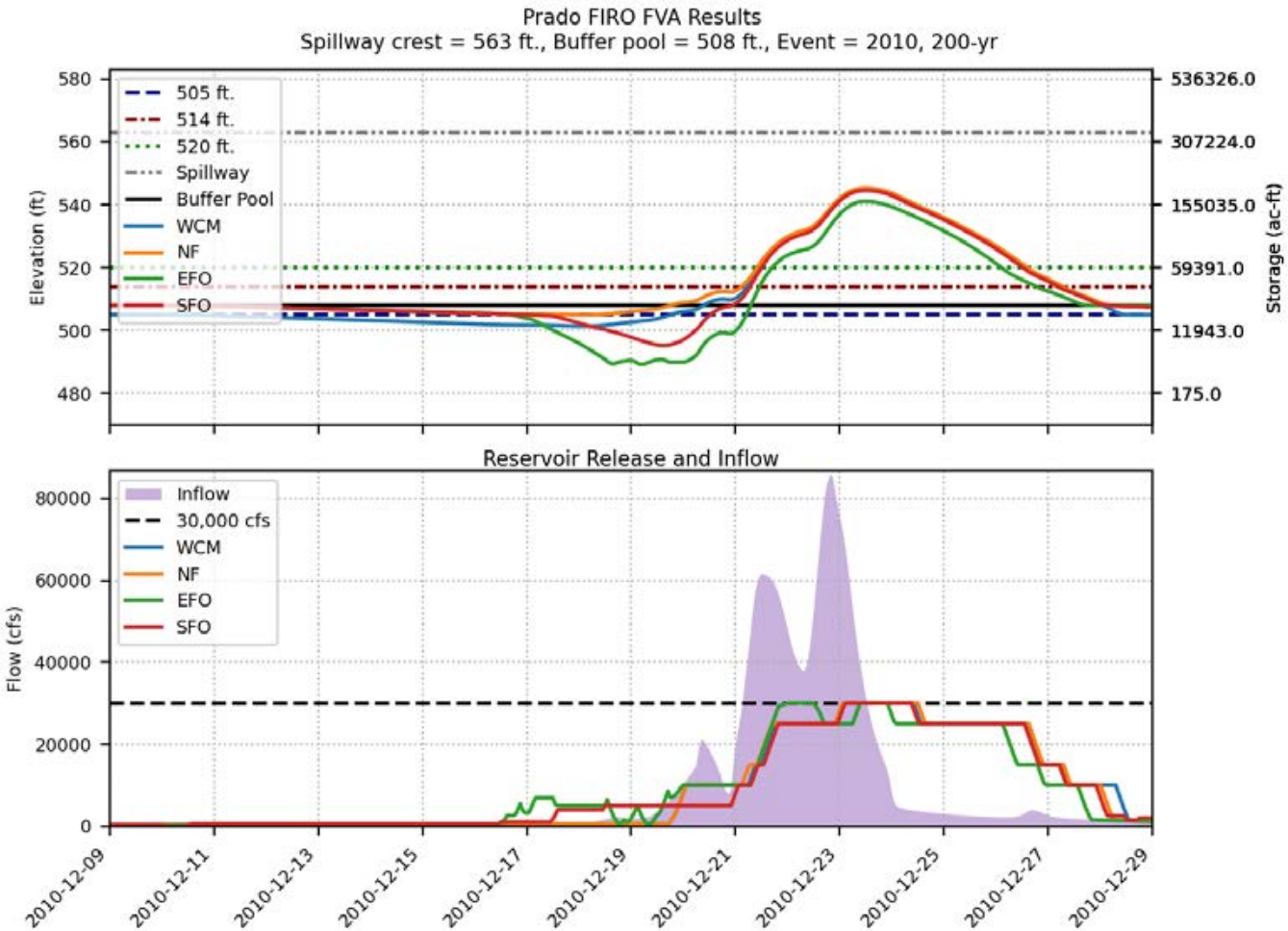
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 508 ft., Event = 2010, 200-yr
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514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
80000
60000
40000
20000
0
2010-12-09
2010-12-11
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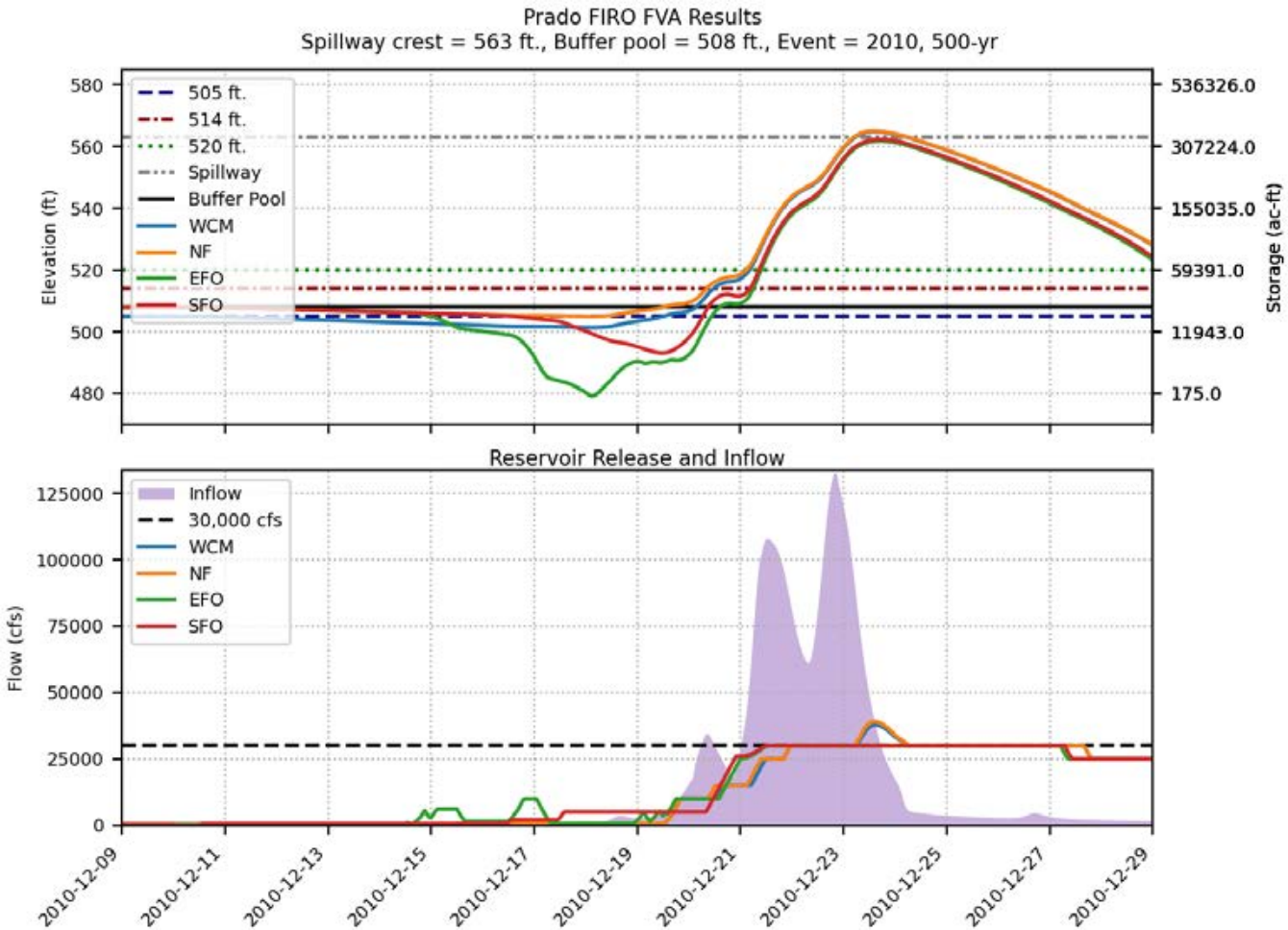
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 508 ft., Event = 2010, 500-yr
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514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
580
560
540
520
500
480
536326.0
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59391.0
11943.0
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Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
125000
100000
75000
50000
25000
0
2010-12-09
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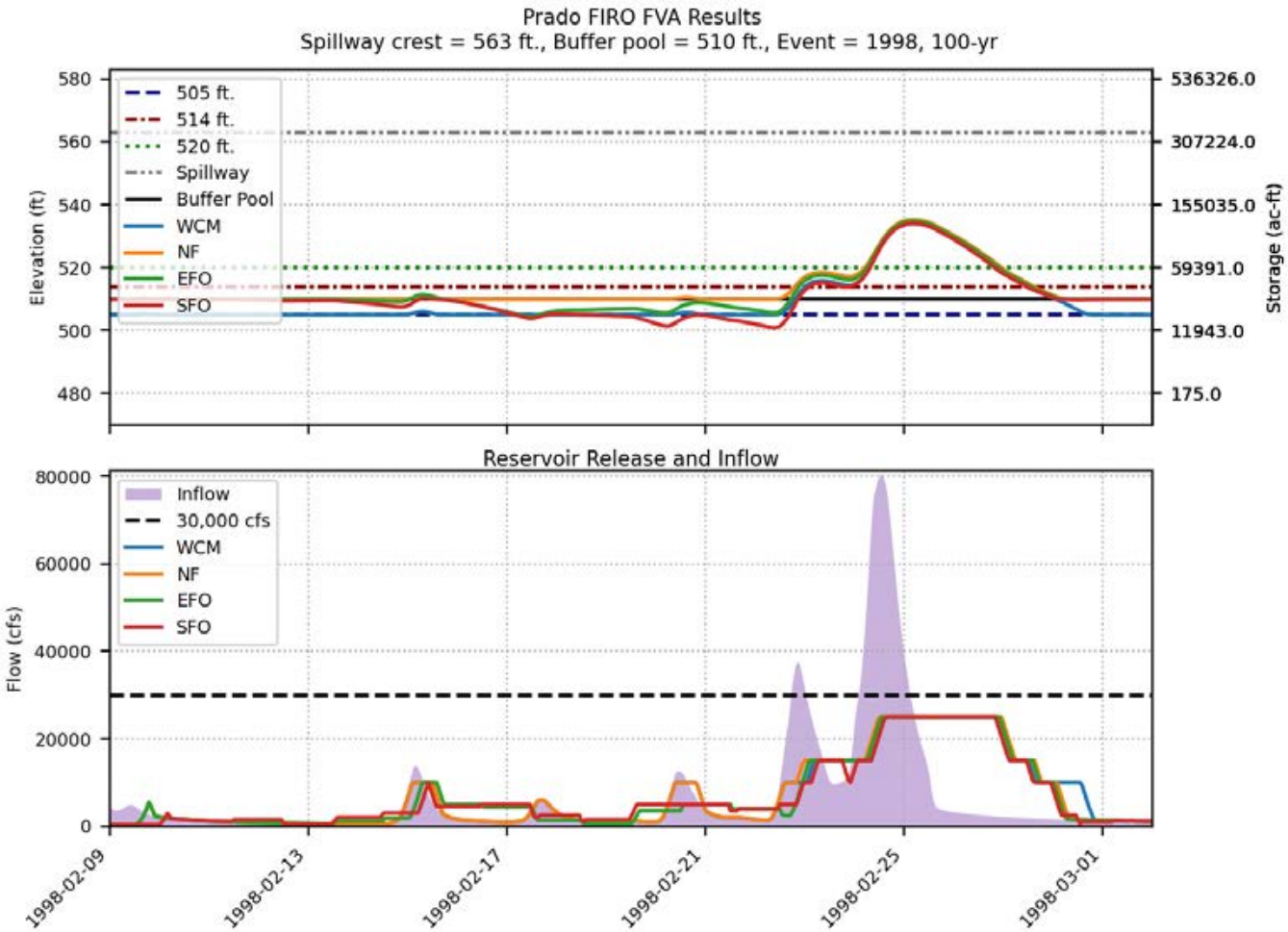
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 510 ft., Event = 1998, 100-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
WCM
NF
EFO
SFO
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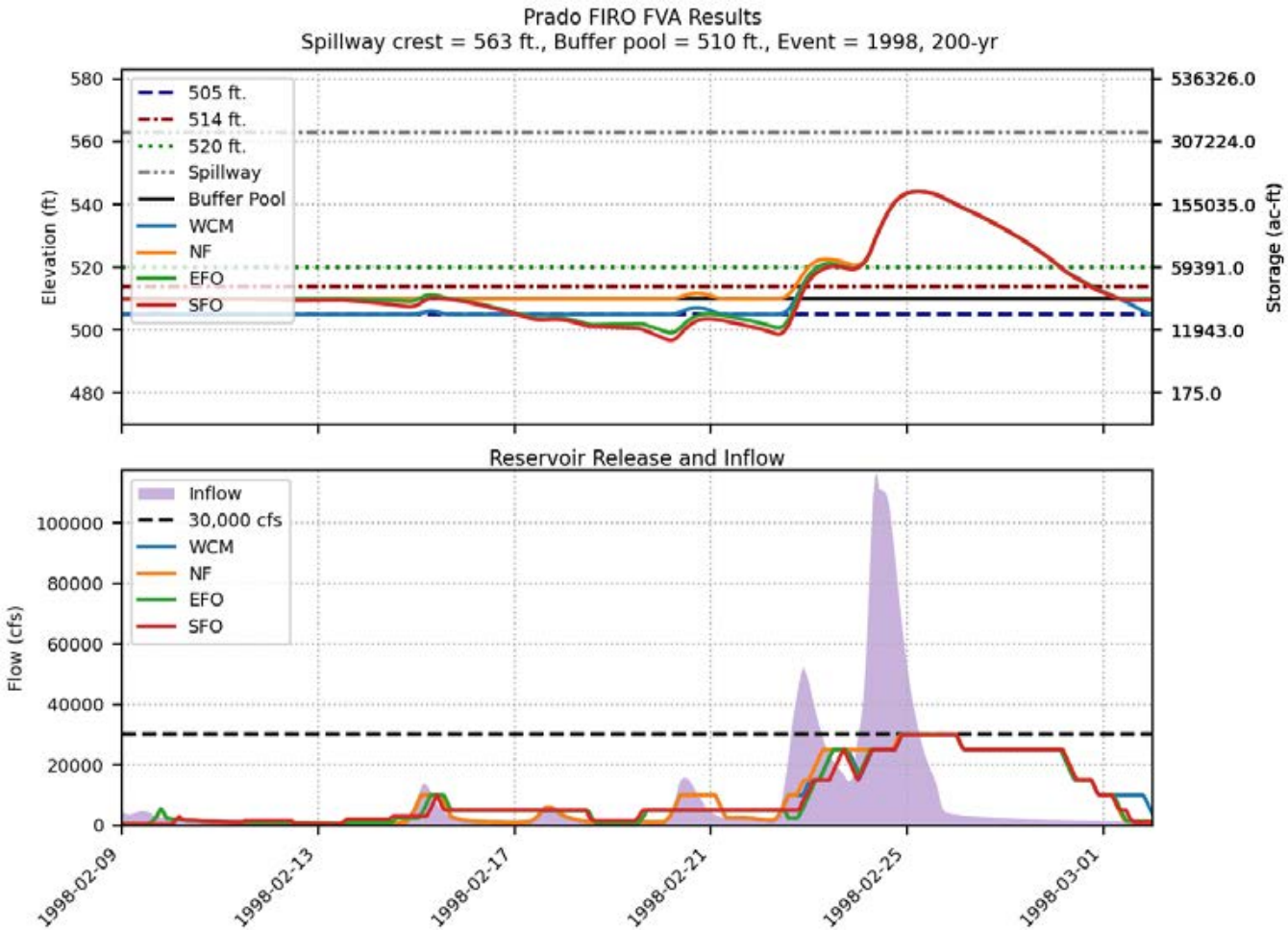
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 510 ft., Event = 1998, 200-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
580
560
540
520
500
480
536326.0
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59391.0
11943.0
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Reservoir Release and Inflow
Flow (cfs)
Inflow
30,000 cfs
WCM
NF
EFO
SFO
100000
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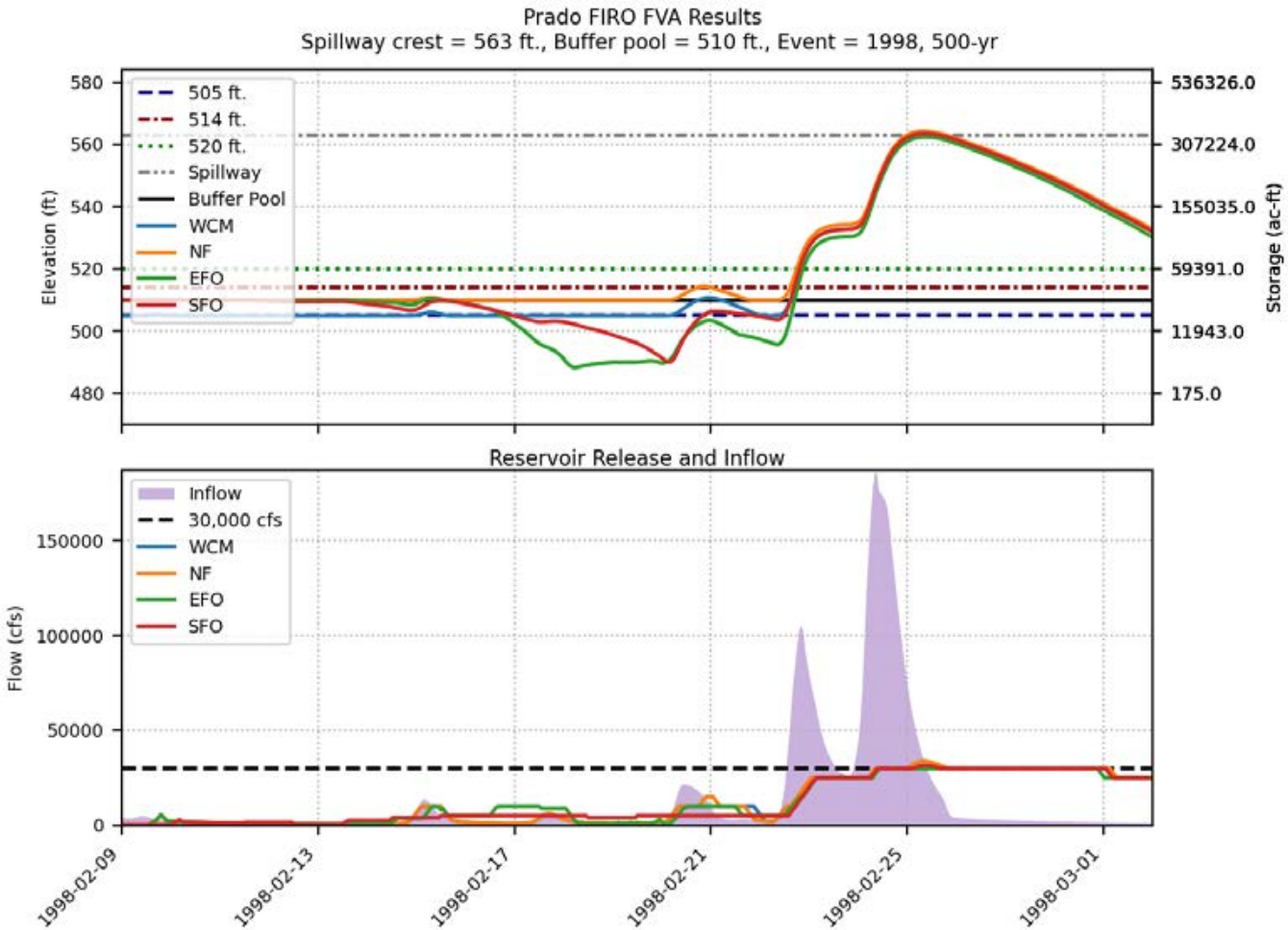
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 510 ft., Event = 1998, 500-yr
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514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
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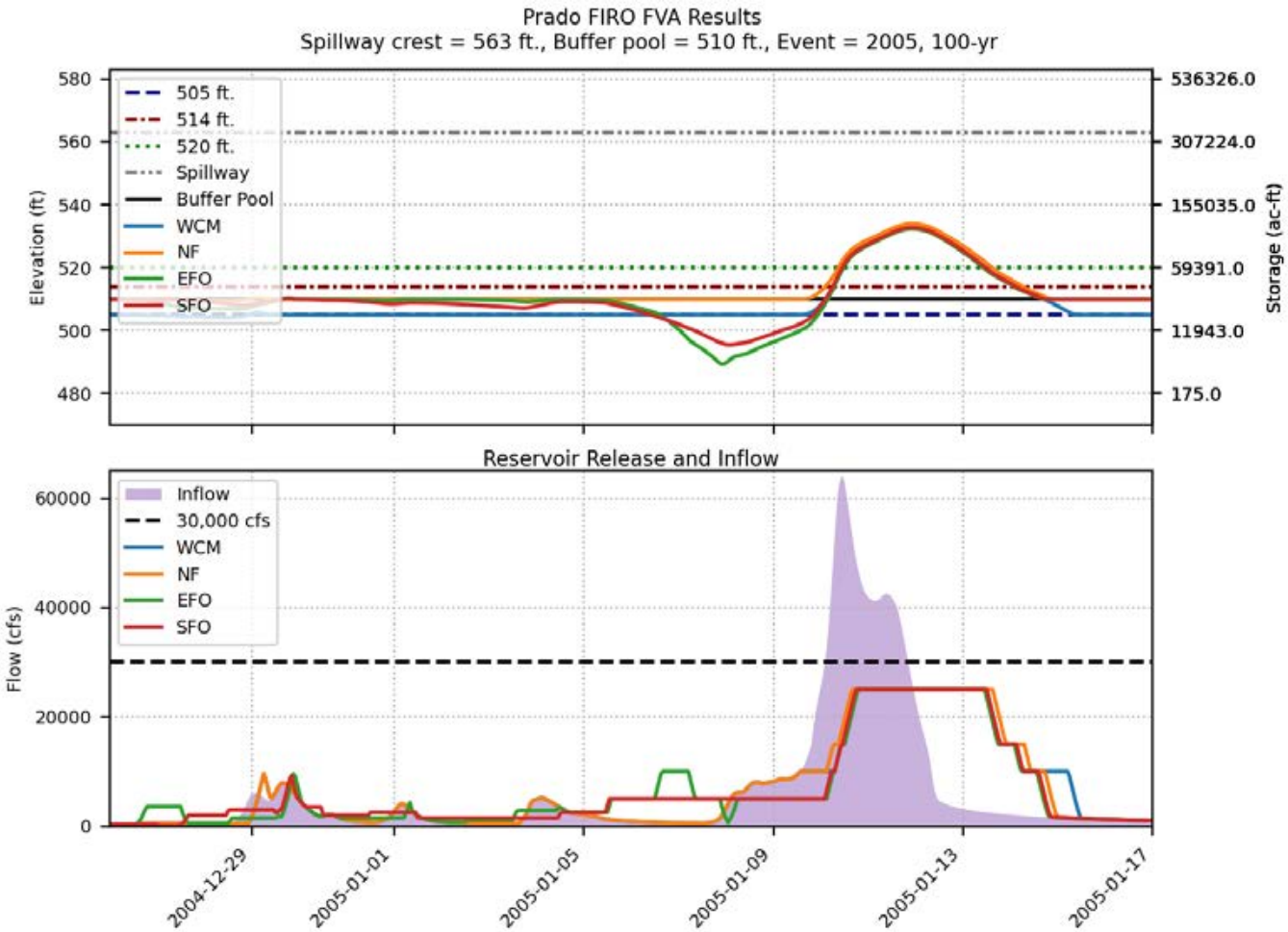
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 510 ft., Event = 2005, 100-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
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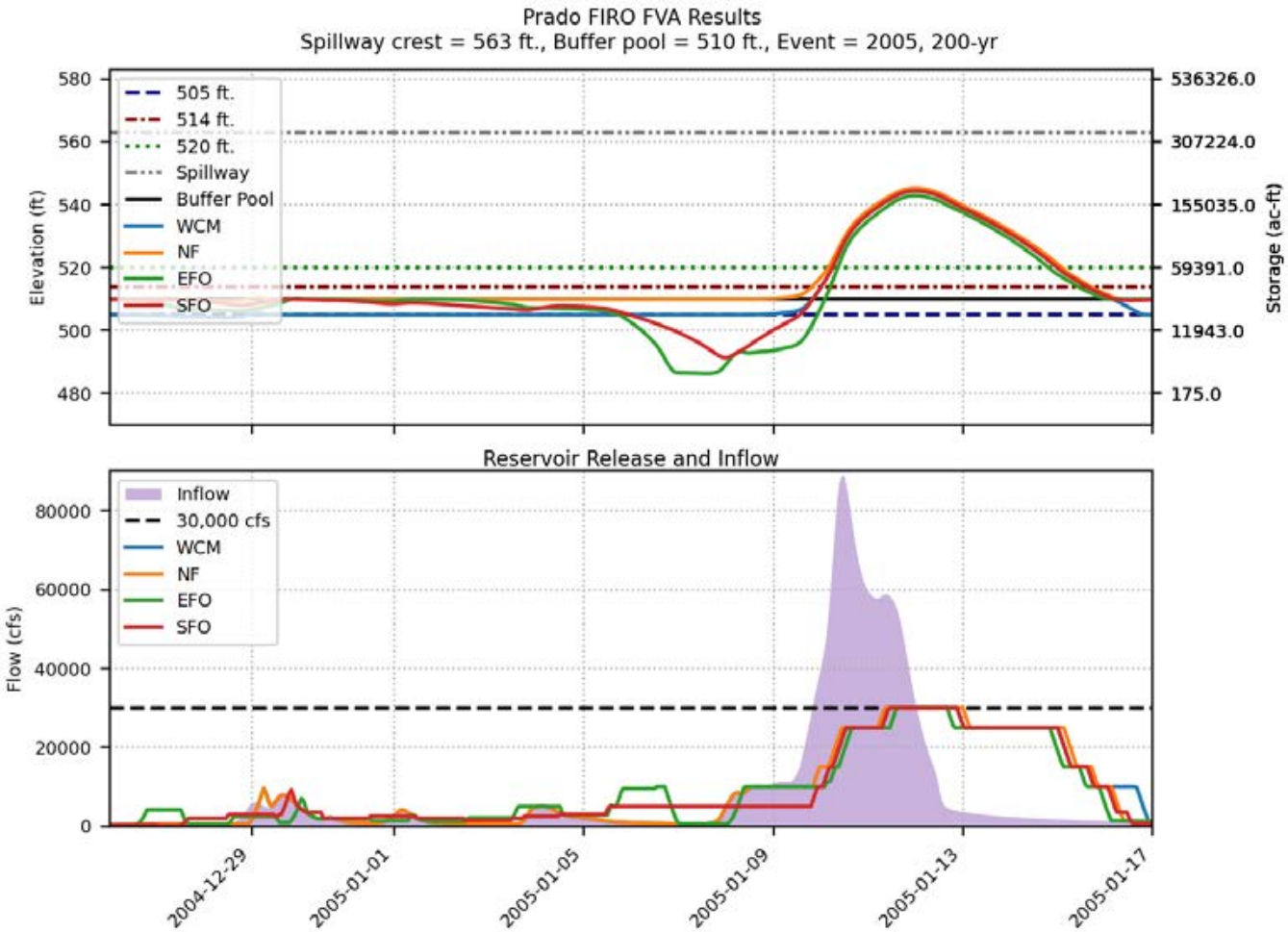
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 510 ft., Event = 2005, 200-yr
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514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
580
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500
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536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
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EFO
SFO
Flow (cfs)
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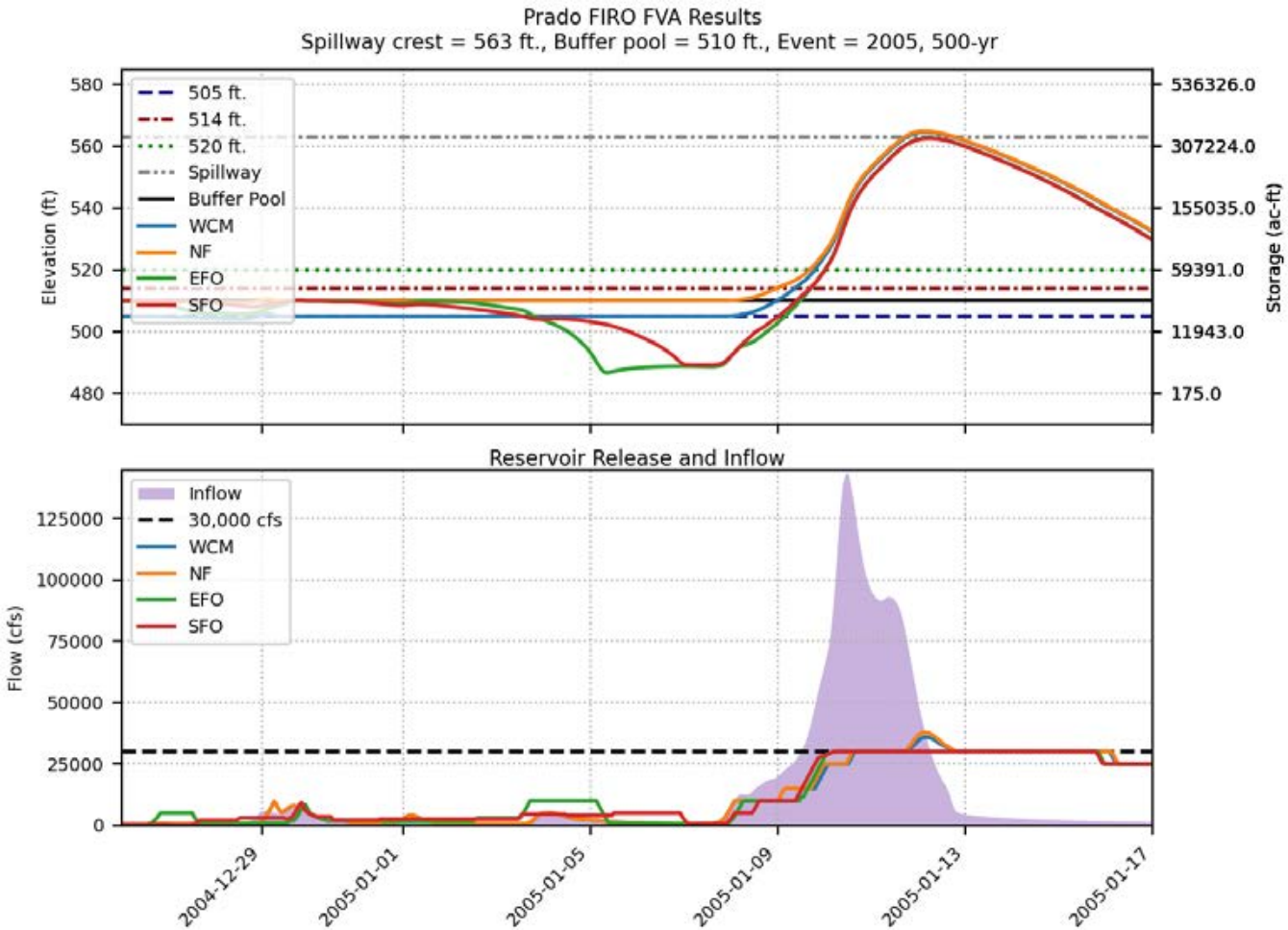
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 510 ft., Event = 2005, 500-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
580
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540
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500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
125000
100000
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2005-01-01
2005-01-05
2005-01-09
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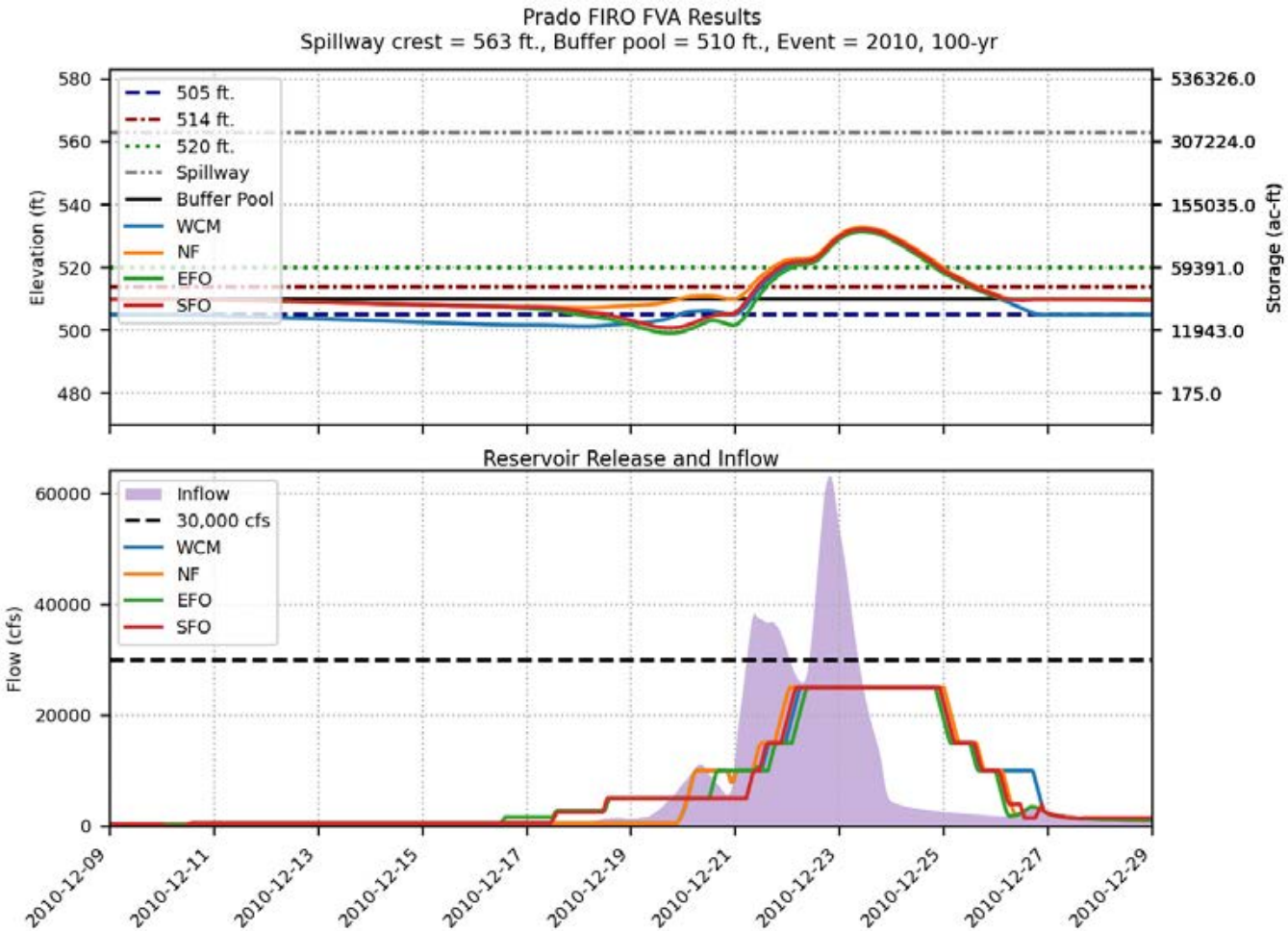
2005-01-17


Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 510 ft., Event = 2010, 100-yr
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514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
60000
40000
20000
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2010-12-09
2010-12-11
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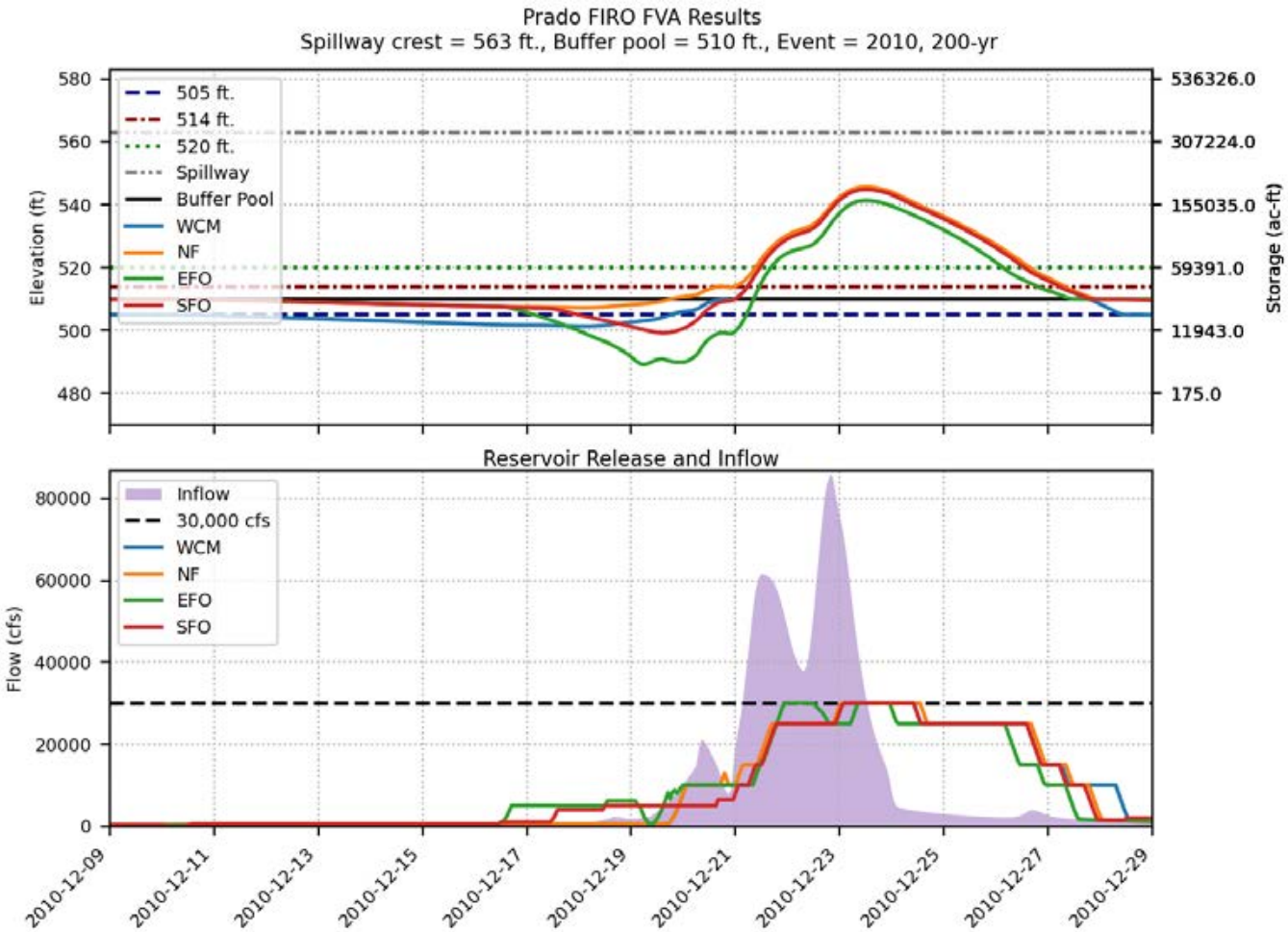
2010-12-29


Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 510 ft., Event = 2010, 200-yr
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514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
580
560
540
520
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480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
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30,000 cfs
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EFO
SFO
Flow (cfs)
80000
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2010-12-09
2010-12-11
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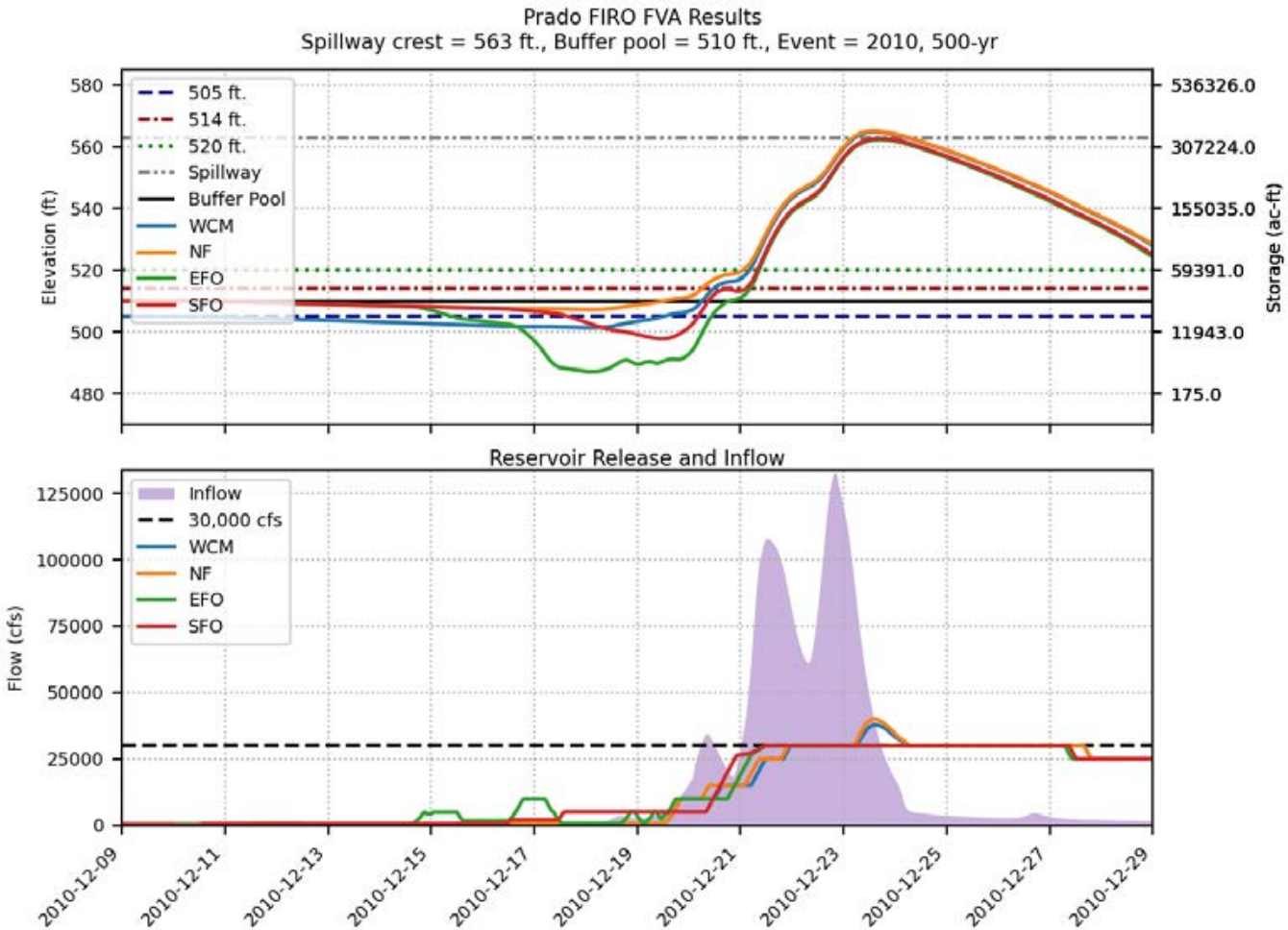
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 510 ft., Event = 2010, 500-yr
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514 ft.
520 ft.
Spillway
Buffer Pool
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
580
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520
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307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
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EFO
SFO
Flow (cfs)
125000
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2010-12-09
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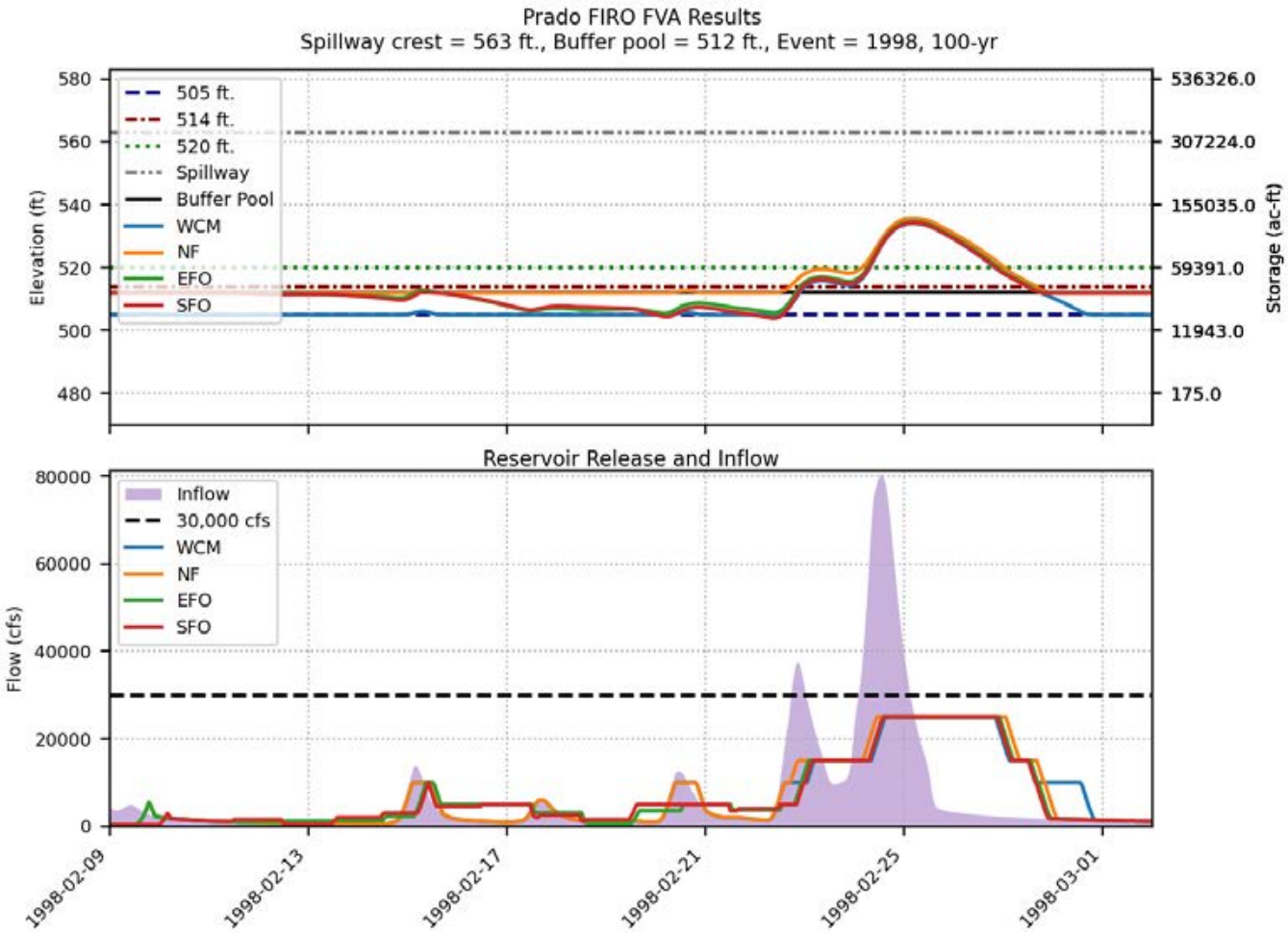
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 512 ft., Event = 1998, 100-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
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536326.0
307224.0
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Reservoir Release and Inflow
Flow (cfs)
Inflow
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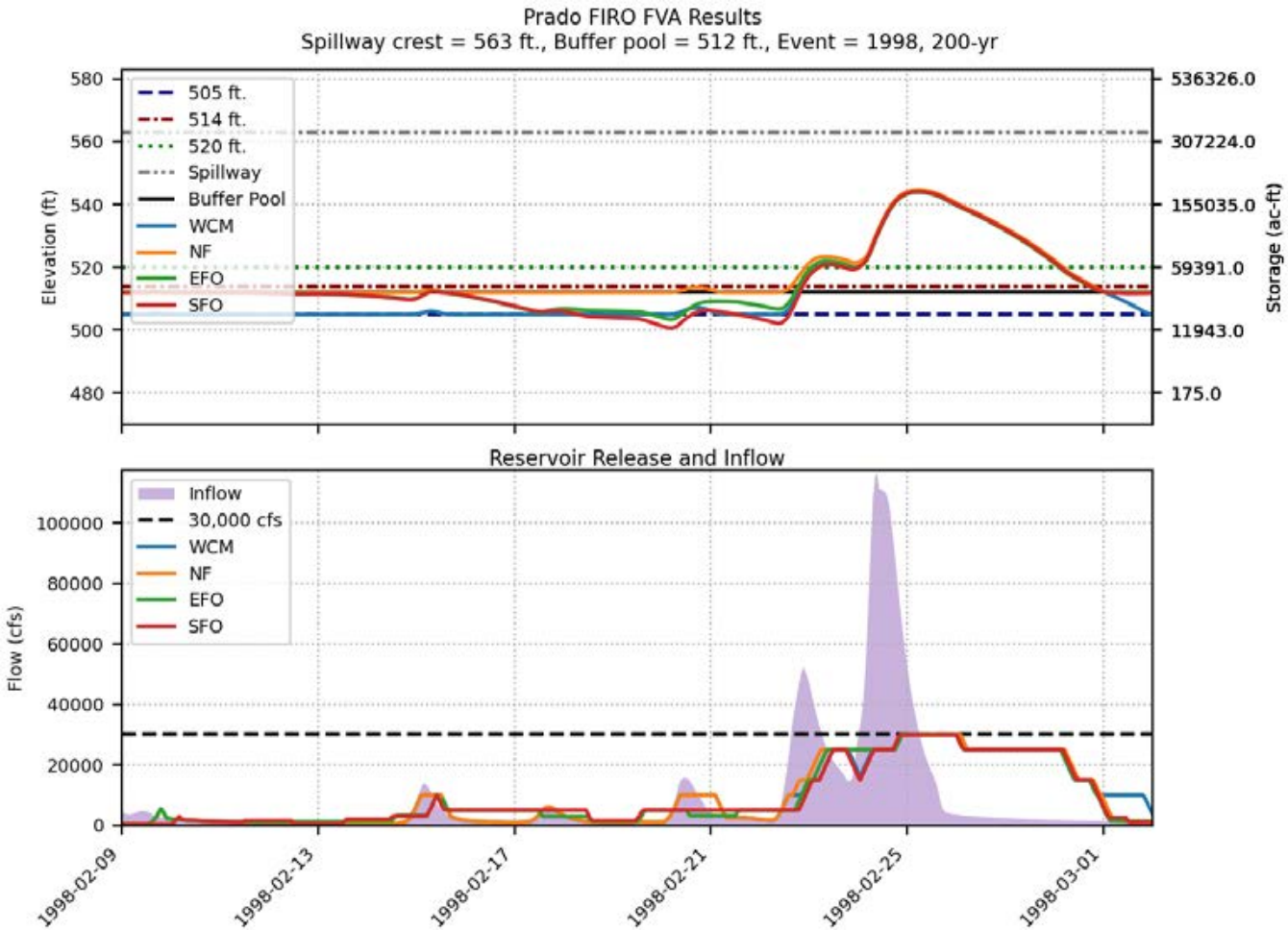
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 512 ft., Event = 1998, 200-yr
Elevation (ft)
Storage (ac-ft)
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
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Reservoir Release and Inflow
Flow (cfs)
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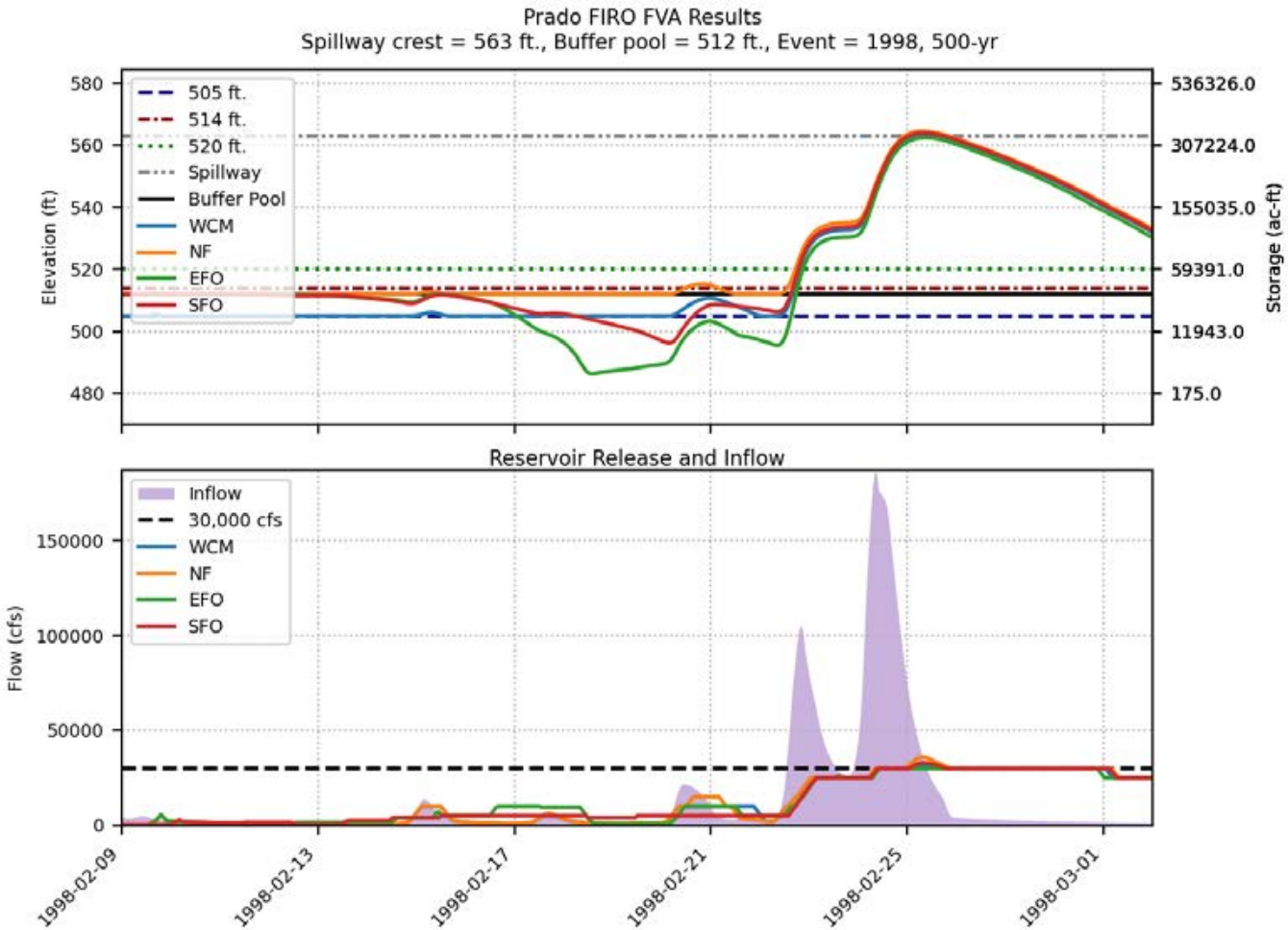
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 512 ft., Event = 1998, 500-yr
505 ft.
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520 ft.
Spillway
Buffer Pool
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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Flow (cfs)
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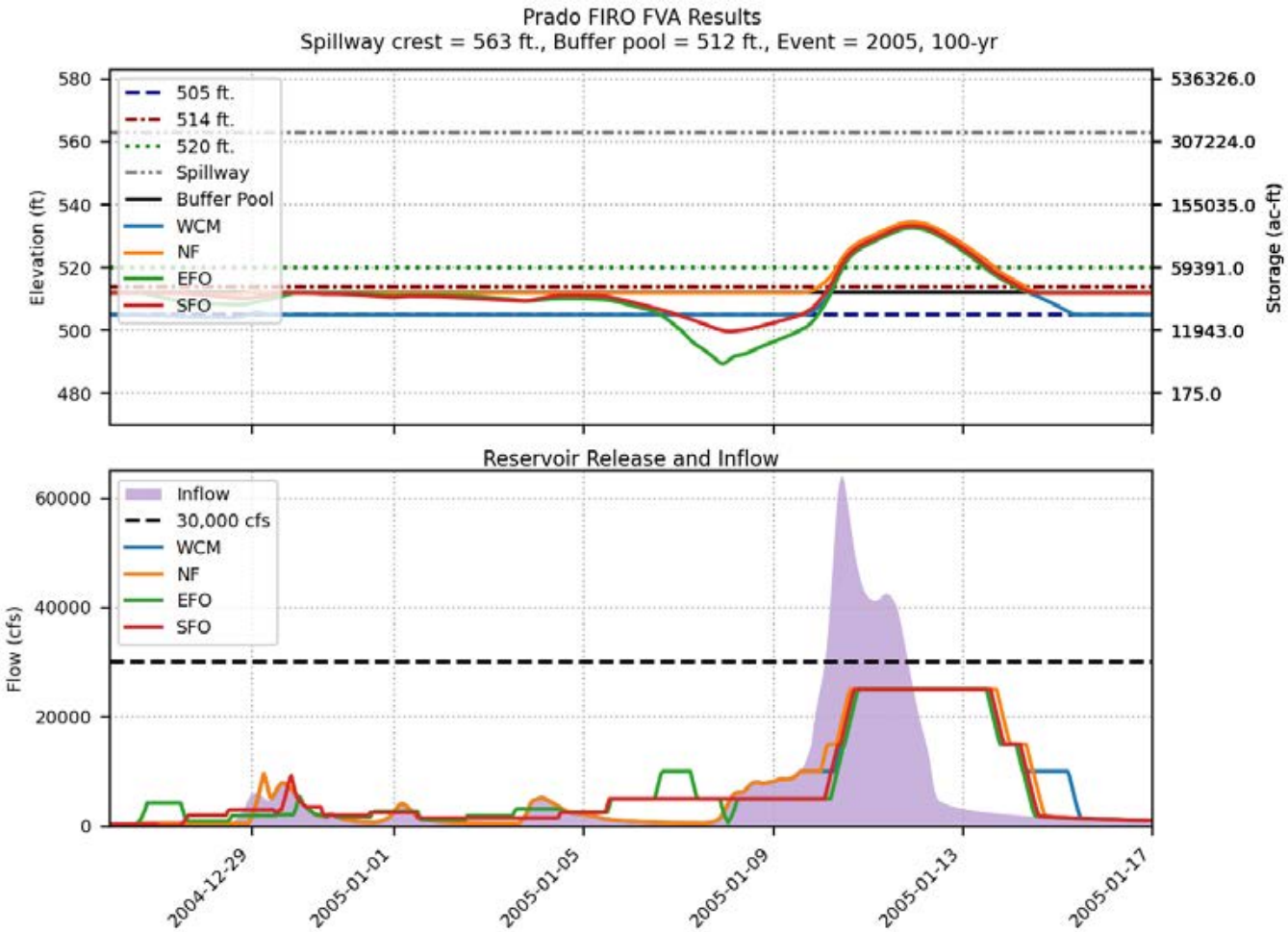
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 512 ft., Event = 2005, 100-yr
505 ft.
514 ft.
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Spillway
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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Flow (cfs)
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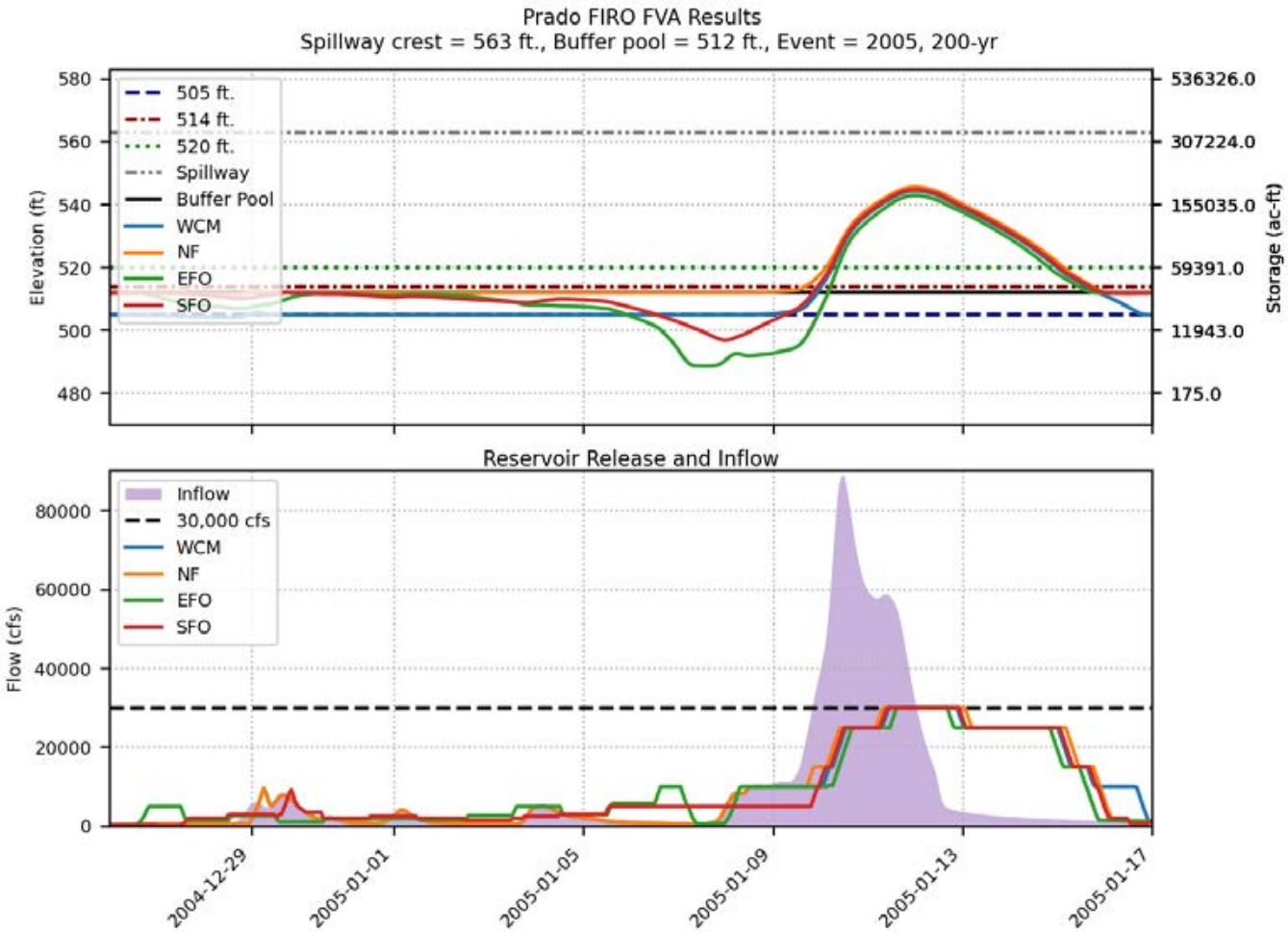
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 512 ft., Event = 2005, 200-yr
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Spillway
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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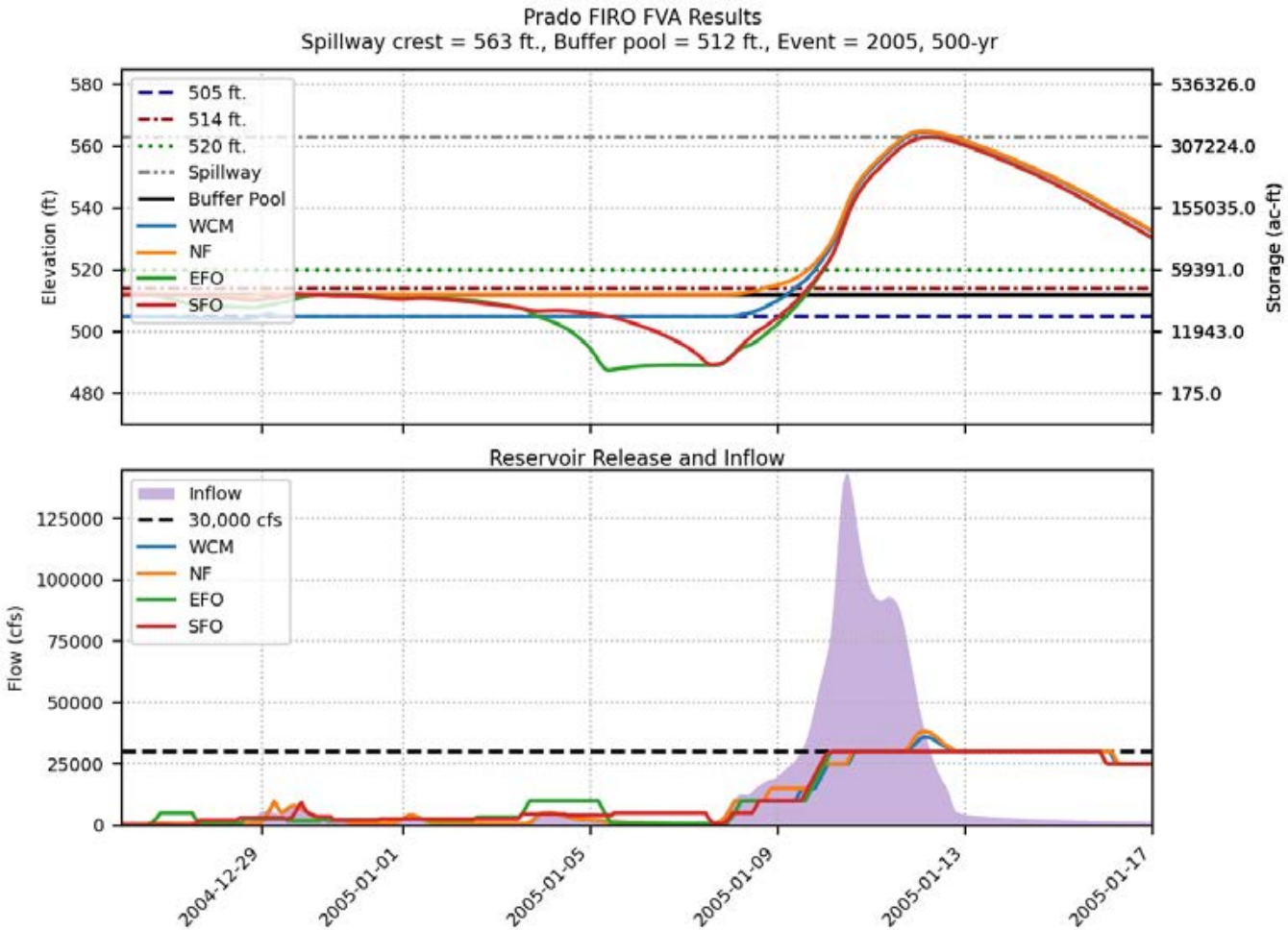
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 512 ft., Event = 2005, 500-yr
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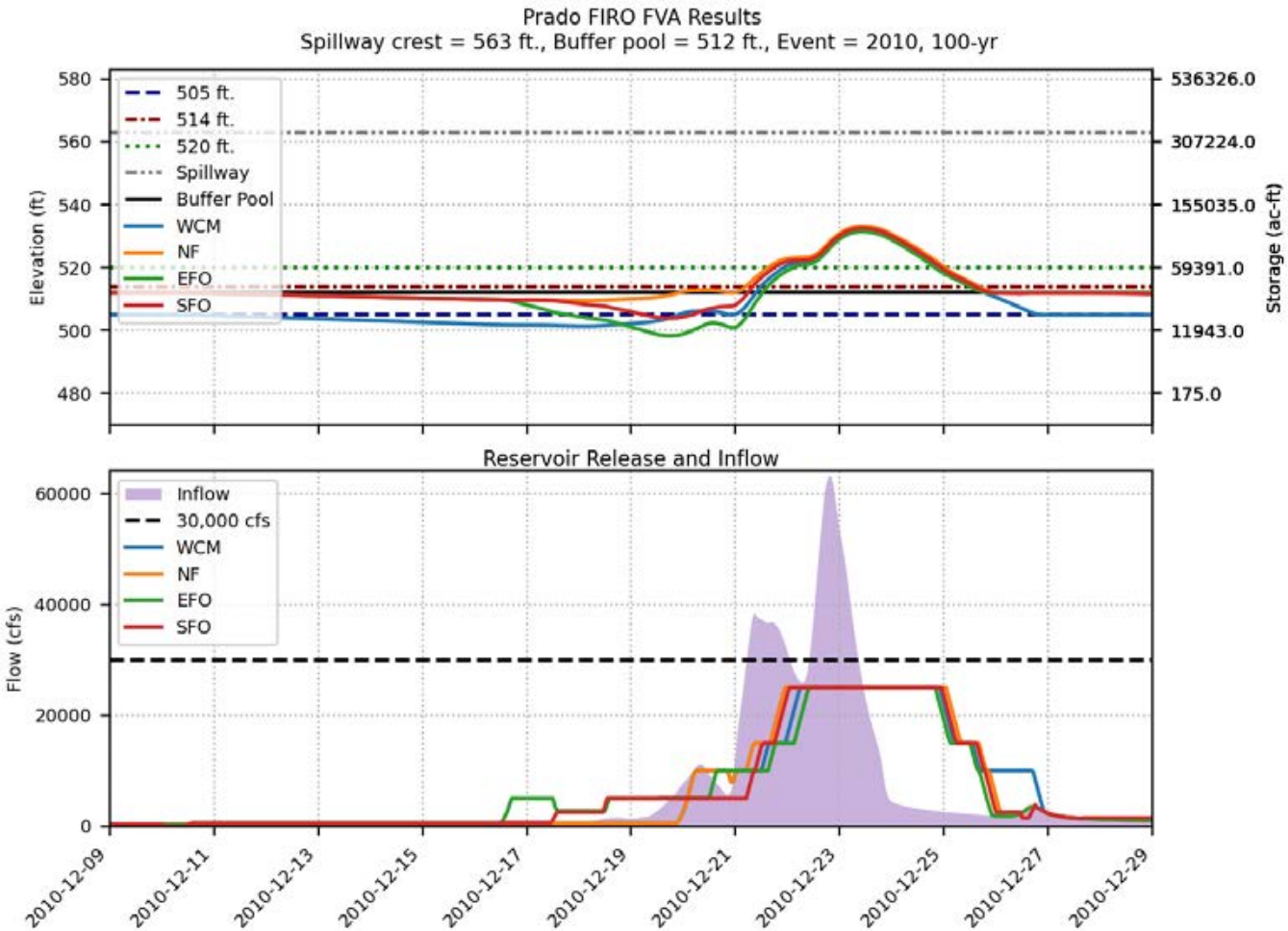
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 512 ft., Event = 2010, 100-yr
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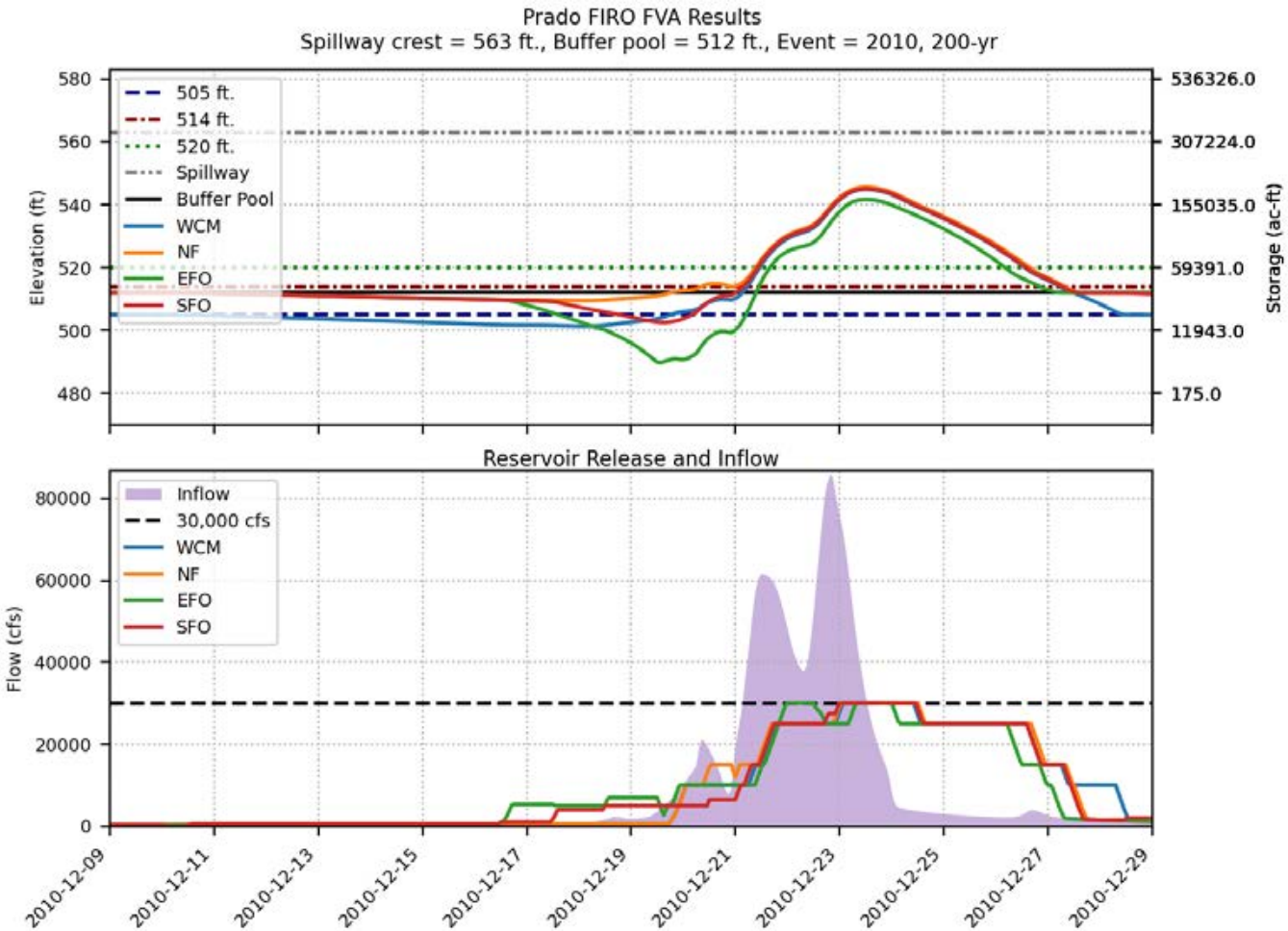
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 512 ft., Event = 2010, 200-yr
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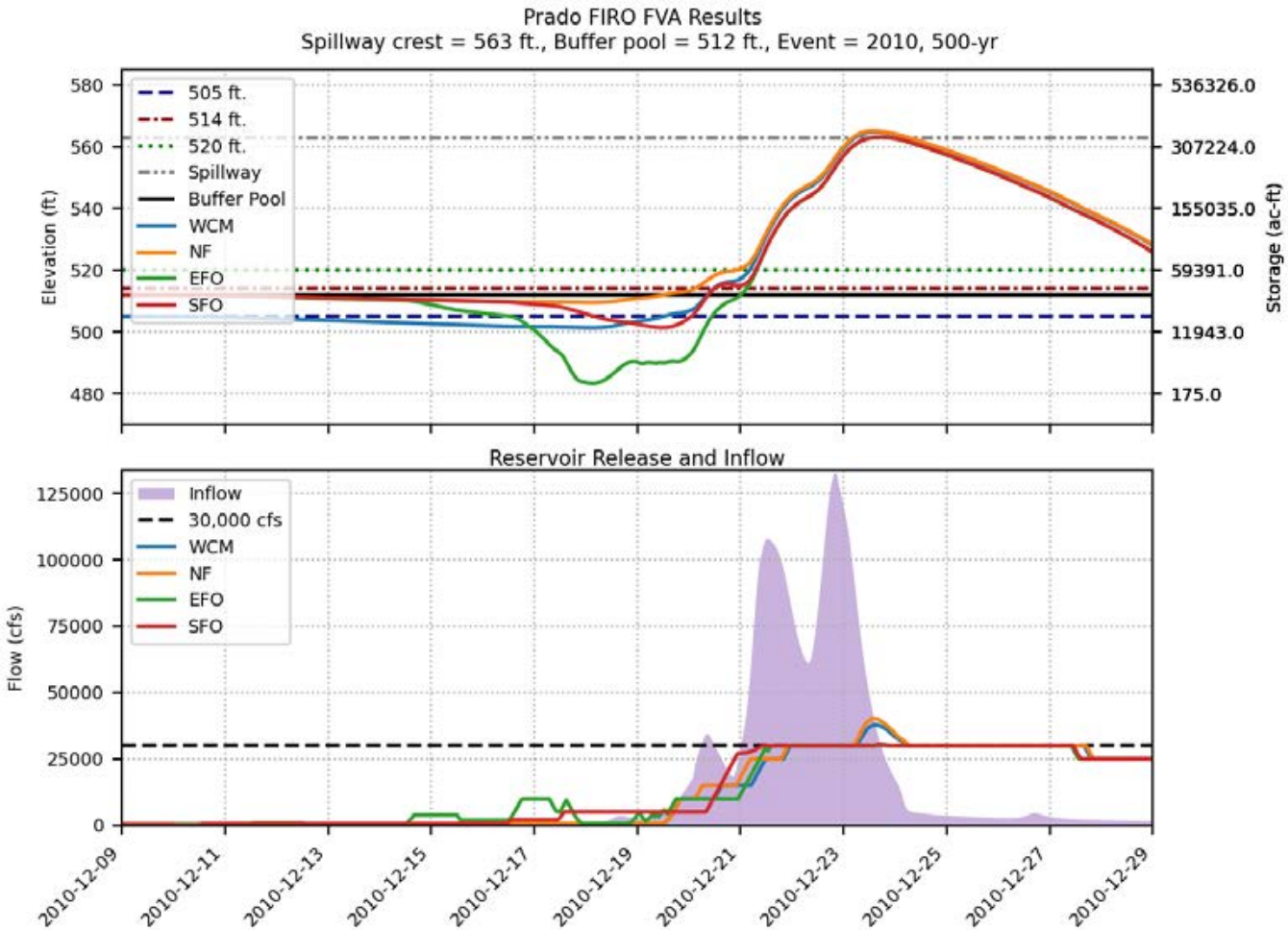
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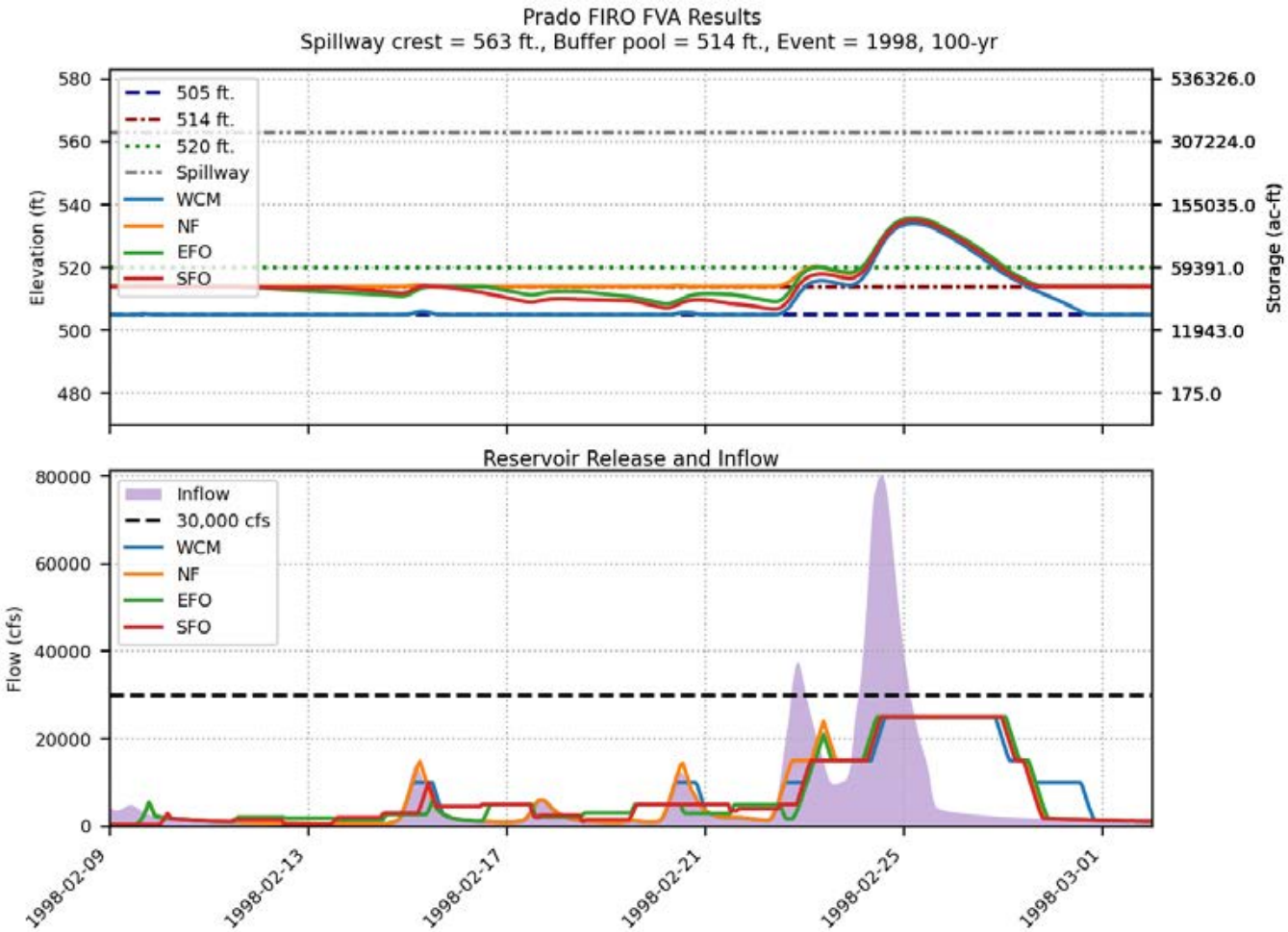
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Spillway crest = 563 ft., Buffer pool = 514 ft., Event = 1998, 100-yr
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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Flow (cfs)
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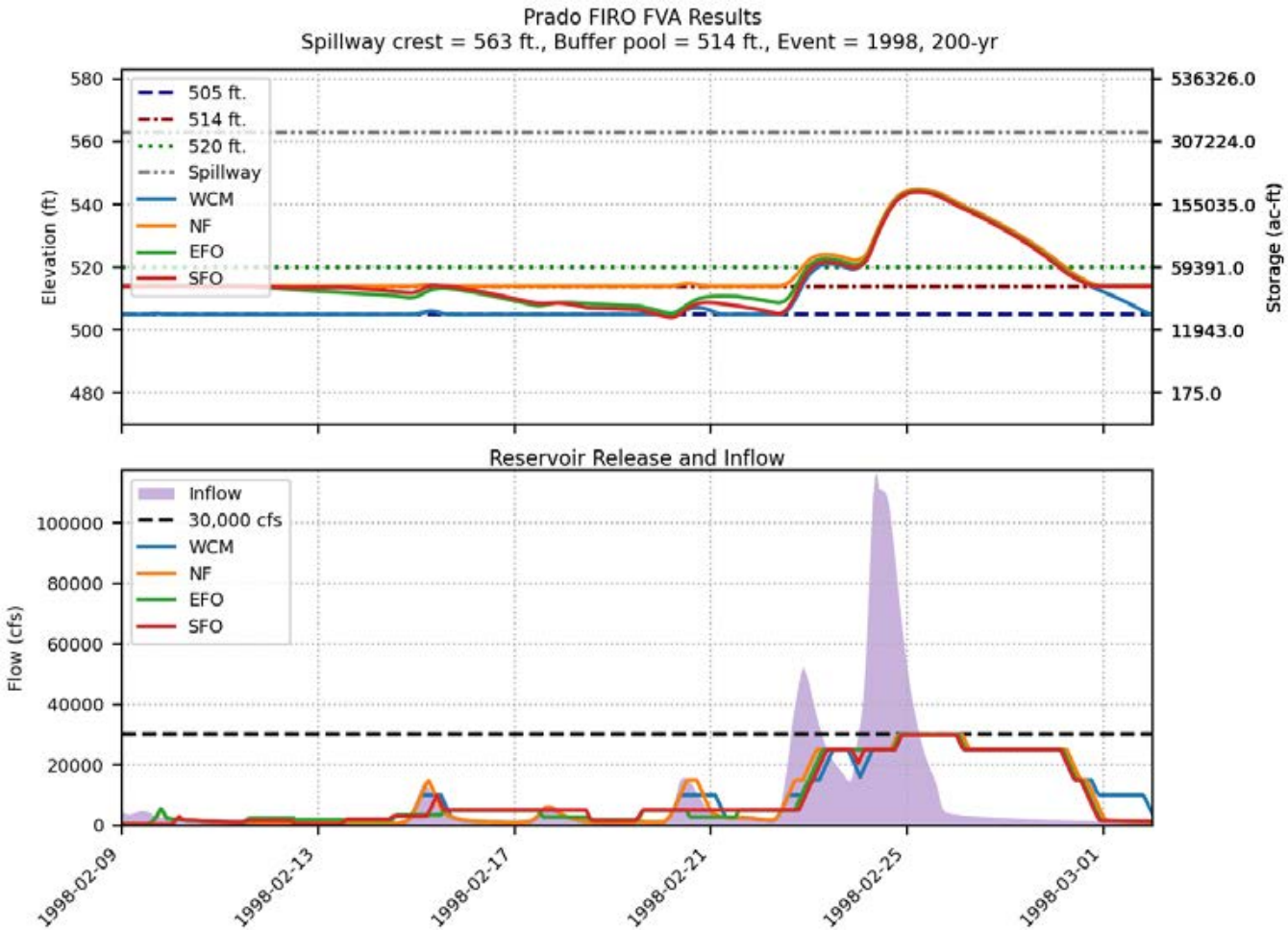
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 514 ft., Event = 1998, 200-yr
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514 ft.
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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Flow (cfs)
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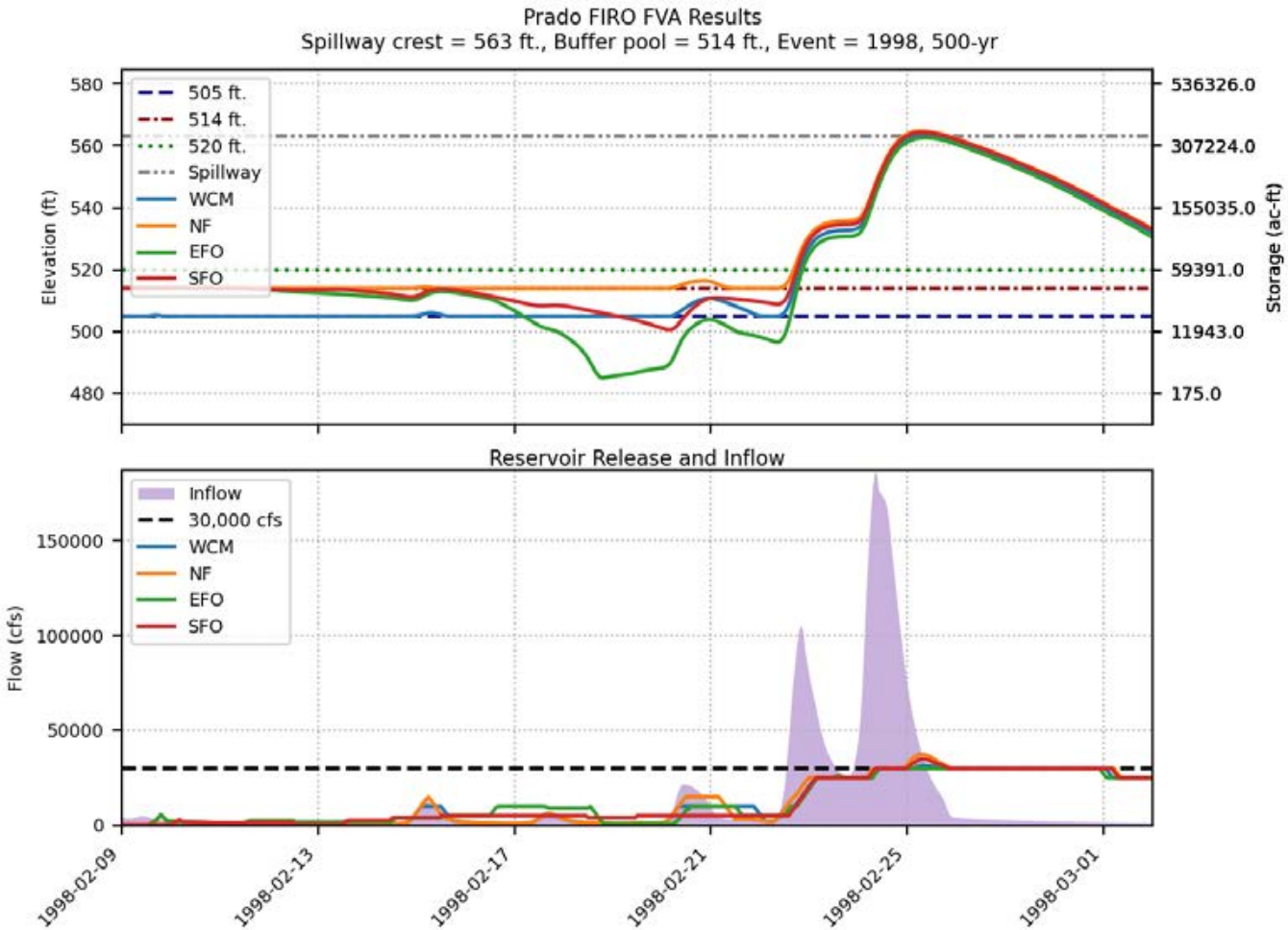
Prado FIRO FVA Results
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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Flow (cfs)
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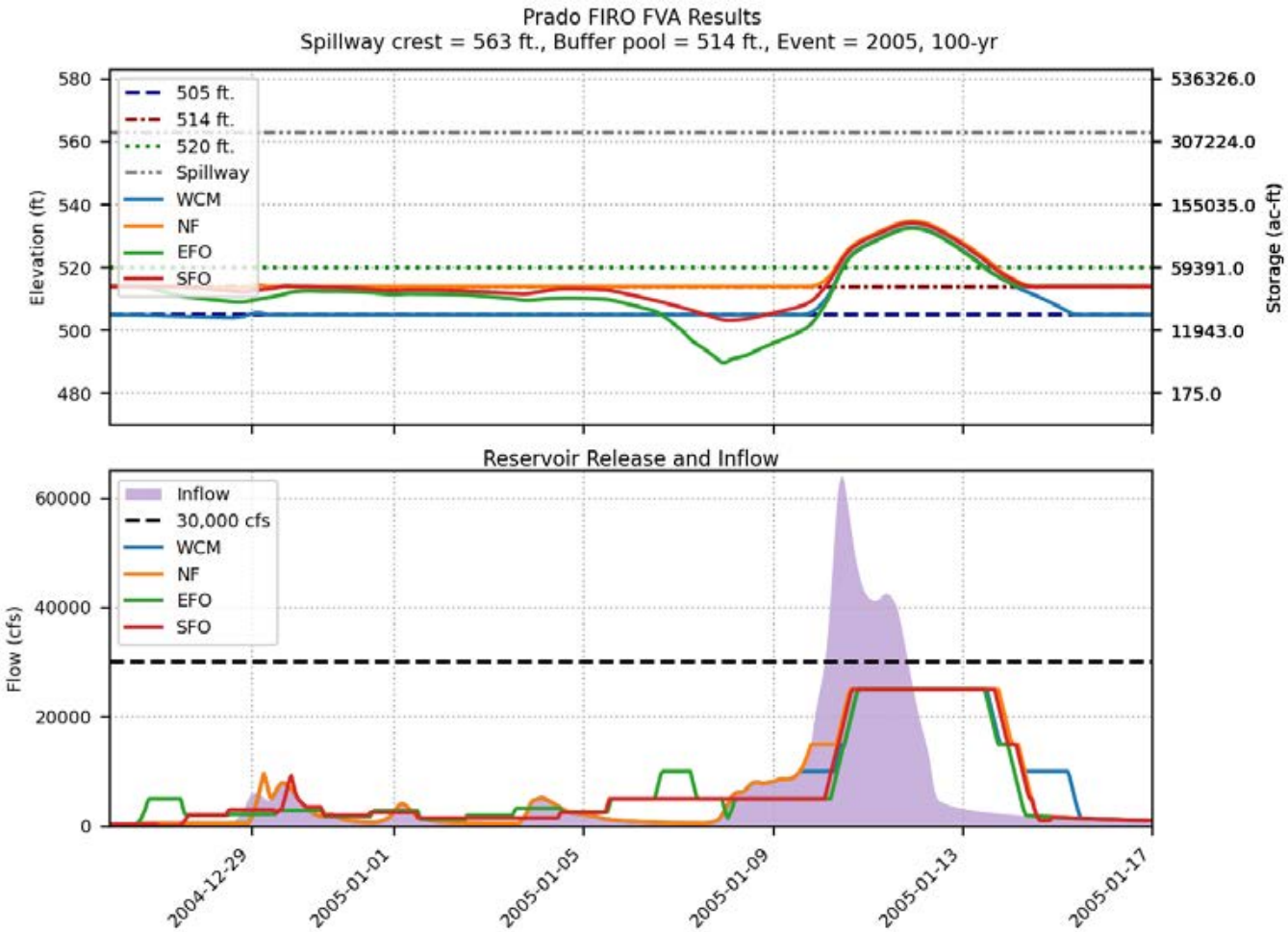
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 514 ft., Event = 2005, 100-yr
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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Flow (cfs)
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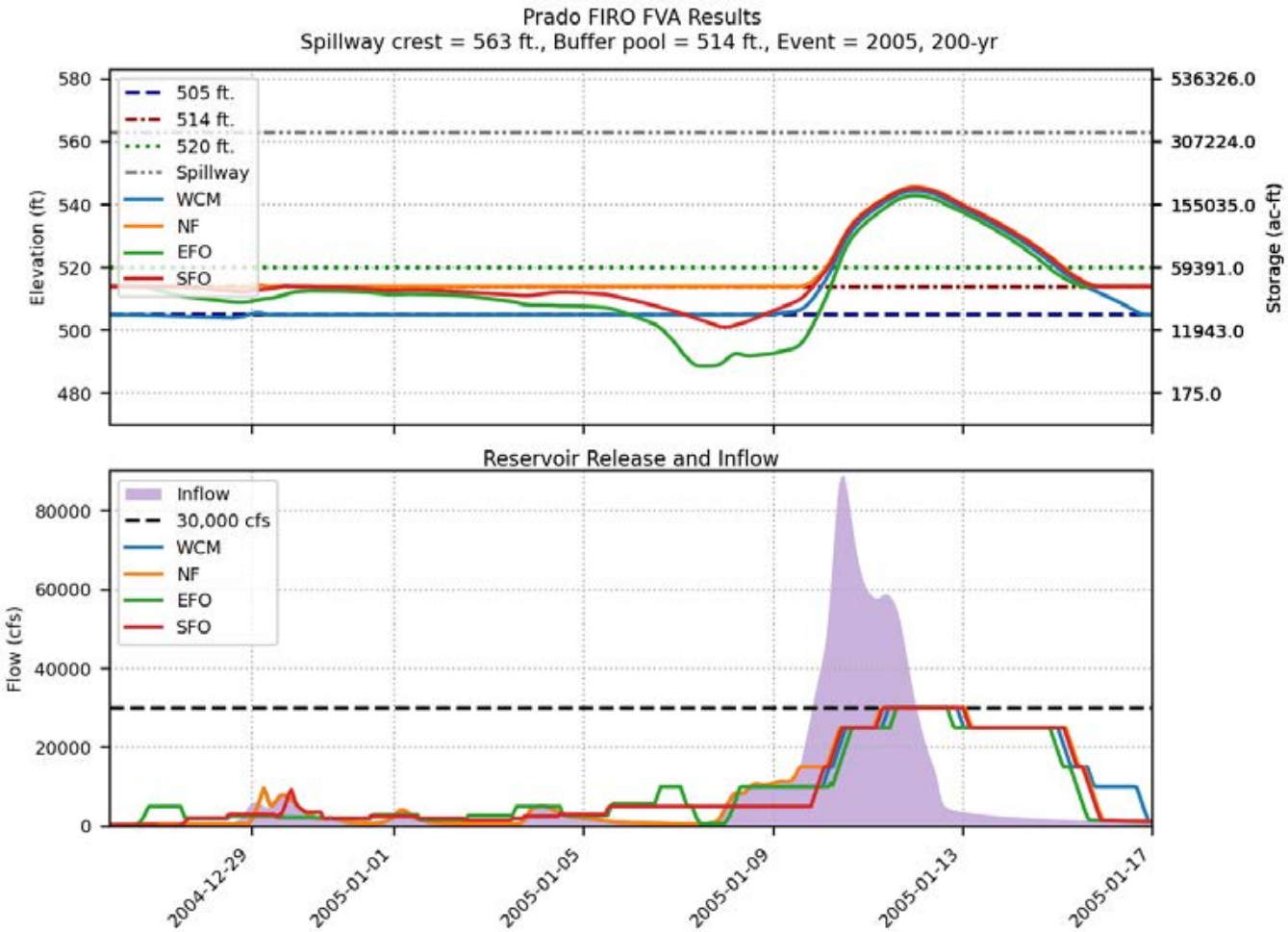
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 514 ft., Event = 2005, 200-yr
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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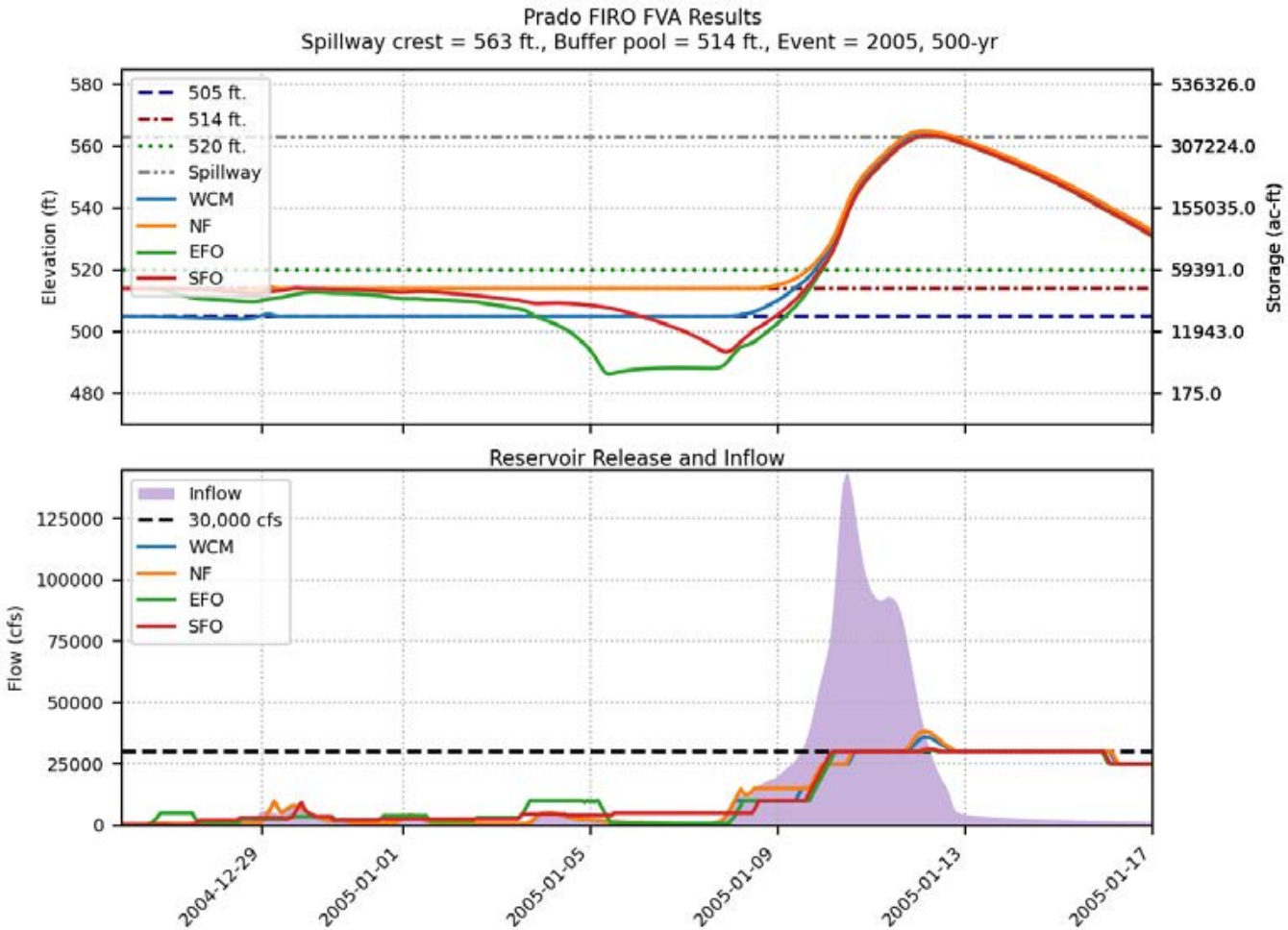
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Spillway crest = 563 ft., Buffer pool = 514 ft., Event = 2005, 500-yr
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Reservoir Release and Inflow
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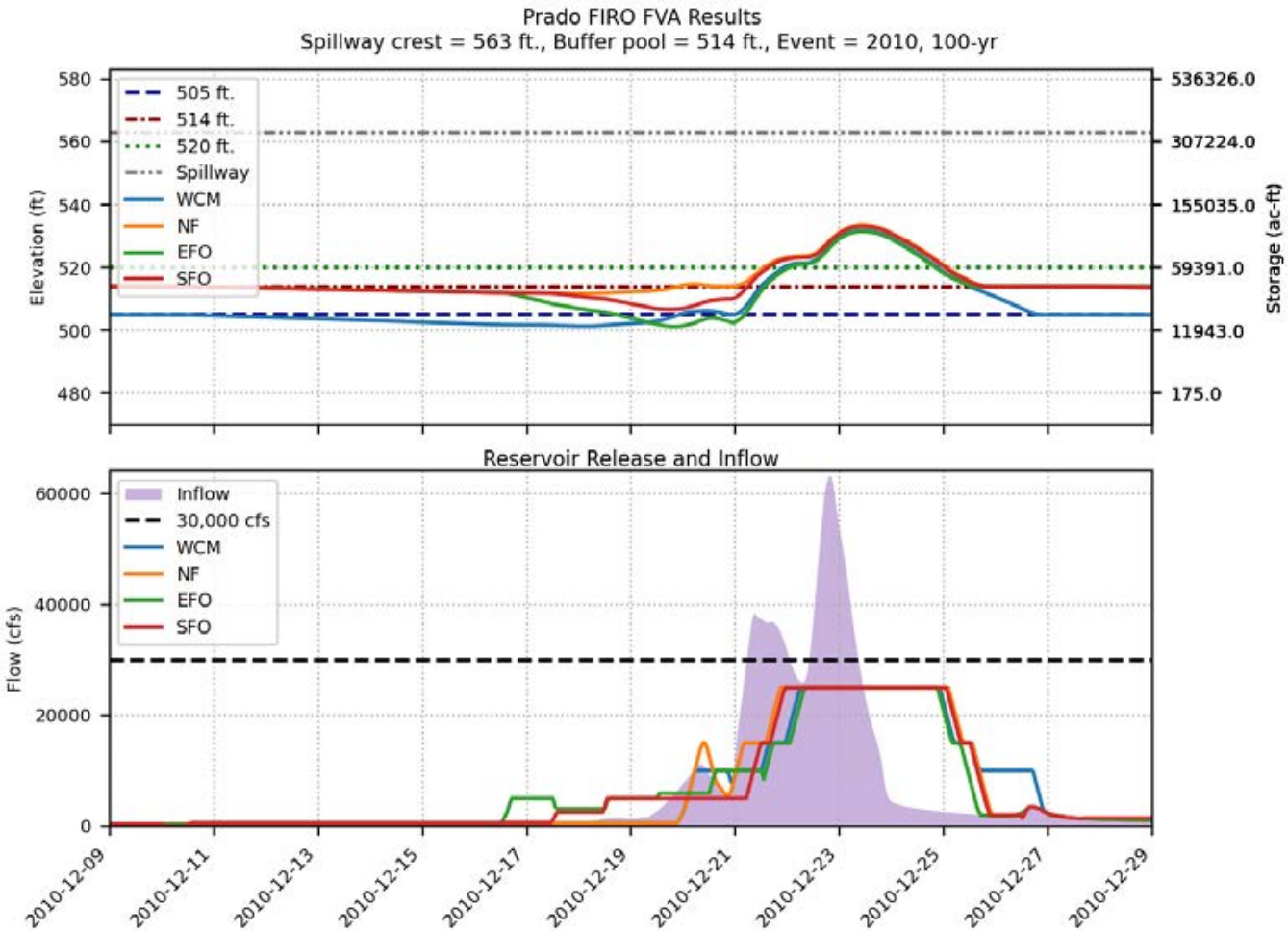
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 514 ft., Event = 2010, 100-yr
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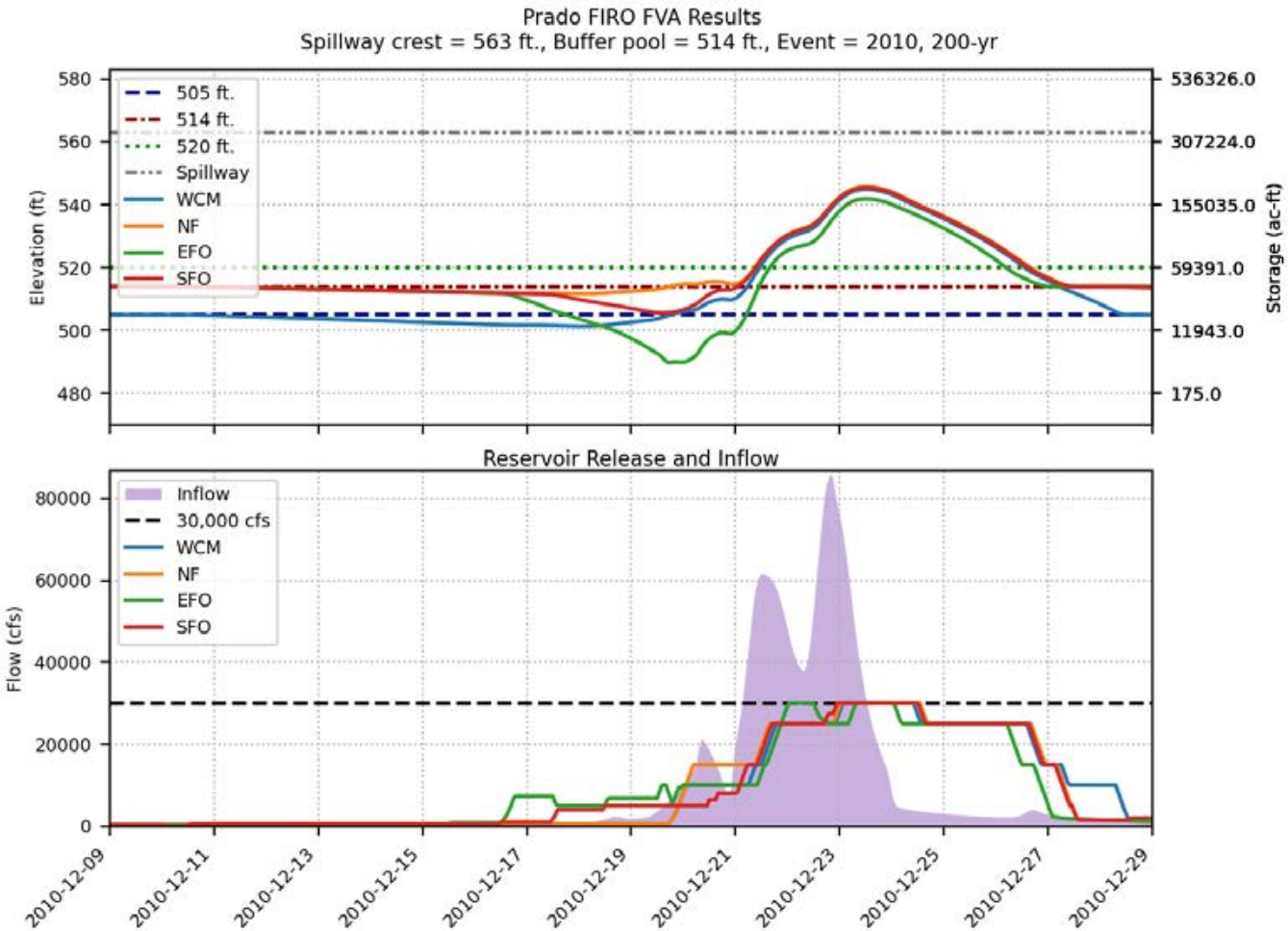
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Spillway
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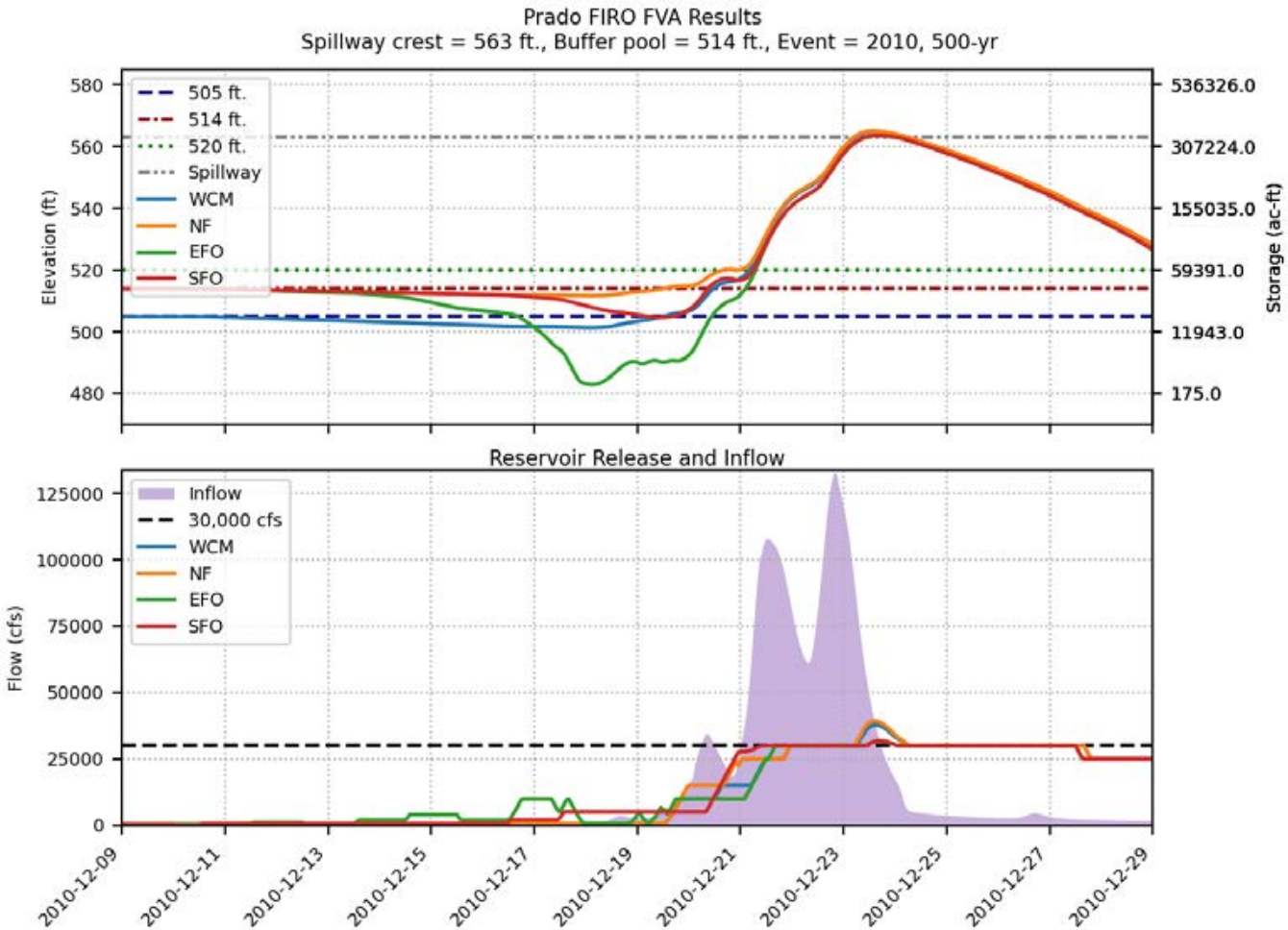
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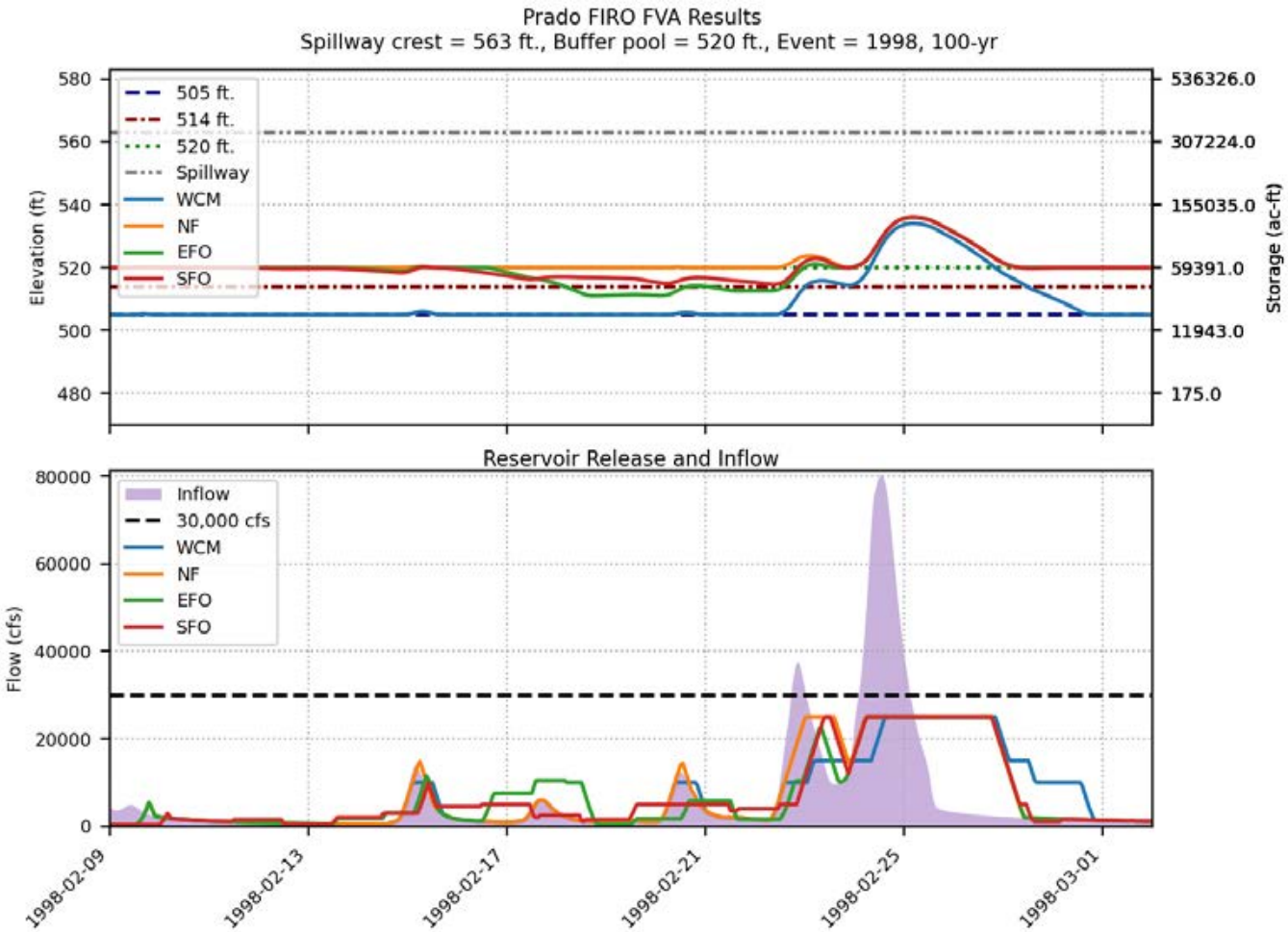
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Elevation (ft)
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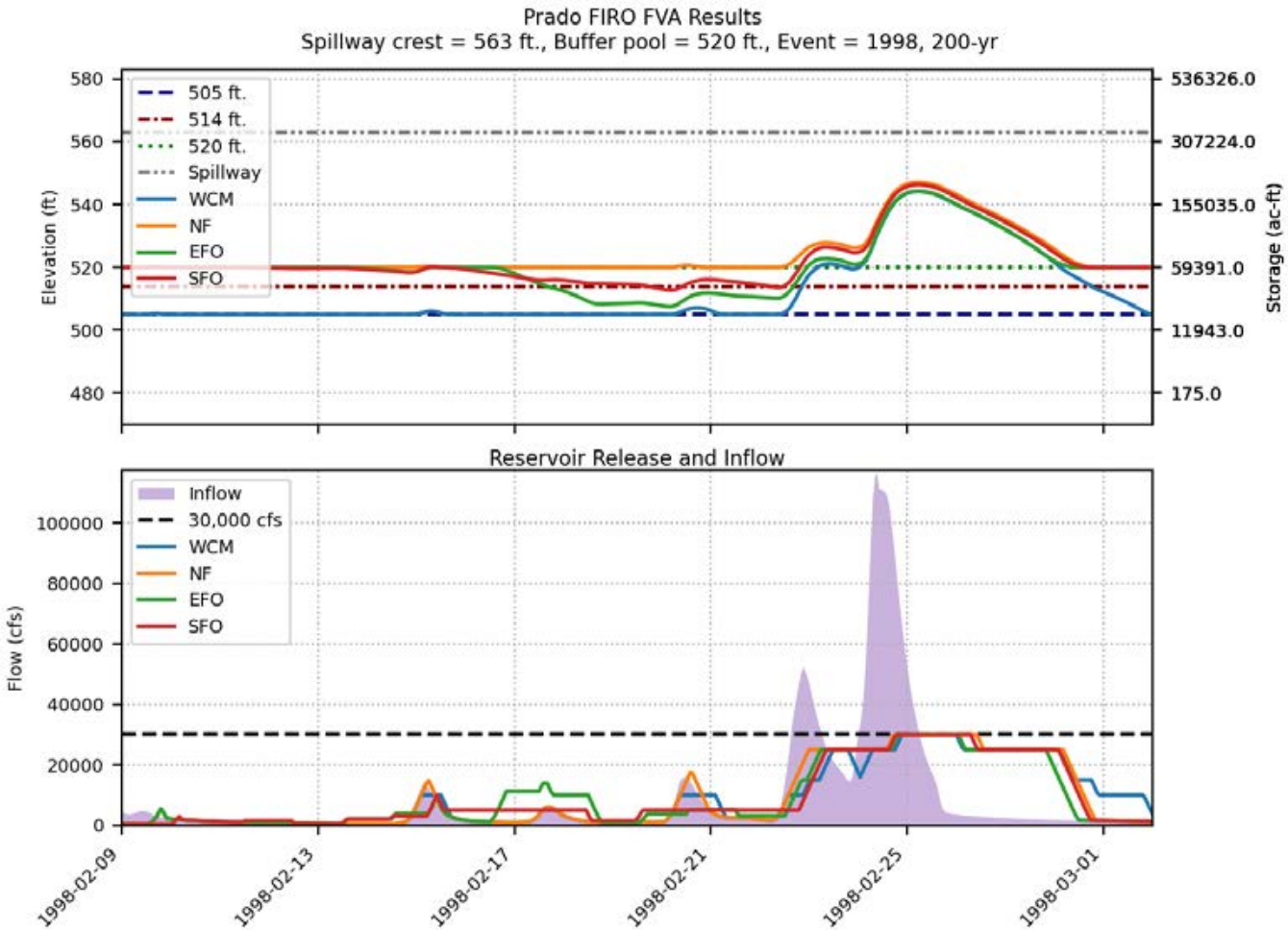
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Spillway crest = 563 ft., Buffer pool = 520 ft., Event = 1998, 200-yr
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NF
EFO
SFO
Flow (cfs)
100000
80000
60000
40000
20000
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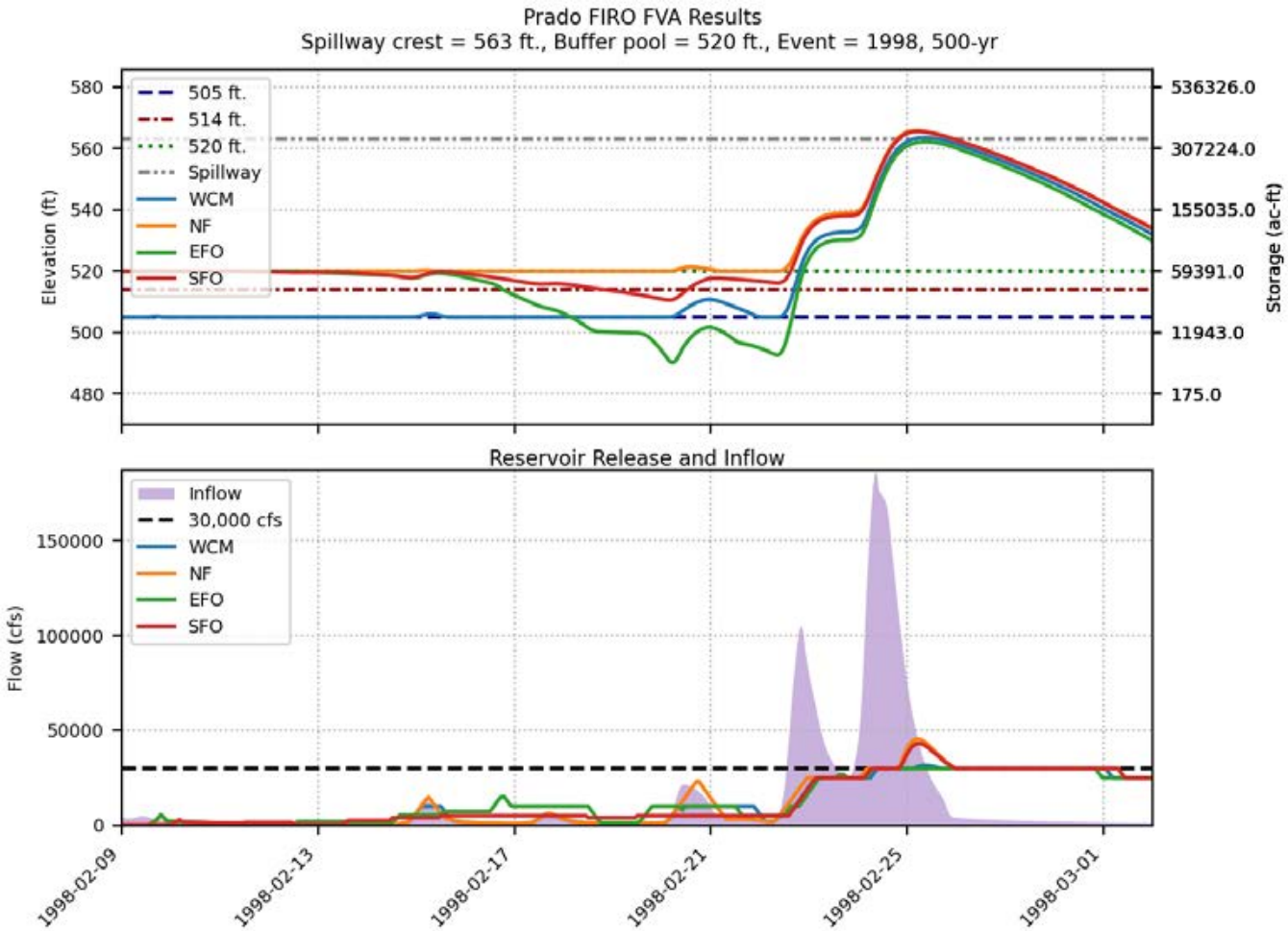
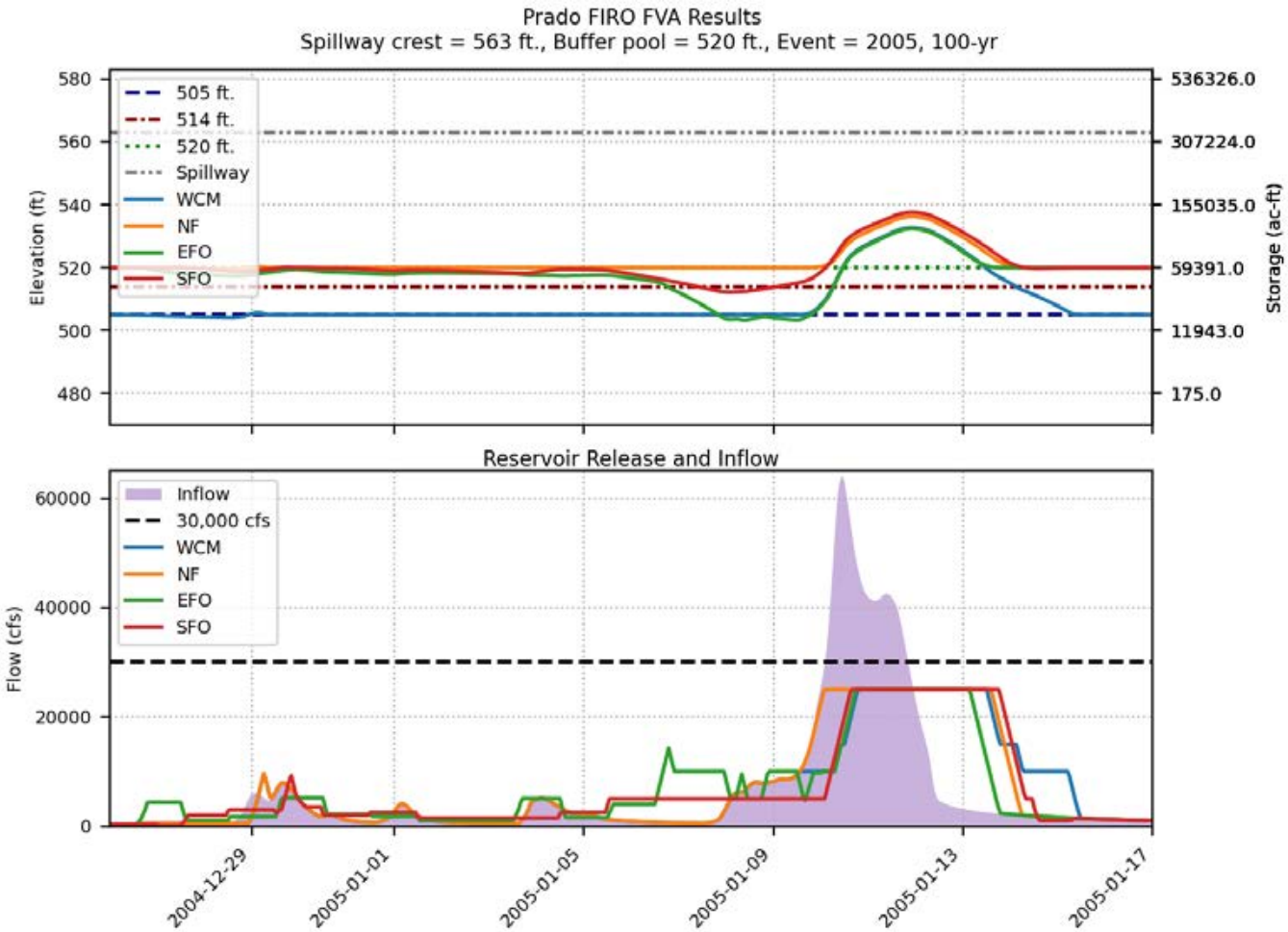
1998-02-13
1998-02-17
1998-02-21
1998-02-25
1998-03-01


Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 520 ft., Event = 1998, 500-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
150000
100000
50000
0
1998-02-09
1998-02-13
1998-02-17
1998-02-21
1998-02-25
1998-03-01


Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 520 ft., Event = 2005, 100-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
60000
40000
20000
0
2004-12-29
2005-01-01
2005-01-05
2005-01-09
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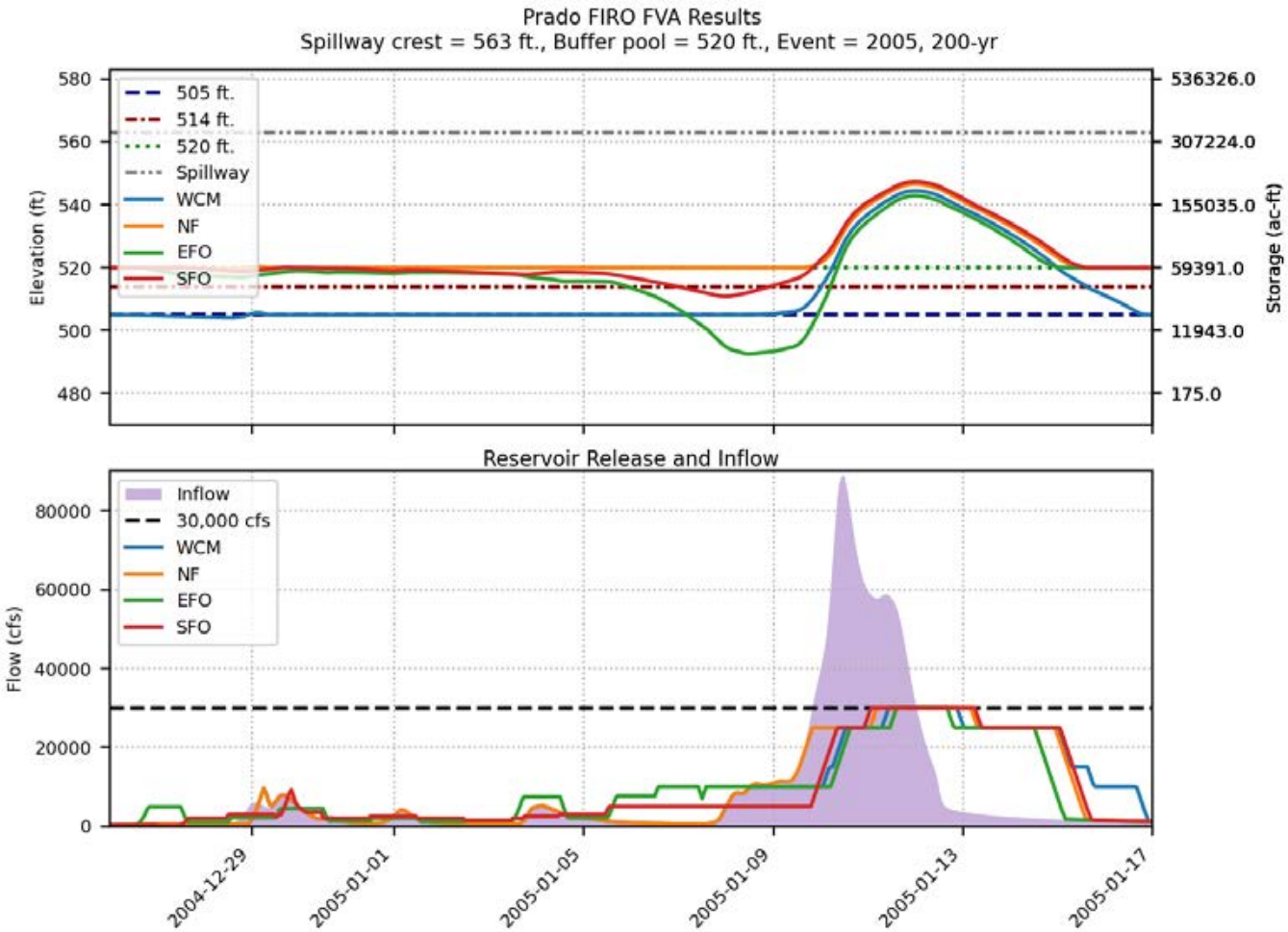
2005-01-17


Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 520 ft., Event = 2005, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
80000
60000
40000
20000
0
2004-12-29
2005-01-01
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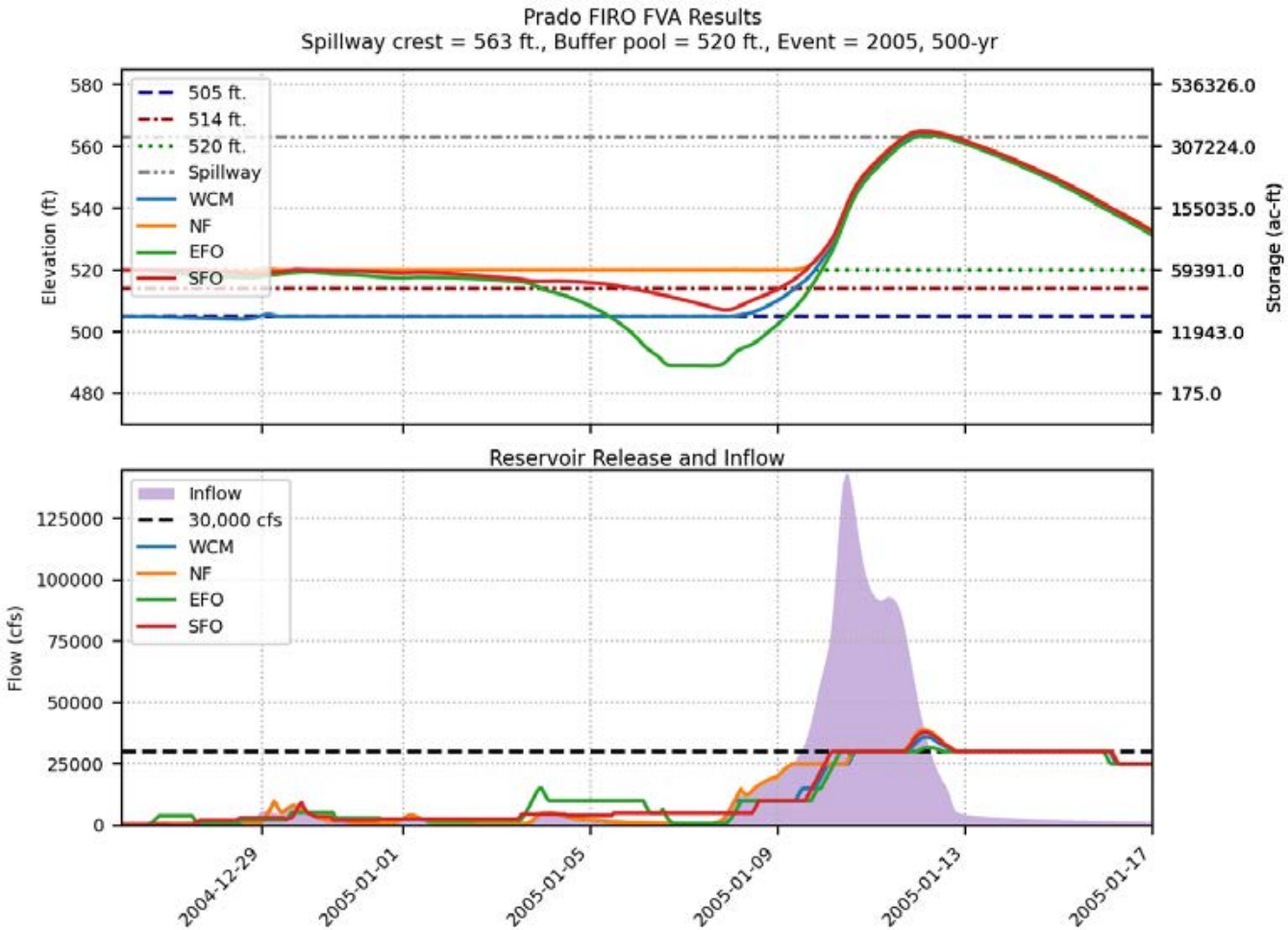
2005-01-17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514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
125000
100000
75000
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25000
0
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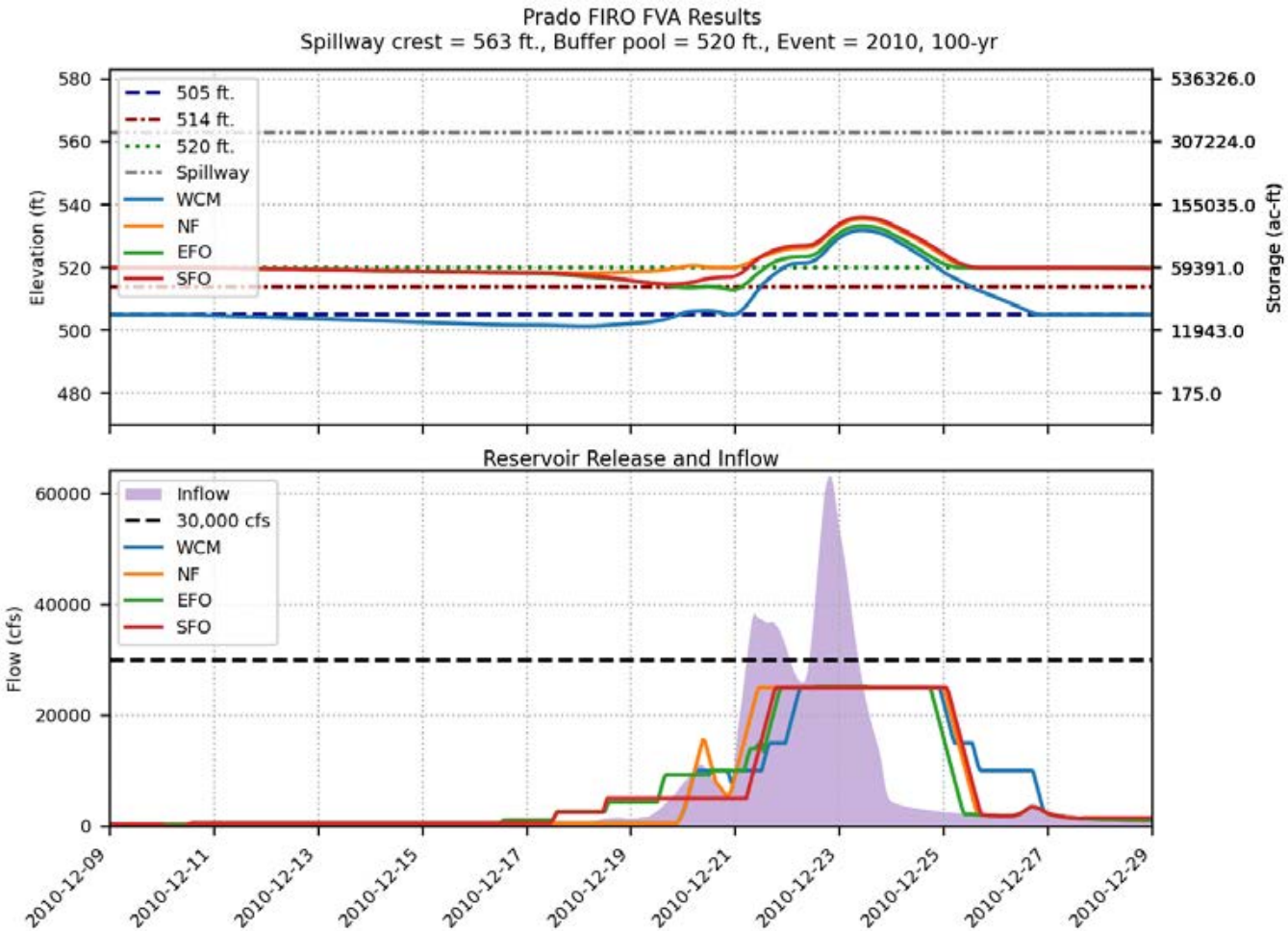
Prado FIRO FVA Results
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514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
60000
40000
20000
0
2010-12-09
2010-12-11
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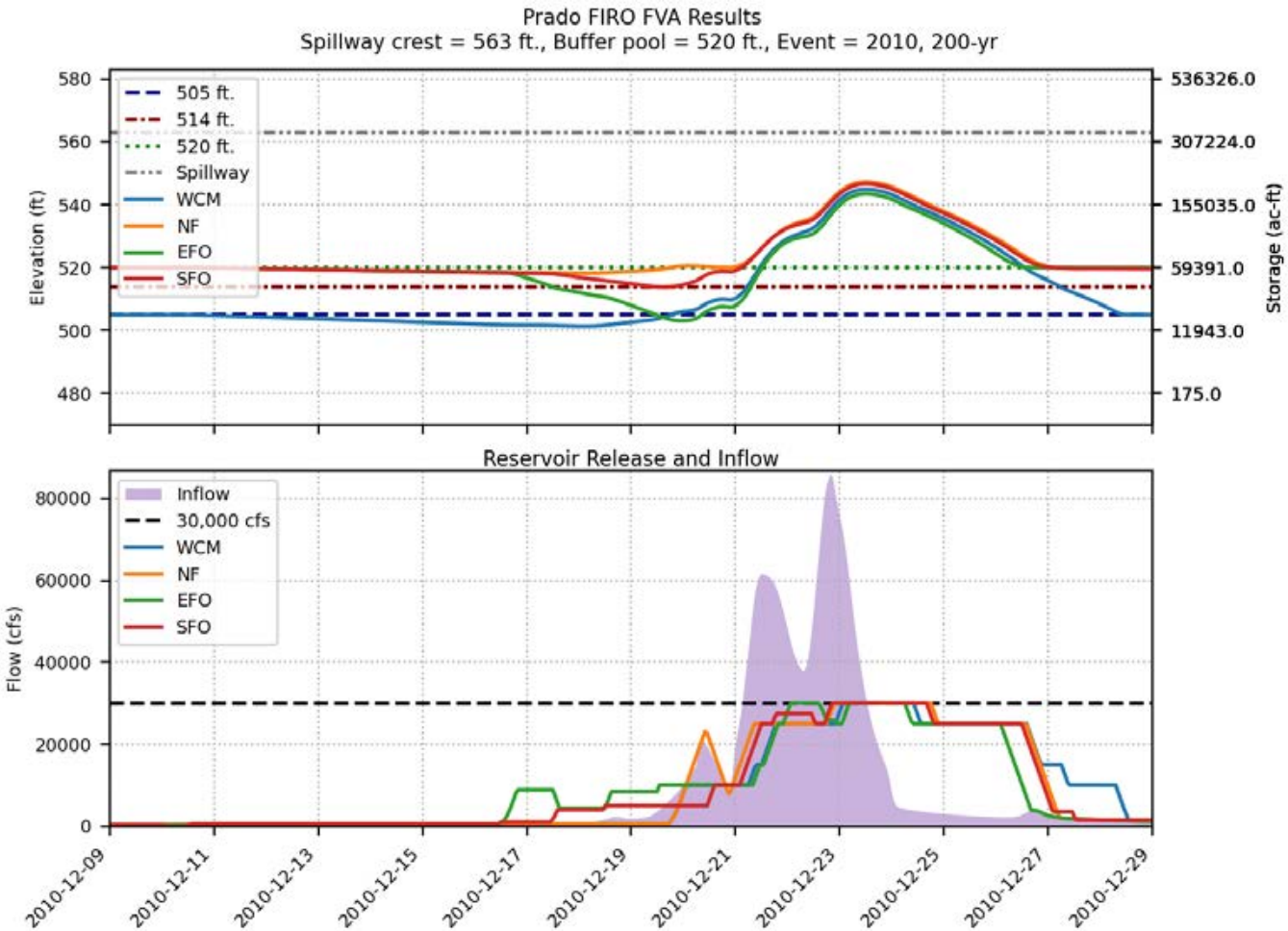
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 520 ft., Event = 2010, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
Elevation (ft)
Storage (ac-ft)
580
560
540
520
500
480
536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
80000
60000
40000
20000
0
2010-12-09
2010-12-11
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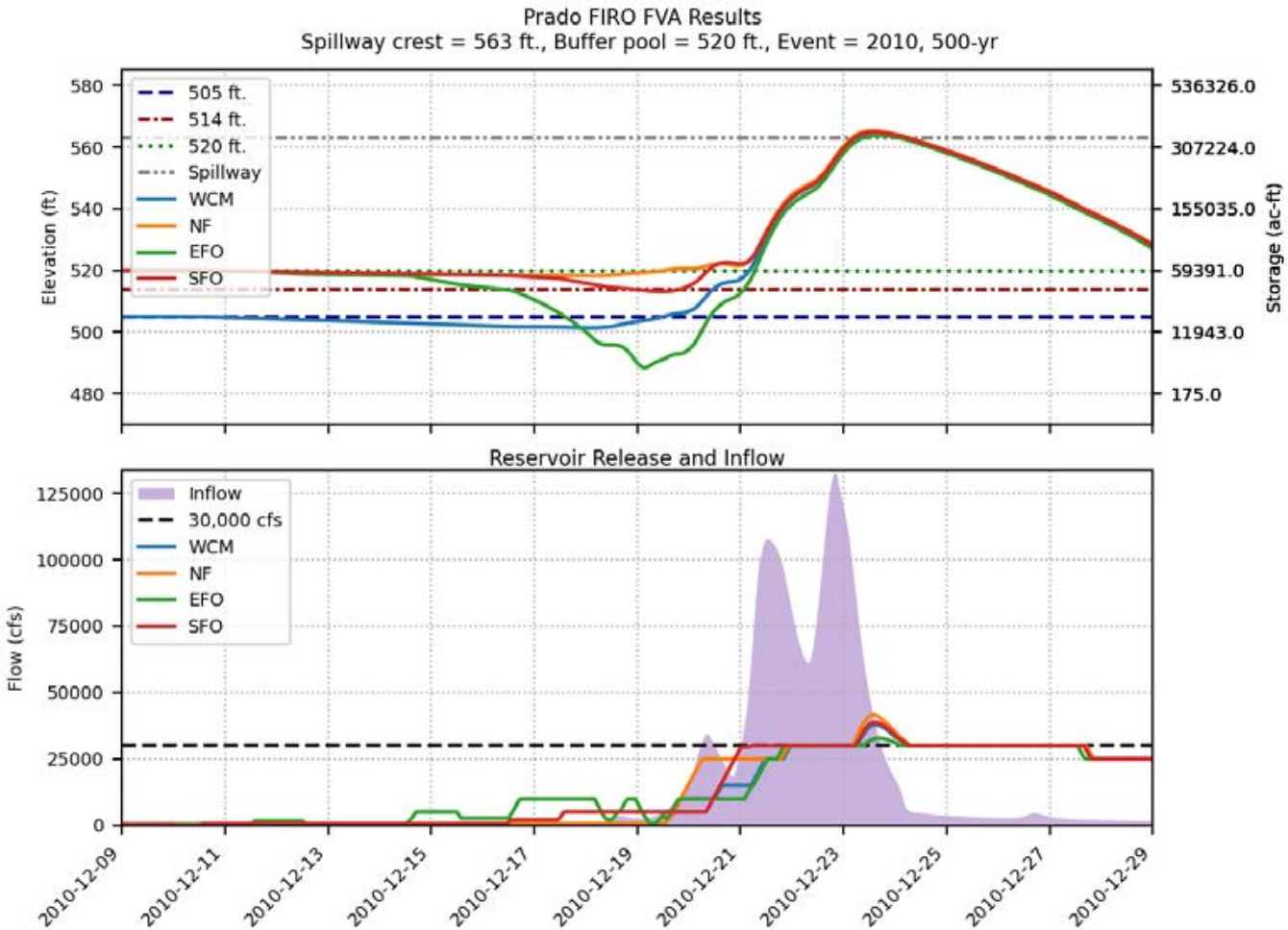
2010-12-29


Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 520 ft., Event = 2010, 500-yr
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514 ft.
520 ft.
Spillway
WCM
NF
EFO
SFO
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536326.0
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
NF
EFO
SFO
Flow (cfs)
125000
100000
75000
50000
25000
0
2010-12-09
2010-12-11
2010-12-13
2010-12-15
2010-12-17
2010-12-19
2010-12-21
2010-12-23
2010-12-25
2010-12-27
2010-12-29

Scaled Hindcast Events (No PF No NF)

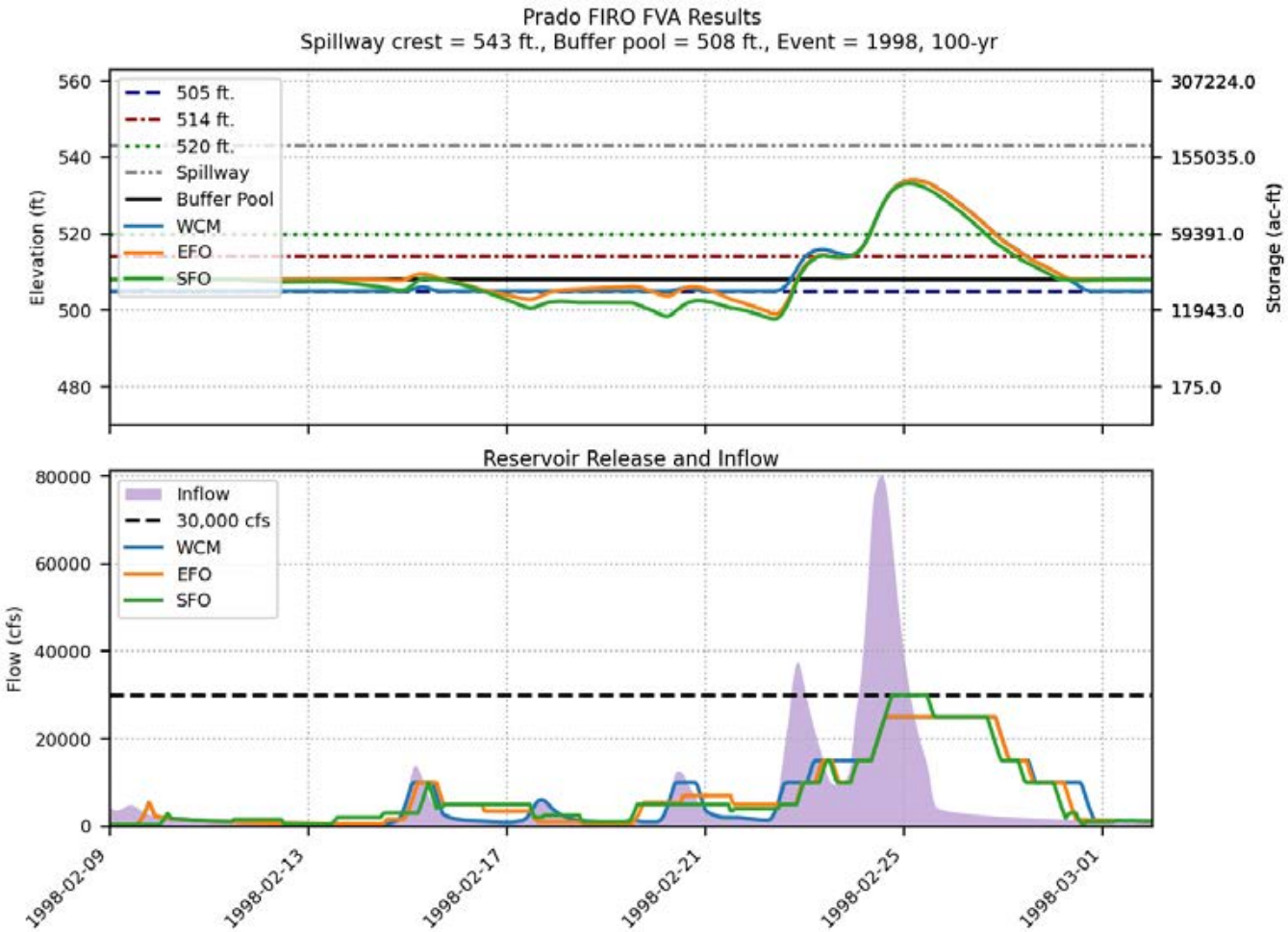
- Upper panel – Reservoir elevation/storage
- Lower panel – Reservoir inflow and release

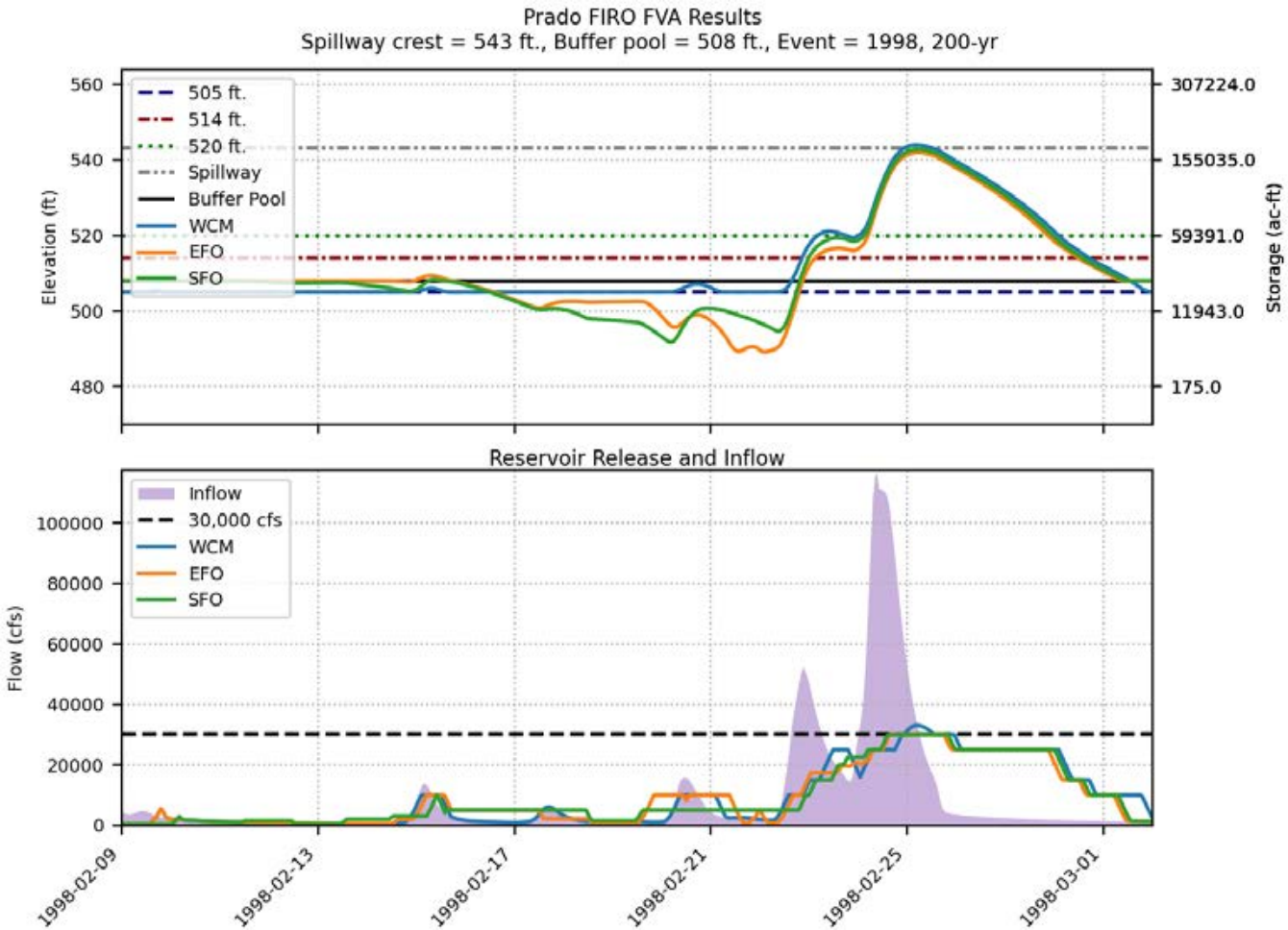
- February 1998
- January 2006
- December 2010

- Scaled to 100-y, 200-yr, 500-yr 3-day inflow volume

Scaled Hindcast Events (No PF No NF)

- Spillway elevations of 543’ and 563’
- Maximum buffer pool elevations
  - 508’, 510’, 512’, 514’, 520’
- WCP alternatives in legend
  - WCM is 505’ Buffer Pool
  - Perfect Forecast alternatives omitted
  - No Forecast alternatives omitted


Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 508 ft., Event = 1998, 100-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
EFO
SFO
Flow (cfs)
80000
60000
40000
20000
0
1998-02-09
1998-02-13
1998-02-17
1998-02-21
1998-02-25
1998-03-01


Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 508 ft., Event = 1998, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
EFO
SFO
Flow (cfs)
100000
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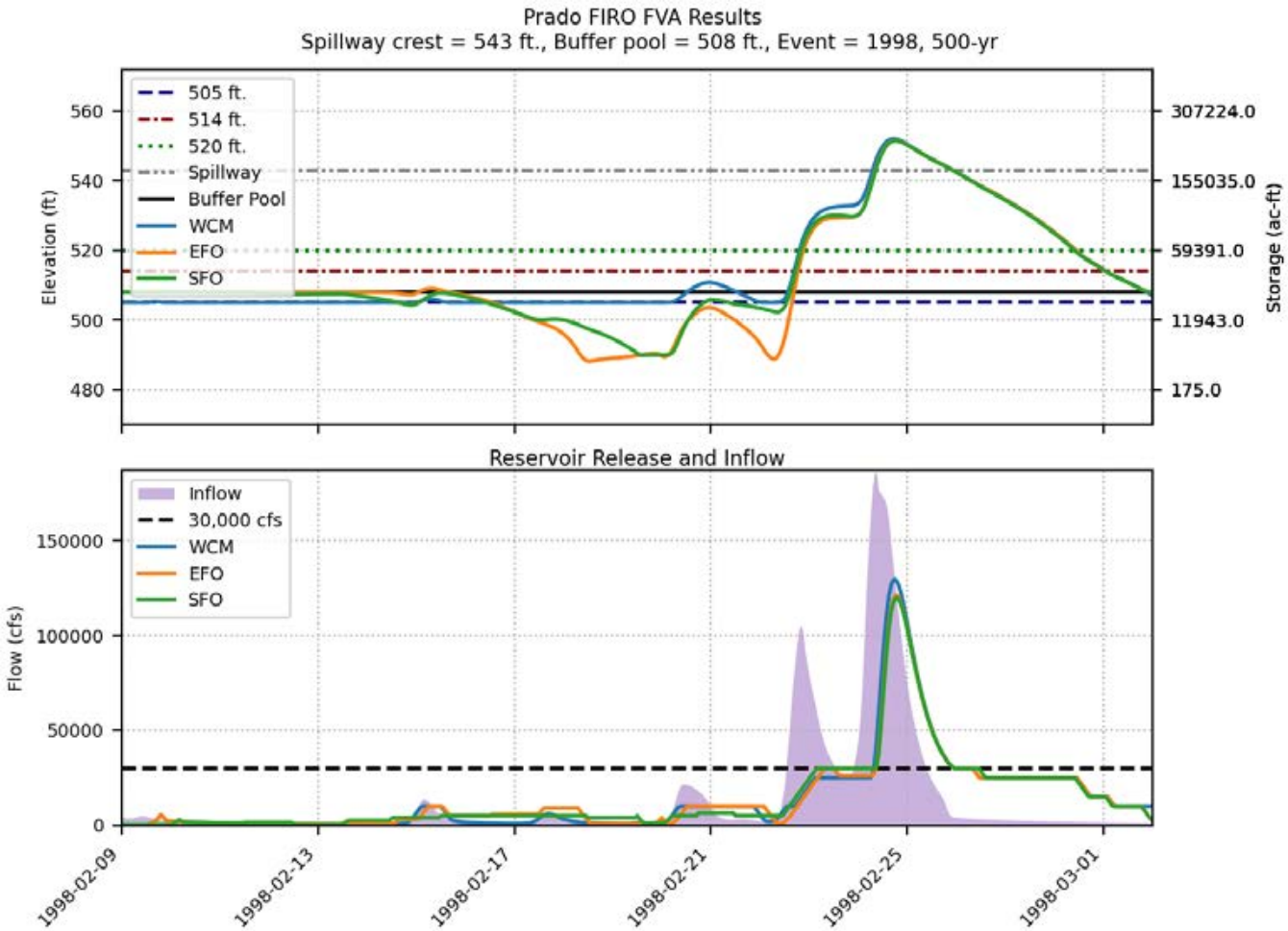
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 508 ft., Event = 1998, 500-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
EFO
SFO
Flow (cfs)
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100000
50000
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1998-02-09
1998-02-13
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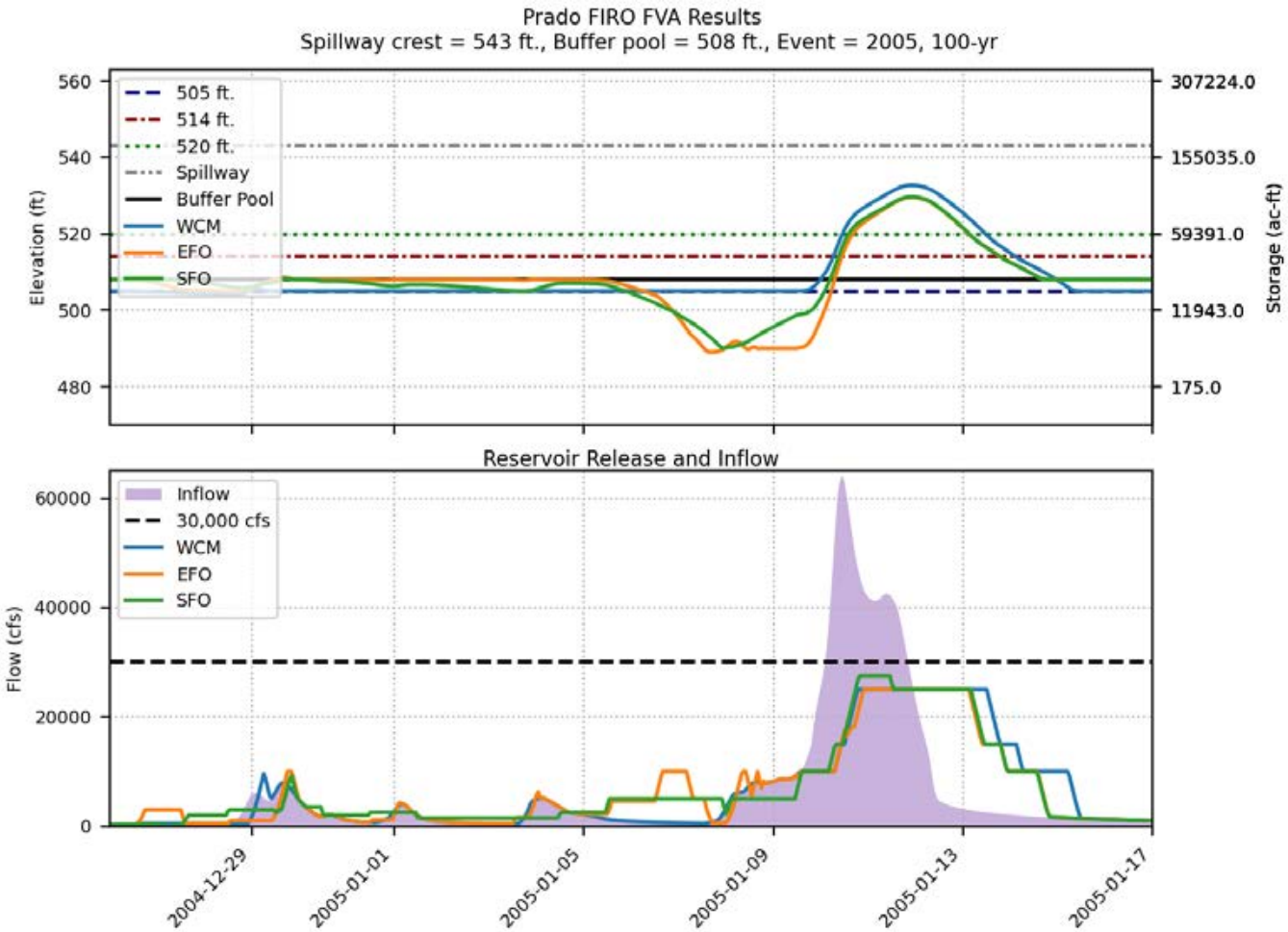
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 508 ft., Event = 2005, 100-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
EFO
SFO
Flow (cfs)
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40000
20000
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2004-12-29
2005-01-01
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2005-01-09
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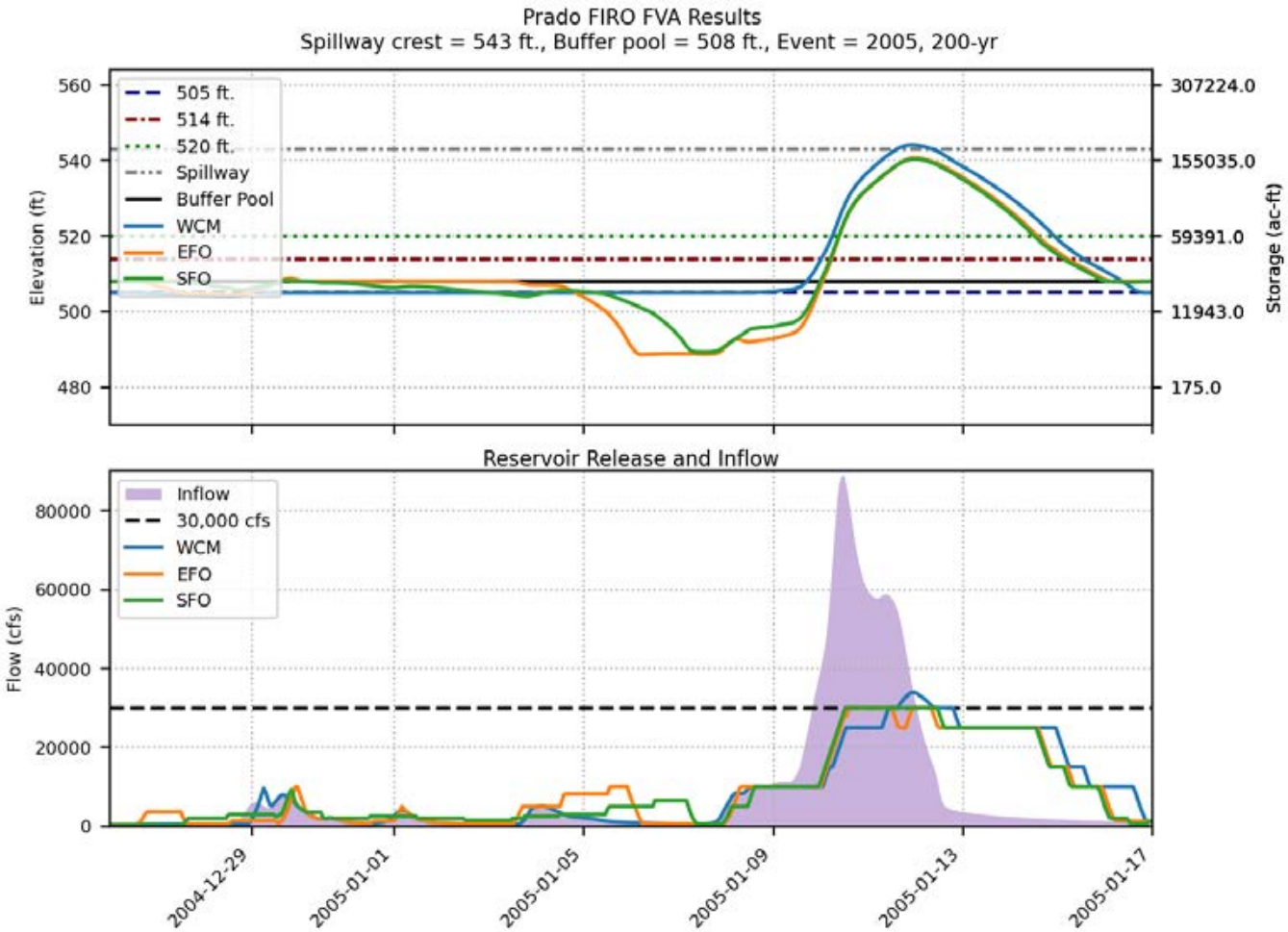
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 508 ft., Event = 2005, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
EFO
SFO
Flow (cfs)
80000
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40000
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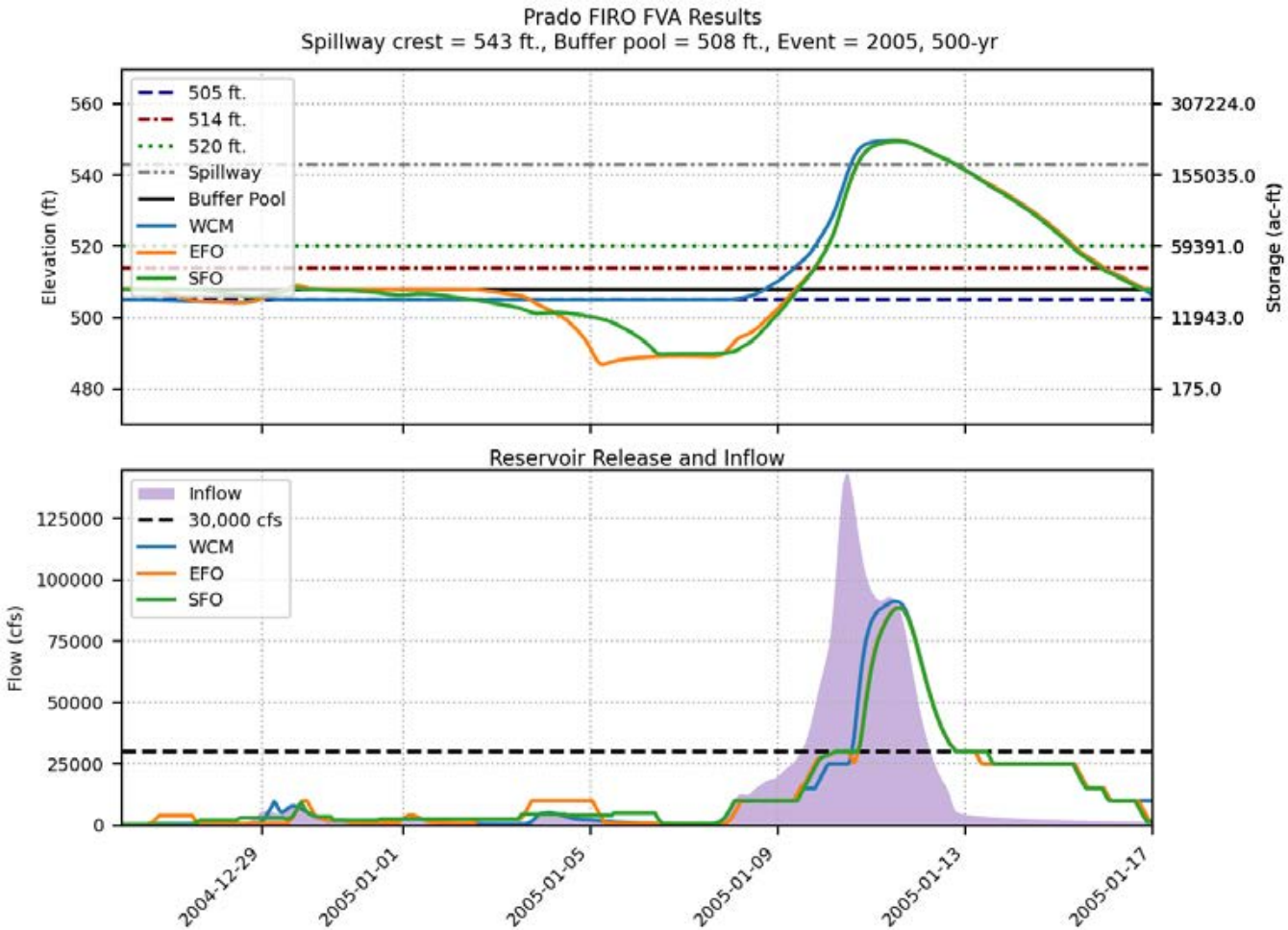
2005-01-17


Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 508 ft., Event = 2005, 500-yr
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514 ft.
520 ft.
Spillway
Buffer Pool
WCM
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
EFO
SFO
Flow (cfs)
125000
100000
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2005-01-01
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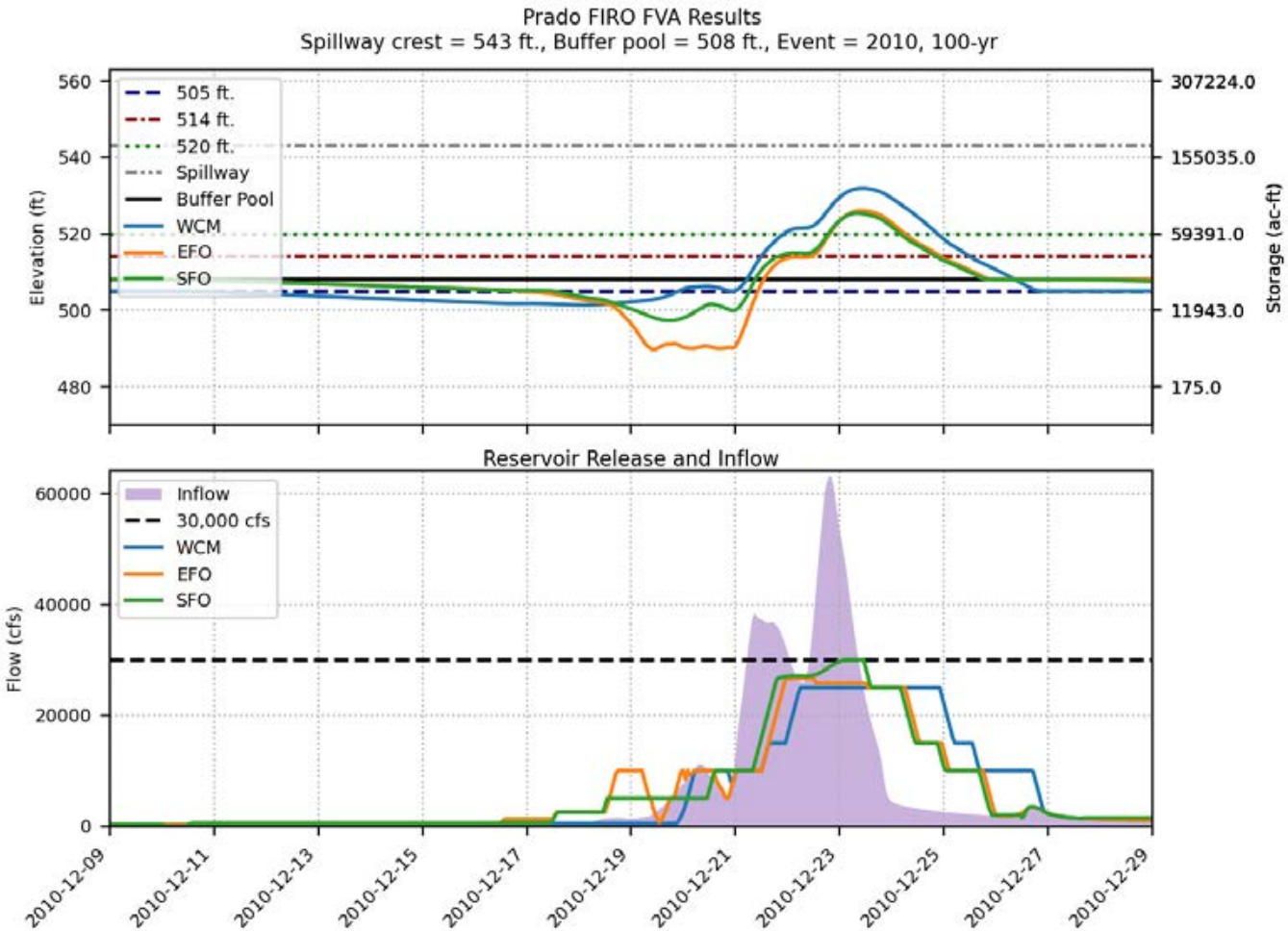
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Spillway crest = 543 ft., Buffer pool = 508 ft., Event = 2010, 100-yr
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514 ft.
520 ft.
Spillway
Buffer Pool
WCM
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
307224.0
155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
EFO
SFO
Flow (cfs)
60000
40000
20000
0
2010-12-09
2010-12-11
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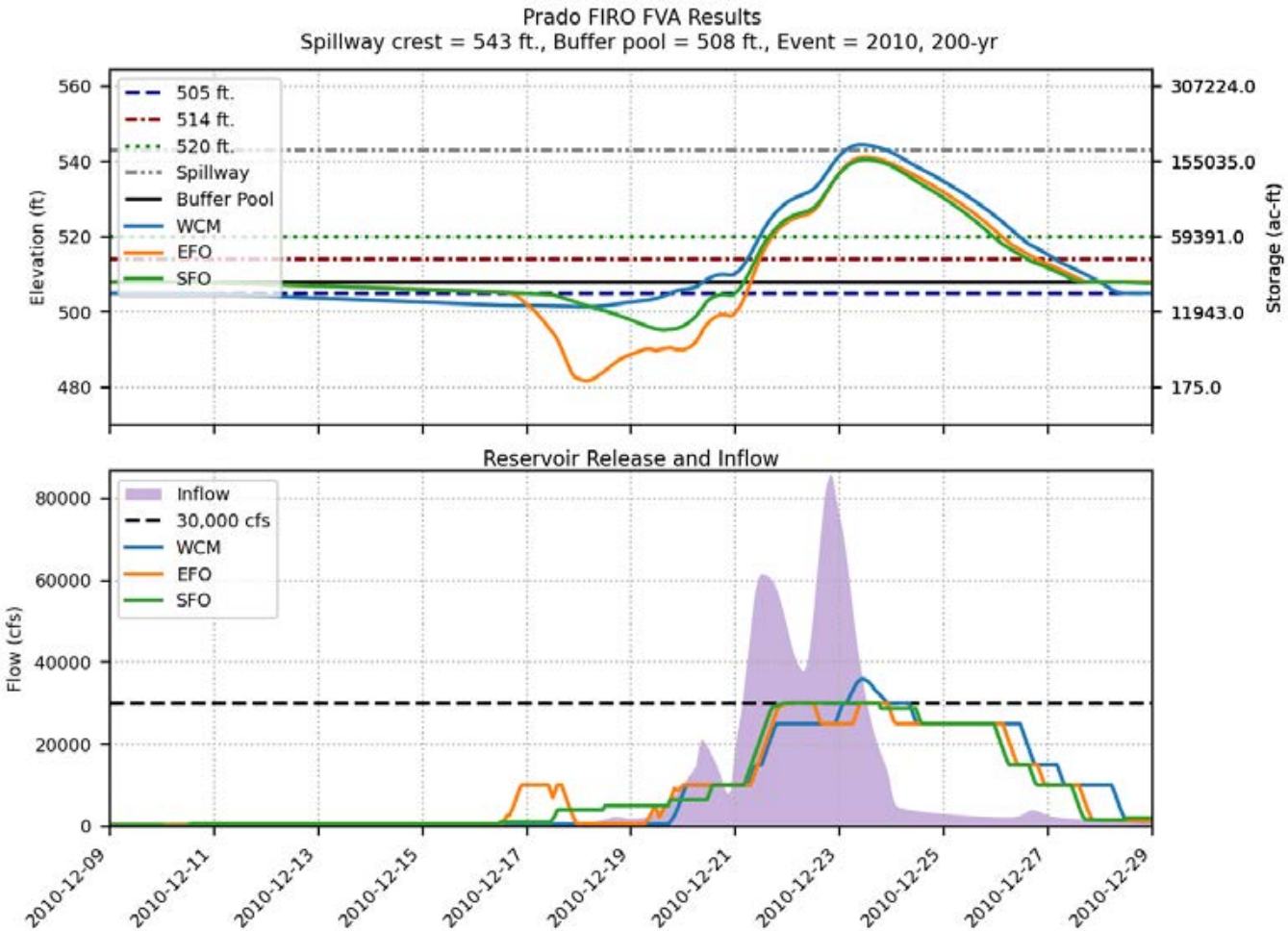
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 508 ft., Event = 2010, 200-yr
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514 ft.
520 ft.
Spillway
Buffer Pool
WCM
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
480
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155035.0
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Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
EFO
SFO
Flow (cfs)
80000
60000
40000
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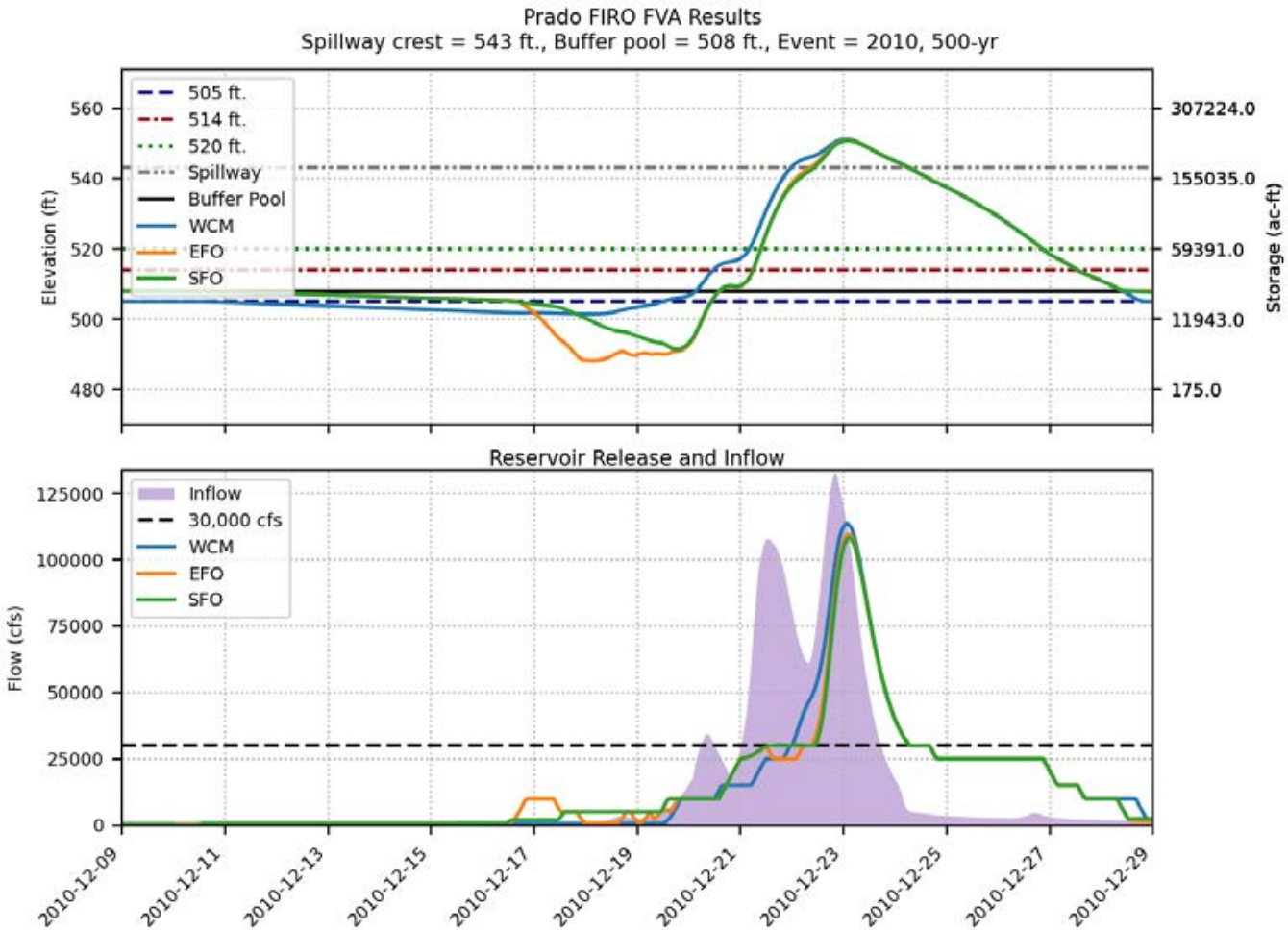
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 508 ft., Event = 2010, 500-yr
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EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
520
500
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Reservoir Release and Inflow
Inflow
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Flow (cfs)
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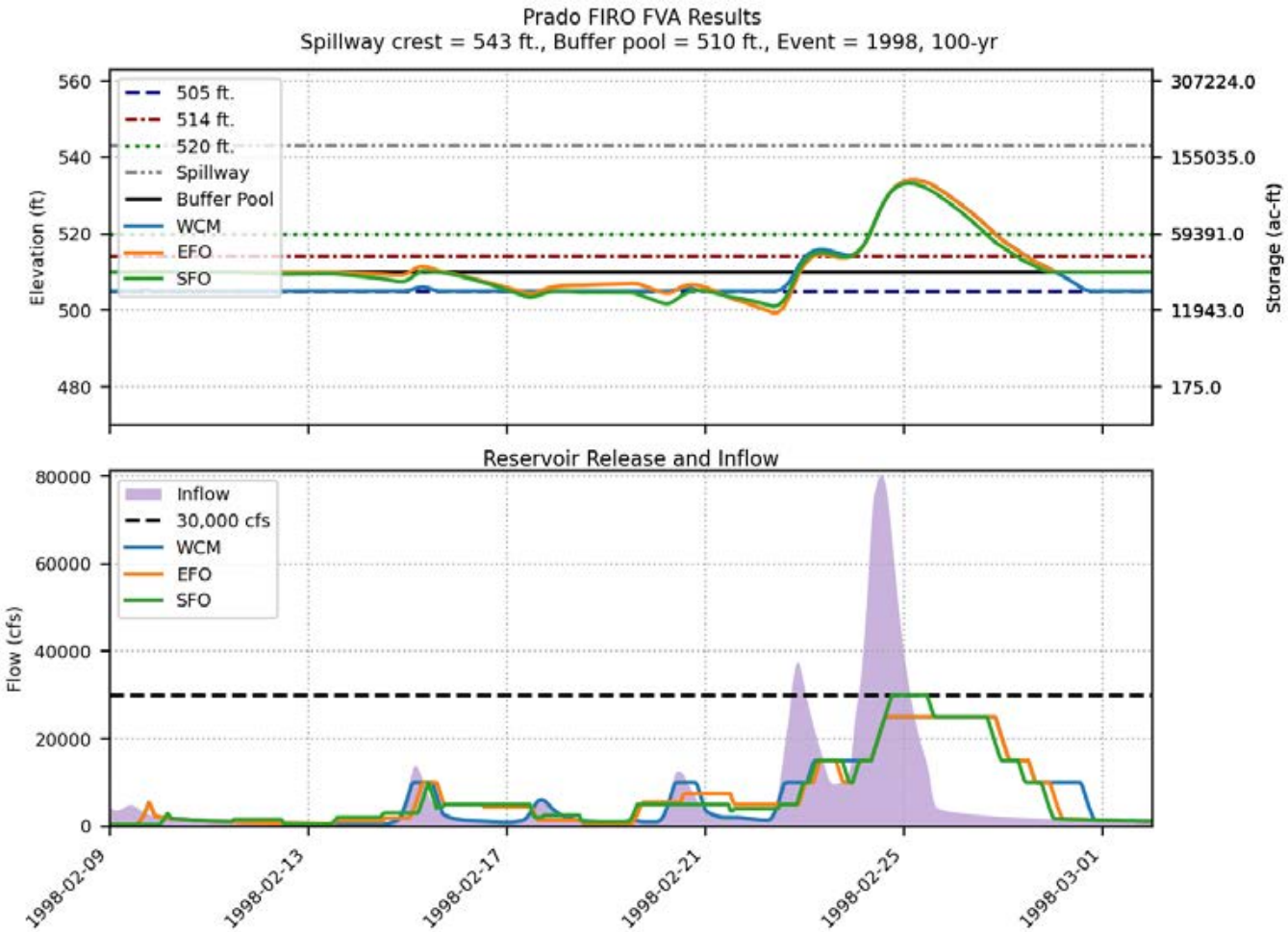
Prado FIRO FVA Results
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Buffer Pool
WCM
EFO
SFO
Elevation (ft)
Storage (ac-ft)
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540
520
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480
307224.0
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Reservoir Release and Inflow
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WCM
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SFO
Flow (cfs)
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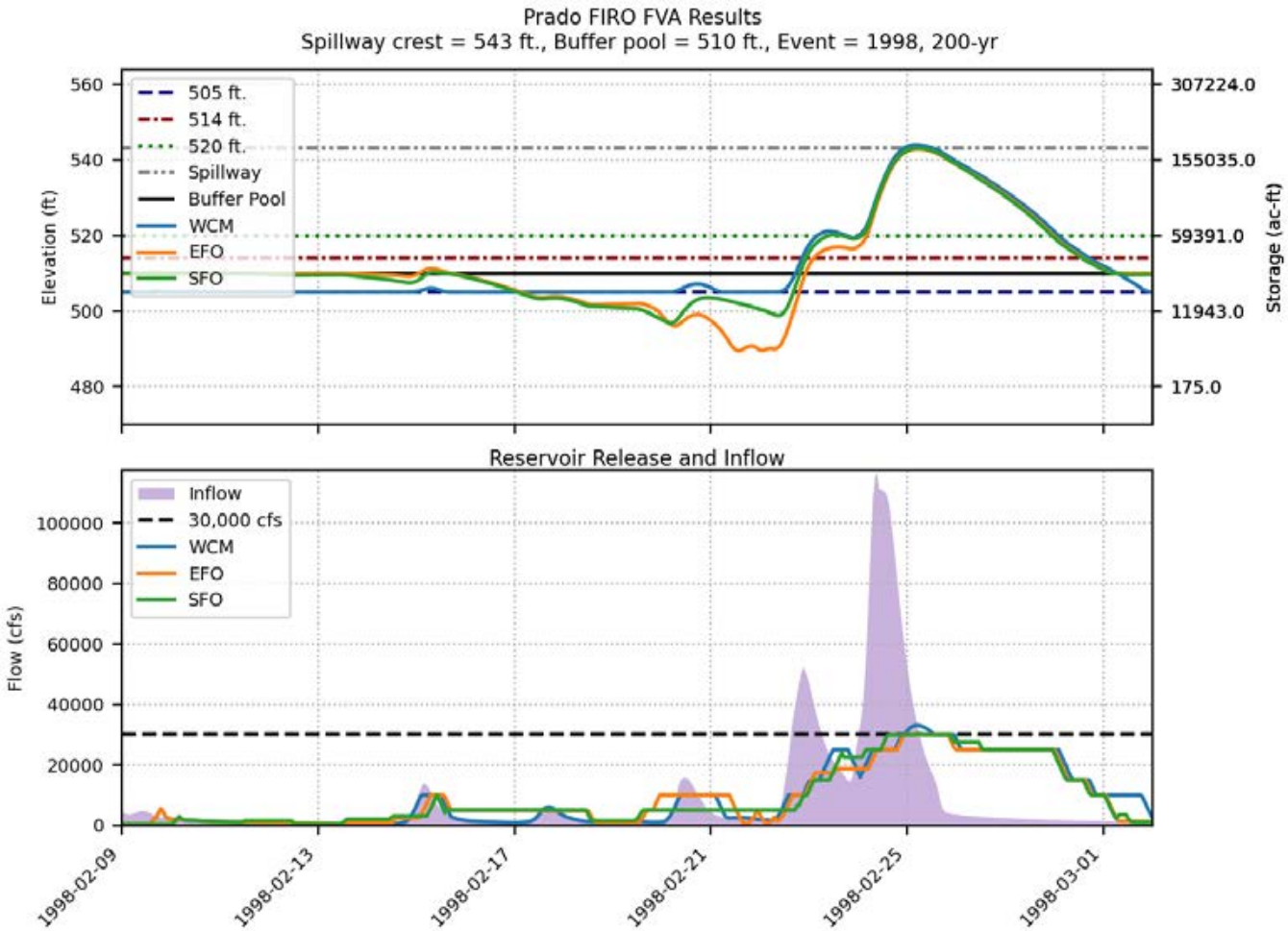
1998-03-01


Prado FIRO FVA Results
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520 ft.
Spillway
Buffer Pool
WCM
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
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520
500
480
307224.0
155035.0
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Reservoir Release and Inflow
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30,000 cfs
WCM
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Flow (cfs)
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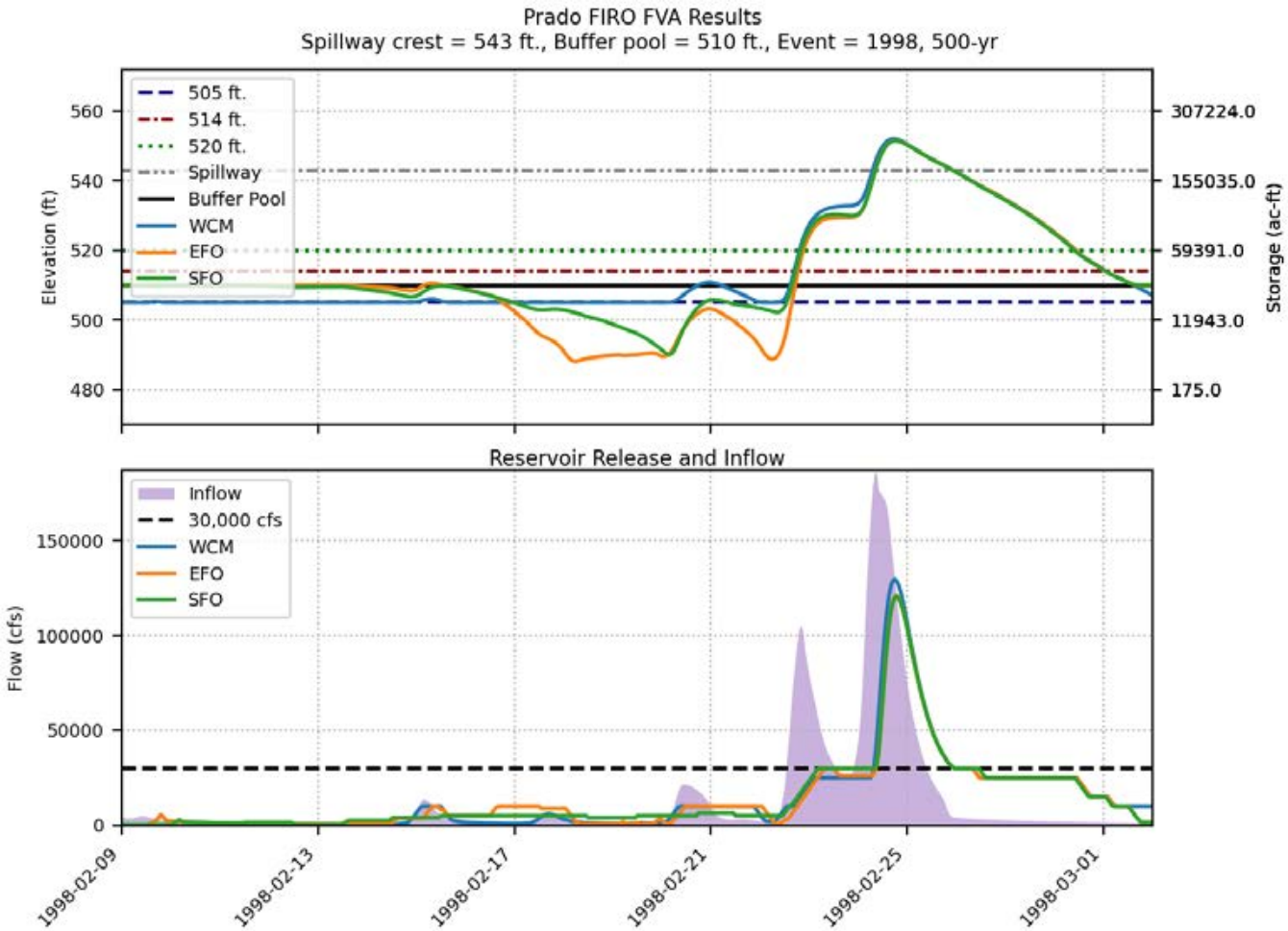
Prado FIRO FVA Results
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514 ft.
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Buffer Pool
WCM
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Inflow
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WCM
EFO
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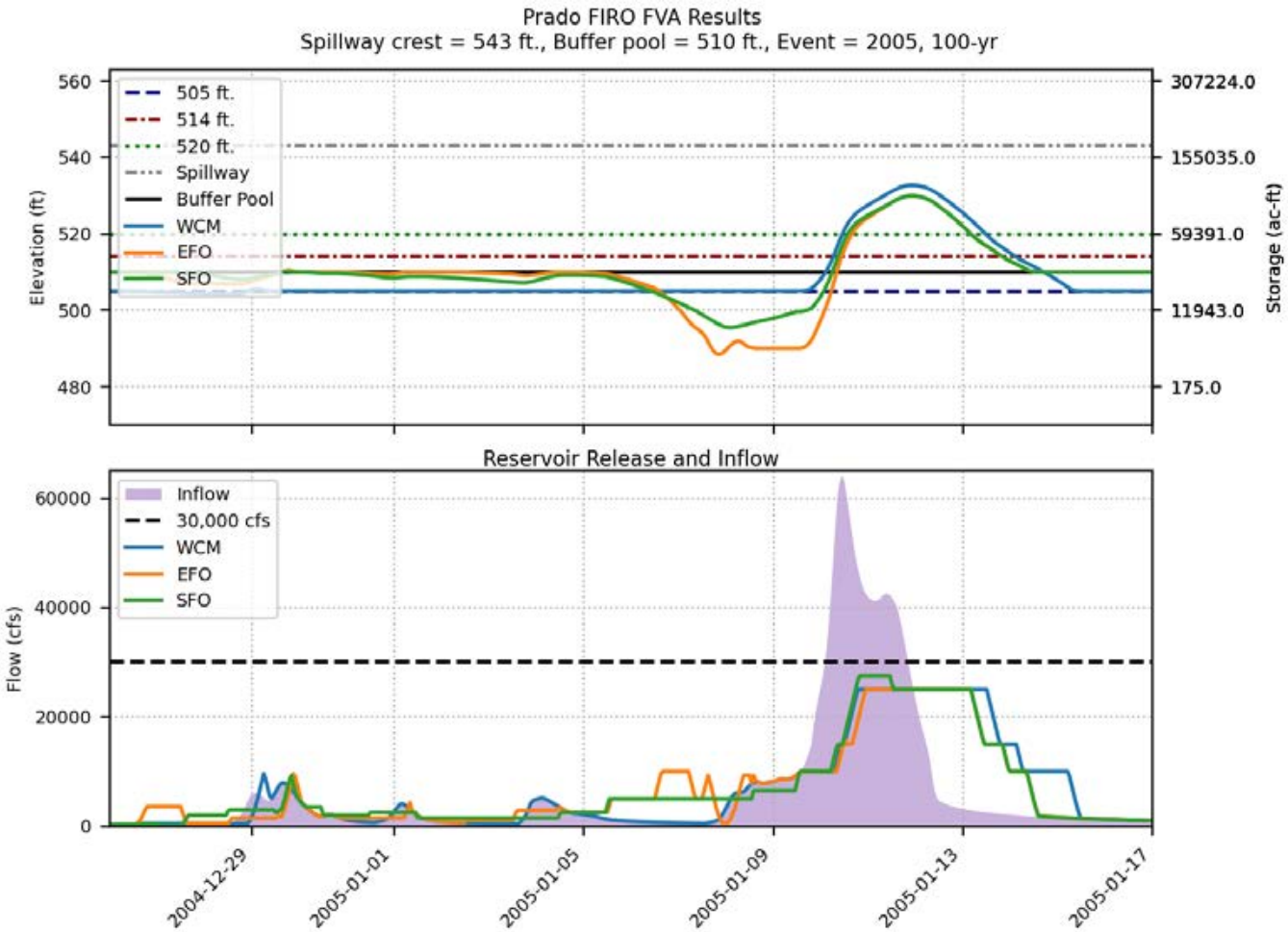
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 510 ft., Event = 2005, 100-yr
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514 ft.
520 ft.
Spillway
Buffer Pool
WCM
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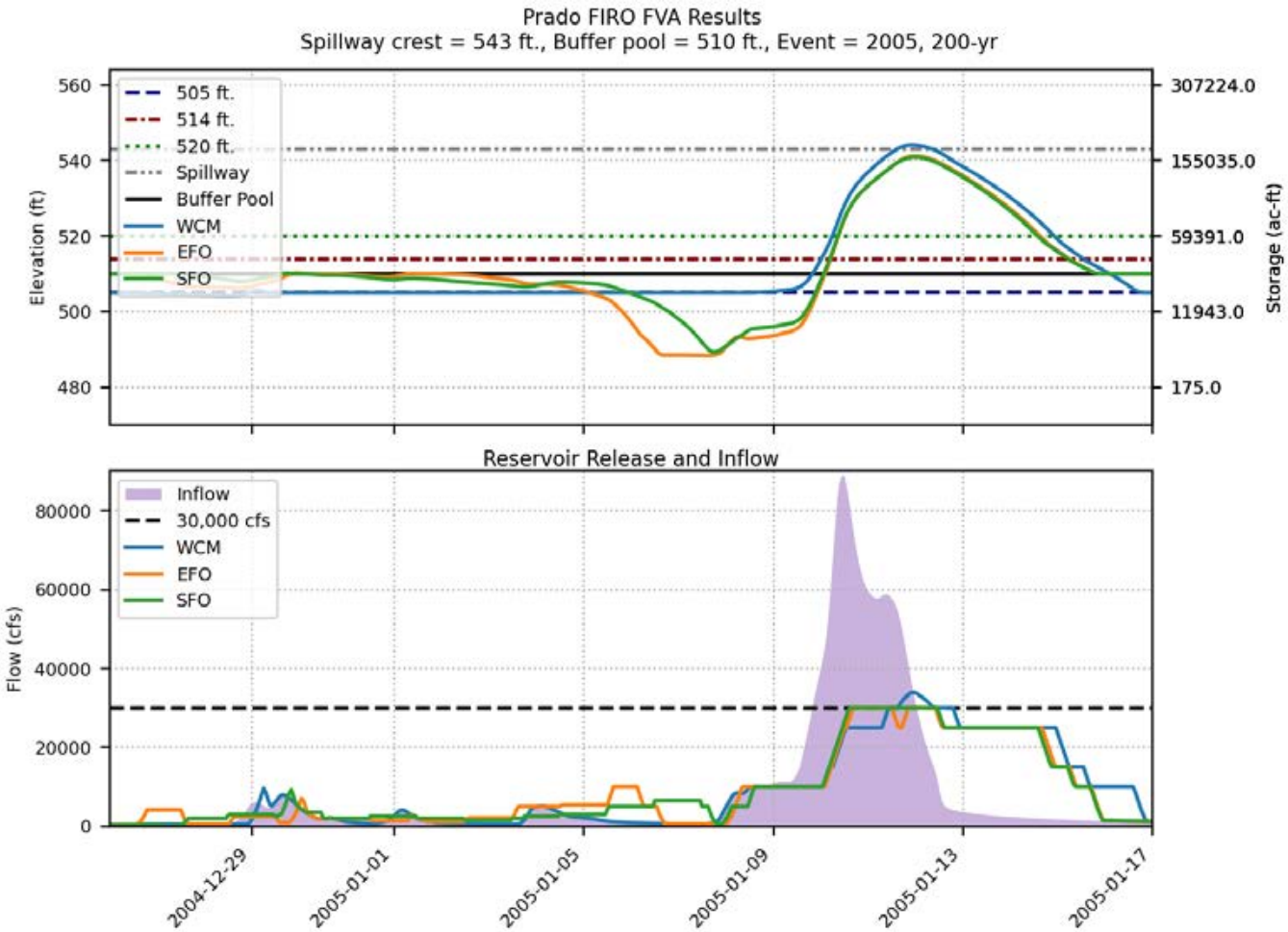
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WCM
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WCM
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Flow (cfs)
80000
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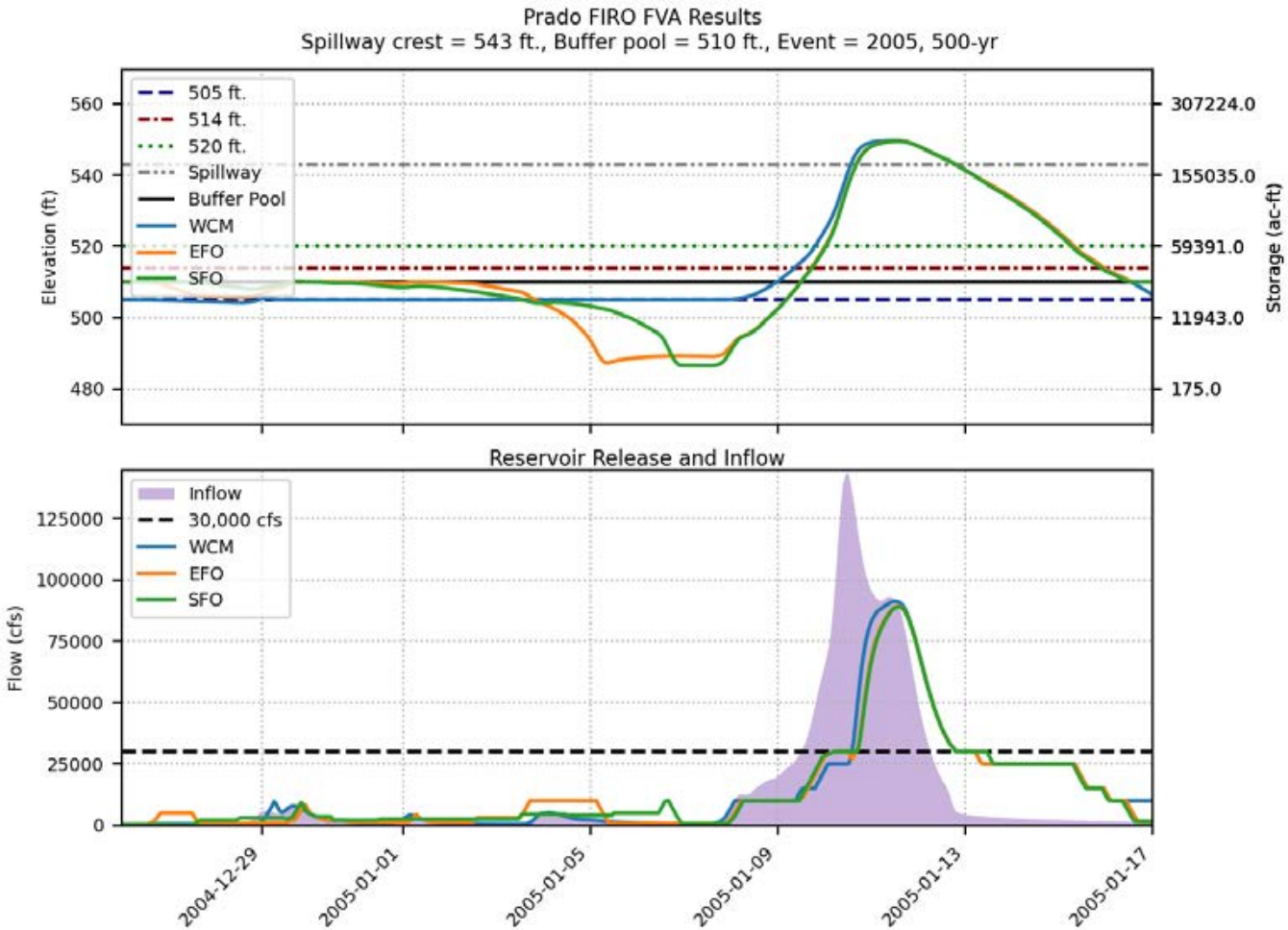
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514 ft.
520 ft.
Spillway
Buffer Pool
WCM
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SFO
Elevation (ft)
Storage (ac-ft)
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155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
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Flow (cfs)
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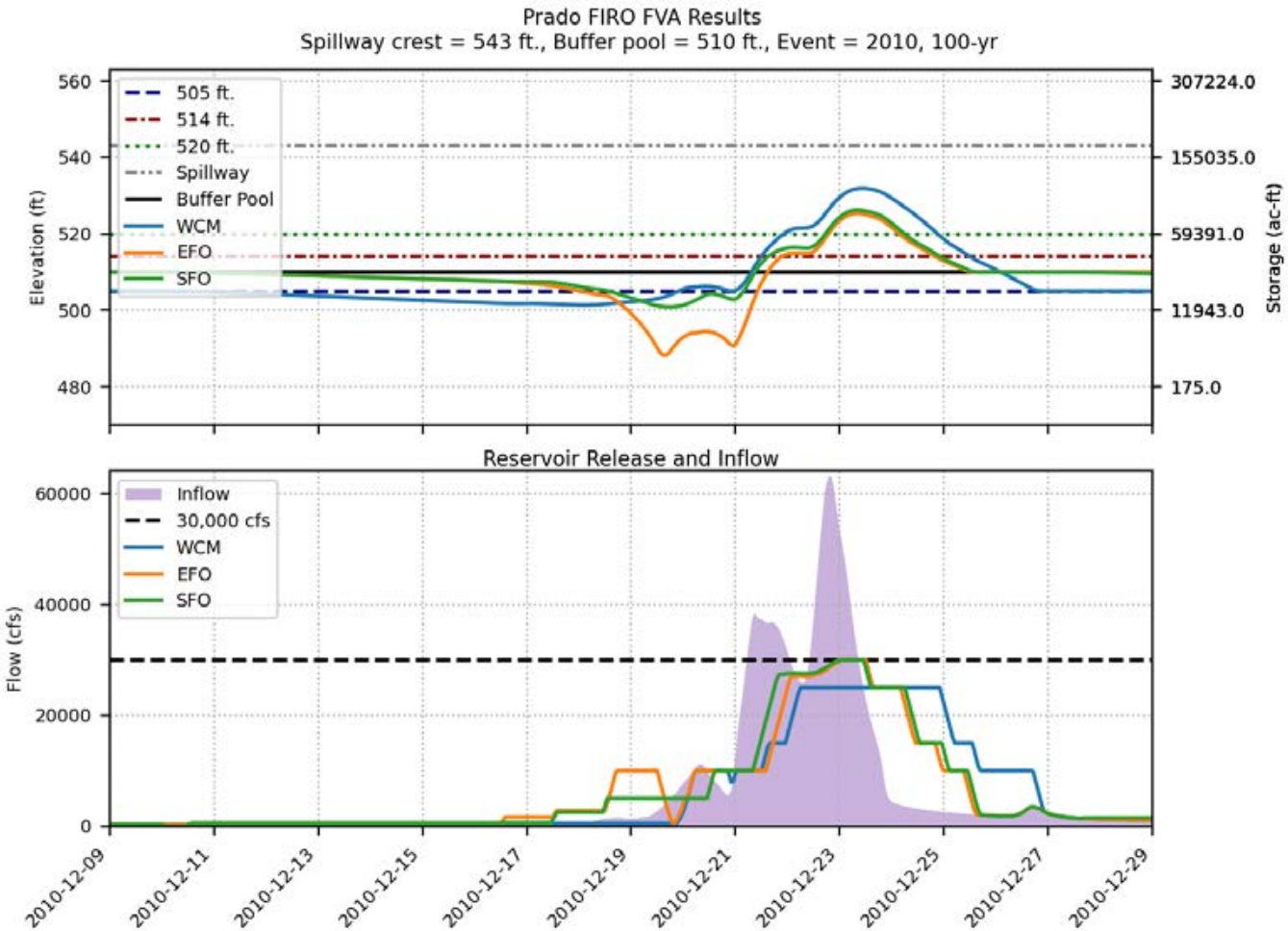
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 510 ft., Event = 2010, 100-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
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SFO
Elevation (ft)
Storage (ac-ft)
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307224.0
155035.0
59391.0
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Reservoir Release and Inflow
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Flow (cfs)
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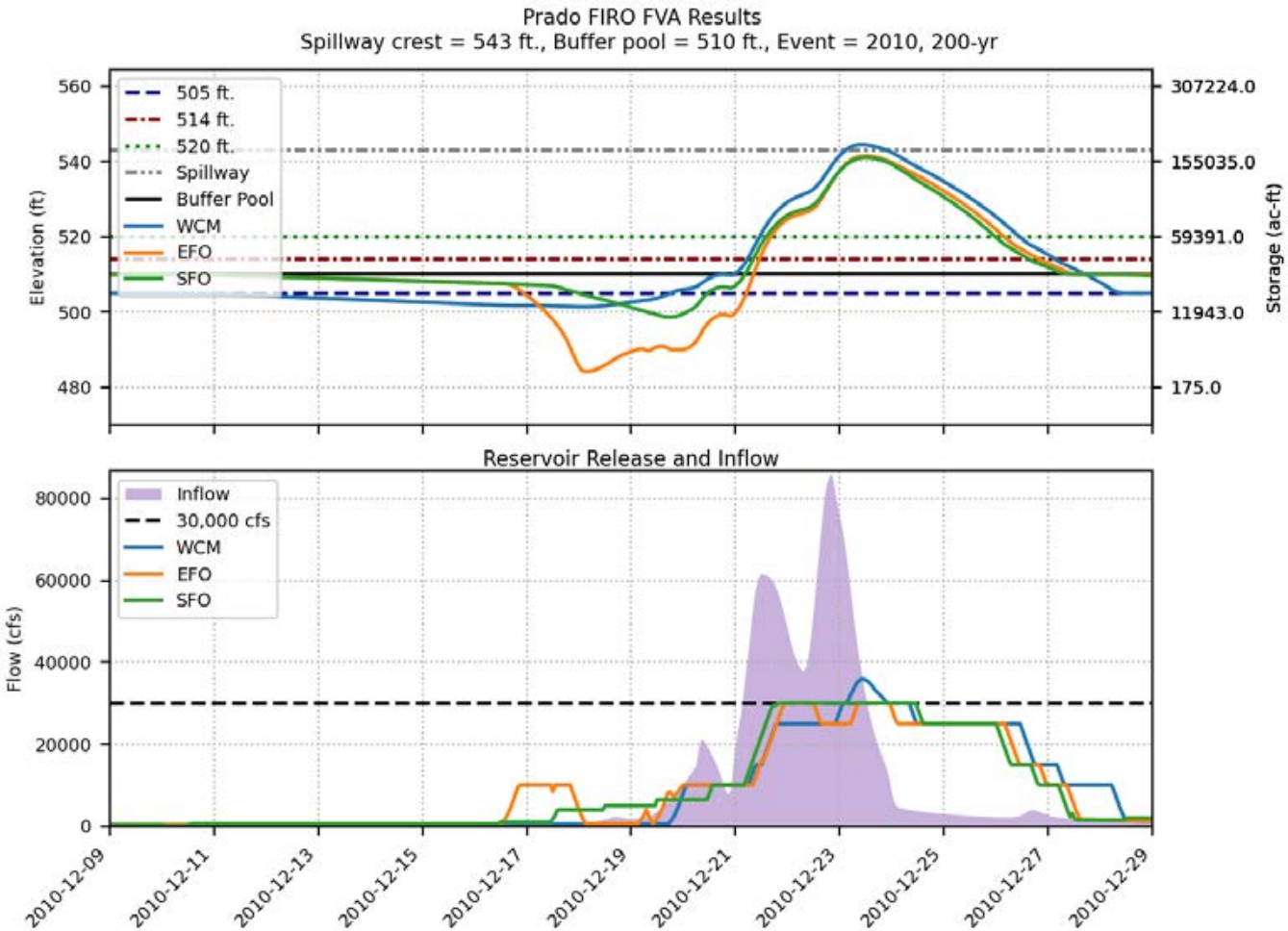
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Spillway crest = 543 ft., Buffer pool = 510 ft., Event = 2010, 200-yr
505 ft.
514 ft.
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Spillway
Buffer Pool
WCM
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SFO
Elevation (ft)
Storage (ac-ft)
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155035.0
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Reservoir Release and Inflow
Inflow
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Flow (cfs)
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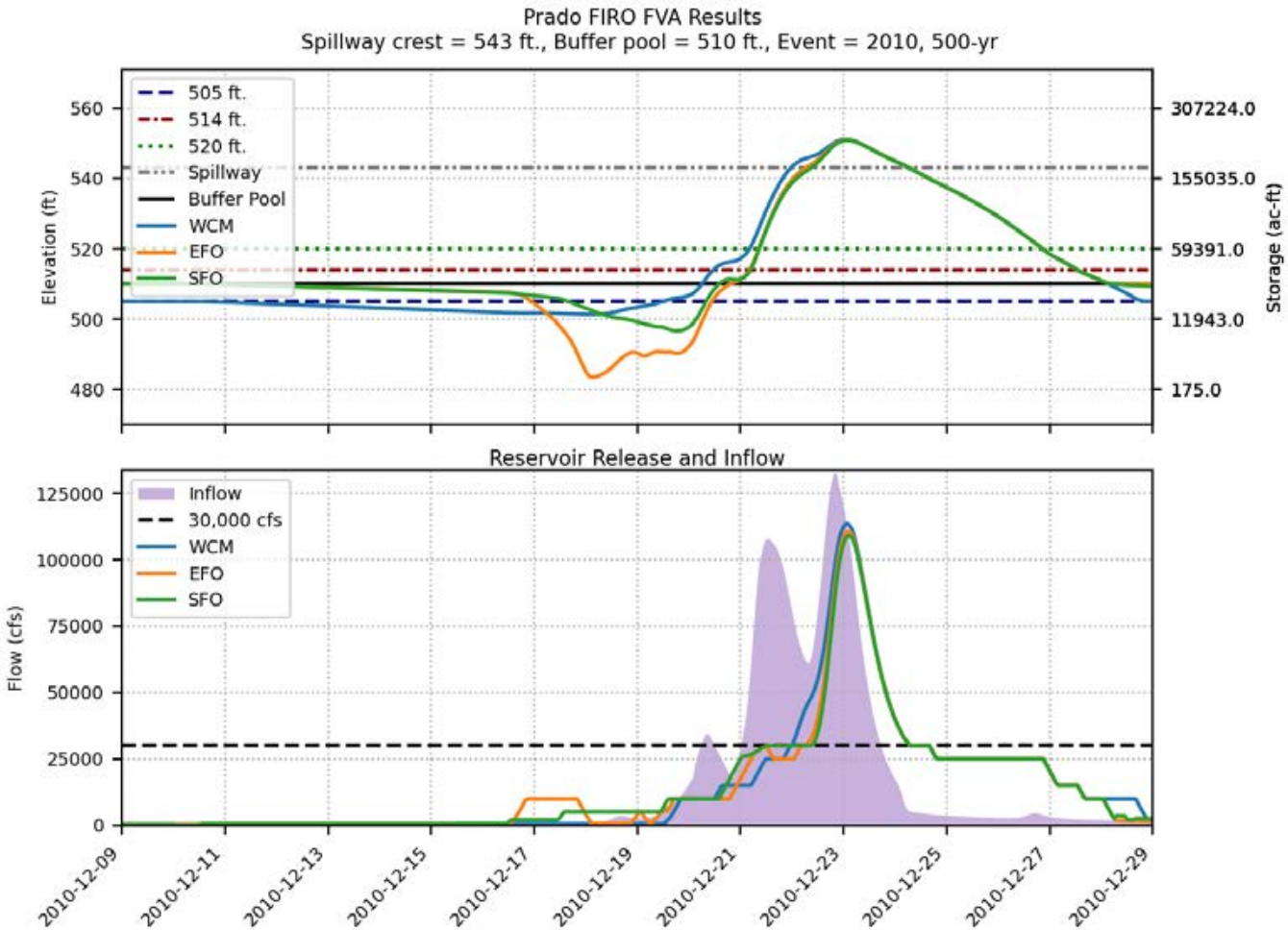
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 510 ft., Event = 2010, 500-yr
505 ft.
514 ft.
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Spillway
Buffer Pool
WCM
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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Flow (cfs)
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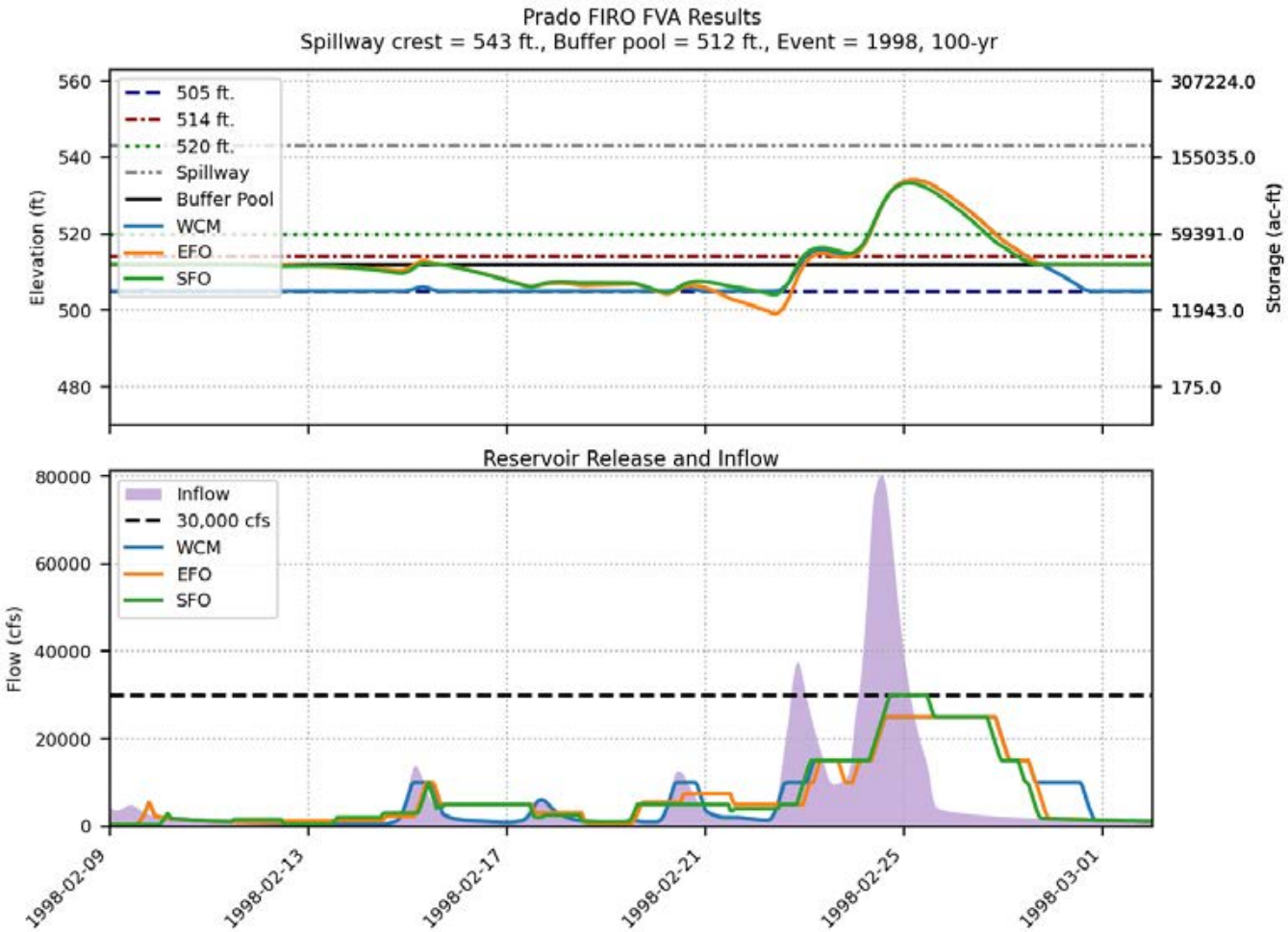
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Spillway crest = 543 ft., Buffer pool = 512 ft., Event = 1998, 100-yr
505 ft.
514 ft.
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WCM
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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Flow (cfs)
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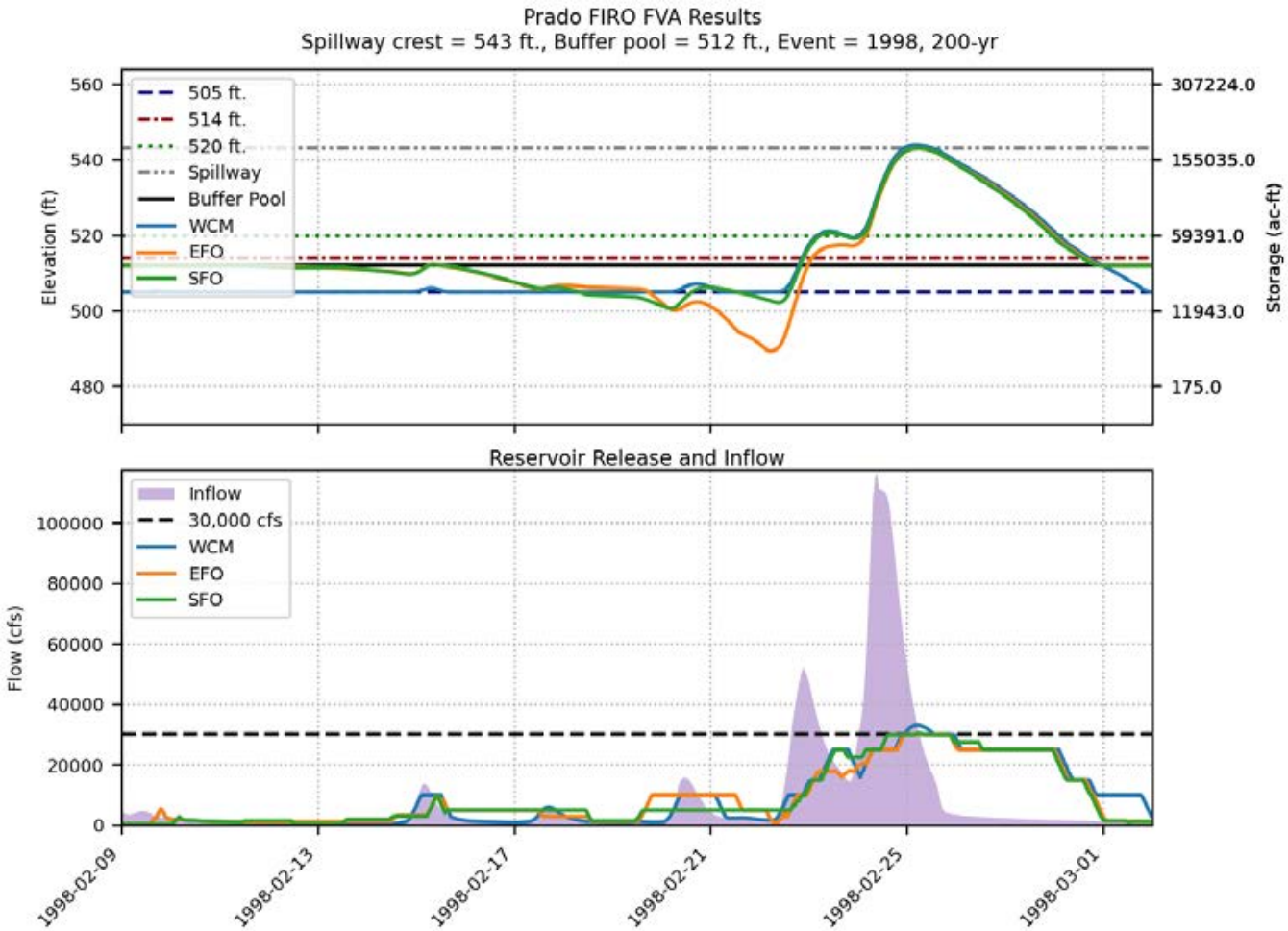
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 512 ft., Event = 1998, 200-yr
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514 ft.
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Spillway
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WCM
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
Inflow
30,000 cfs
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EFO
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Flow (cfs)
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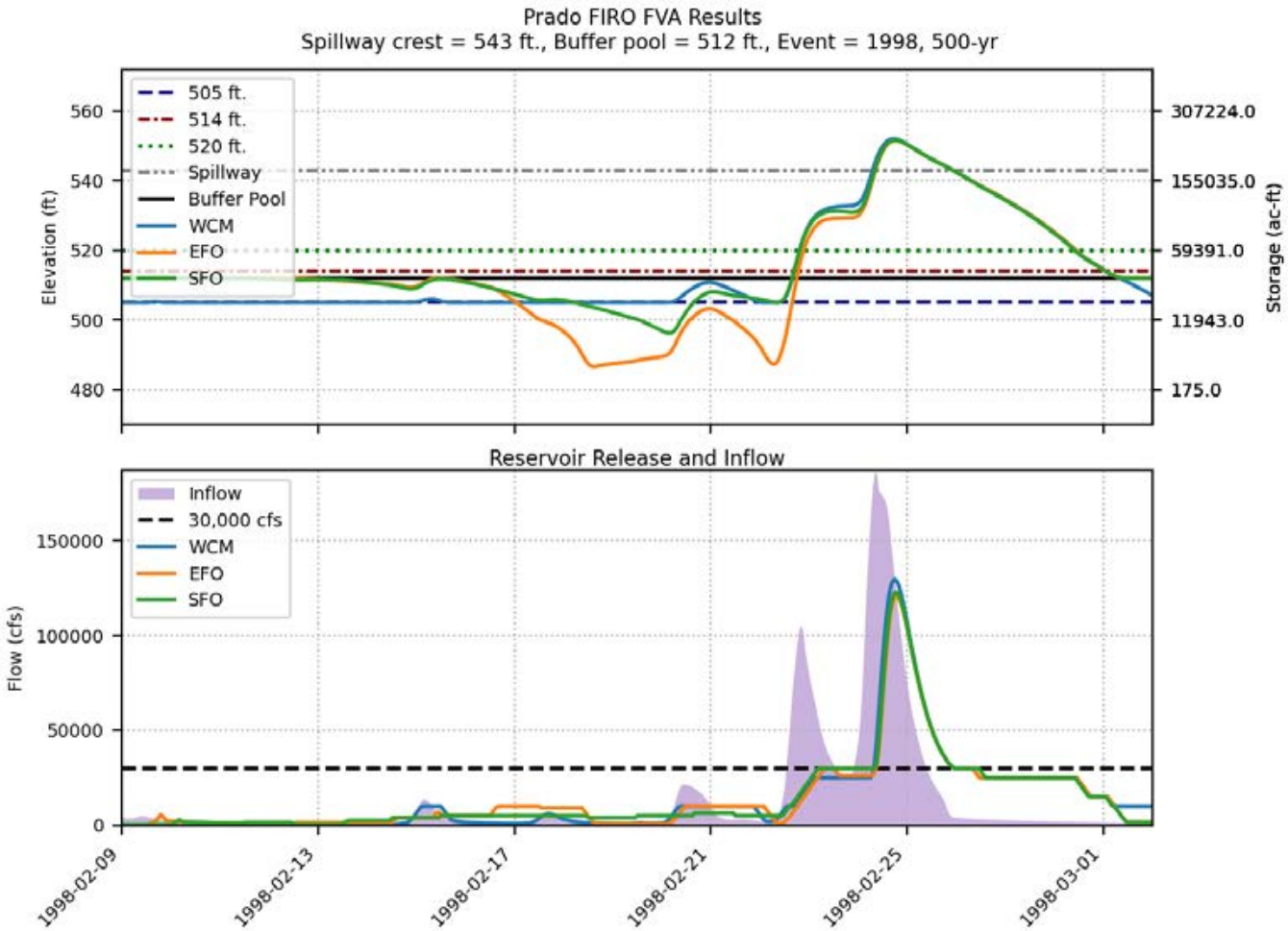
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 512 ft., Event = 1998, 500-yr
505 ft.
514 ft.
520 ft.
Spillway
Buffer Pool
WCM
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
Inflow
30,000 cfs
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Flow (cfs)
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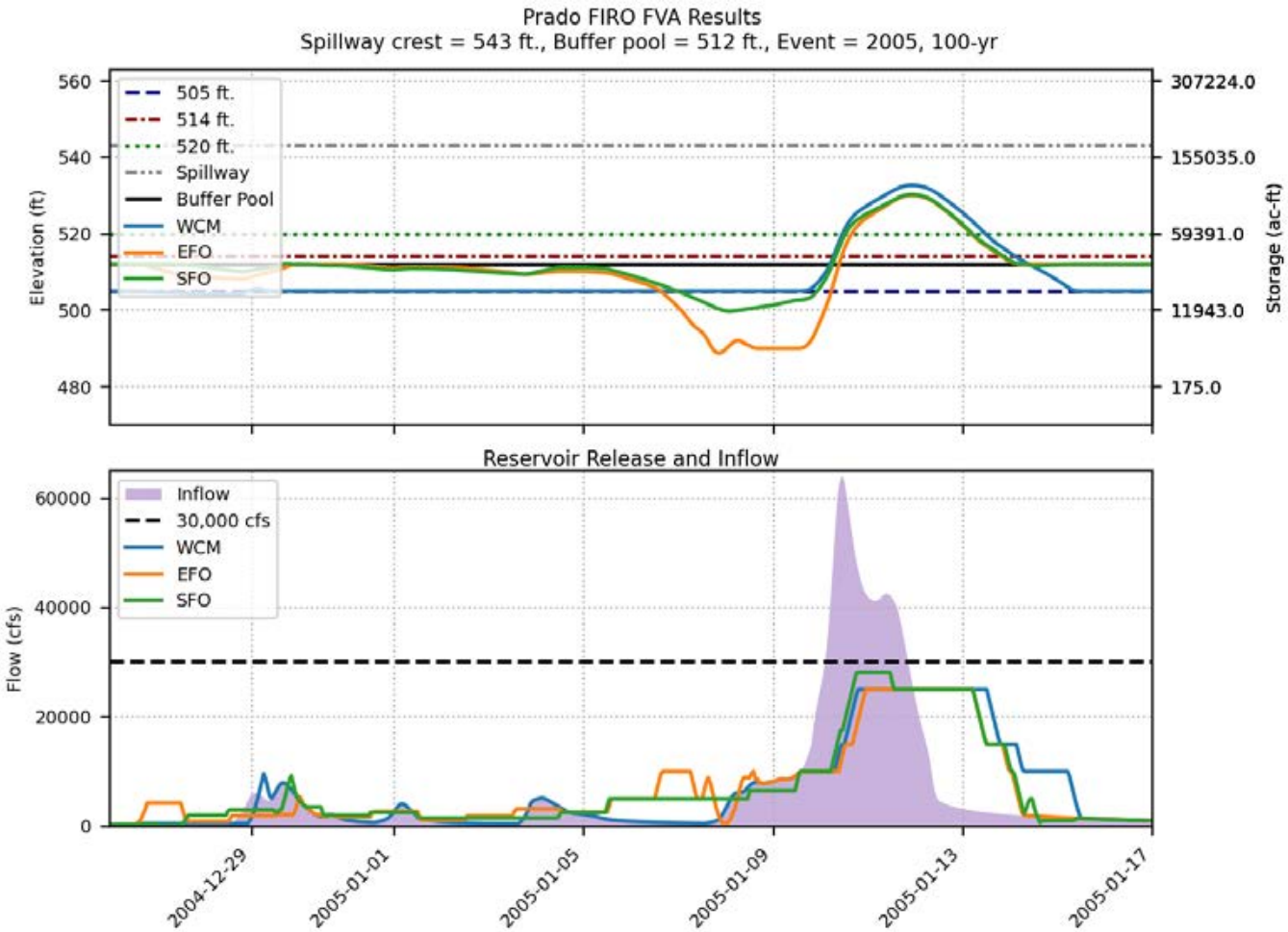
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 512 ft., Event = 2005, 100-yr
505 ft.
514 ft.
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Spillway
Buffer Pool
WCM
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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30,000 cfs
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Flow (cfs)
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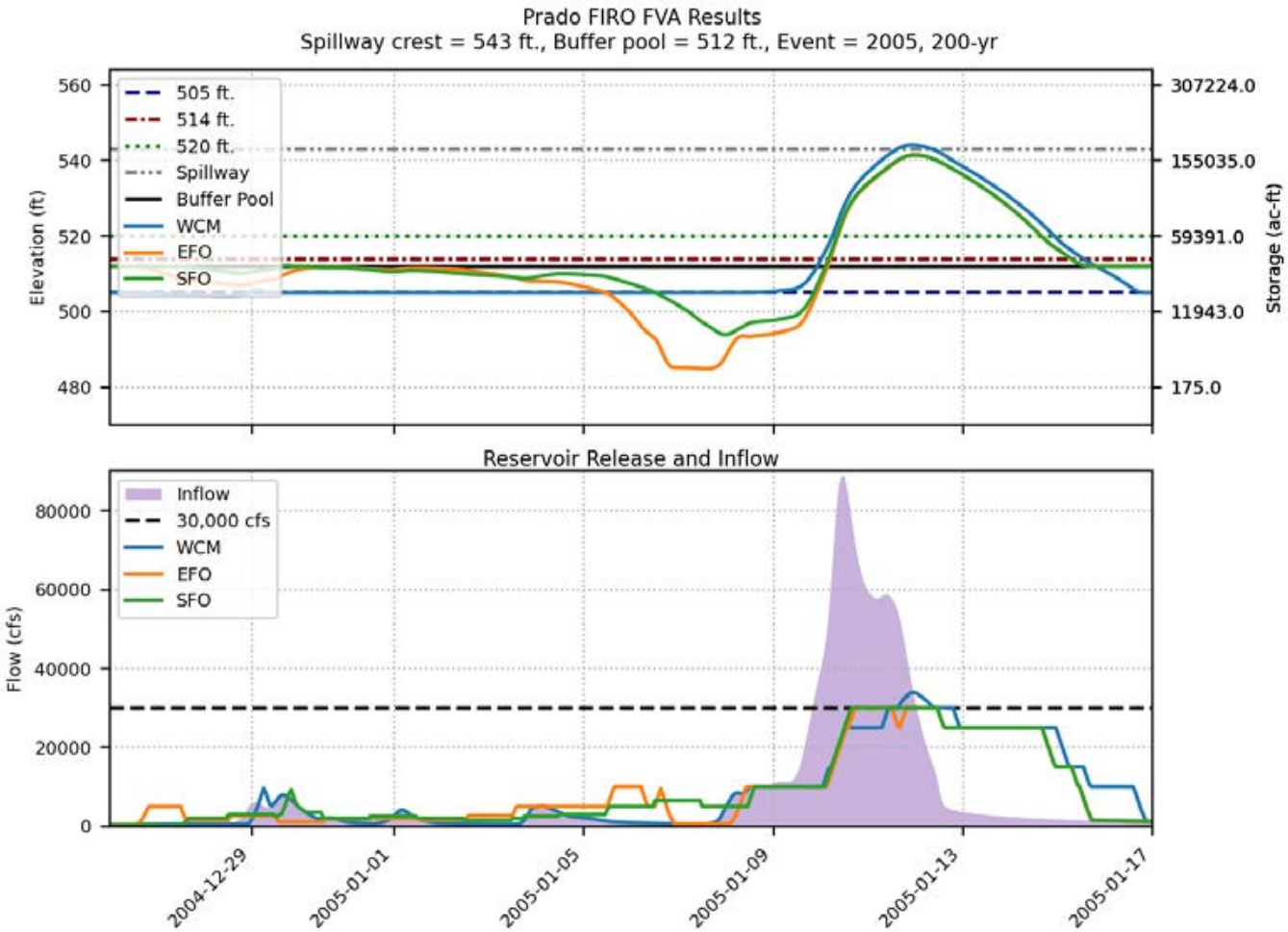
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Spillway crest = 543 ft., Buffer pool = 512 ft., Event = 2005, 200-yr
505 ft.
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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Flow (cfs)
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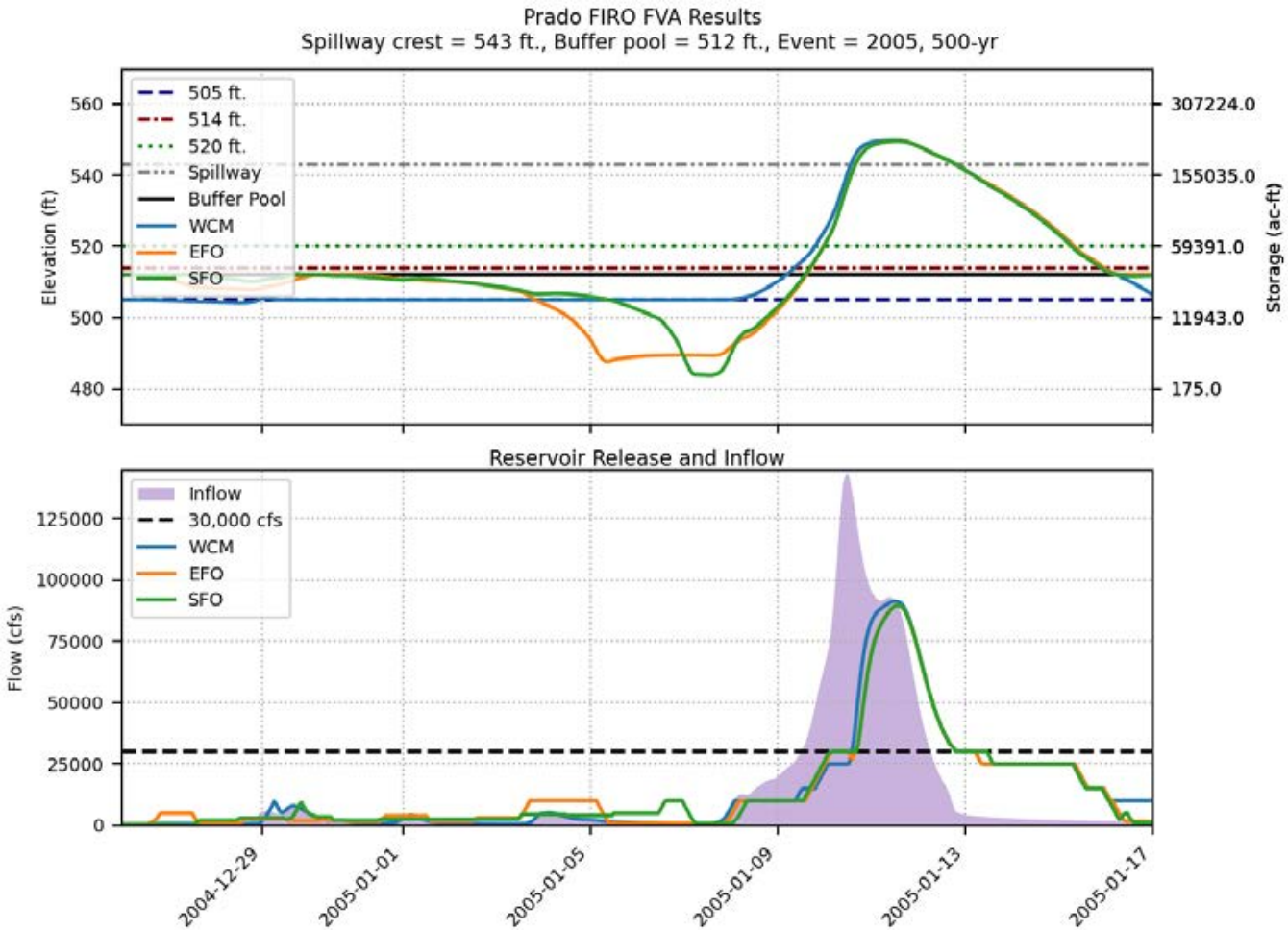
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505 ft.
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Buffer Pool
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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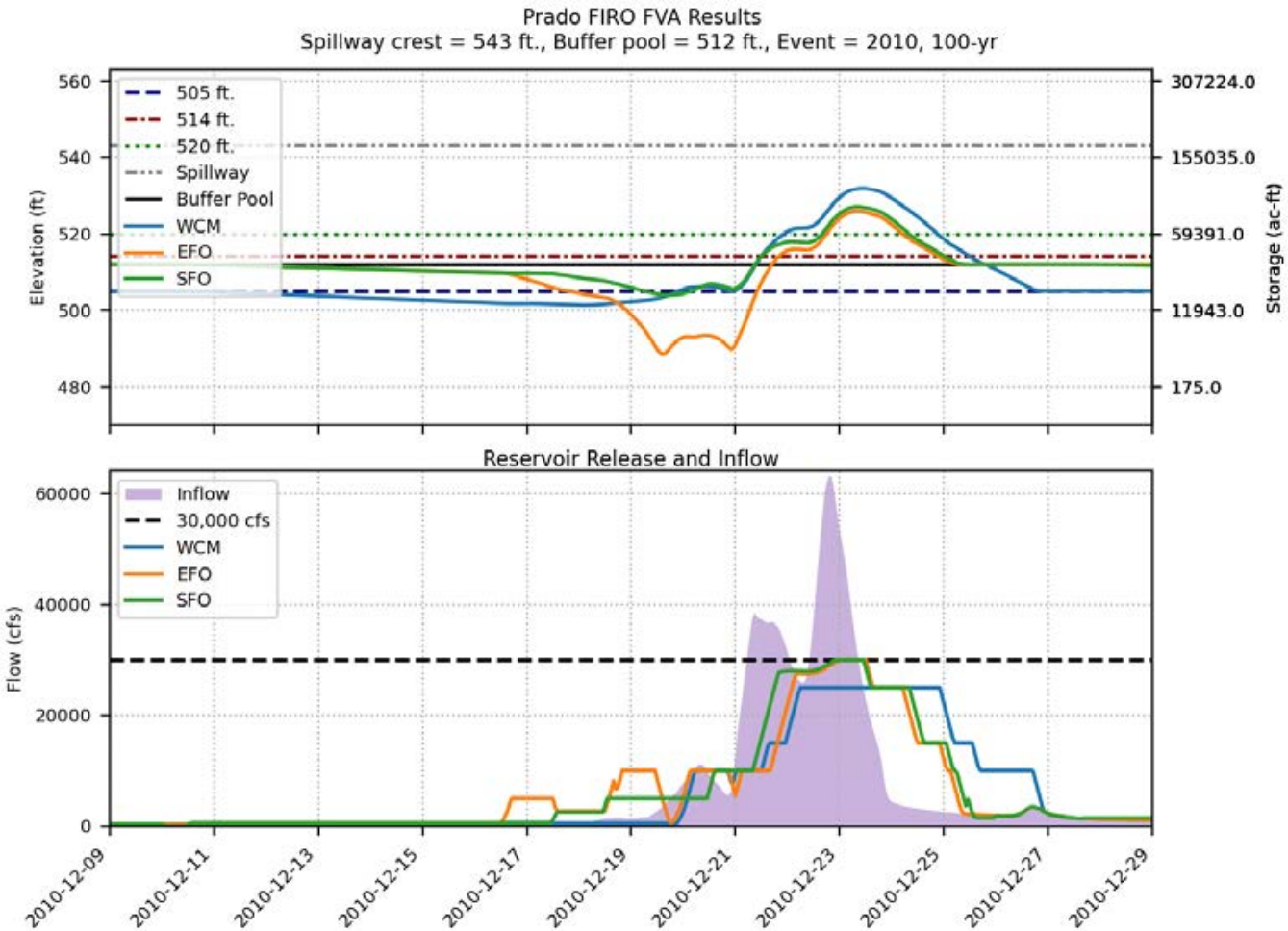
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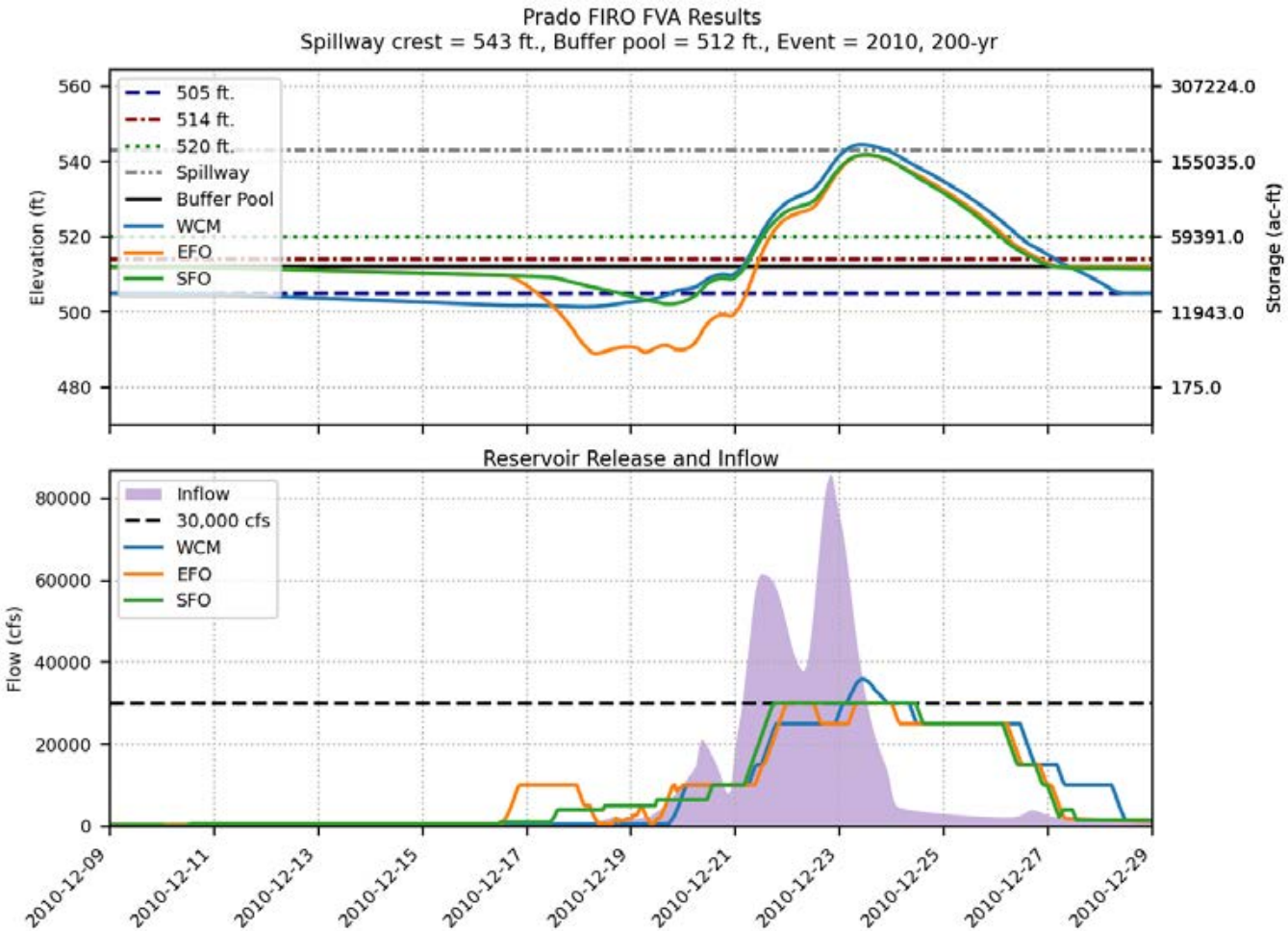
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 512 ft., Event = 2010, 200-yr
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Reservoir Release and Inflow
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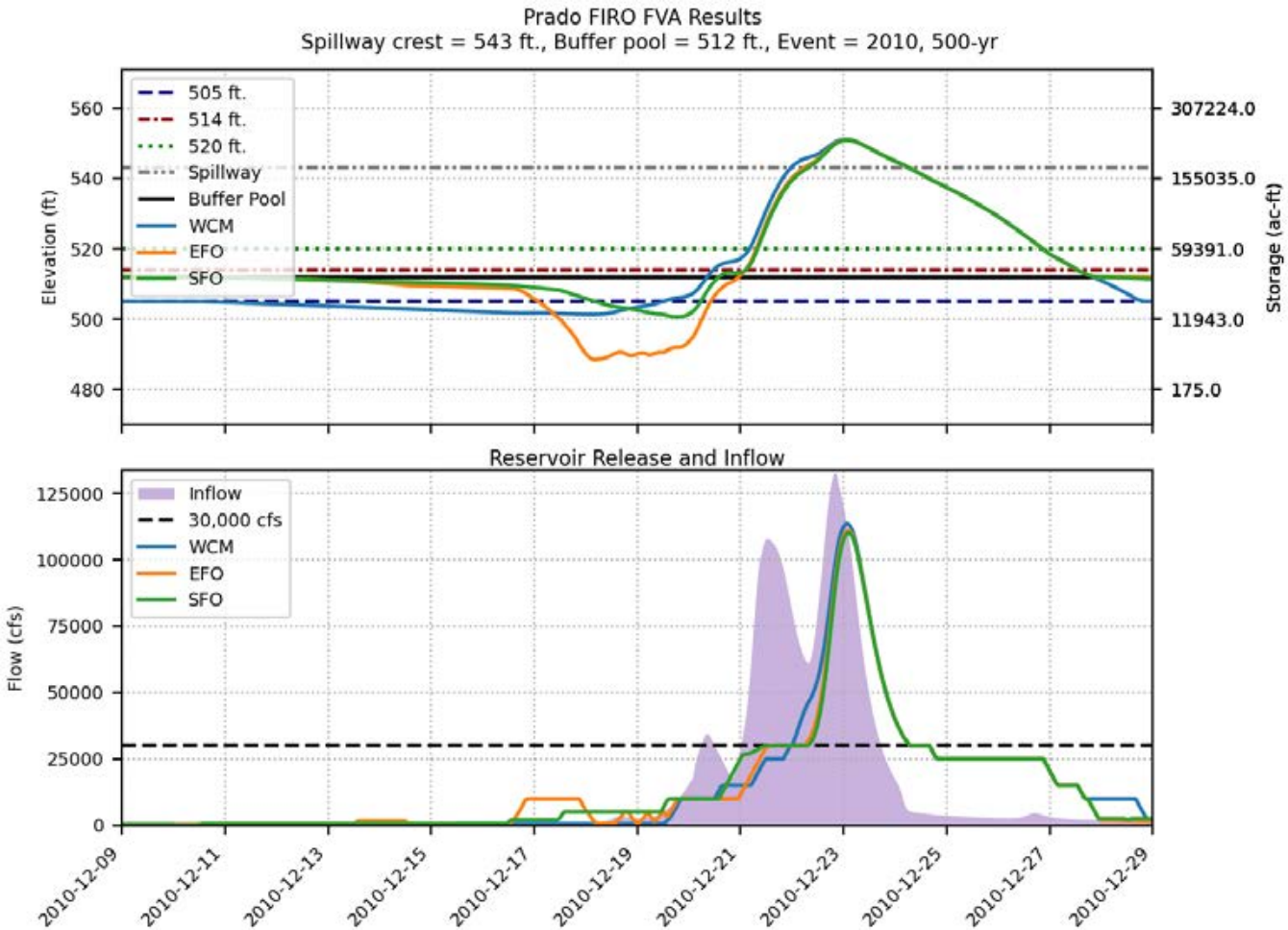
Prado FIRO FVA Results
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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Flow (cfs)
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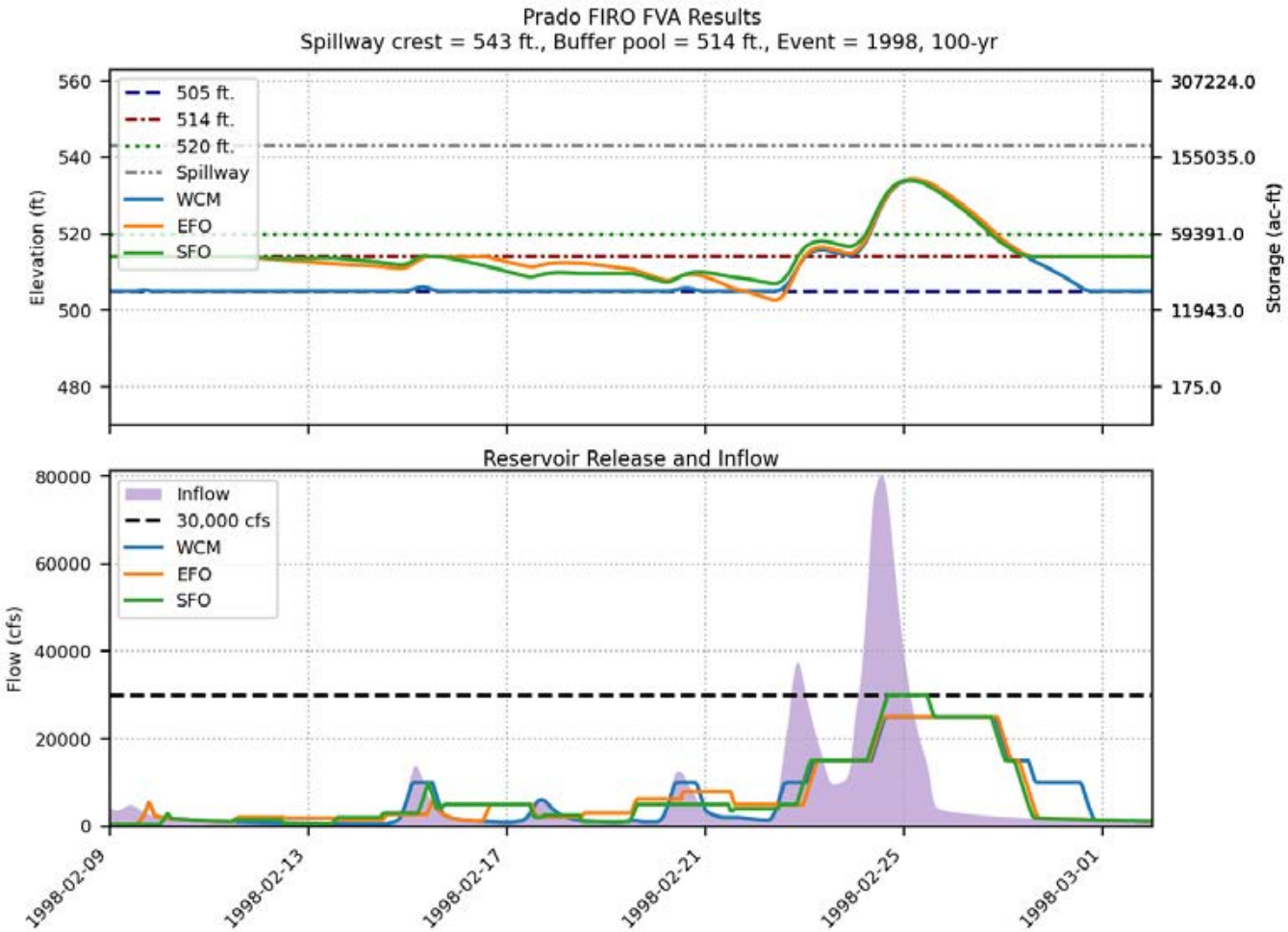
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Elevation (ft)
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Reservoir Release and Inflow
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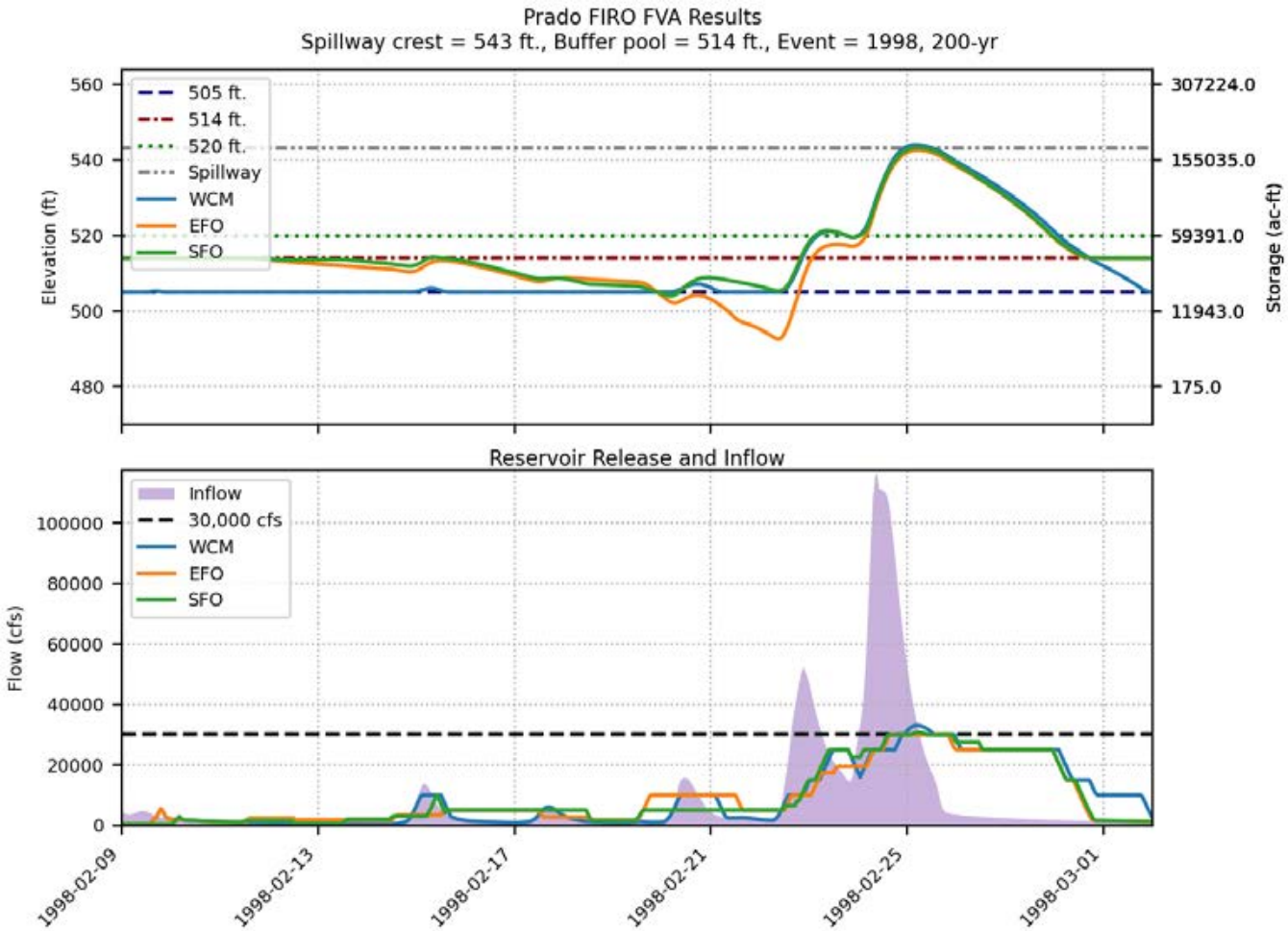
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Elevation (ft)
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Reservoir Release and Inflow
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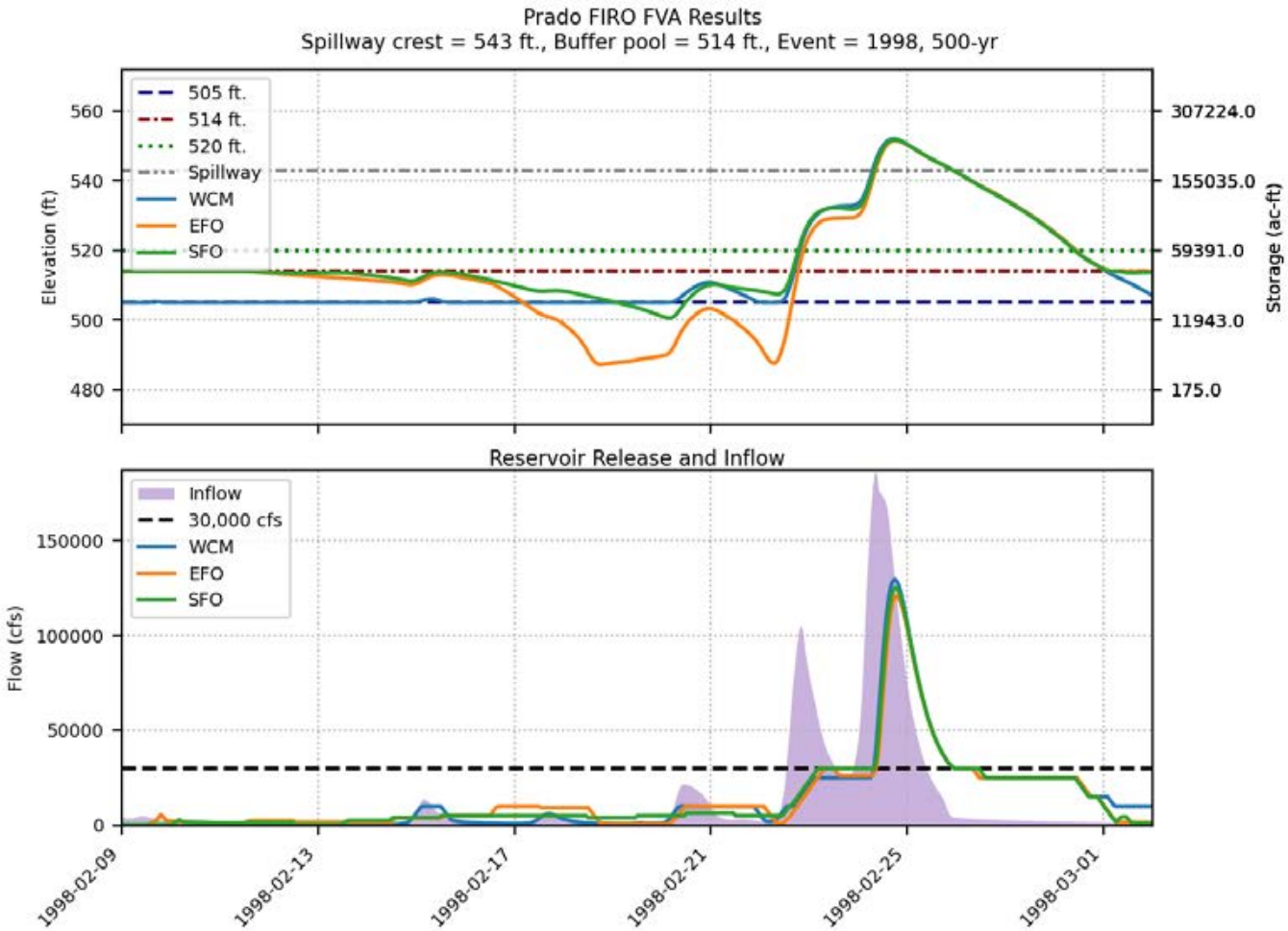
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Reservoir Release and Inflow
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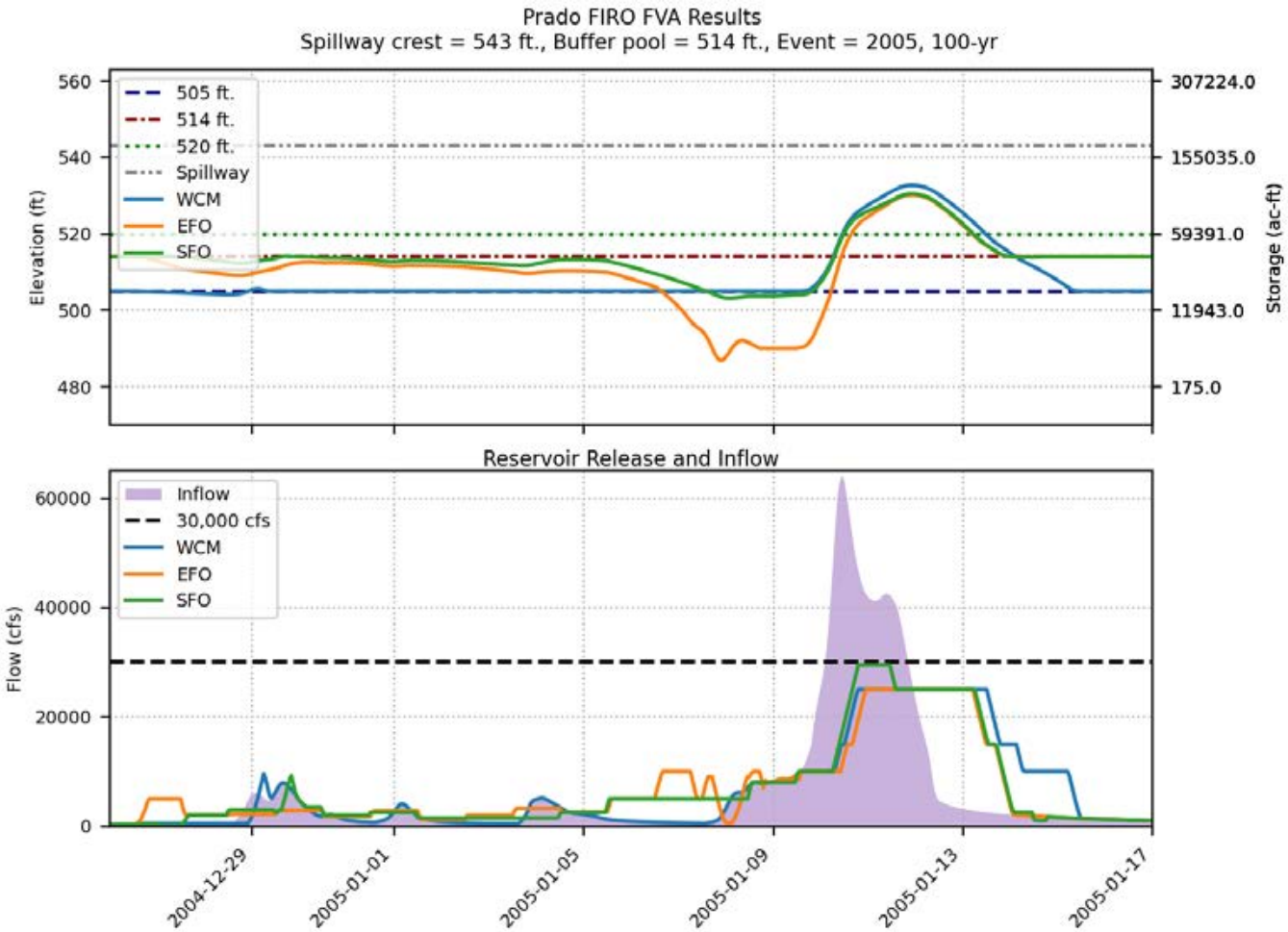
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514 ft.
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Spillway
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Elevation (ft)
Storage (ac-ft)
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59391.0
11943.0
175.0
Reservoir Release and Inflow
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Flow (cfs)
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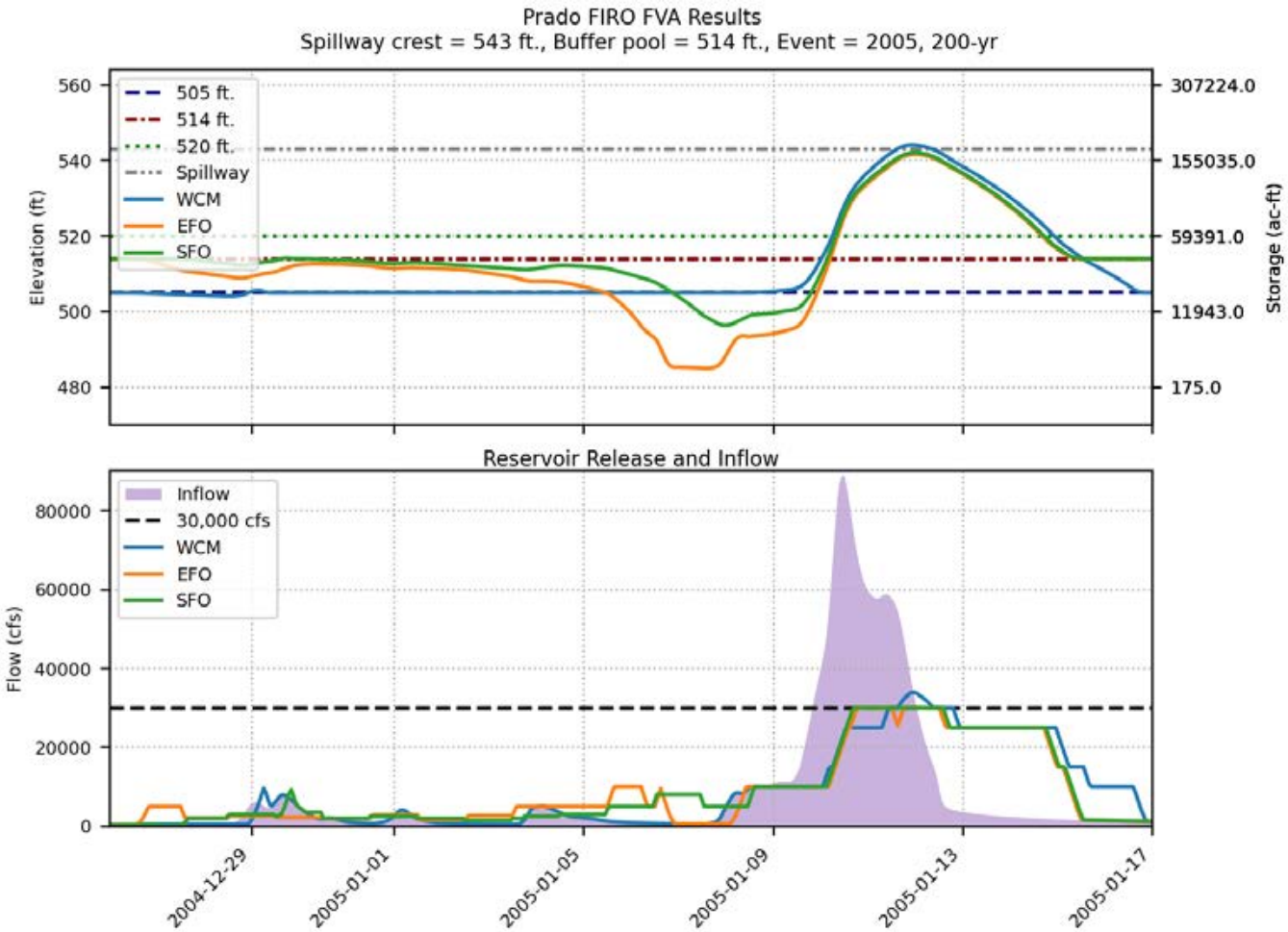
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514 ft.
520 ft.
Spillway
WCM
EFO
SFO
Elevation (ft)
Storage (ac-ft)
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307224.0
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59391.0
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Reservoir Release and Inflow
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30,000 cfs
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Flow (cfs)
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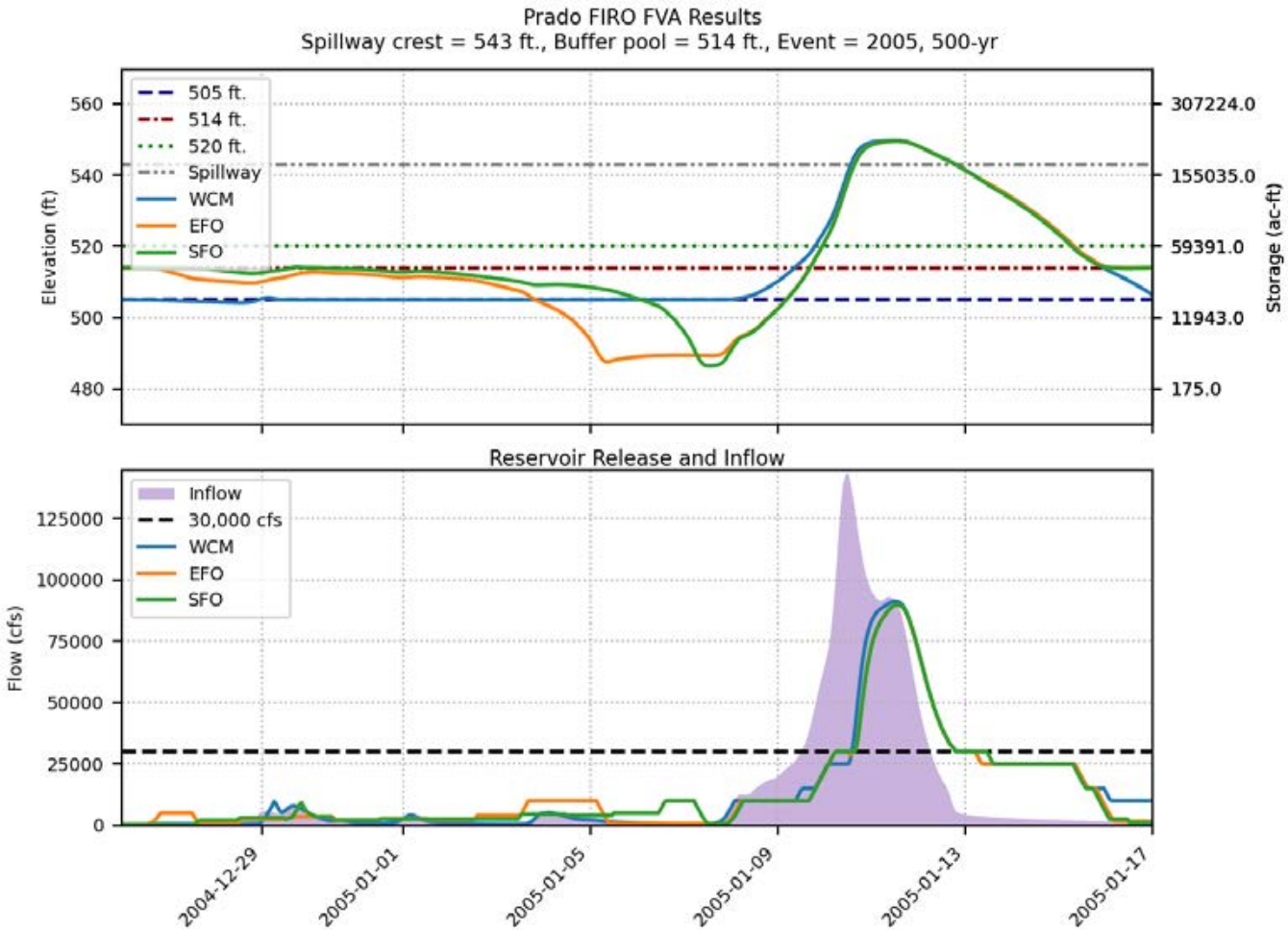
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514 ft.
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Spillway
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EFO
SFO
Elevation (ft)
Storage (ac-ft)
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155035.0
59391.0
11943.0
175.0
Reservoir Release and Inflow
Inflow
30,000 cfs
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Flow (cfs)
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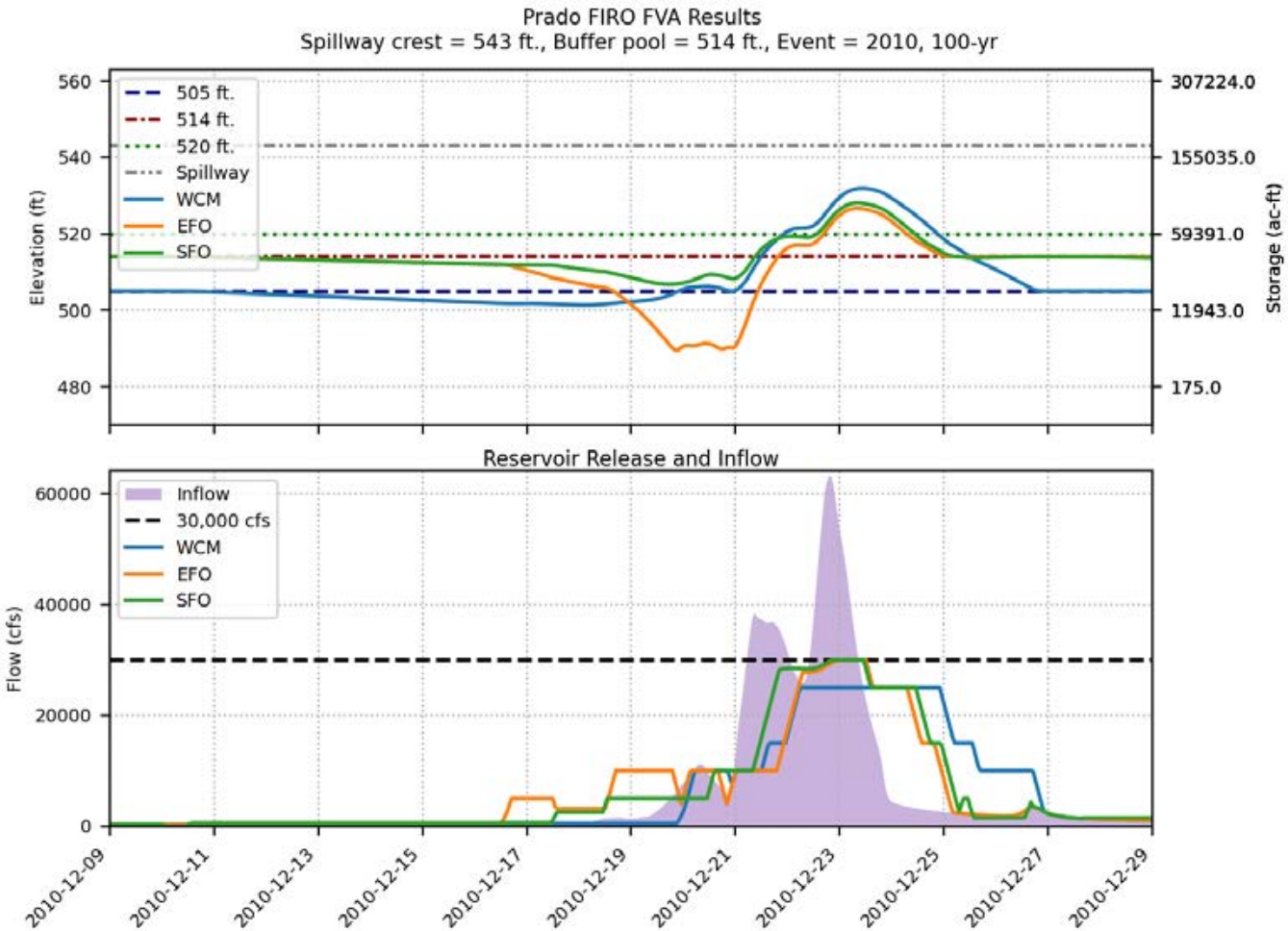
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Spillway
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SFO
Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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Flow (cfs)
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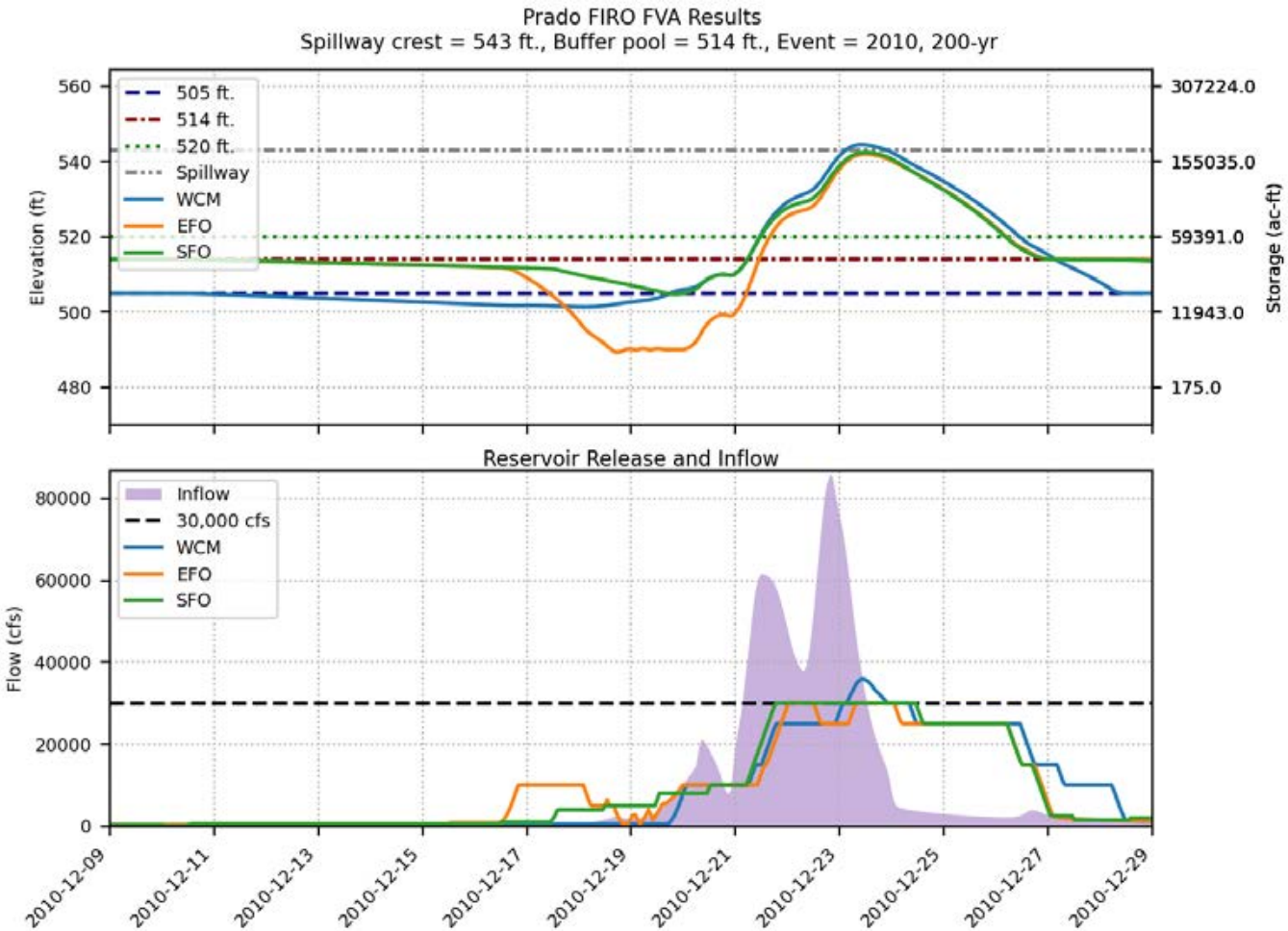
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514 ft.
520 ft.
Spillway
WCM
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Elevation (ft)
Storage (ac-ft)
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307224.0
155035.0
59391.0
11943.0
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Reservoir Release and Inflow
Inflow
30,000 cfs
WCM
EFO
SFO
Flow (cfs)
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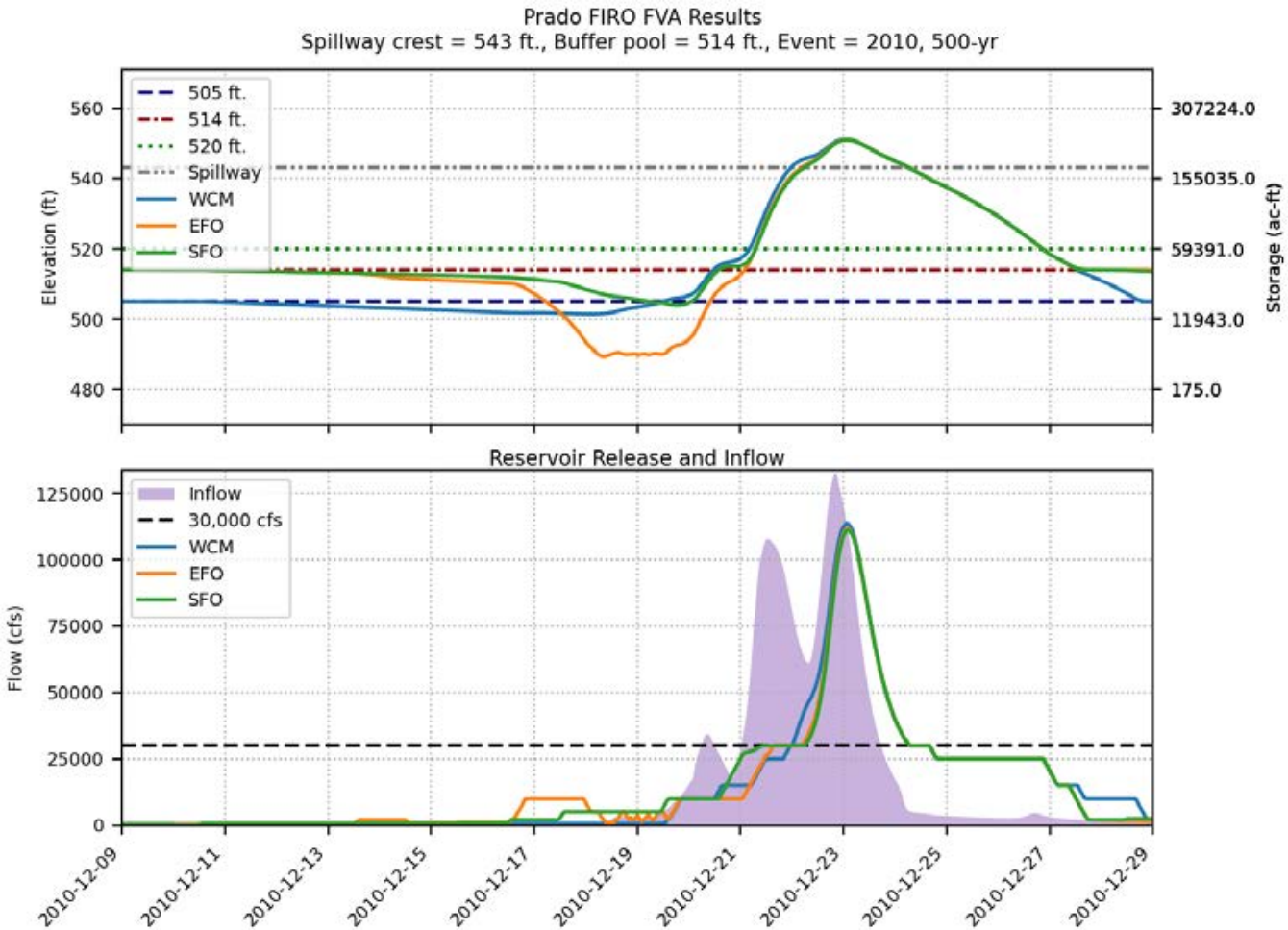
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 514 ft., Event = 2010, 500-yr
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Spillway
WCM
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SFO
Elevation (ft)
Storage (ac-ft)
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Inflow
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Flow (cfs)
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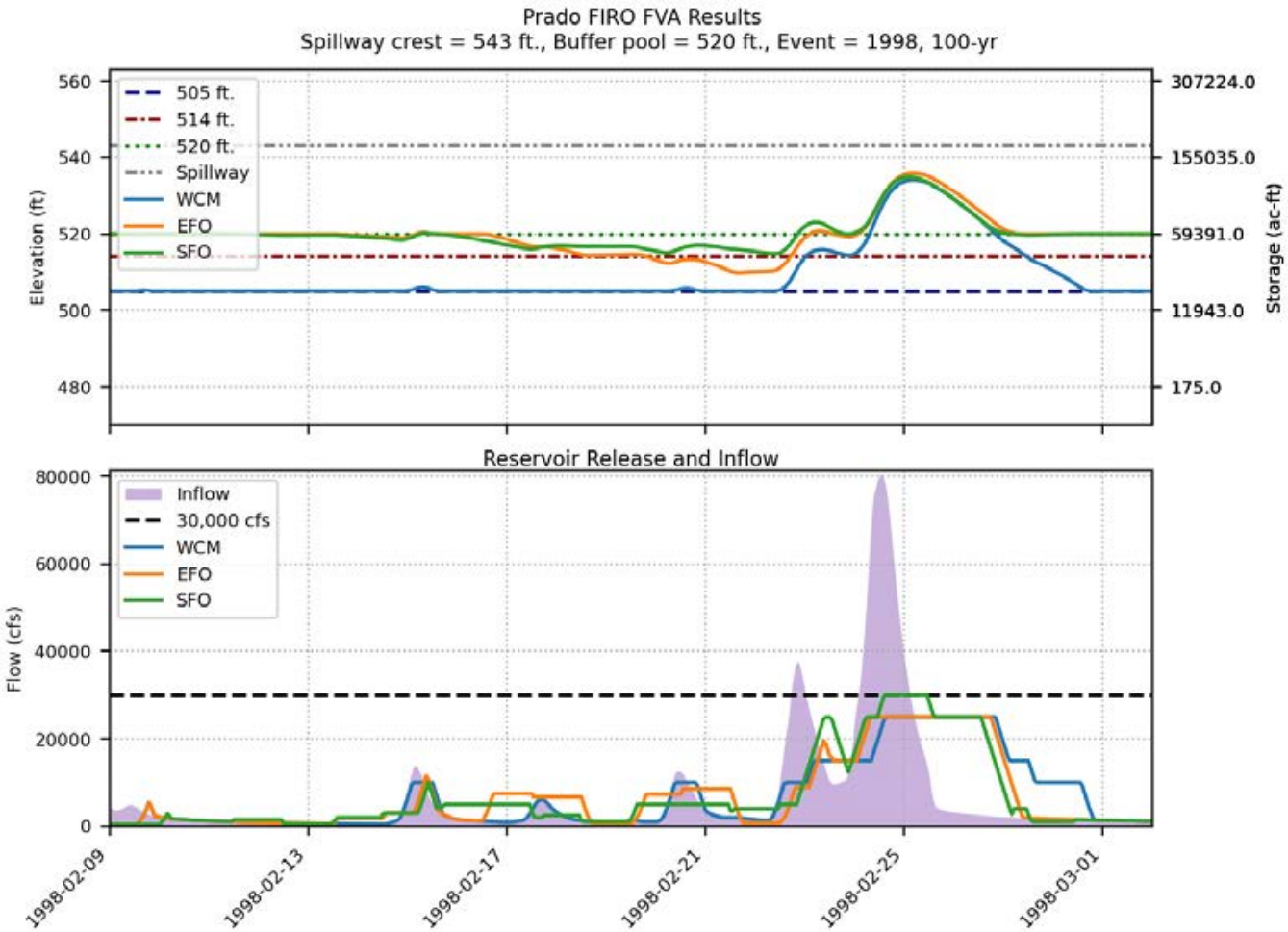
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514 ft.
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Spillway
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Elevation (ft)
Storage (ac-ft)
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307224.0
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Reservoir Release and Inflow
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Flow (cfs)
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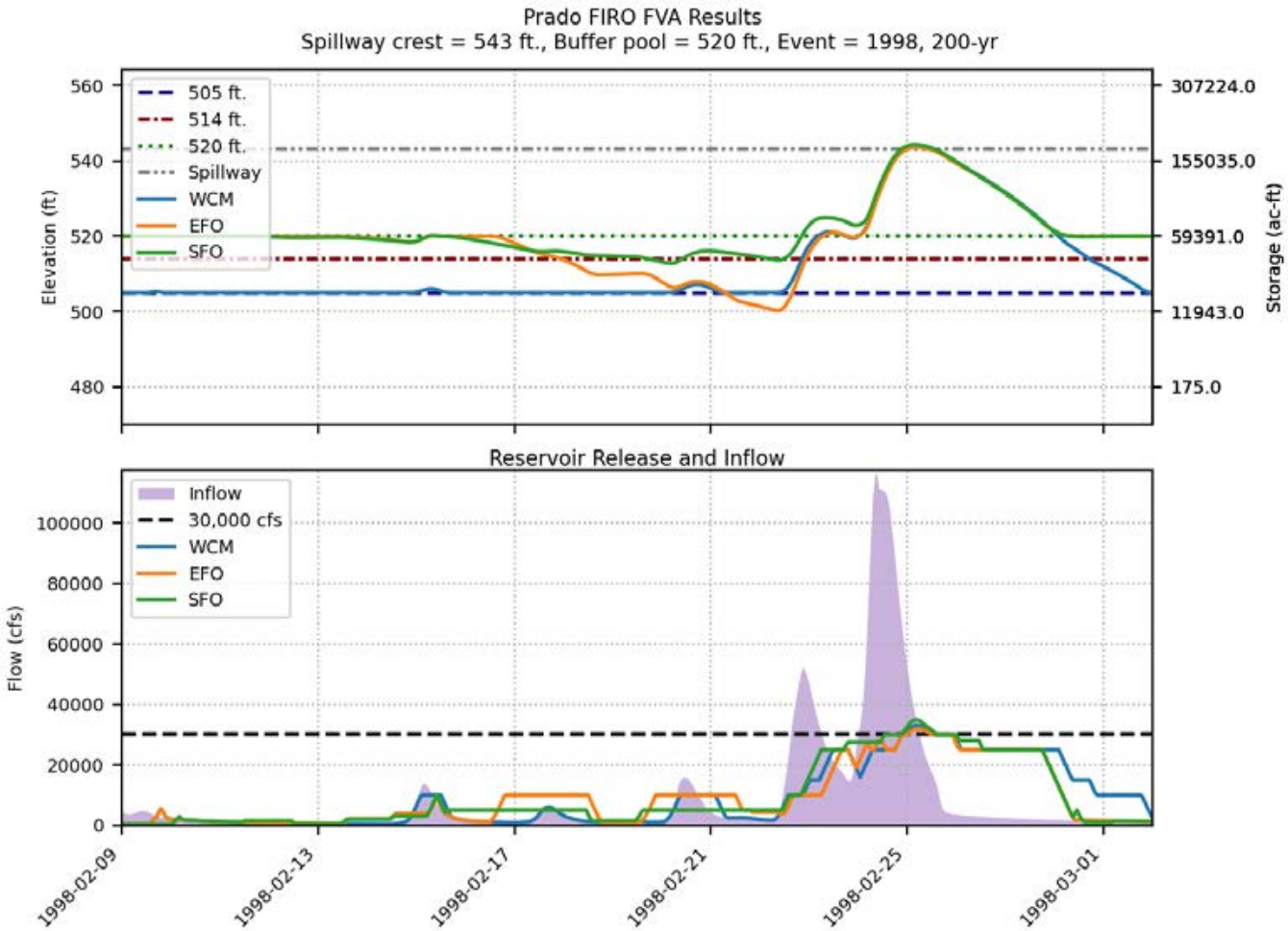
Prado FIRO FVA Results
Spillway crest = 543 ft., Buffer pool = 520 ft., Event = 1998, 200-yr
505 ft.
514 ft.
520 ft.
Spillway
WCM
EFO
SFO
Elevation (ft)
Storage (ac-ft)
560
540
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307224.0
155035.0
59391.0
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Reservoir Release and Inflow
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Flow (cfs)
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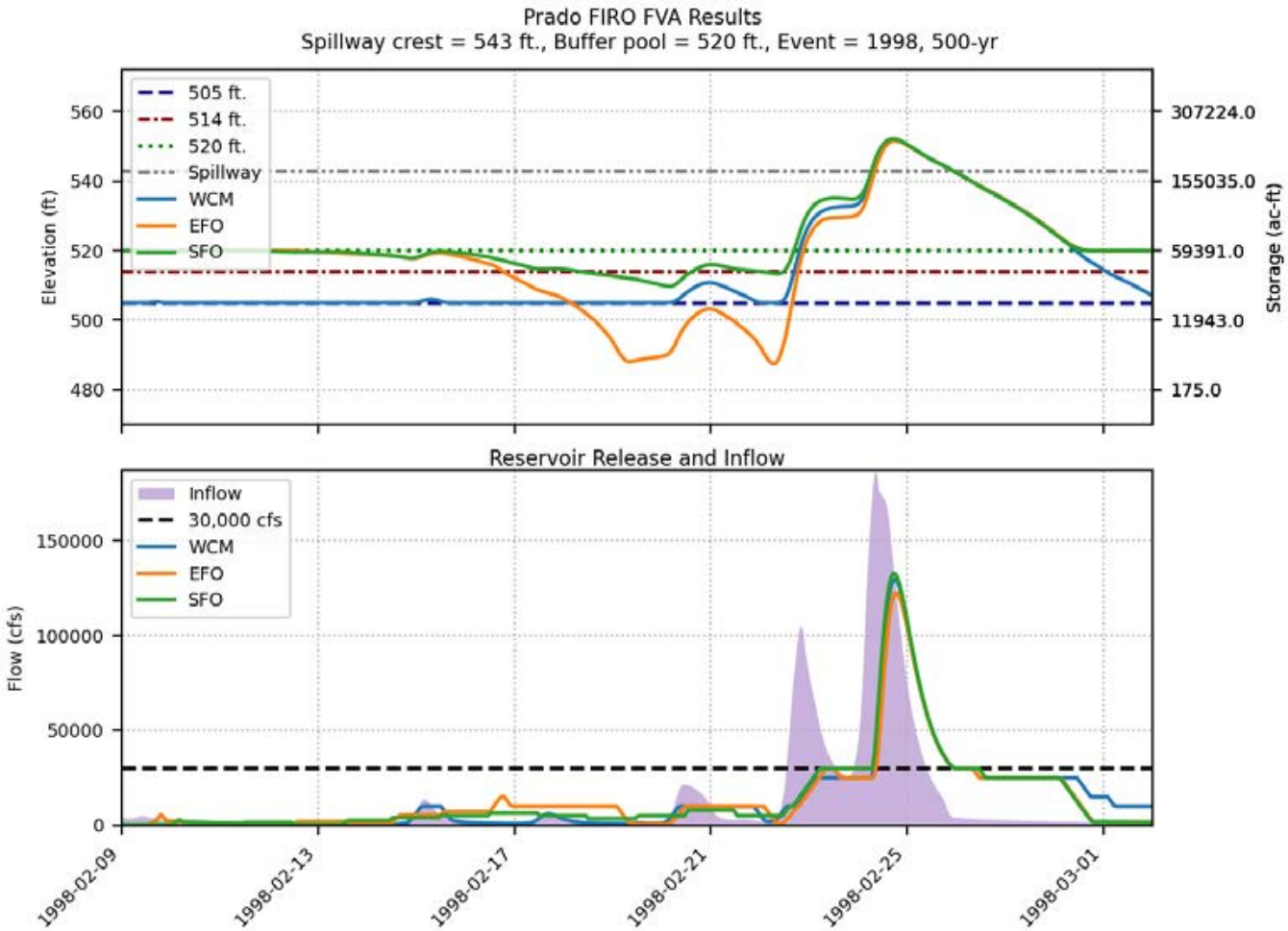
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Spillway crest = 543 ft., Buffer pool = 520 ft., Event = 1998, 500-yr
505 ft.
514 ft.
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Spillway
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EFO
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Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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Flow (cfs)
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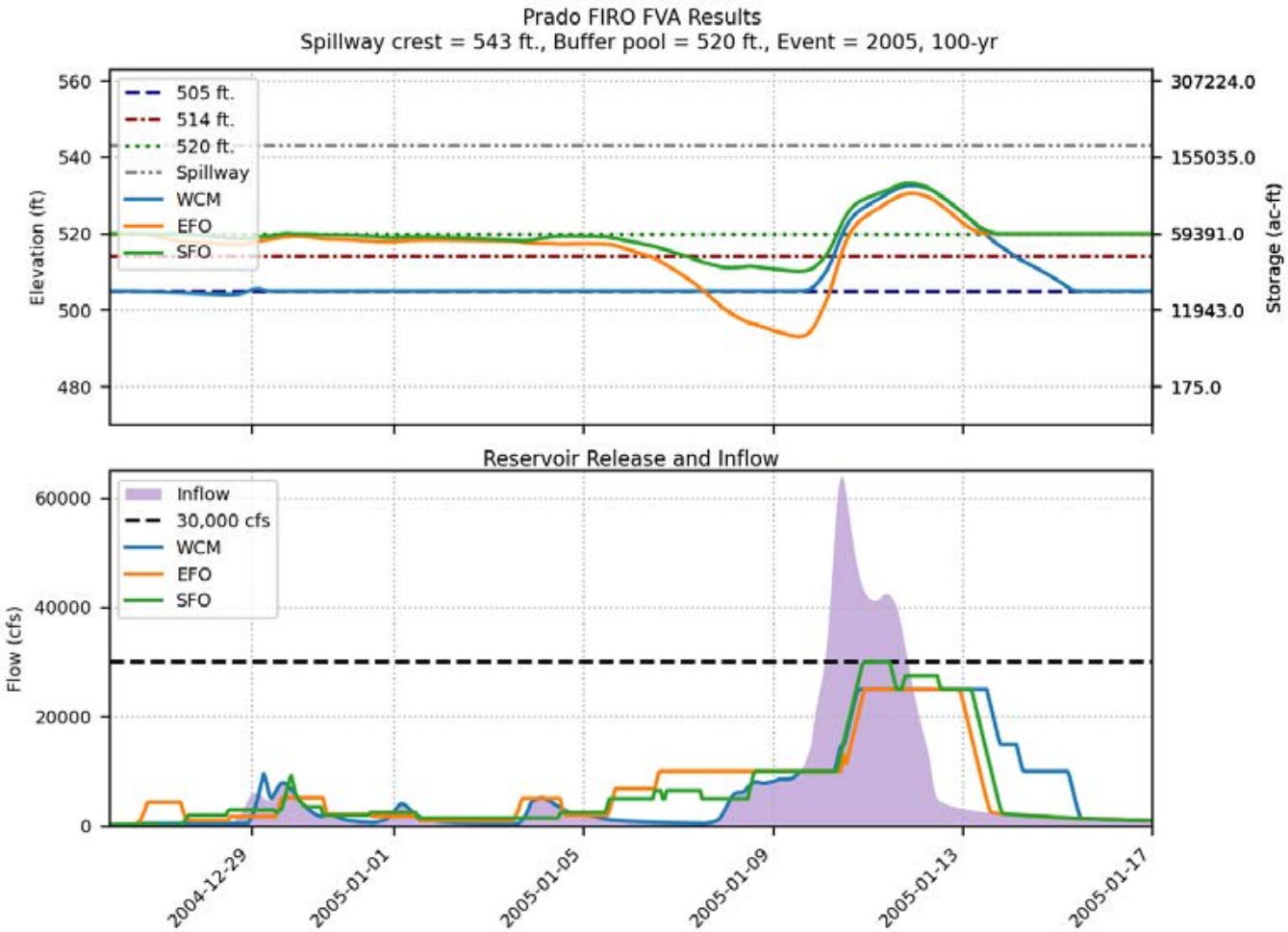
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Spillway crest = 543 ft., Buffer pool = 520 ft., Event = 2005, 100-yr
505 ft.
514 ft.
520 ft.
Spillway
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EFO
SFO
Elevation (ft)
Storage (ac-ft)
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Reservoir Release and Inflow
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Flow (cfs)
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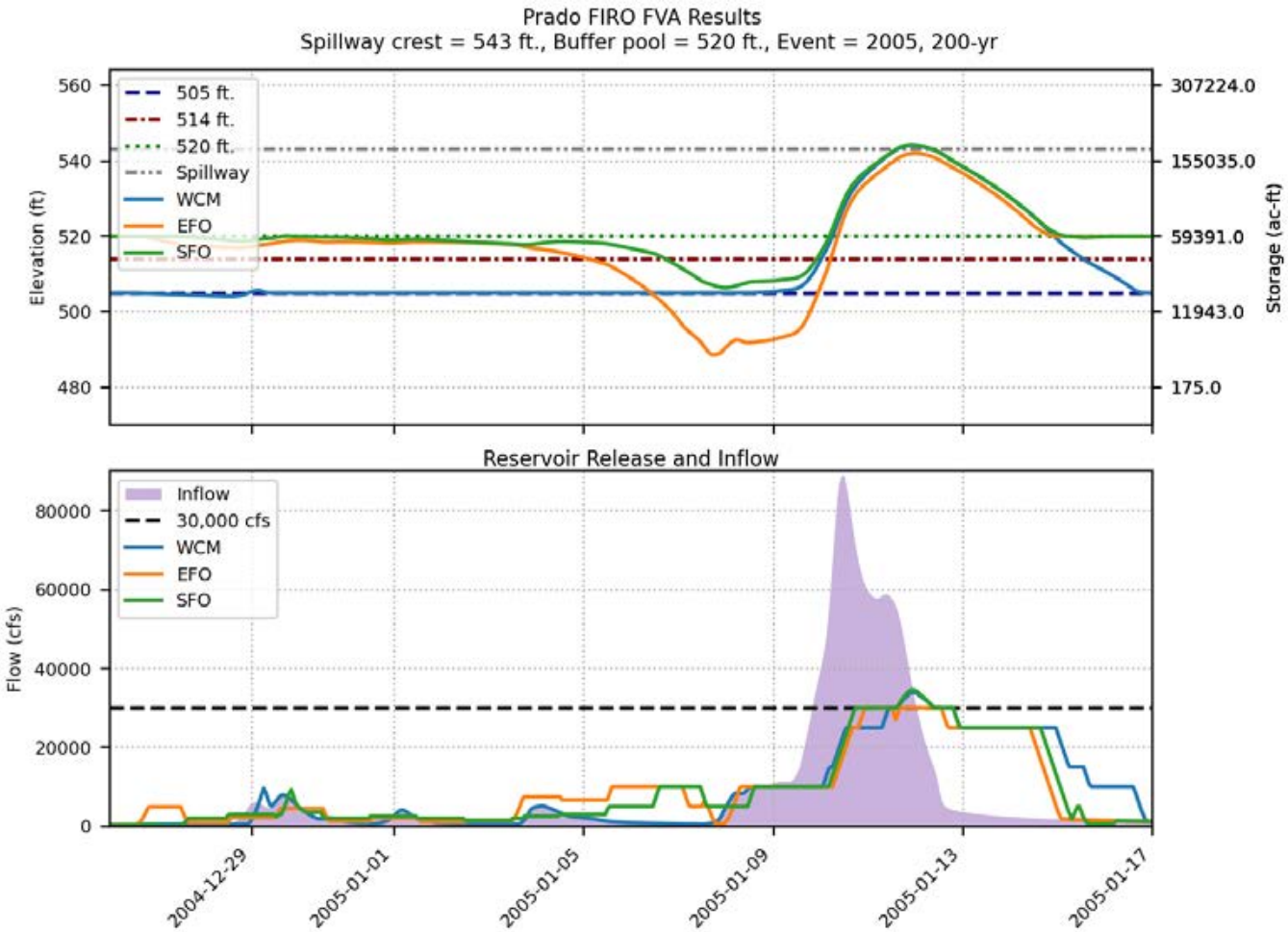
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Spillway crest = 543 ft., Buffer pool = 520 ft., Event = 2005, 200-yr
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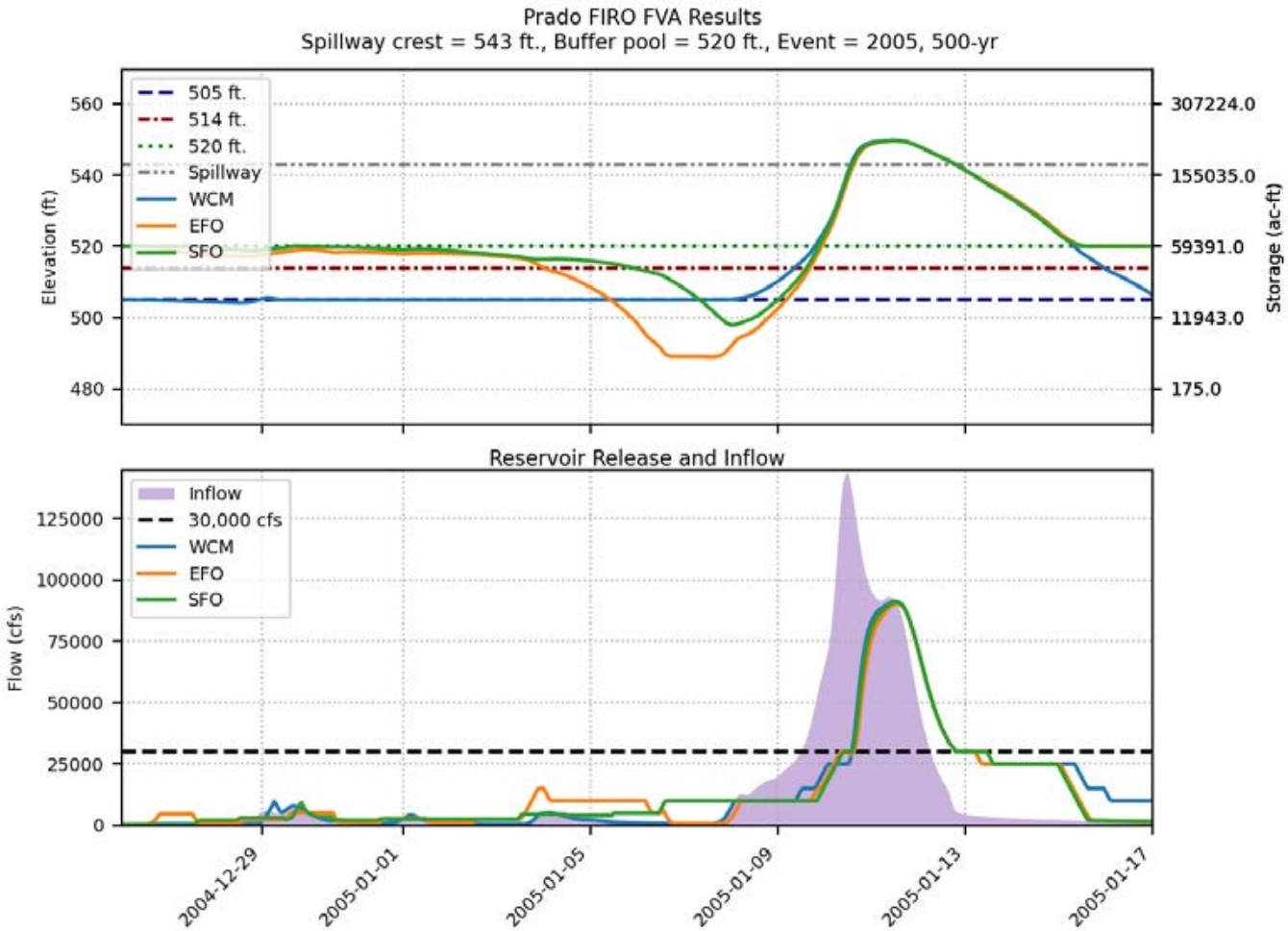
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Spillway crest = 543 ft., Buffer pool = 520 ft., Event = 2005, 500-yr
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Elevation (ft)
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Reservoir Release and Inflow
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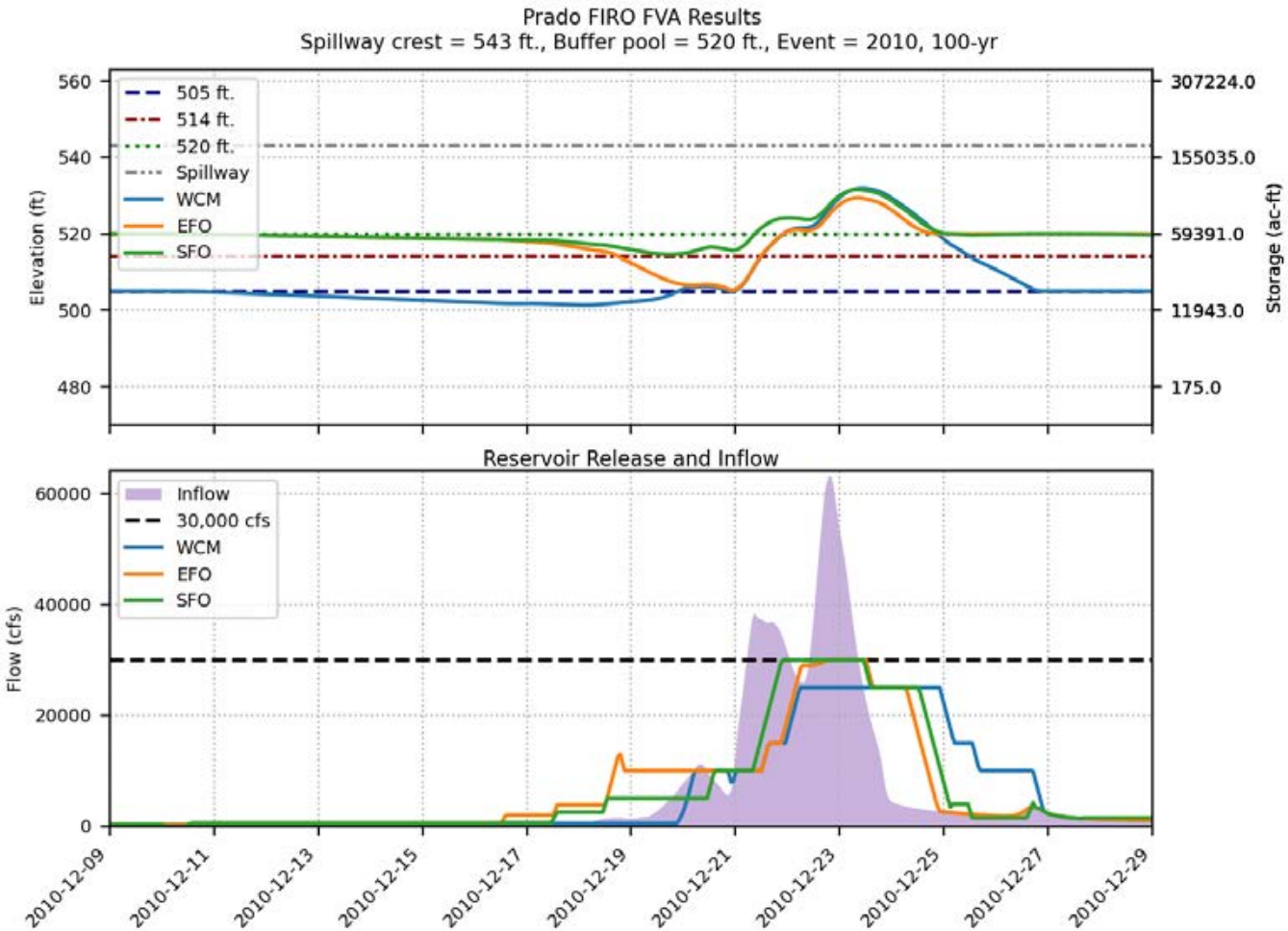
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Spillway crest = 543 ft., Buffer pool = 520 ft., Event = 2010, 100-yr
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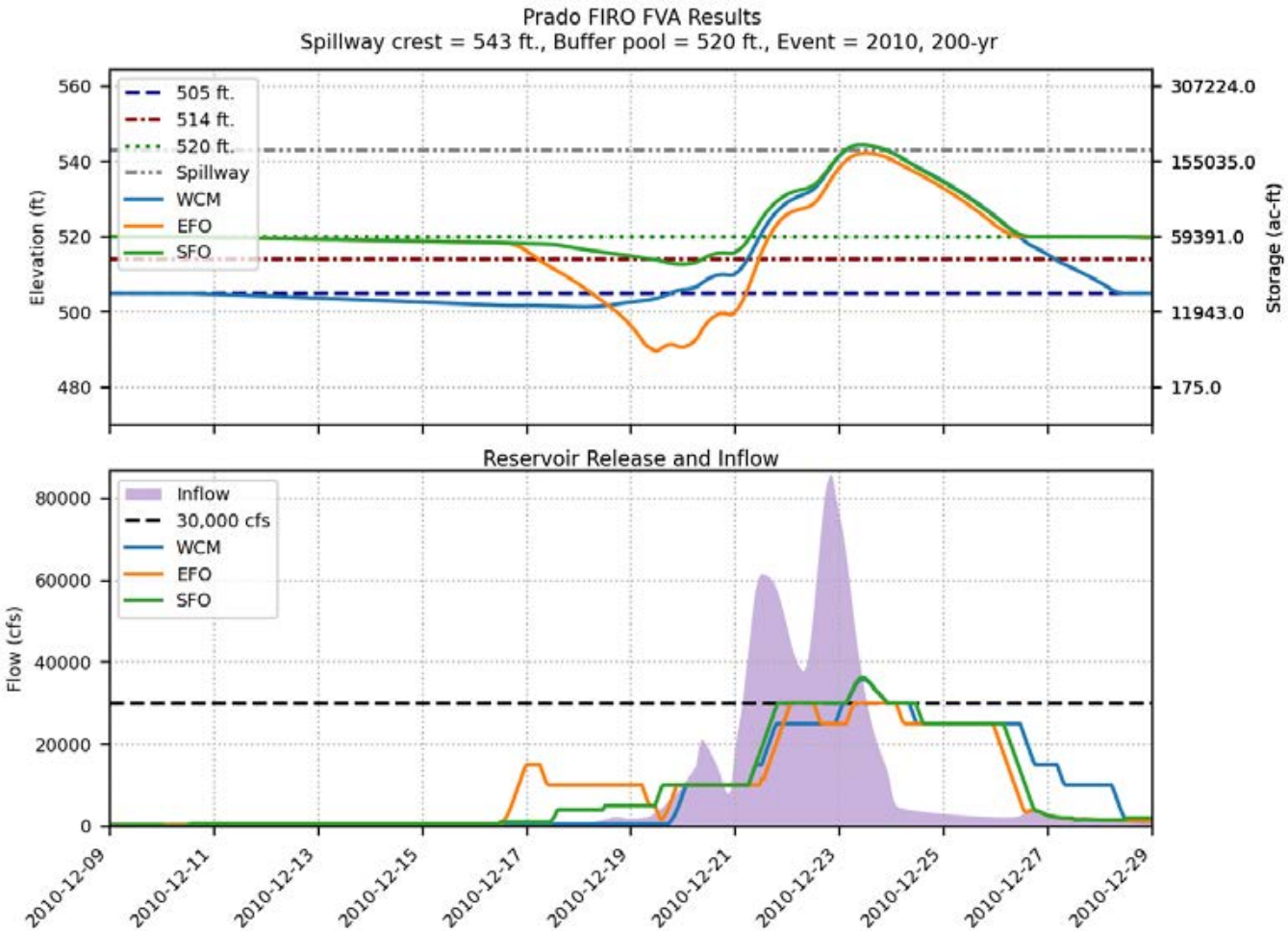
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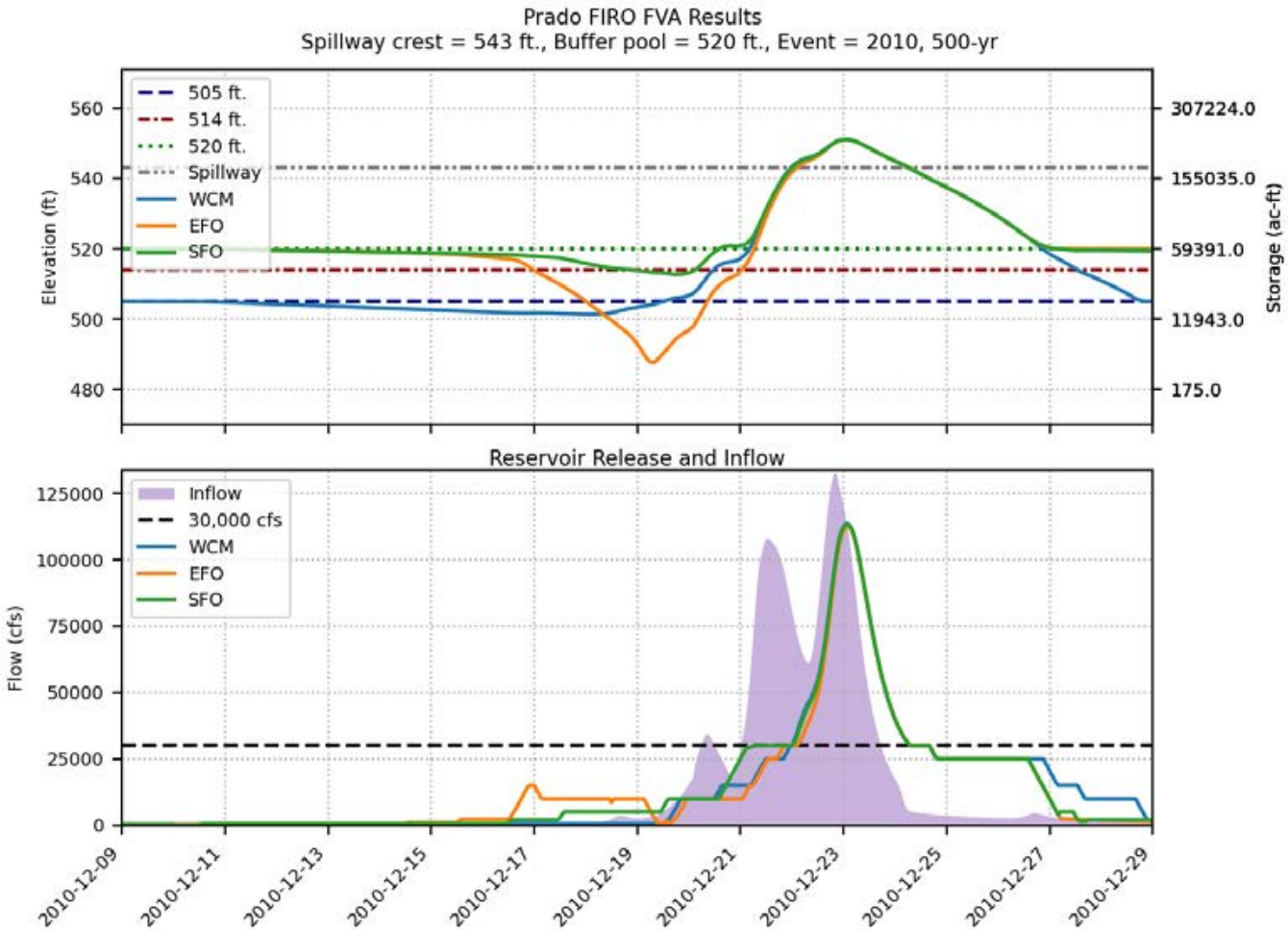
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Spillway crest = 543 ft., Buffer pool = 520 ft., Event = 2010, 500-yr
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Reservoir Release and Inflow
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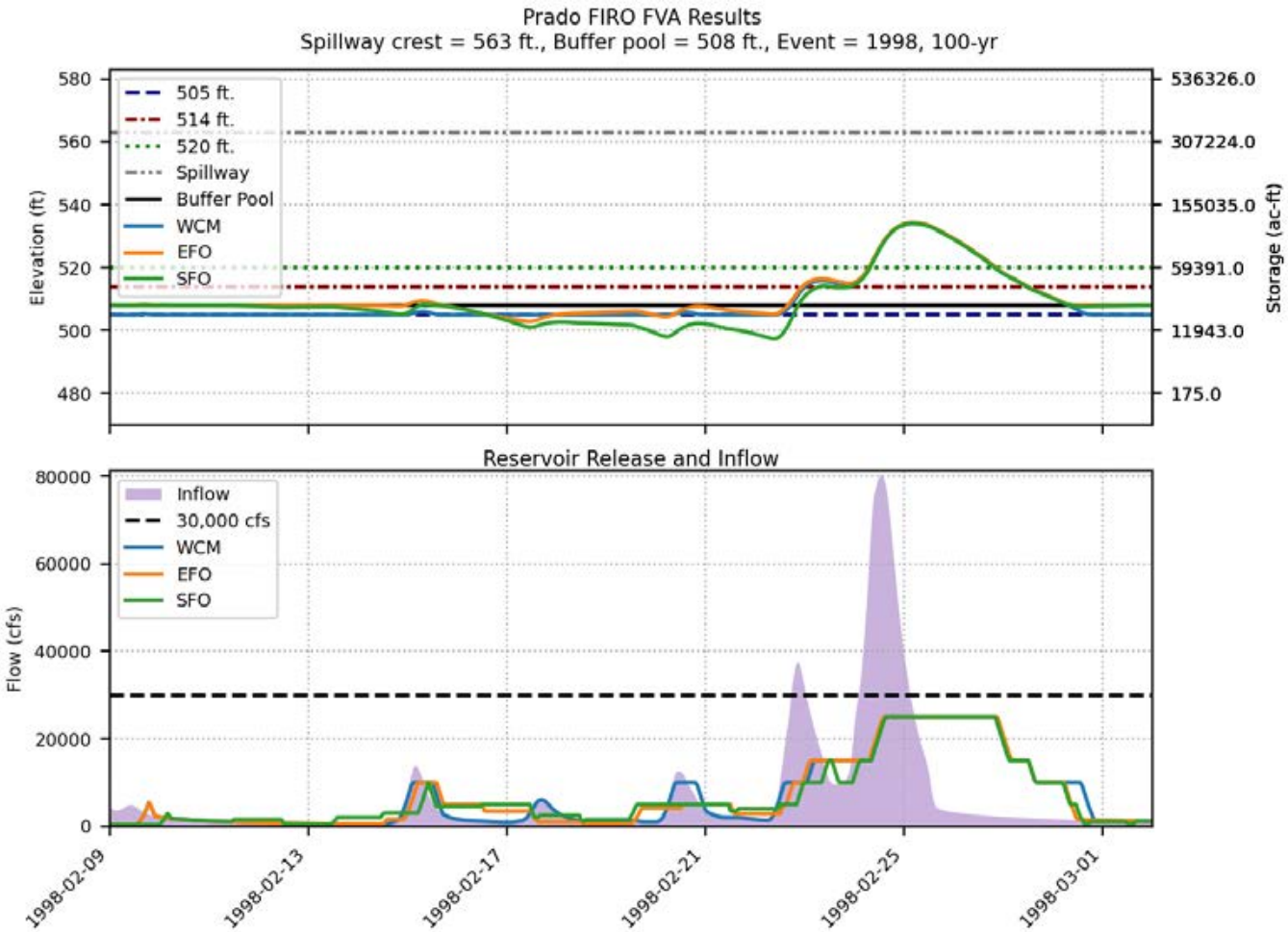
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Elevation (ft)
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Reservoir Release and Inflow
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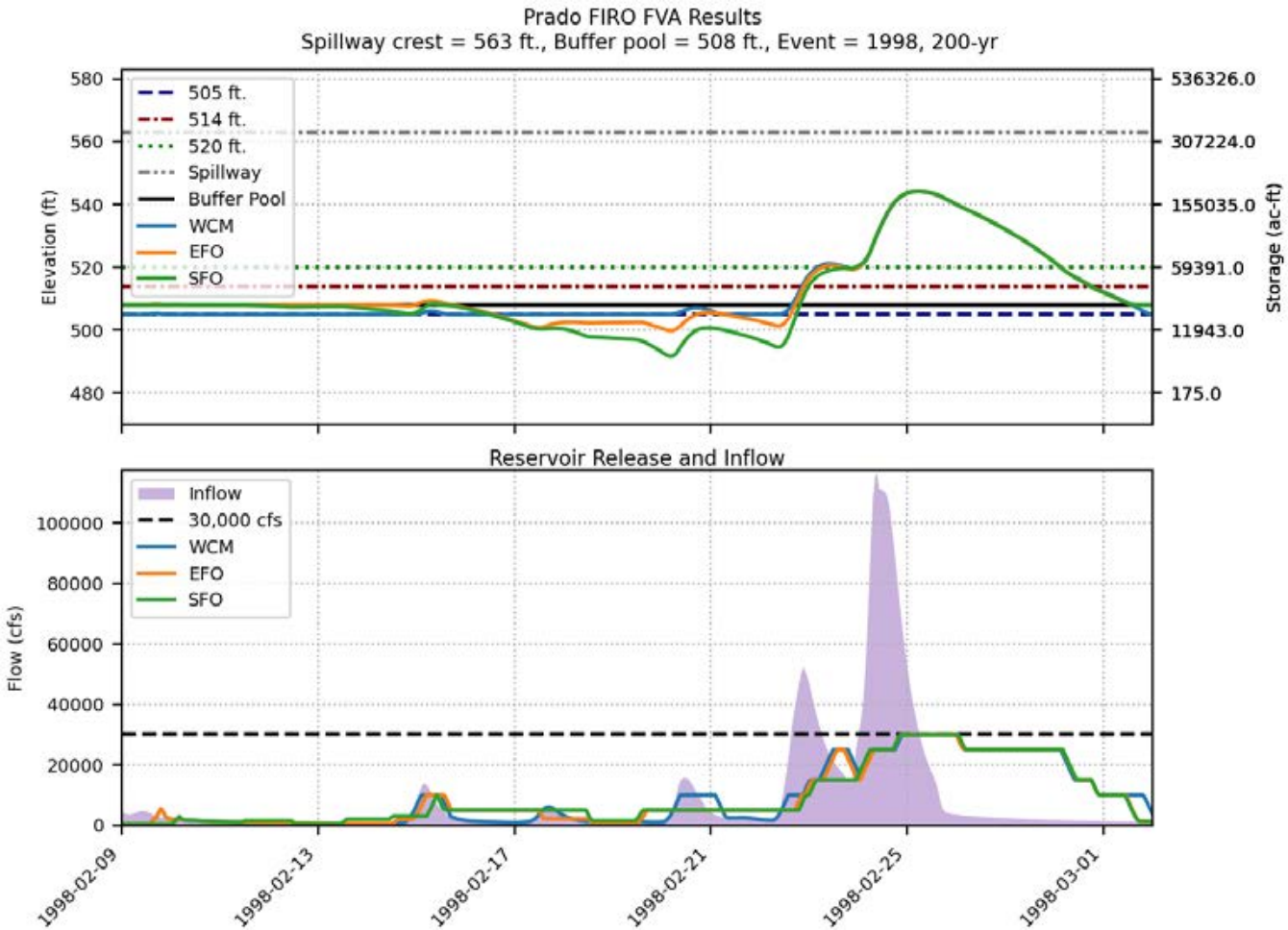
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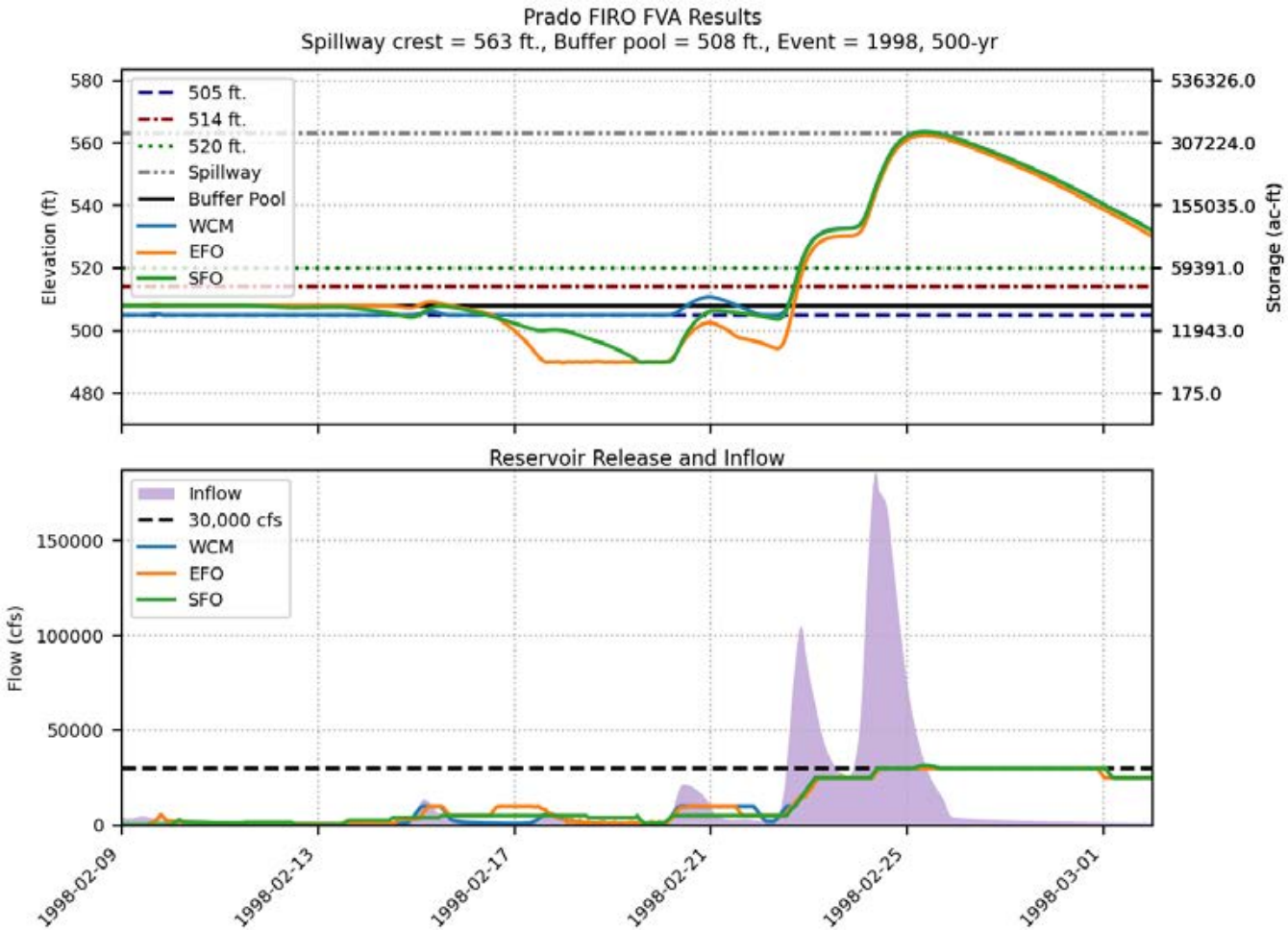
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Spillway crest = 563 ft., Buffer pool = 508 ft., Event = 1998, 500-yr
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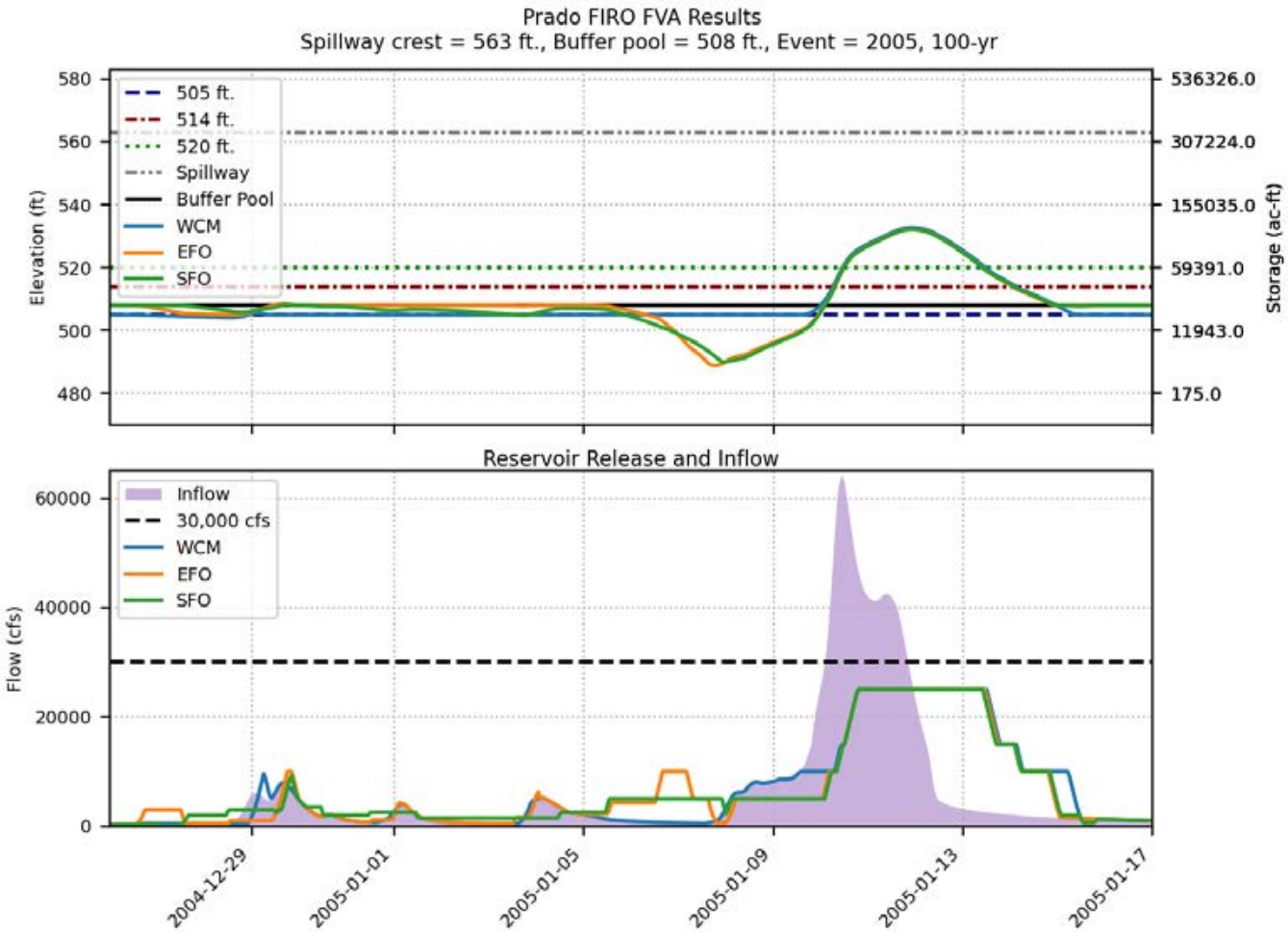
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Reservoir Release and Inflow
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Flow (cfs)
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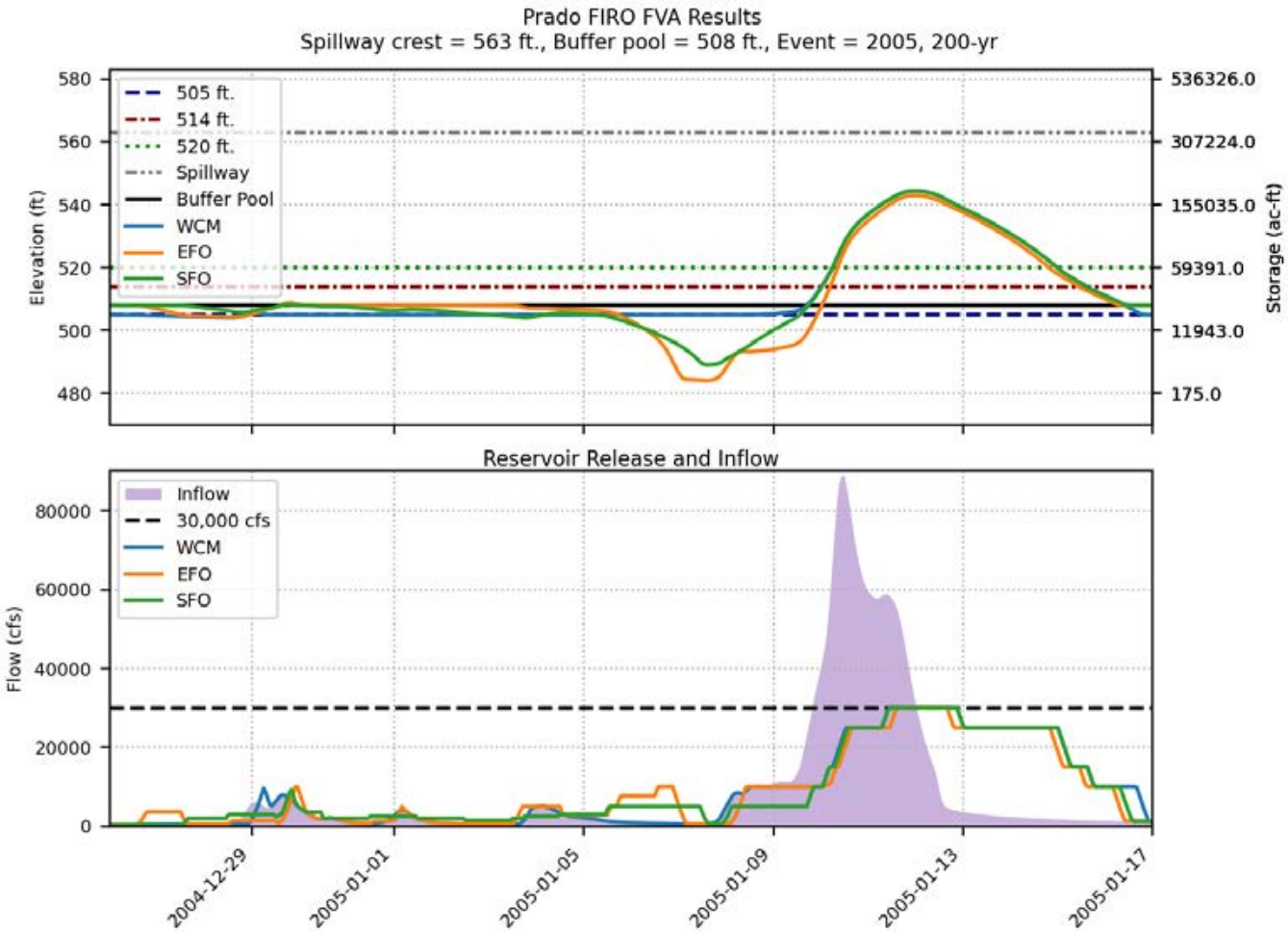
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Elevation (ft)
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Reservoir Release and Inflow
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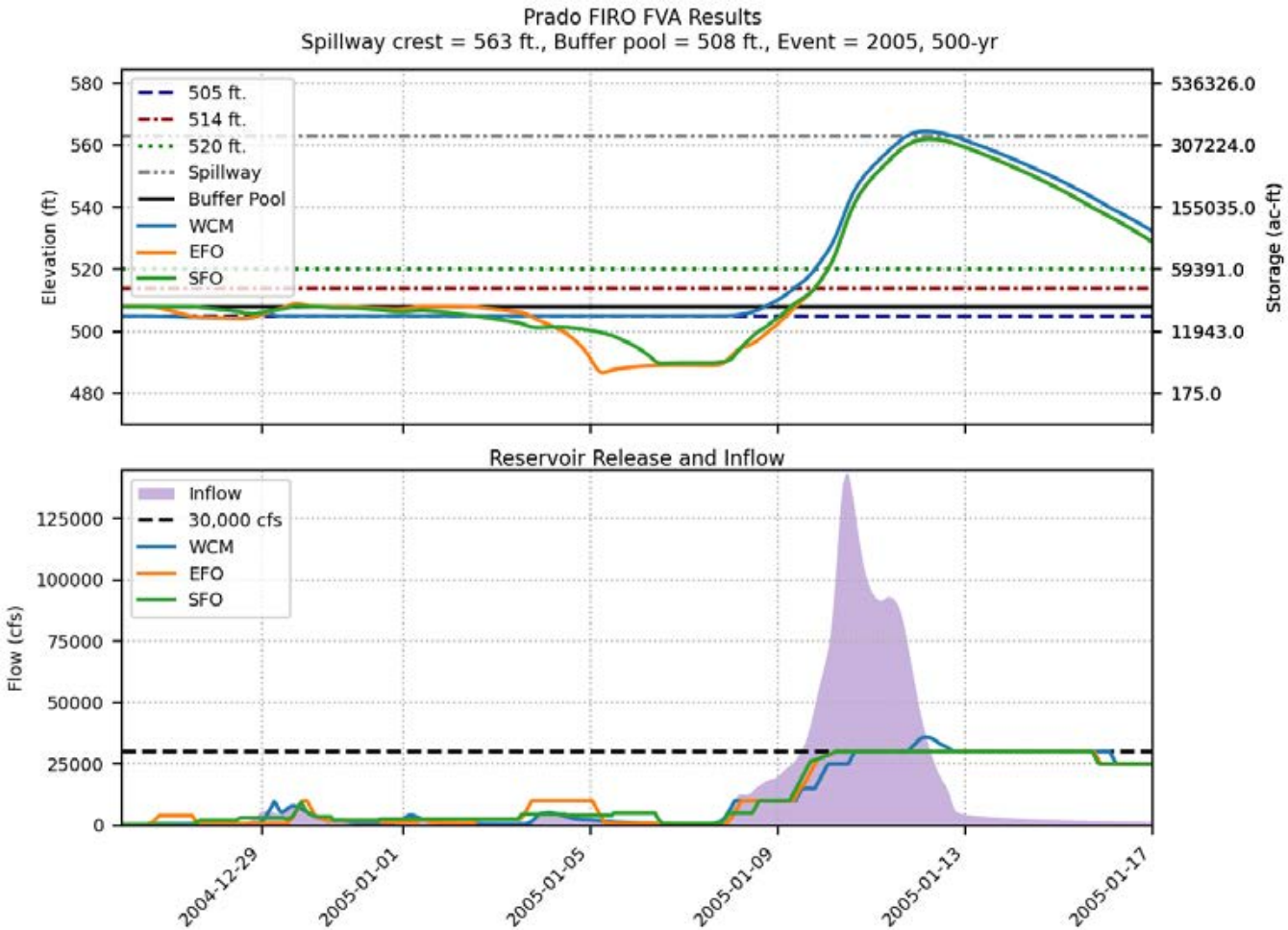
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Elevation (ft)
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Reservoir Release and Inflow
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Flow (cfs)
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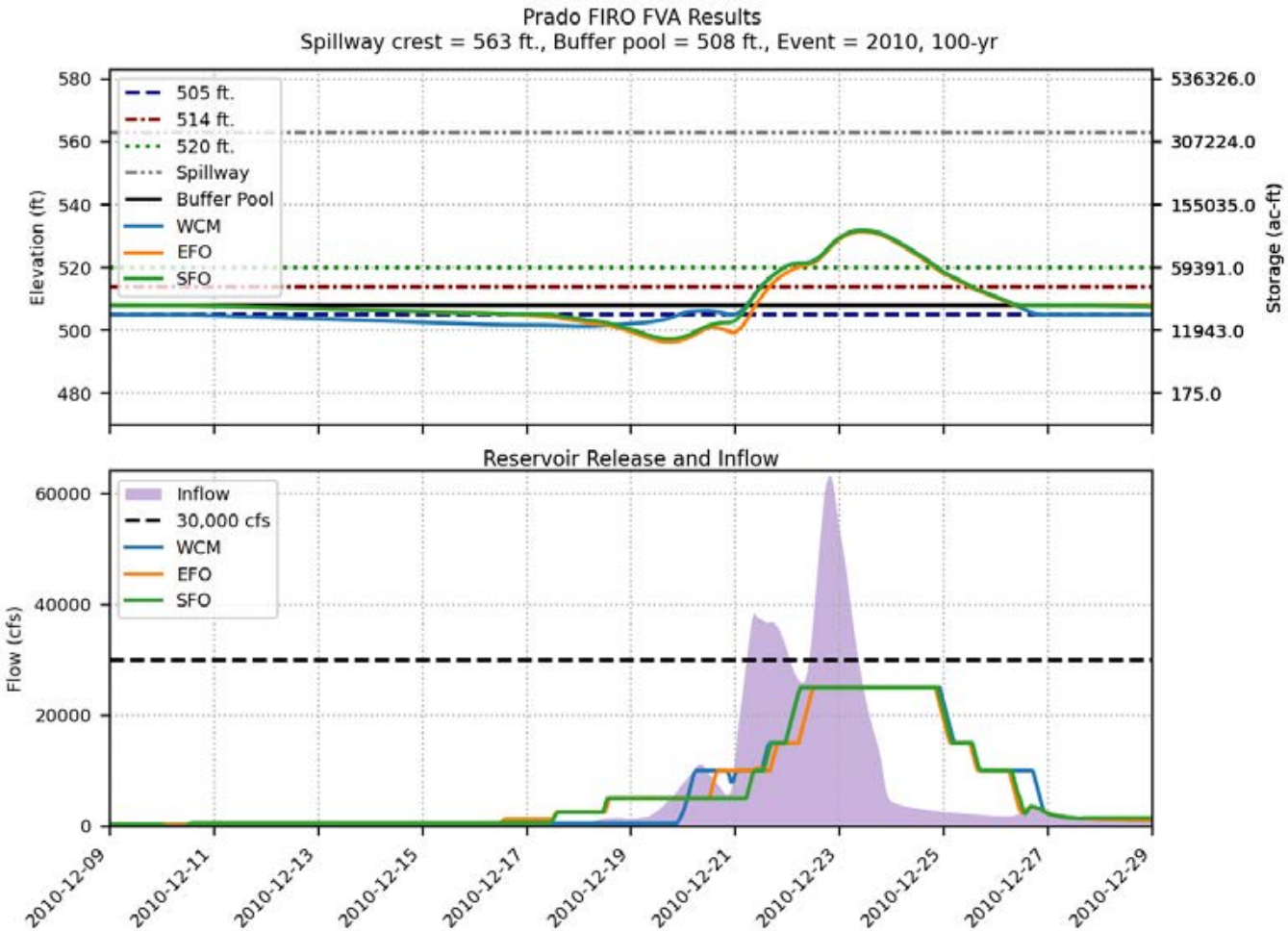
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Spillway
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Elevation (ft)
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Reservoir Release and Inflow
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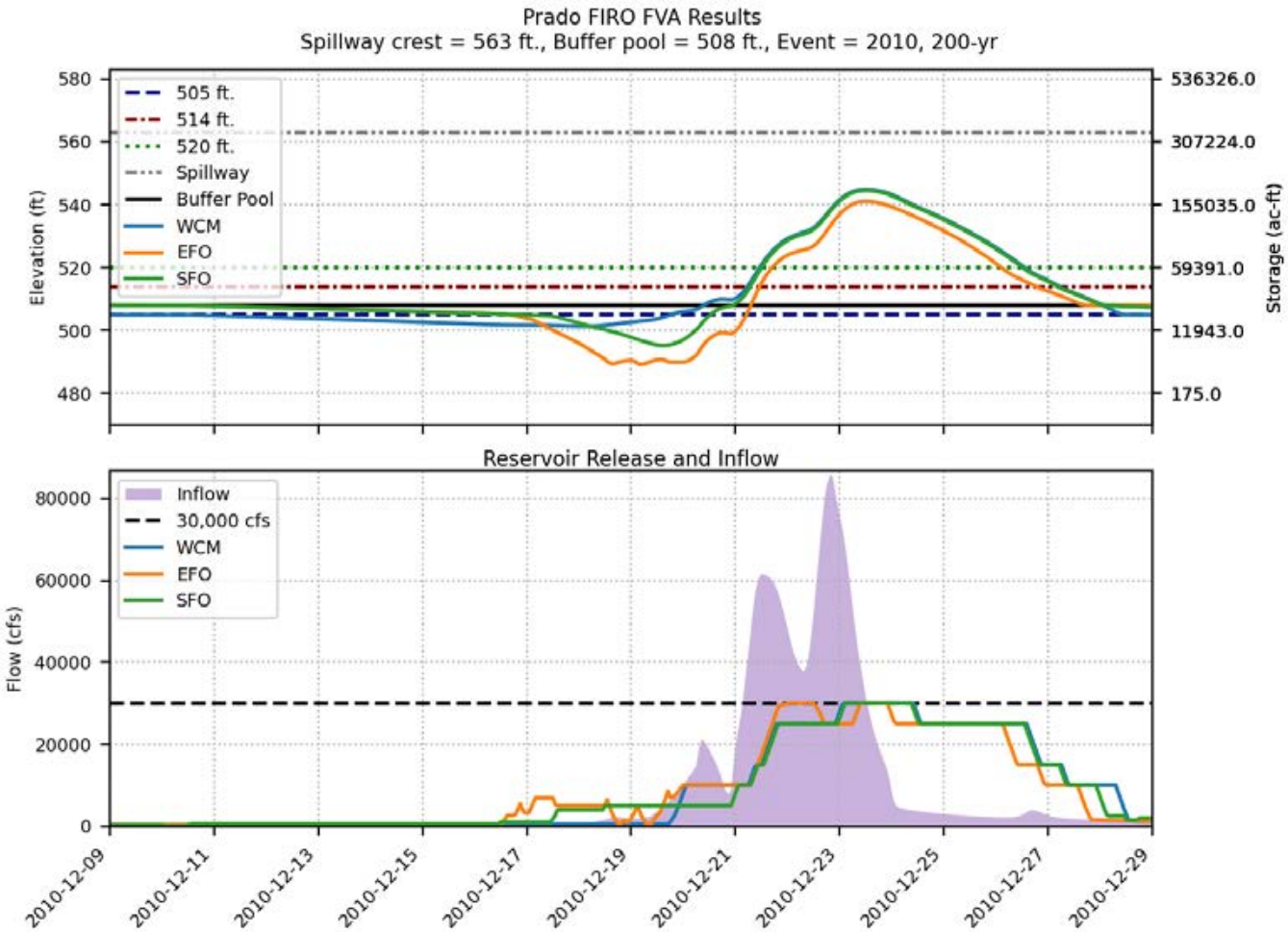
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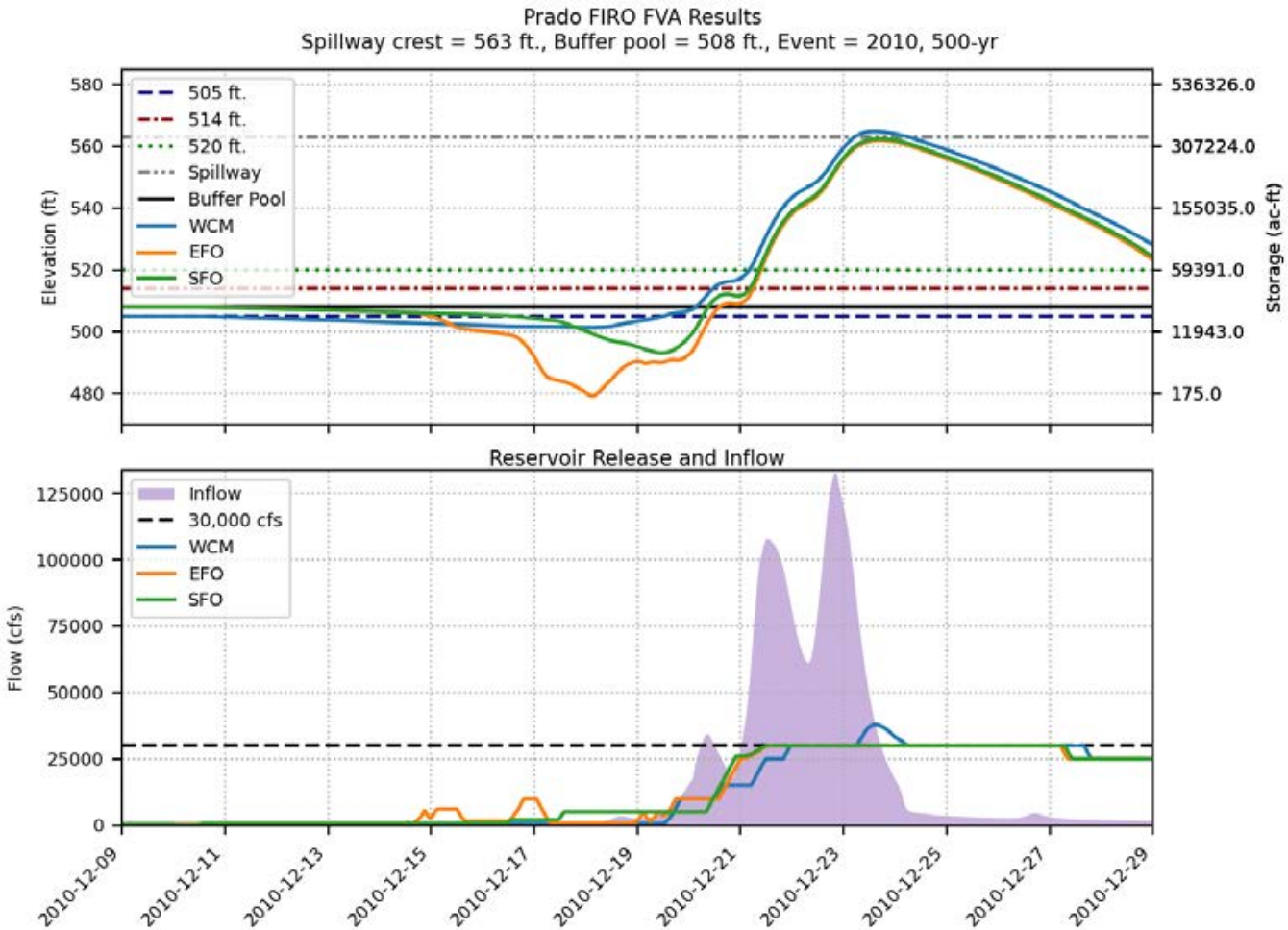
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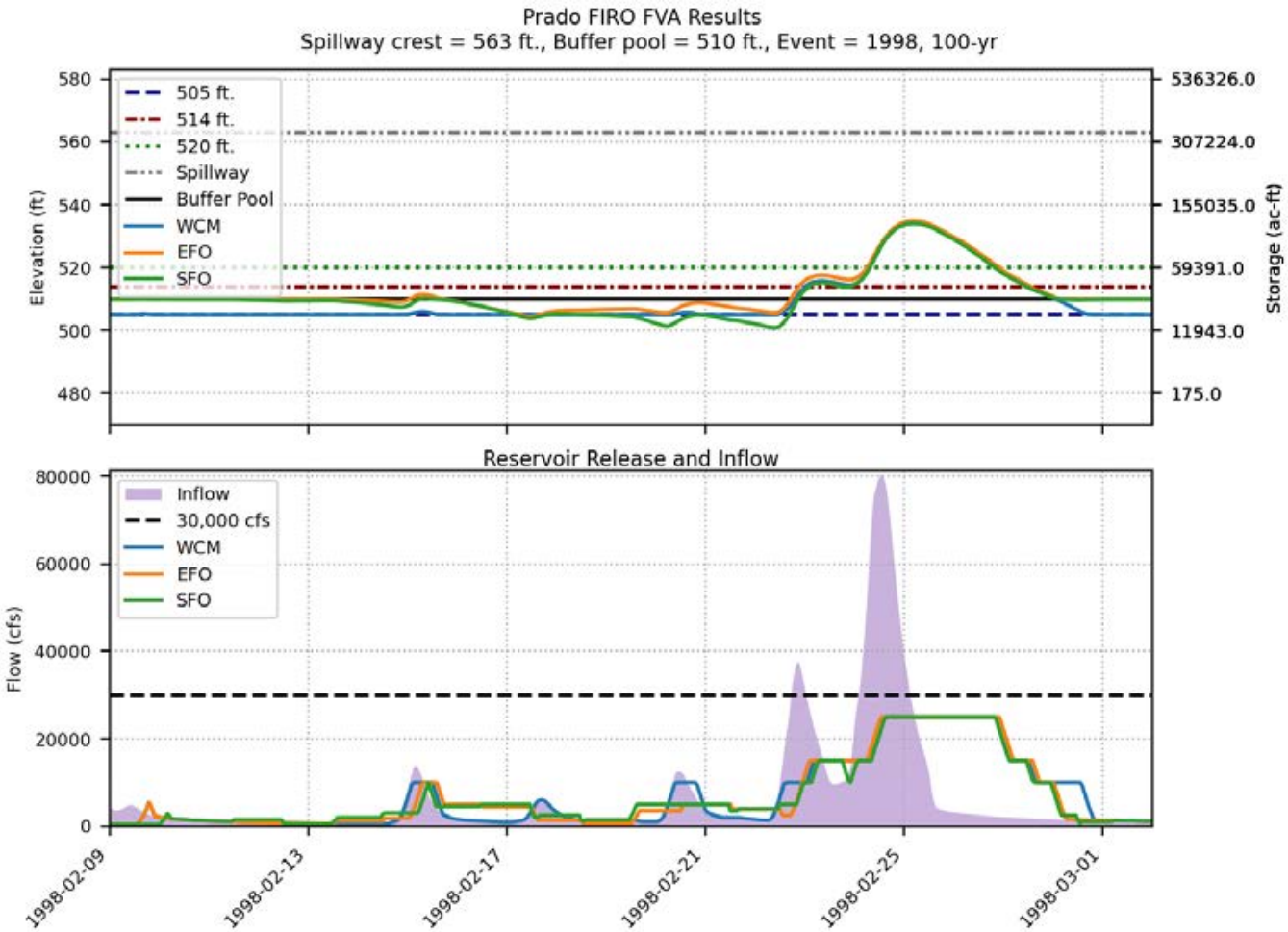
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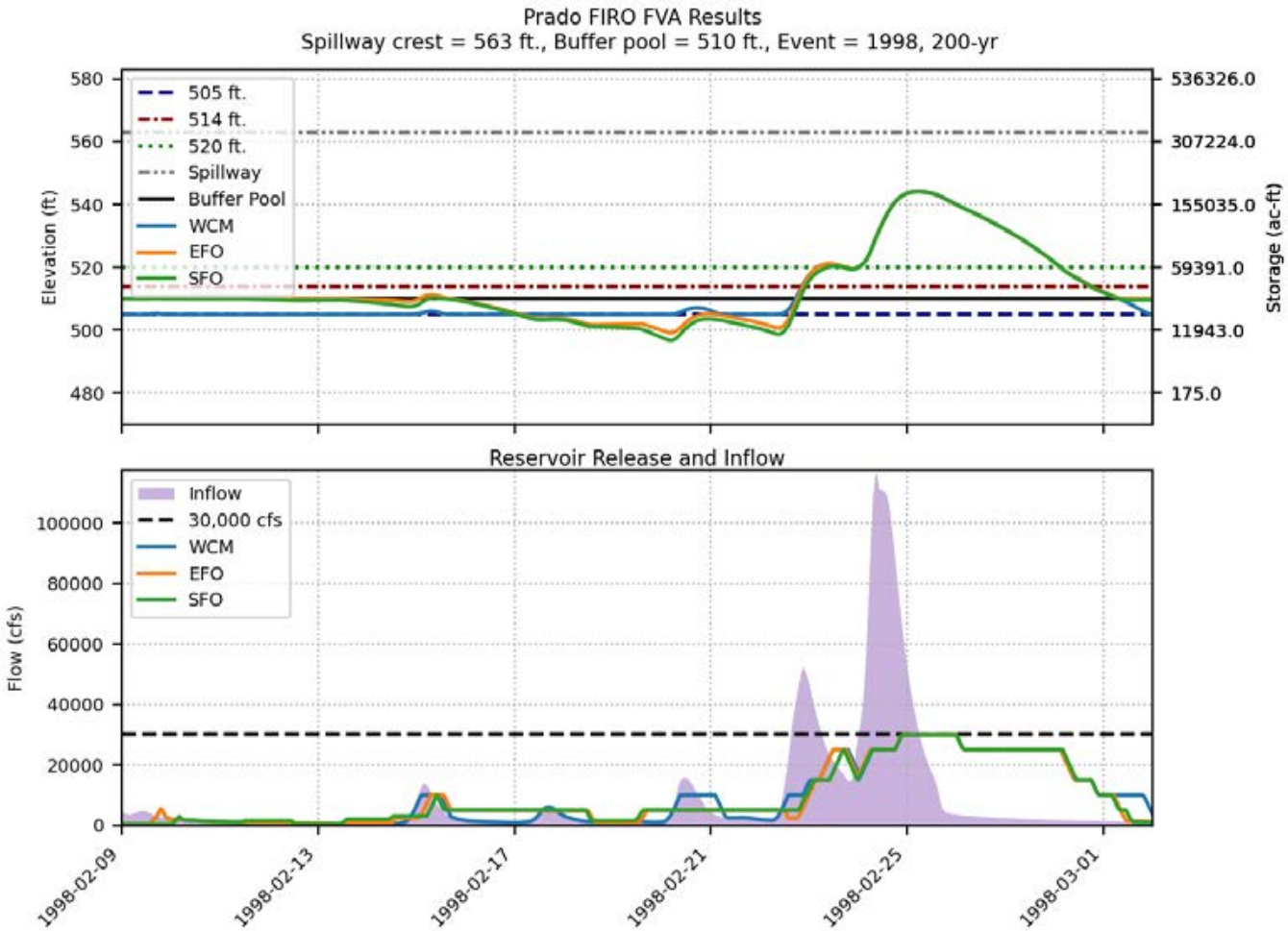
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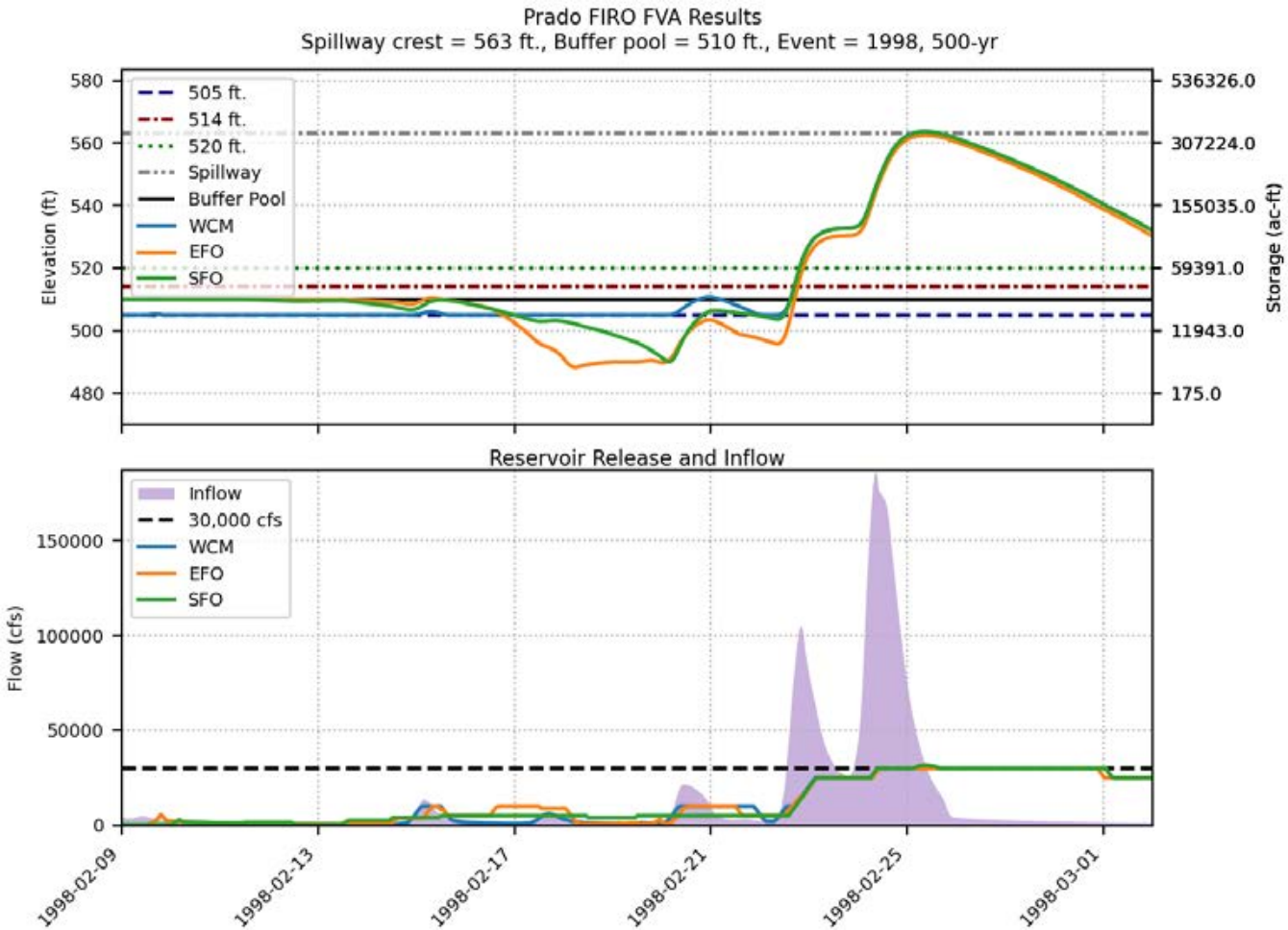
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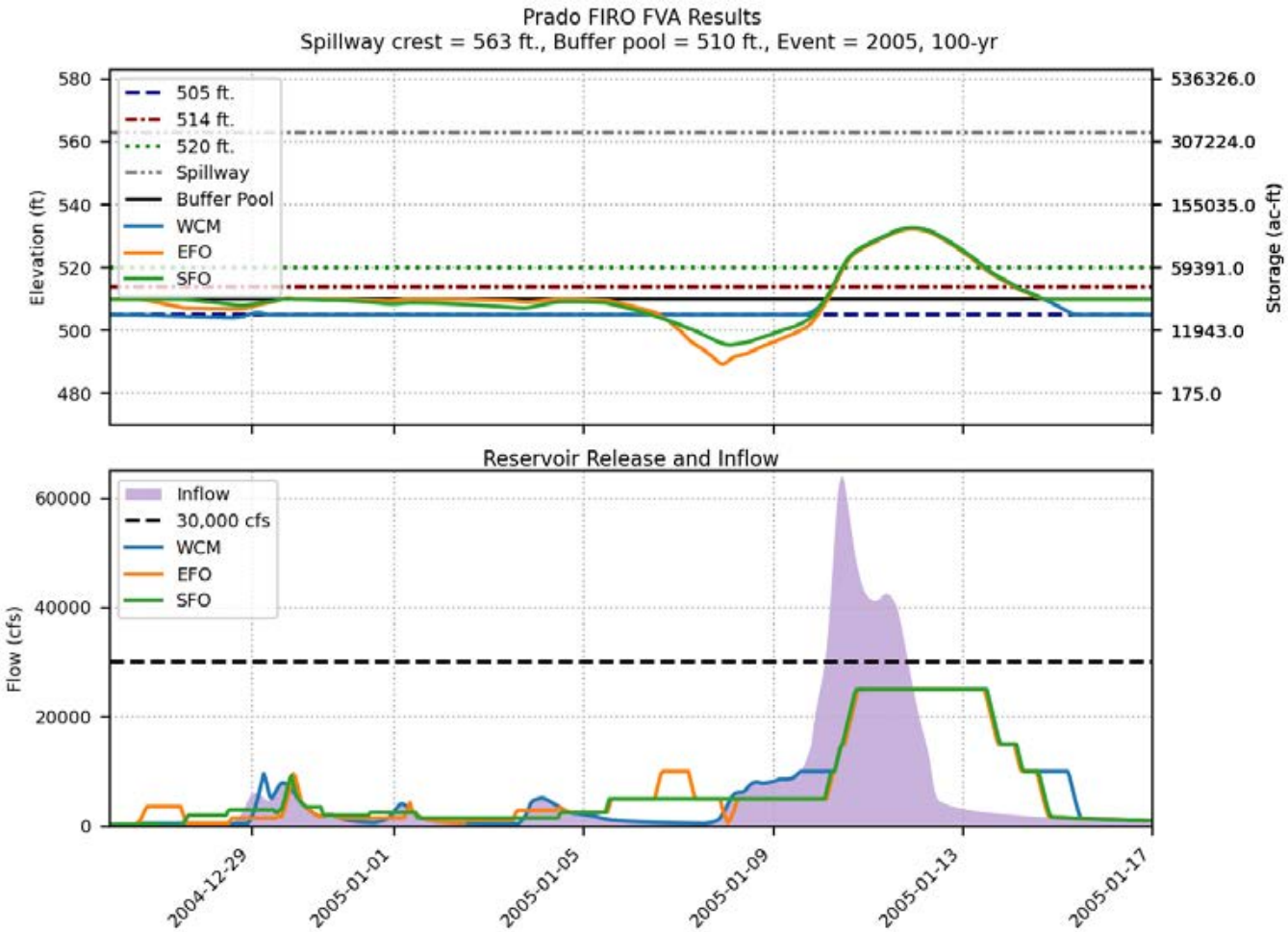
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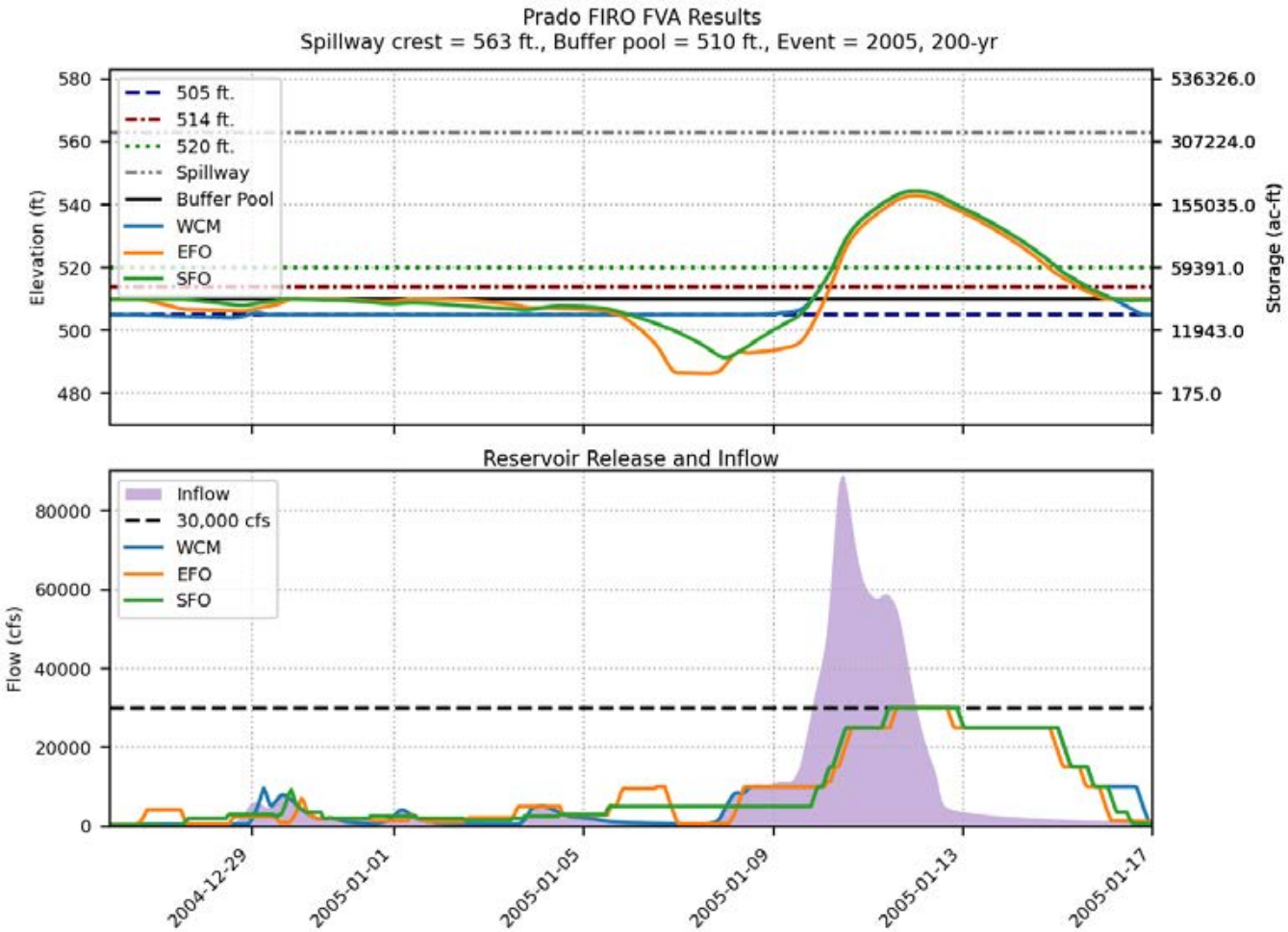
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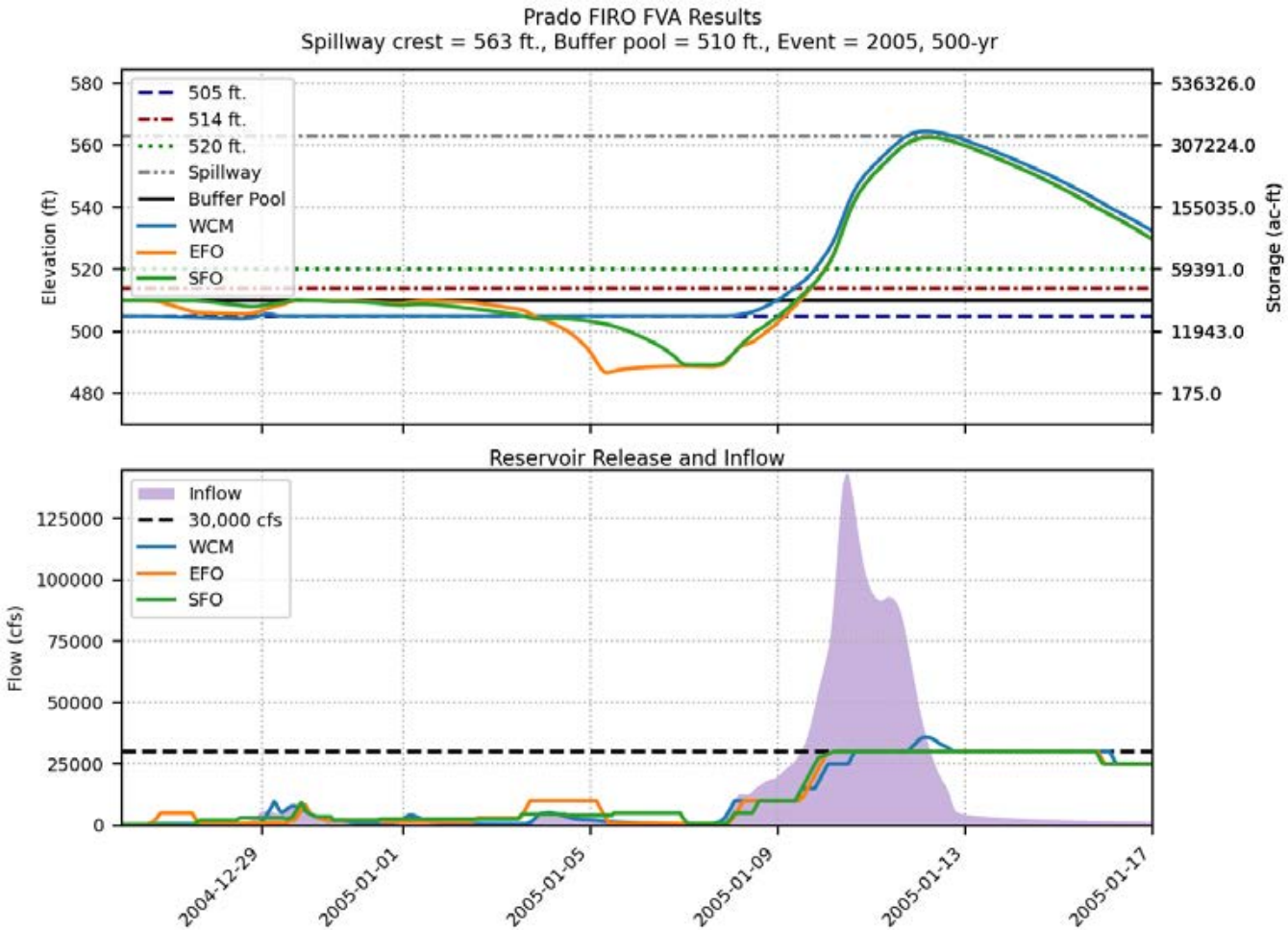
Prado FIRO FVA Results
Spillway crest = 563 ft., Buffer pool = 510 ft., Event = 2005, 500-yr
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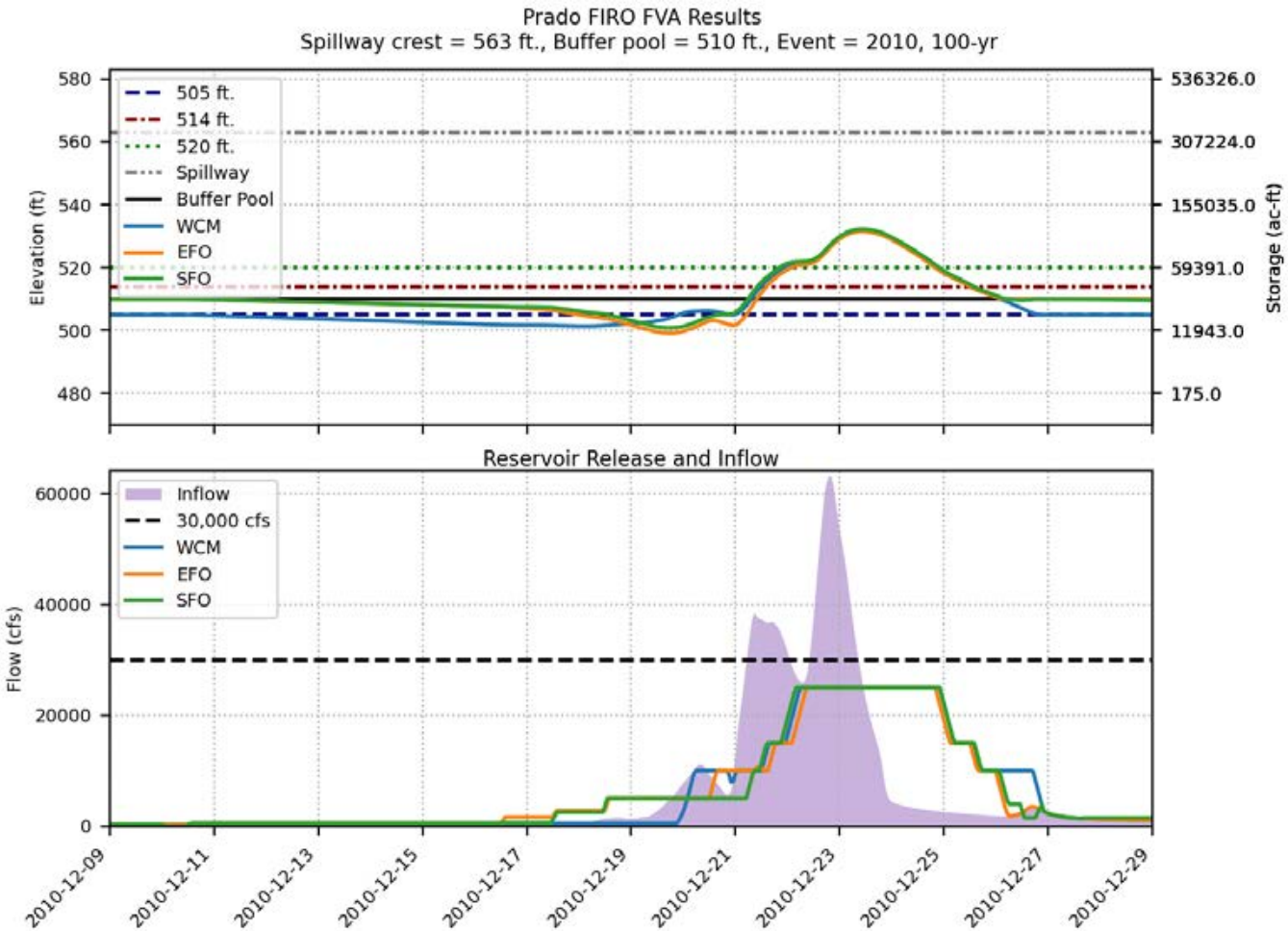
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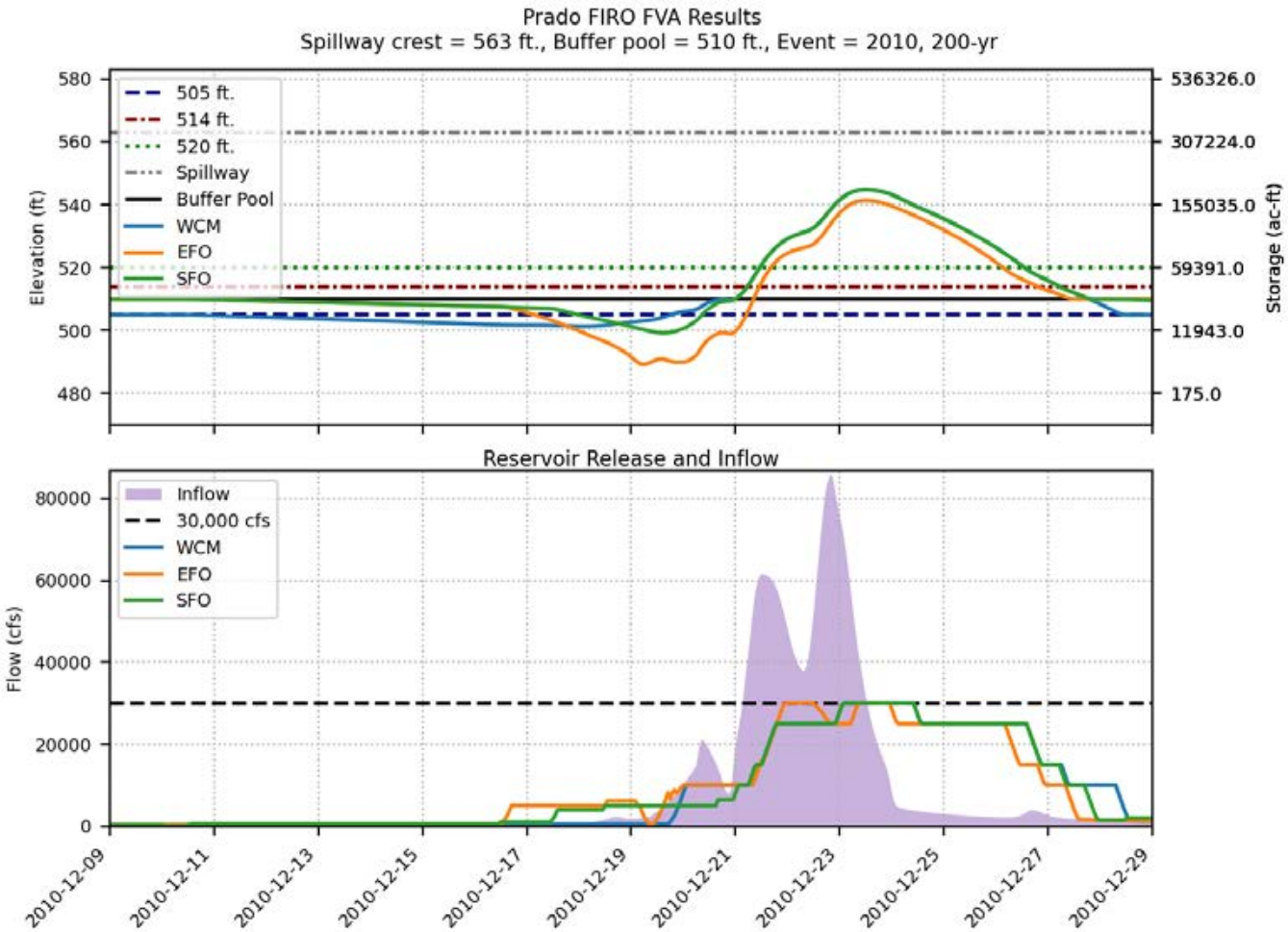
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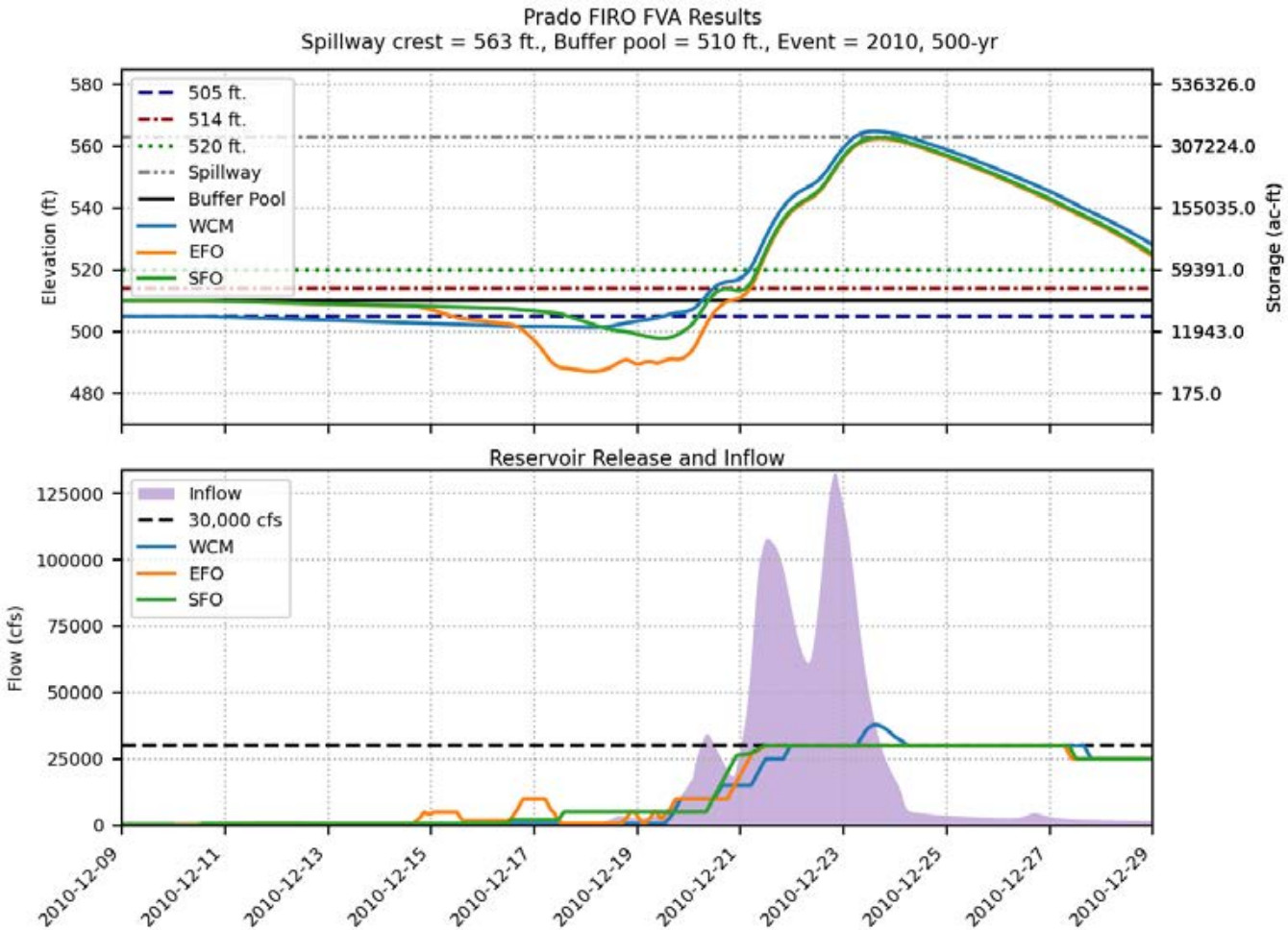
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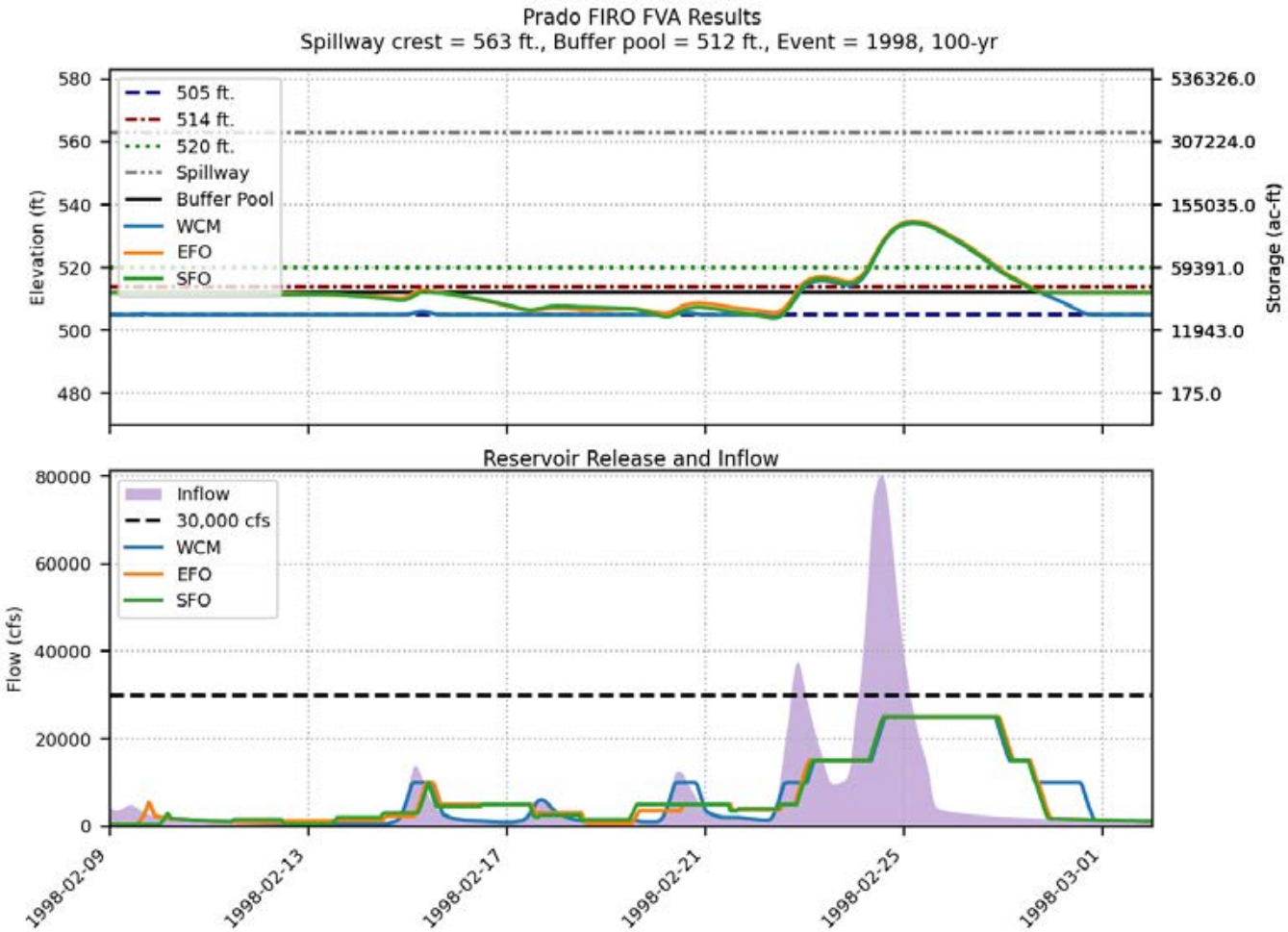
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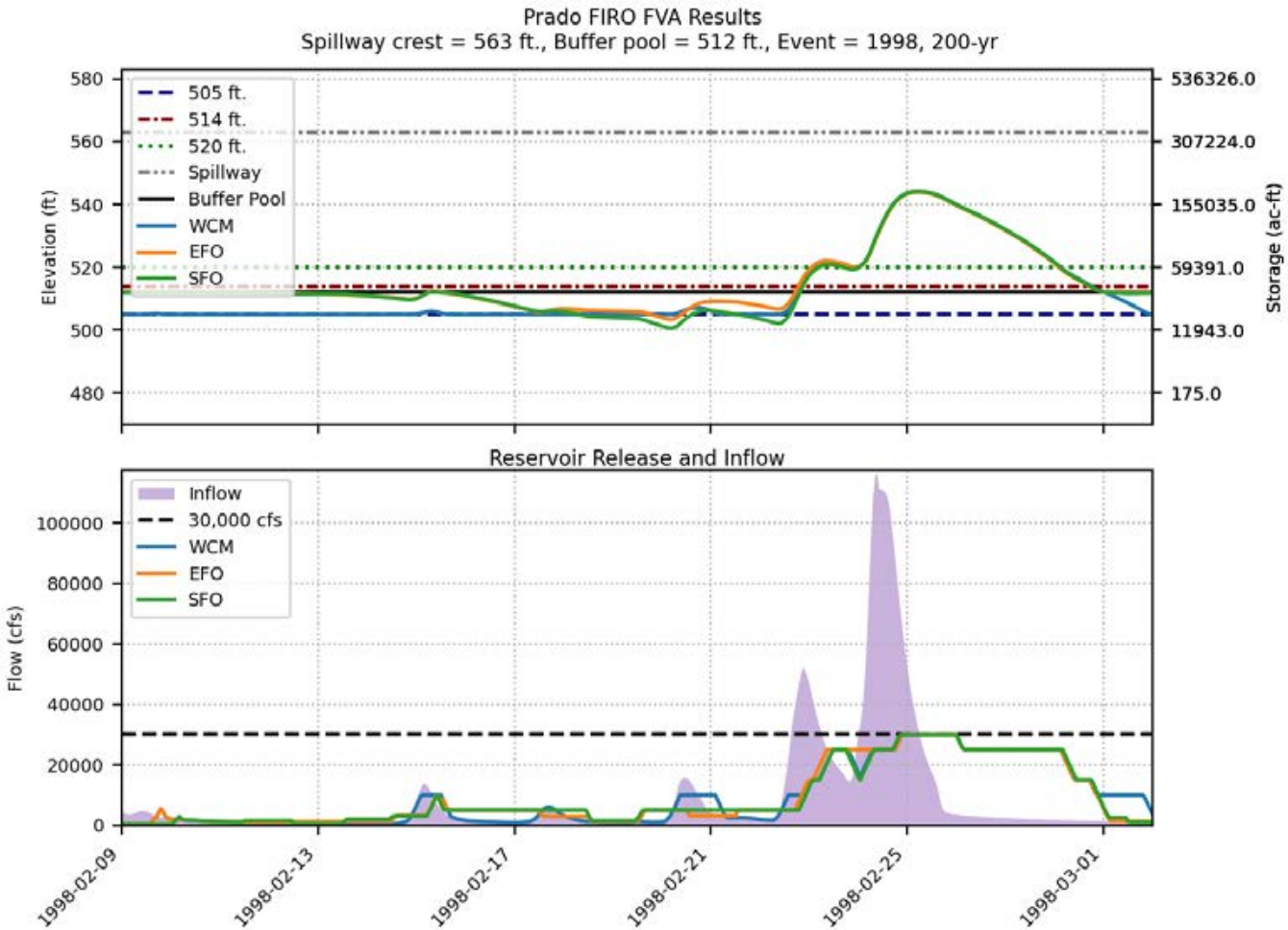
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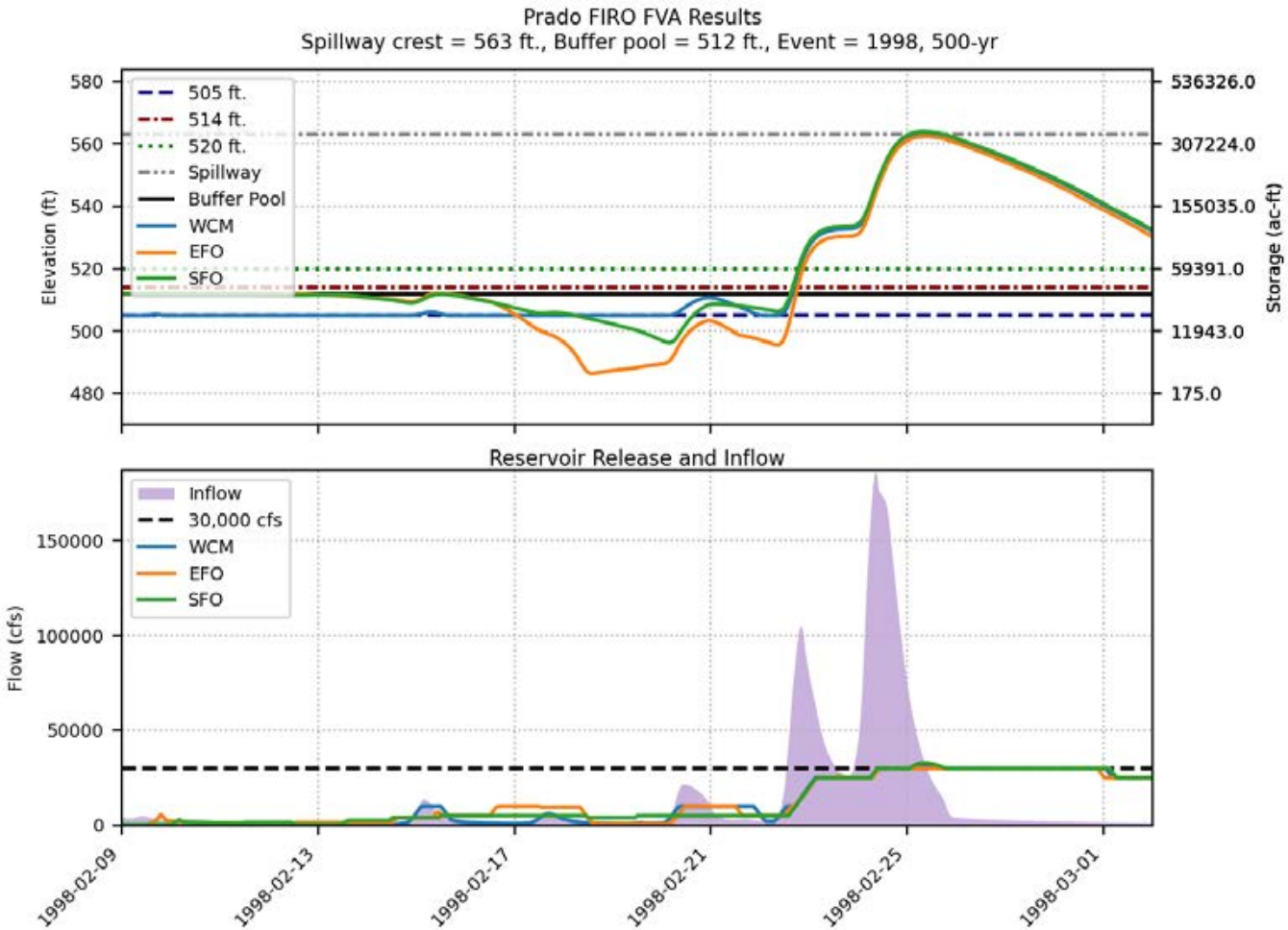
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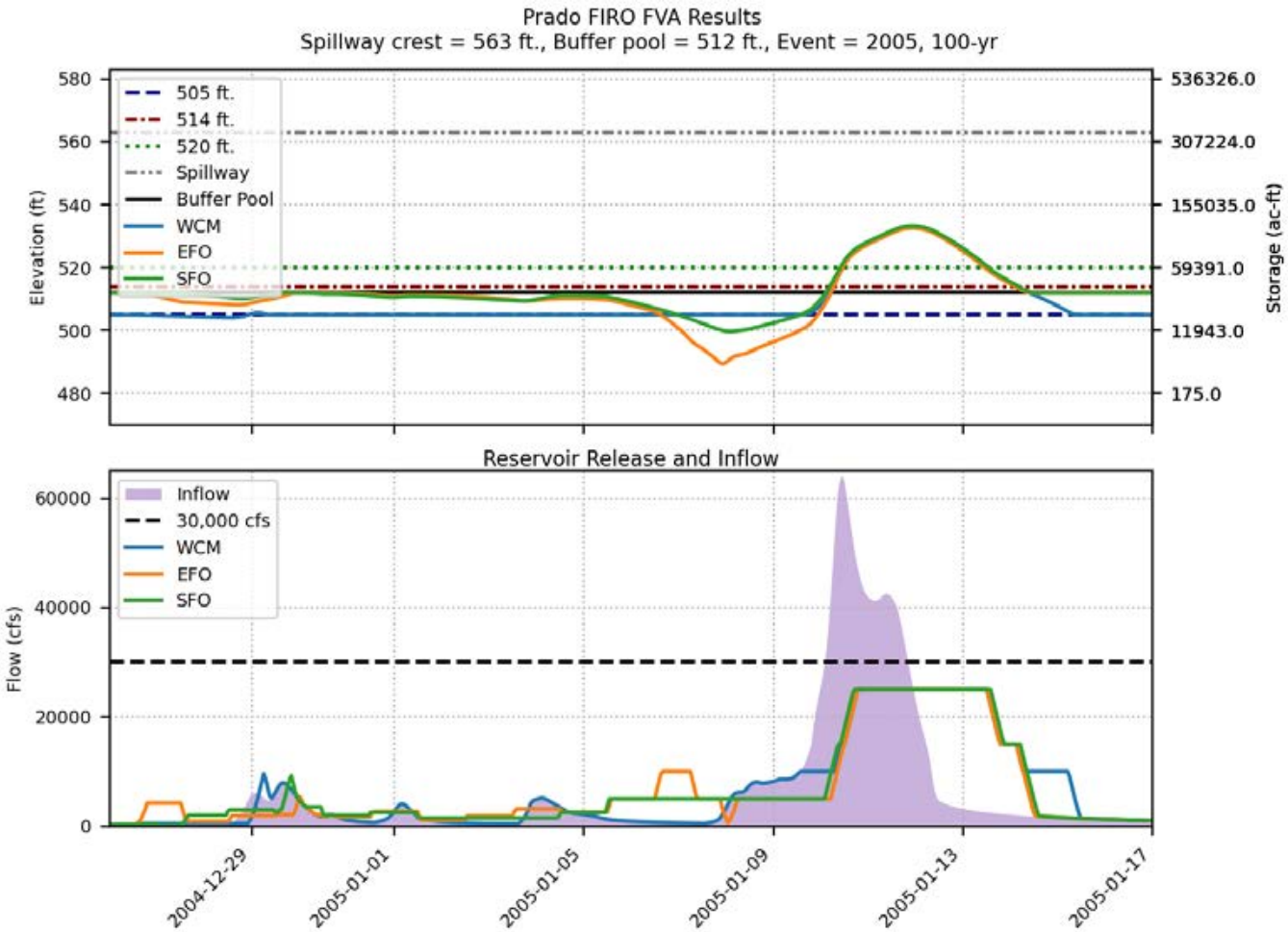
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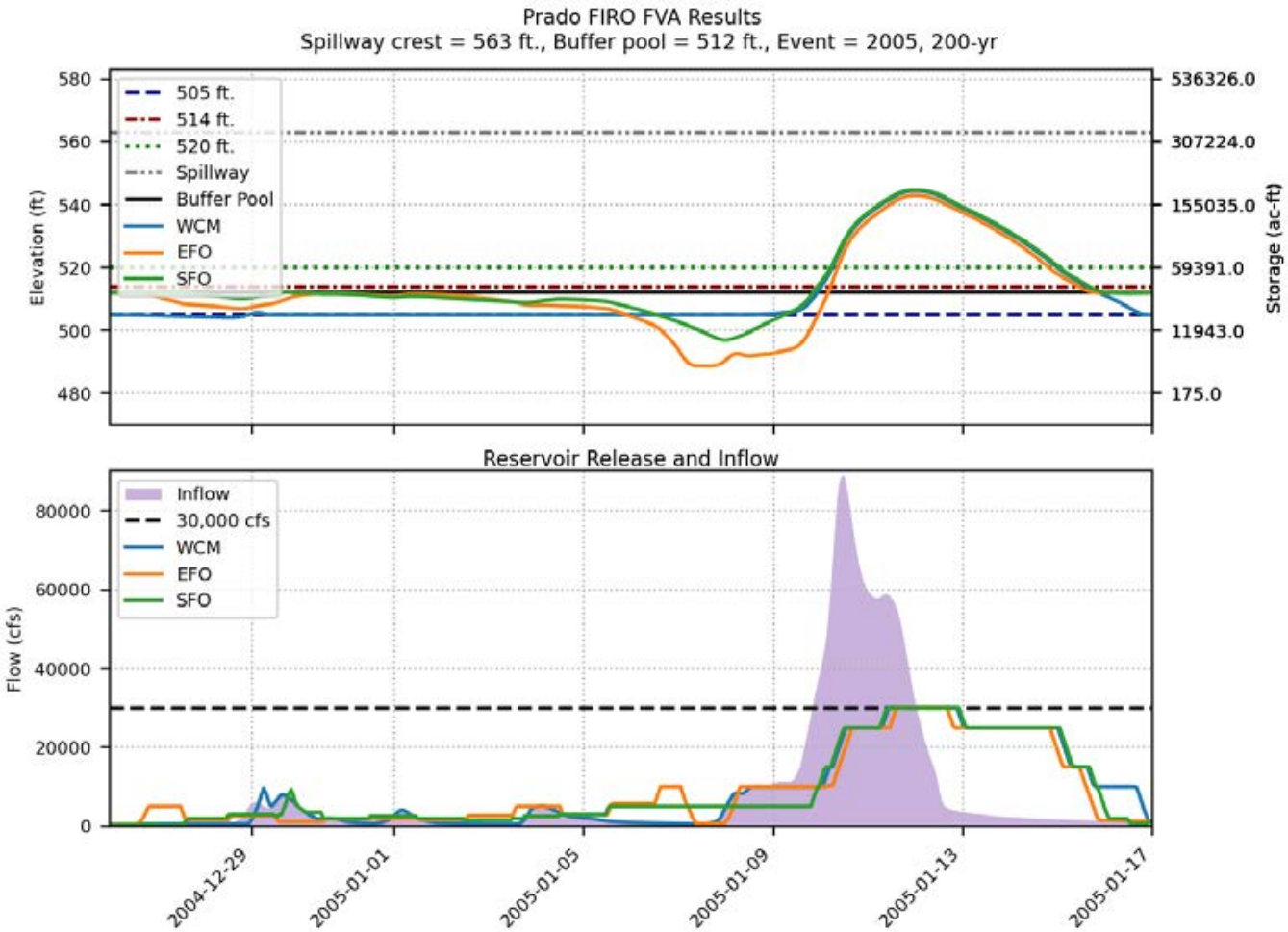
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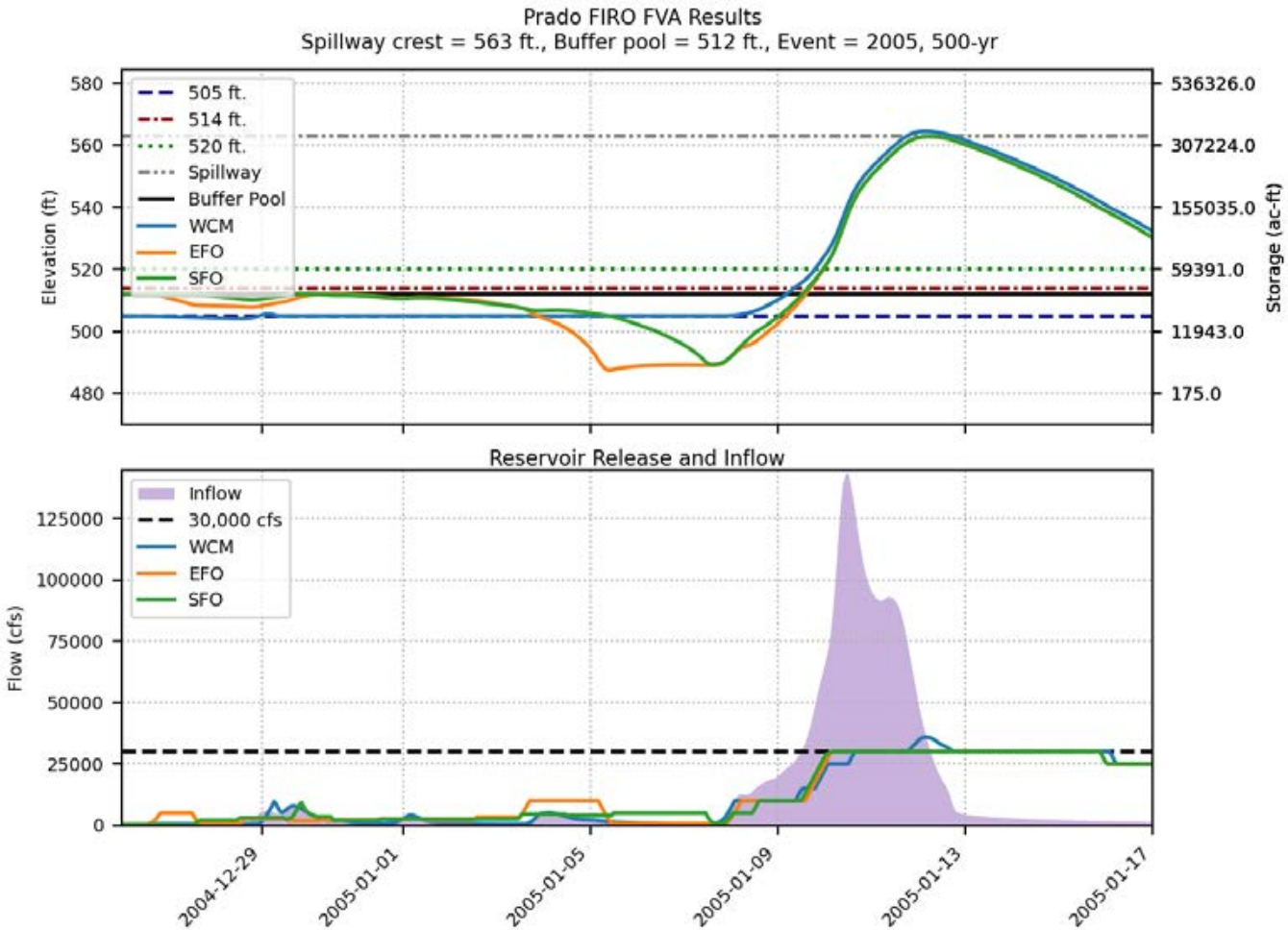
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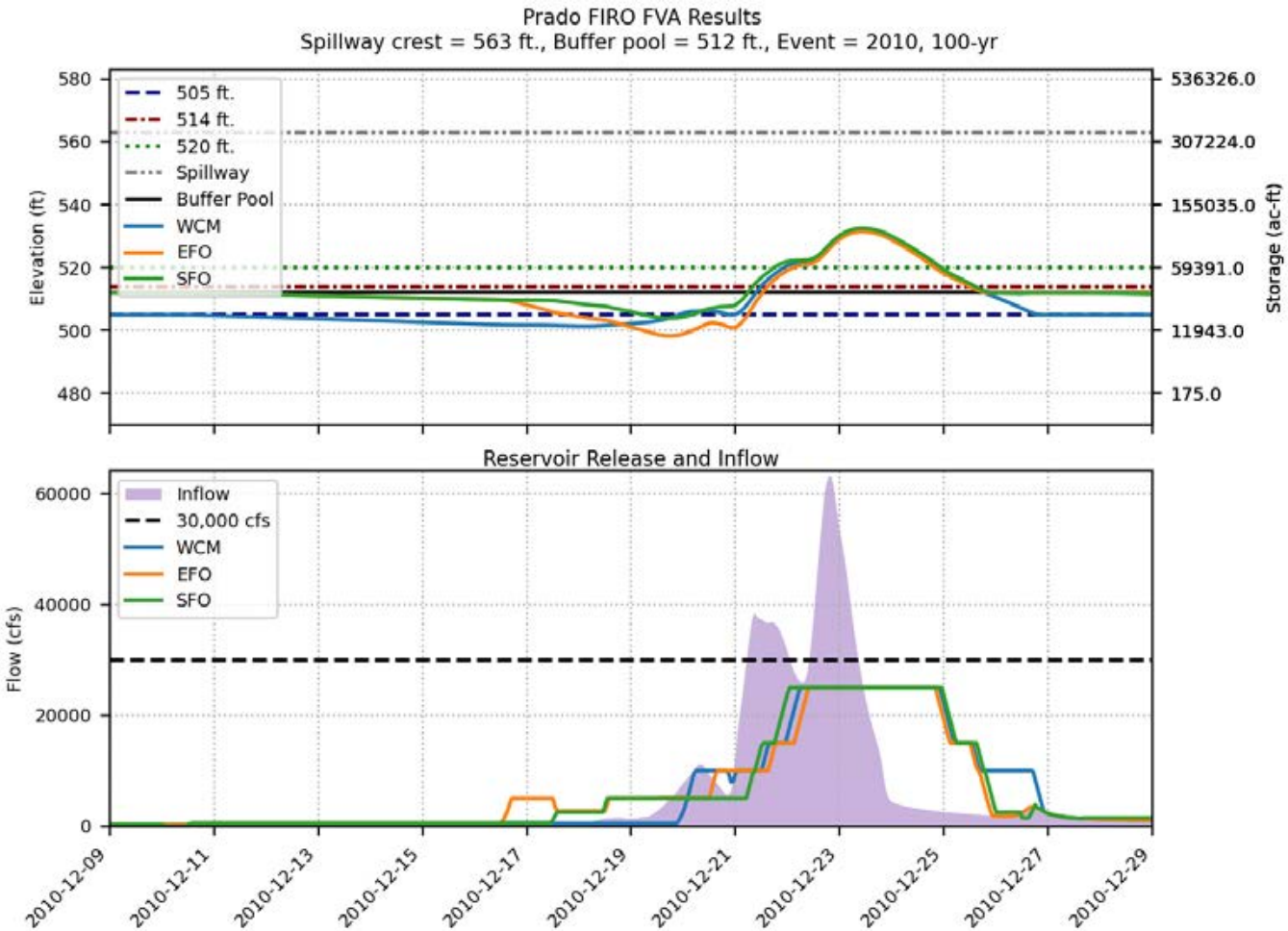
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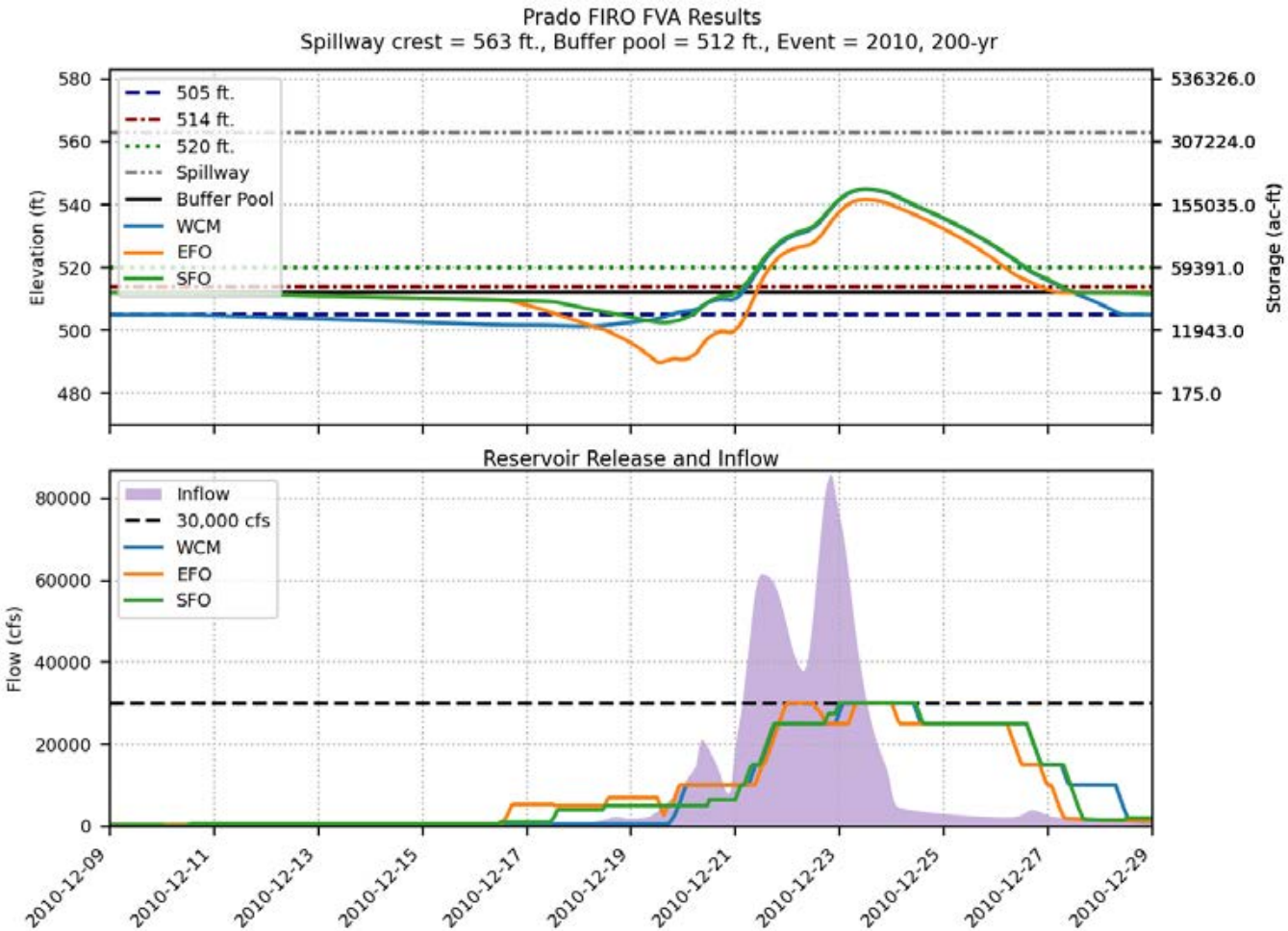
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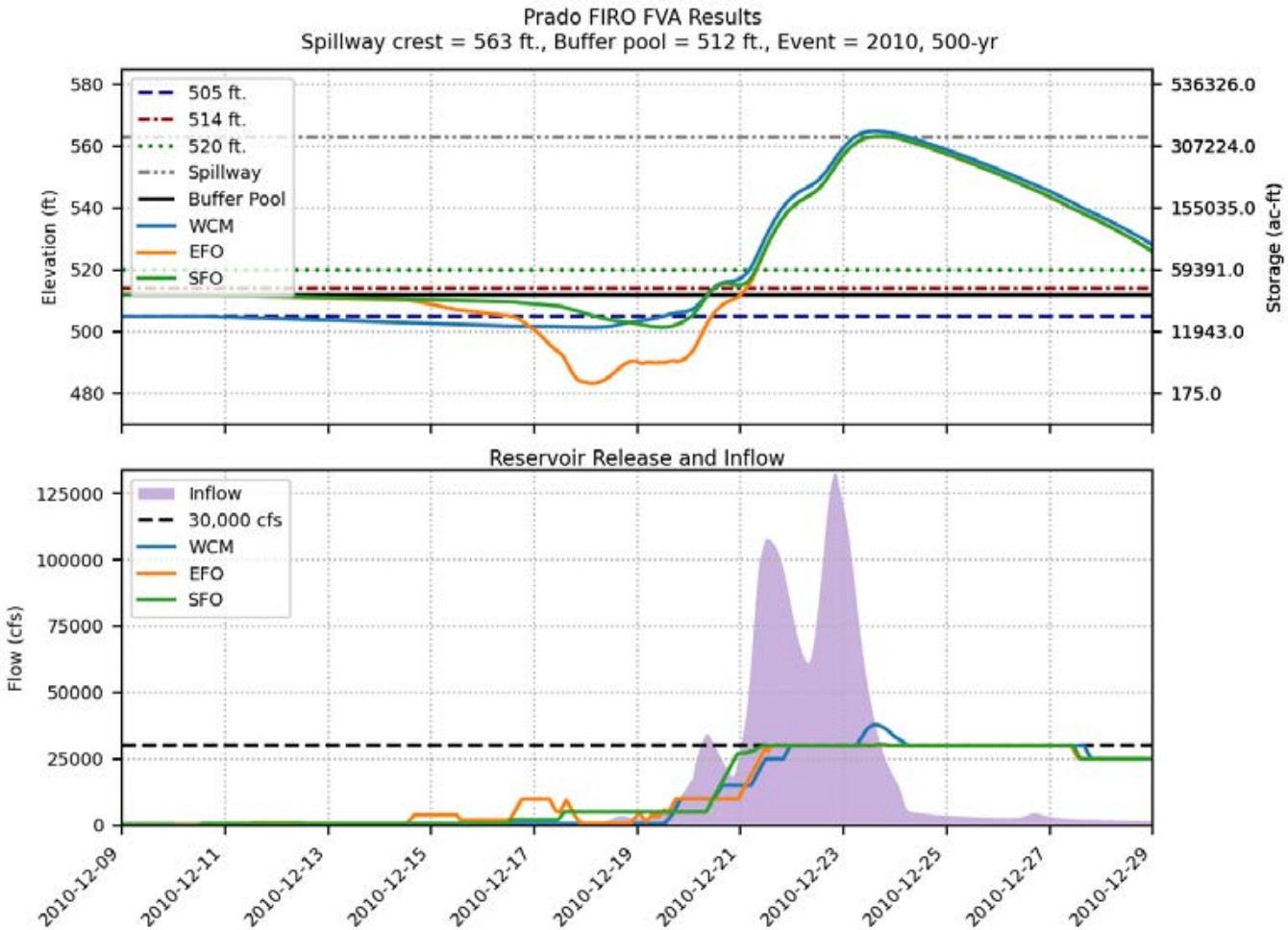
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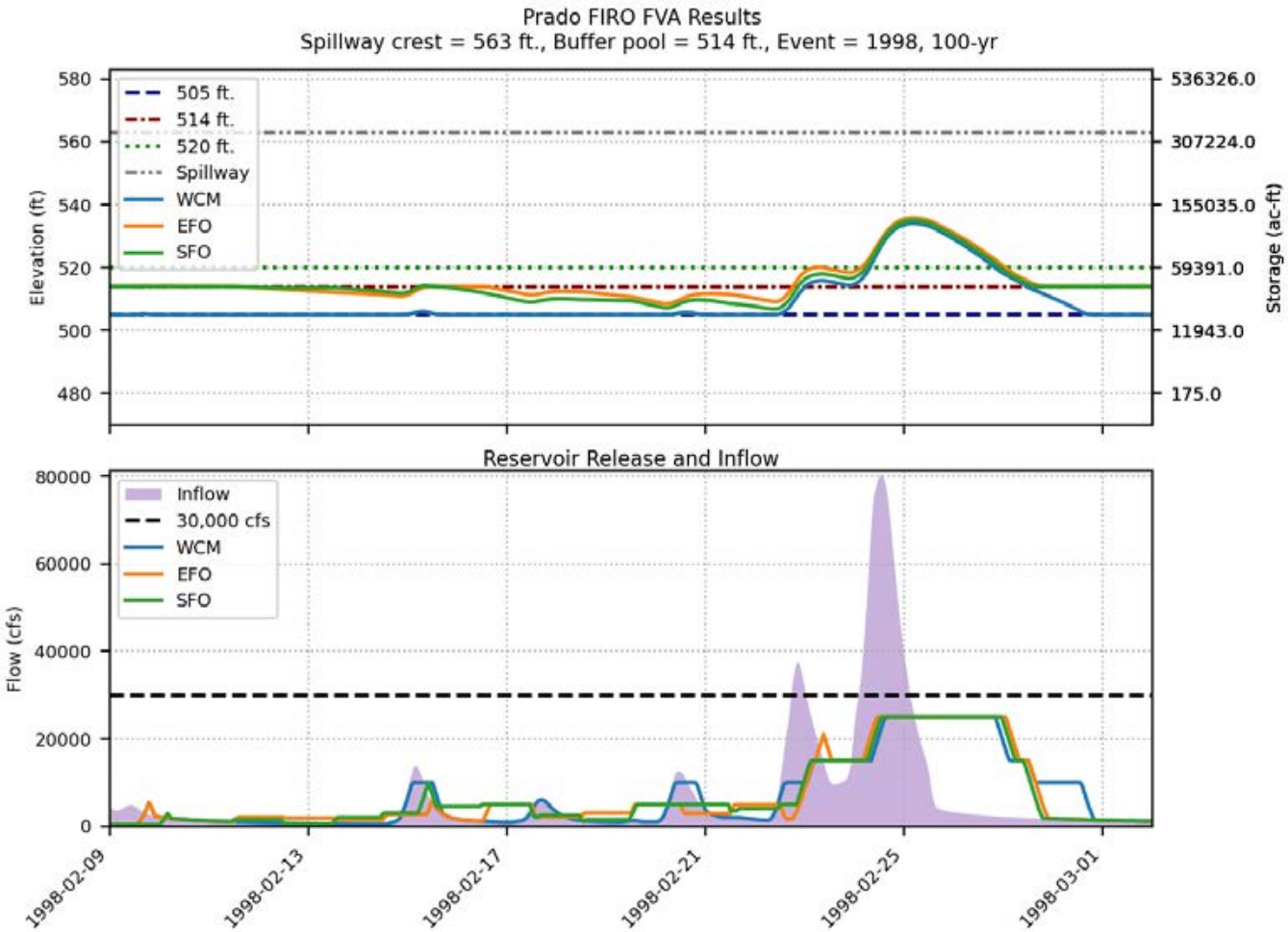
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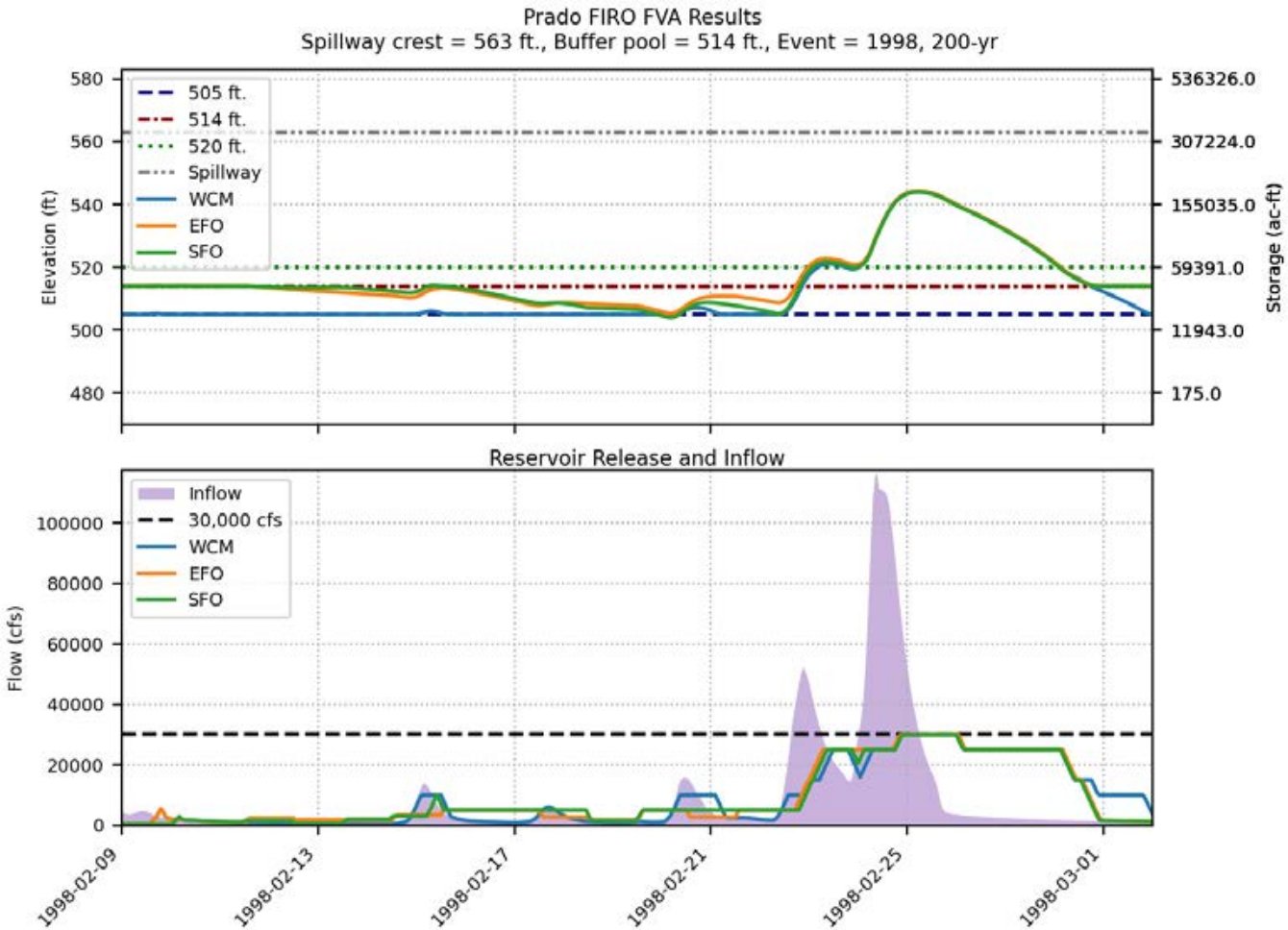
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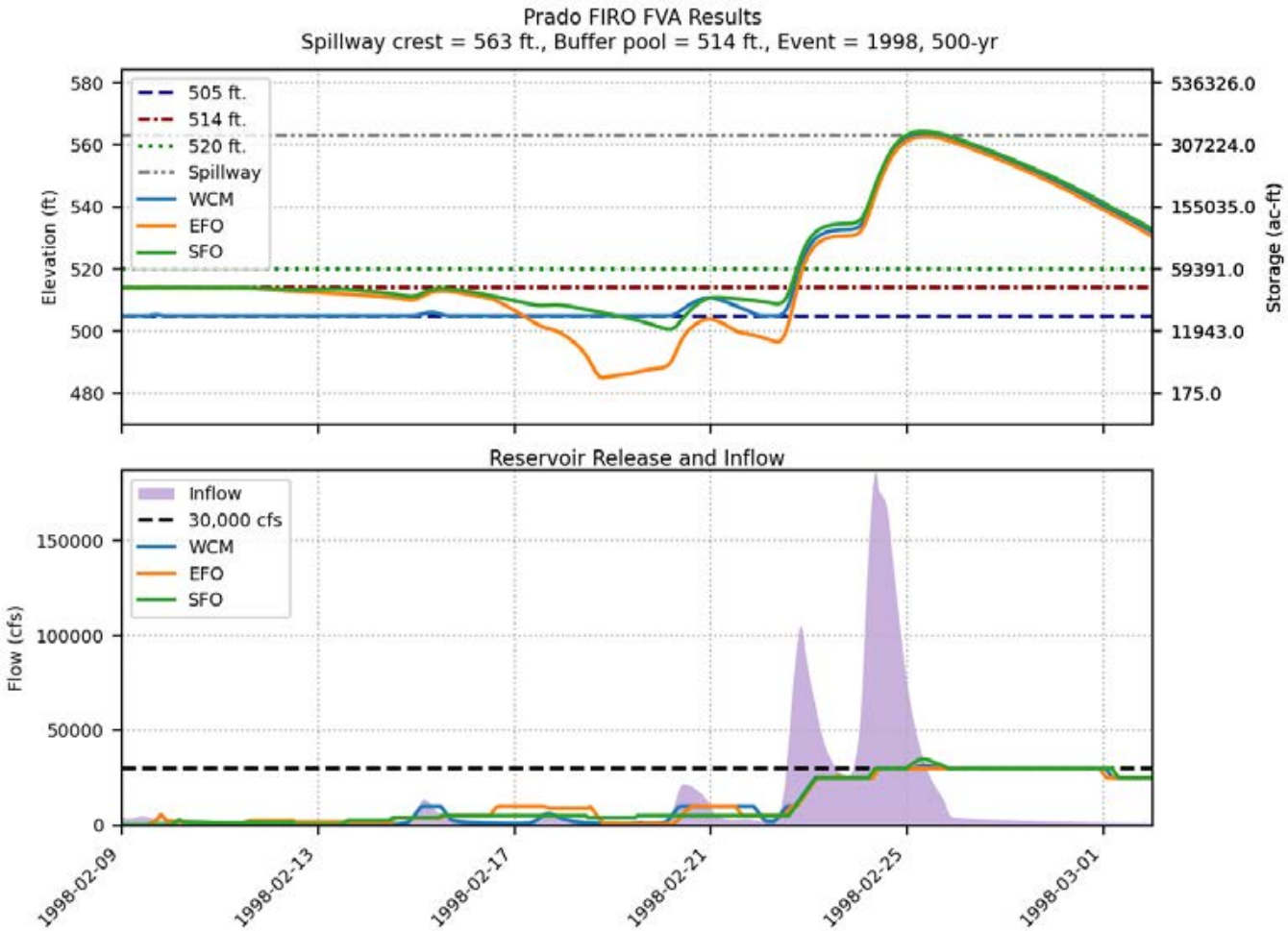
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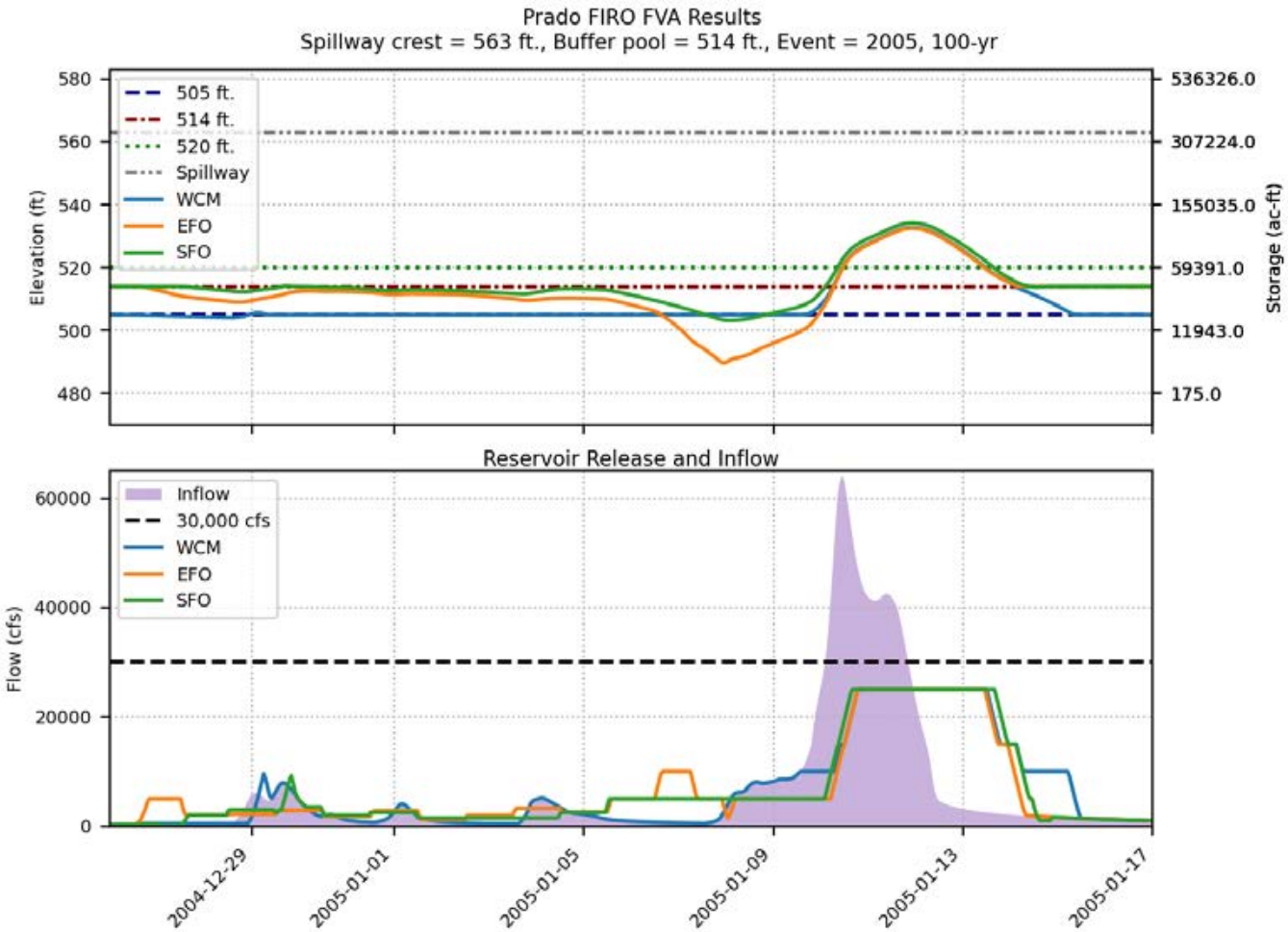
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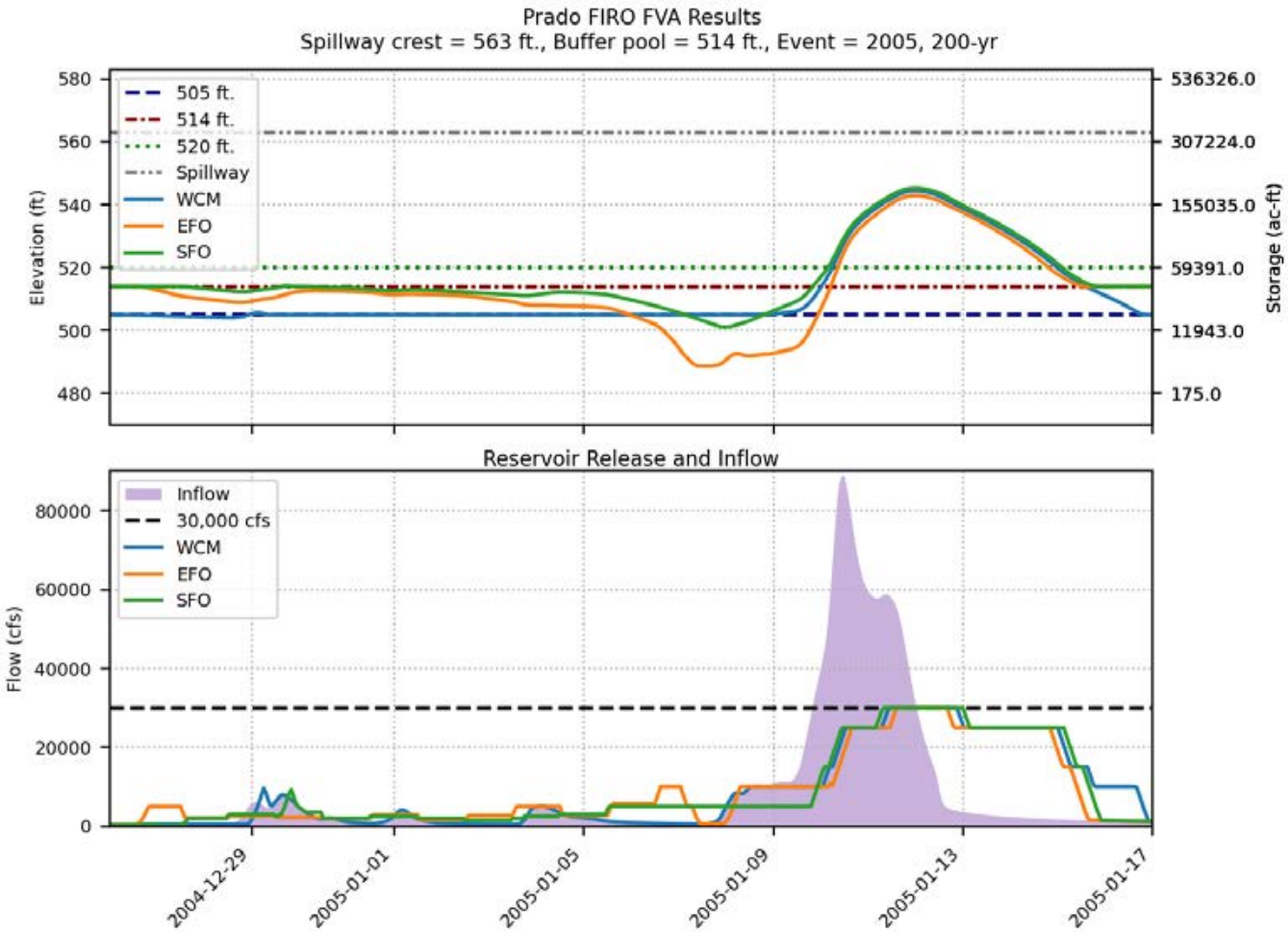
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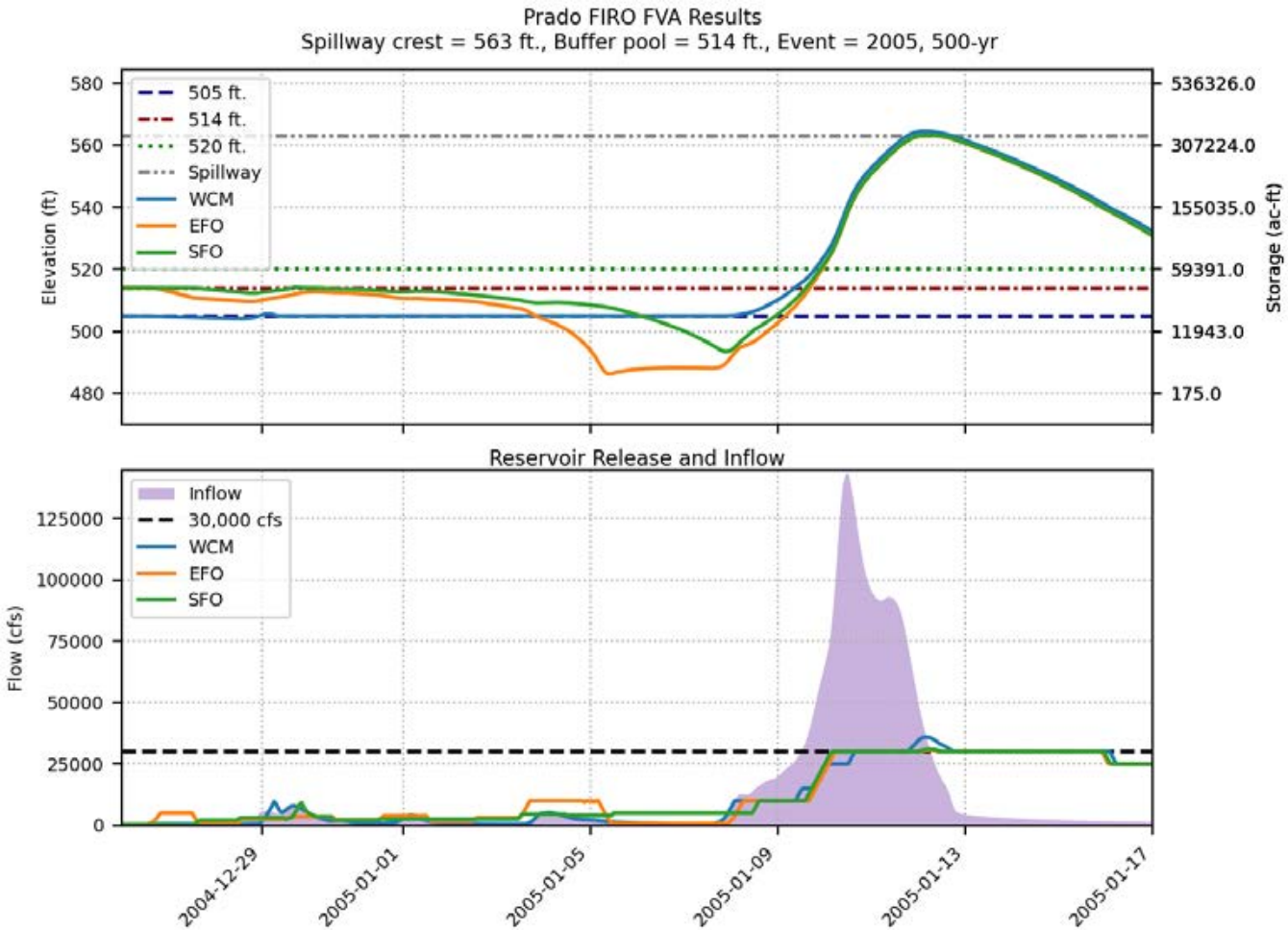
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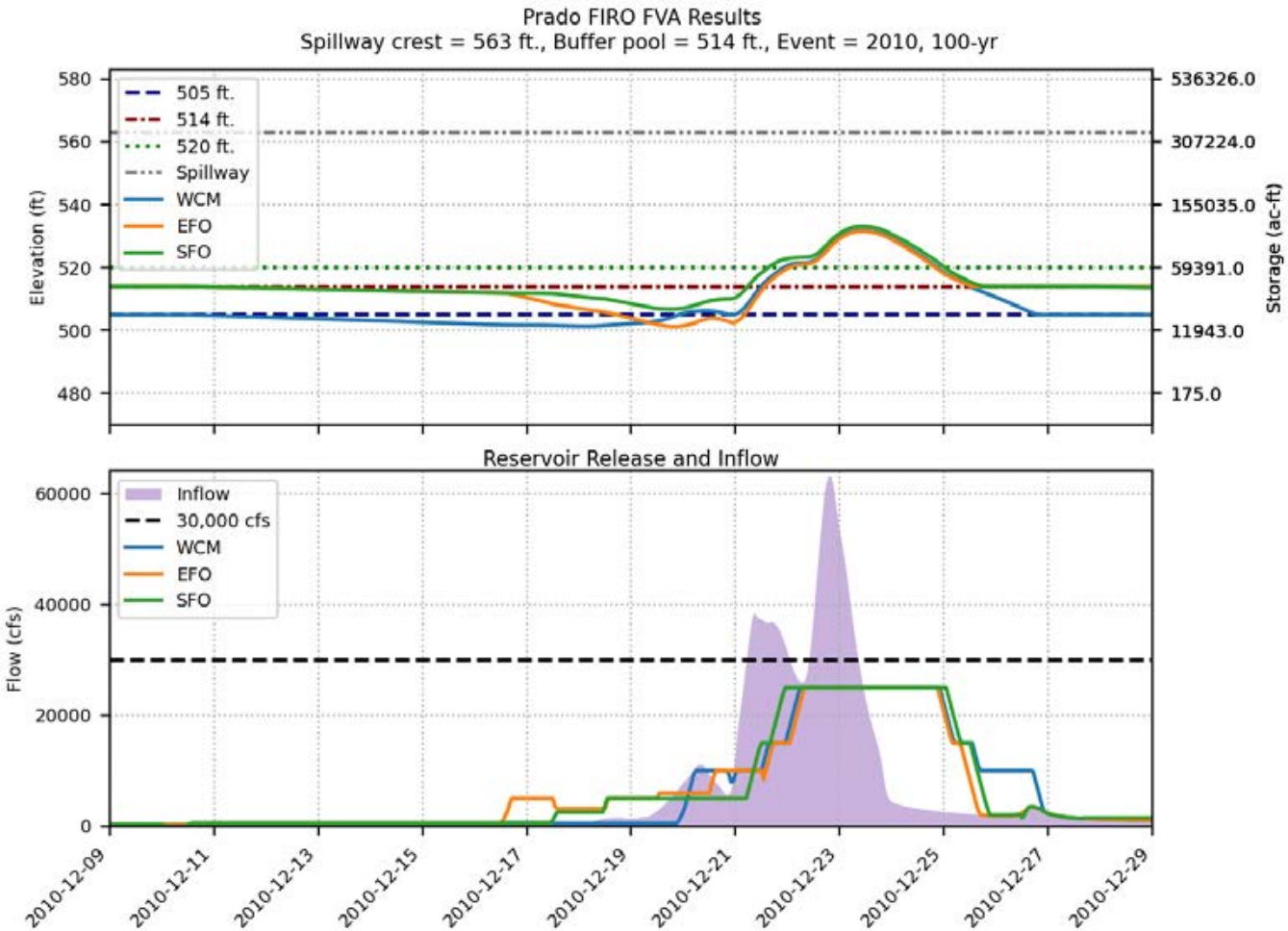
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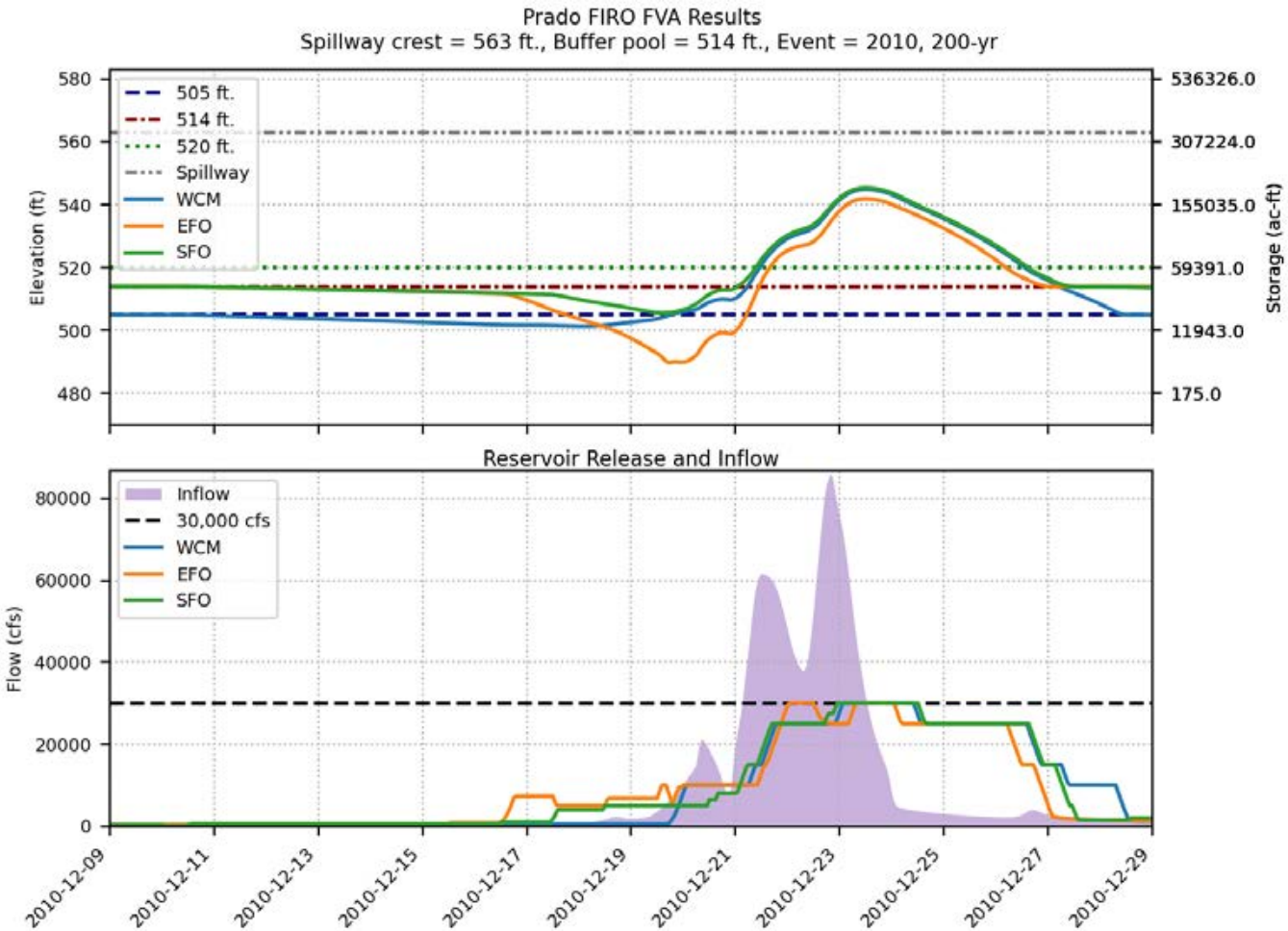
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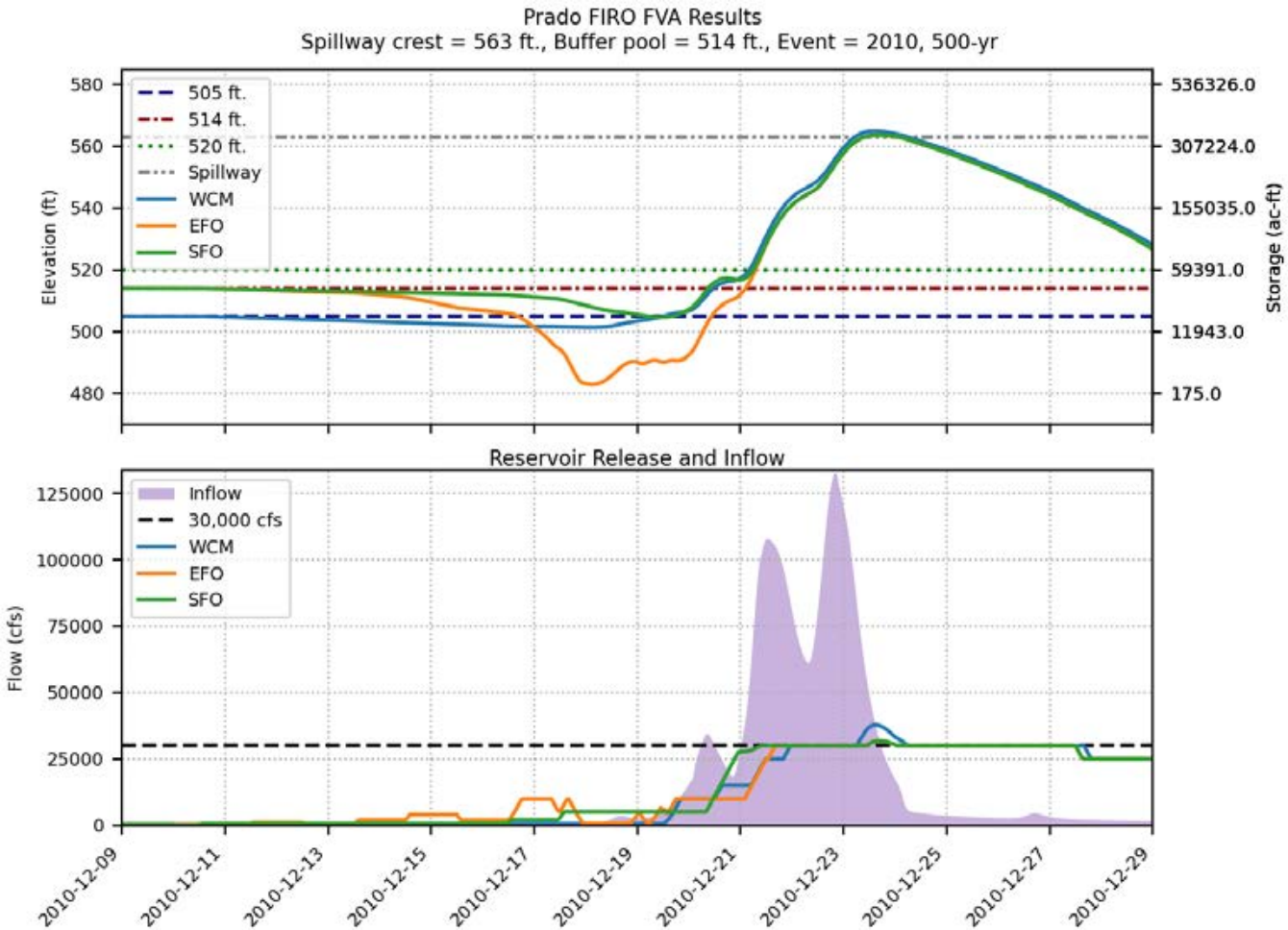
Prado FIRO FVA Results
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505 ft.
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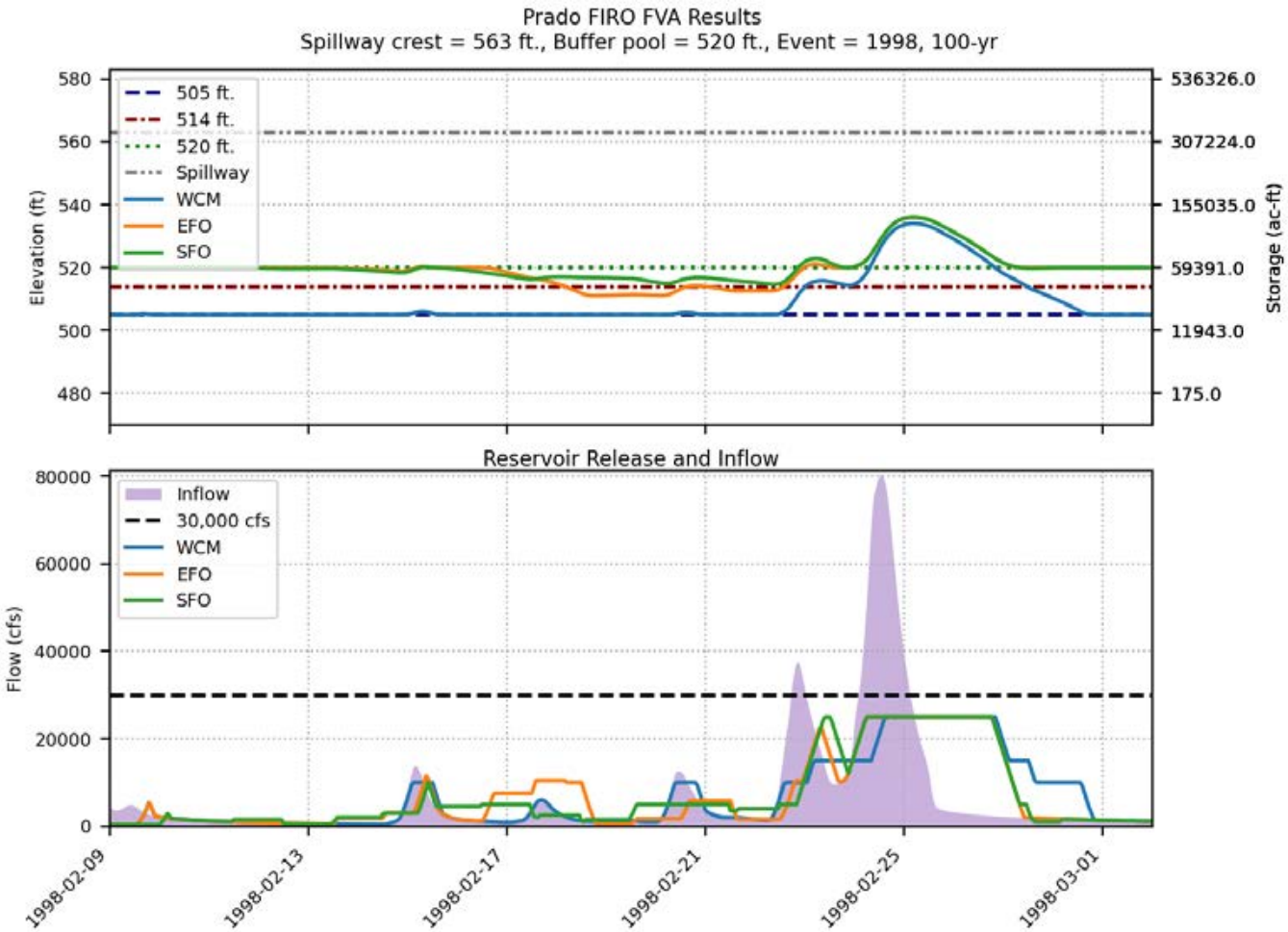
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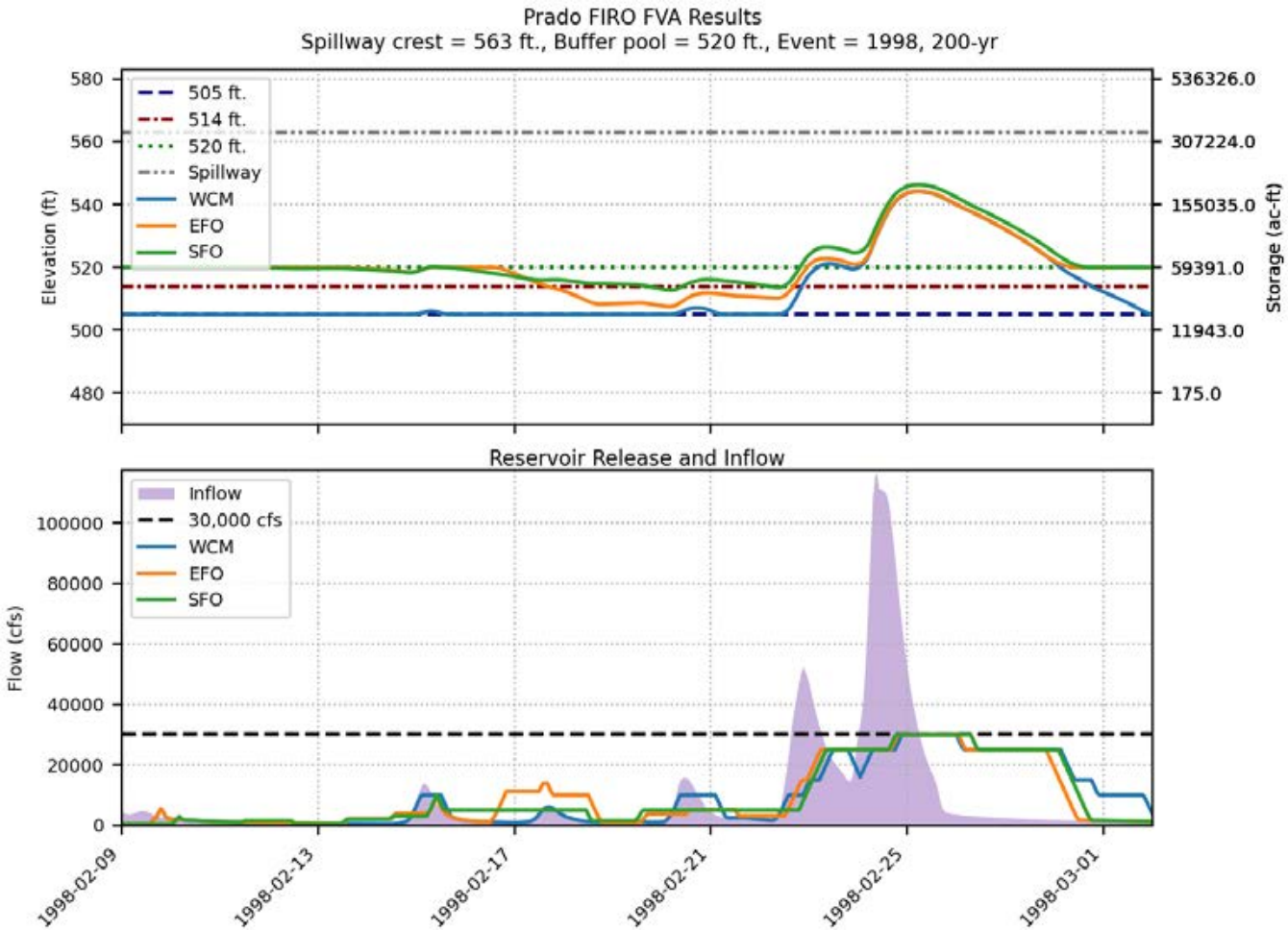
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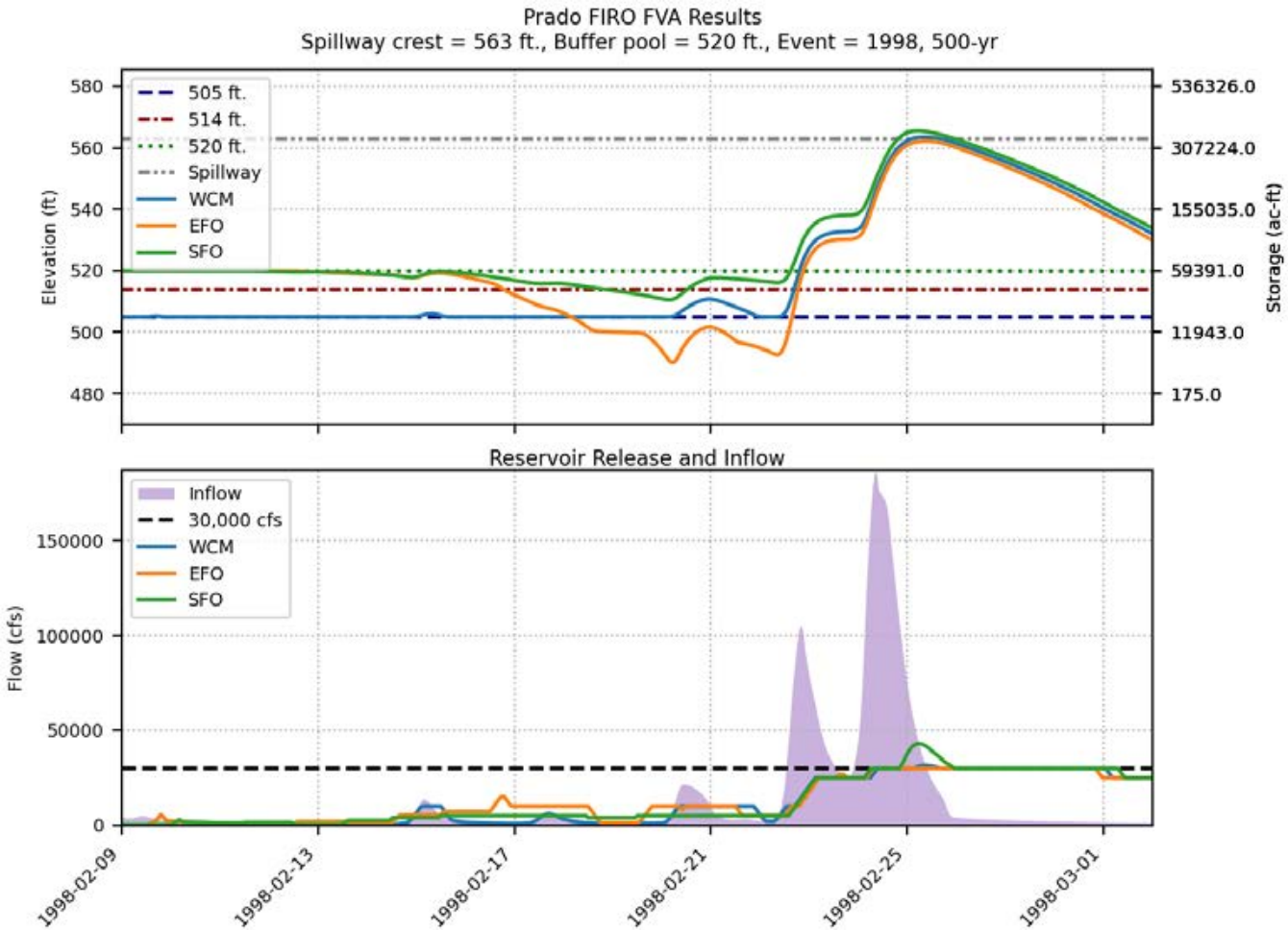
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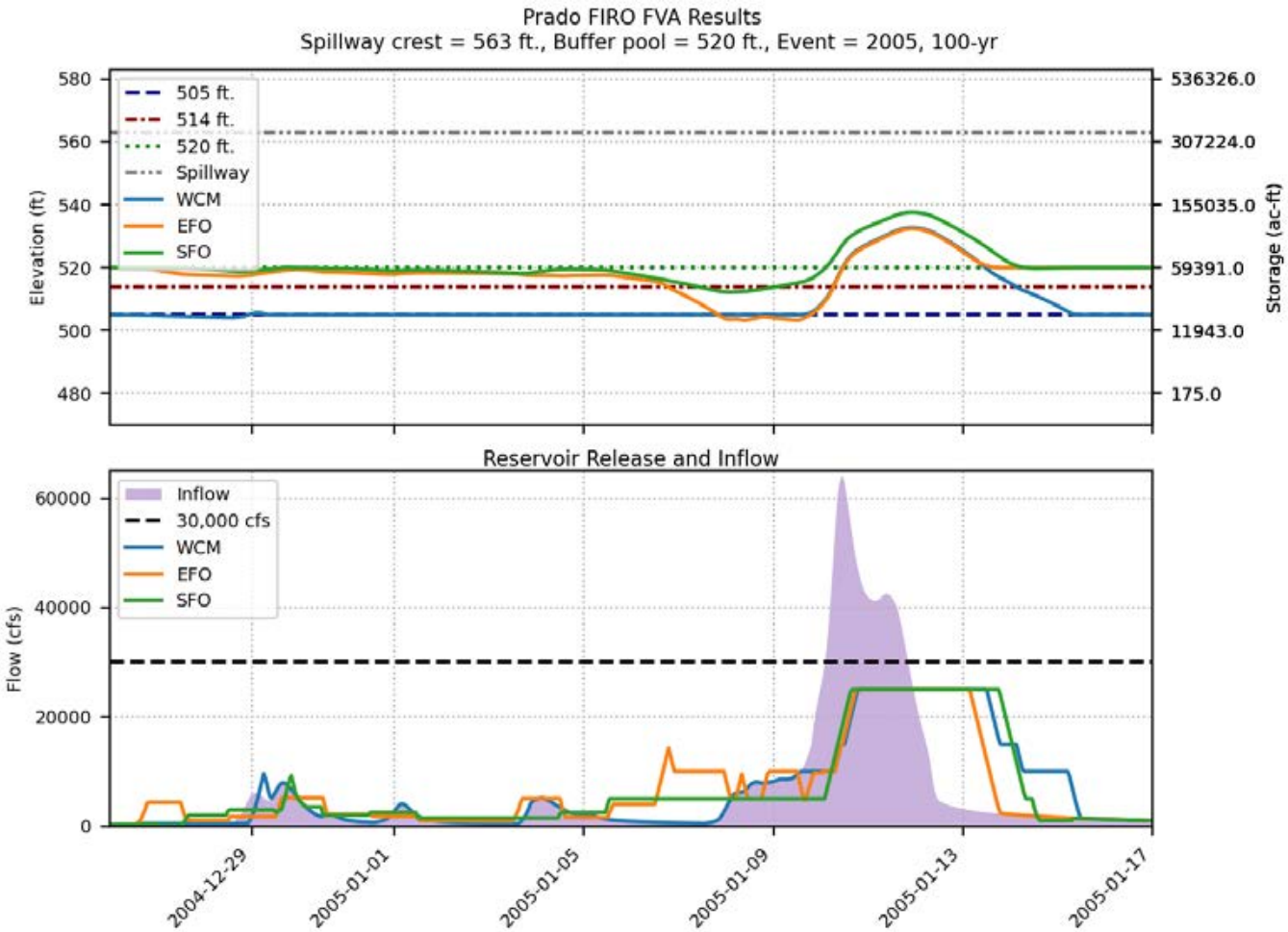
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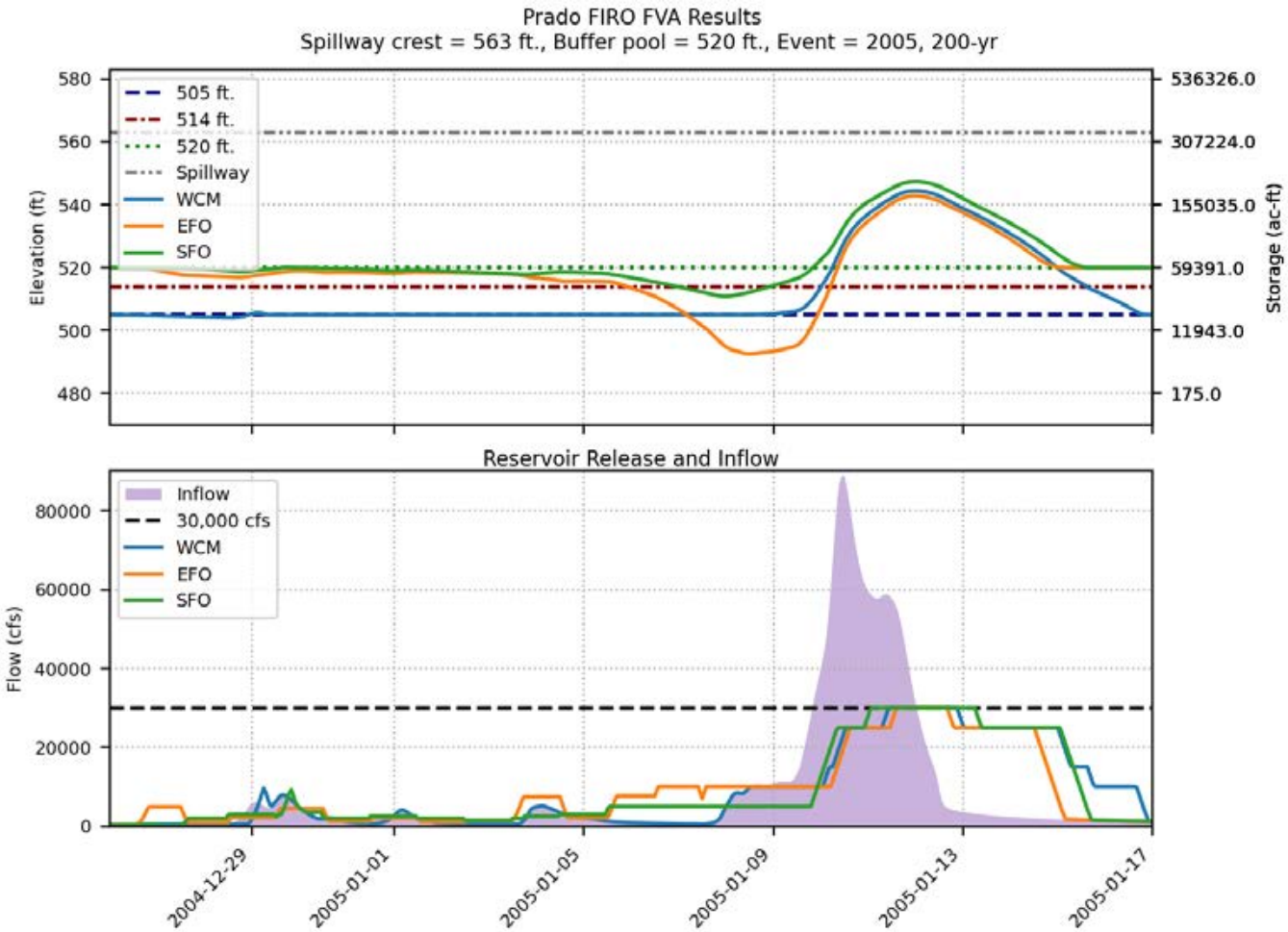
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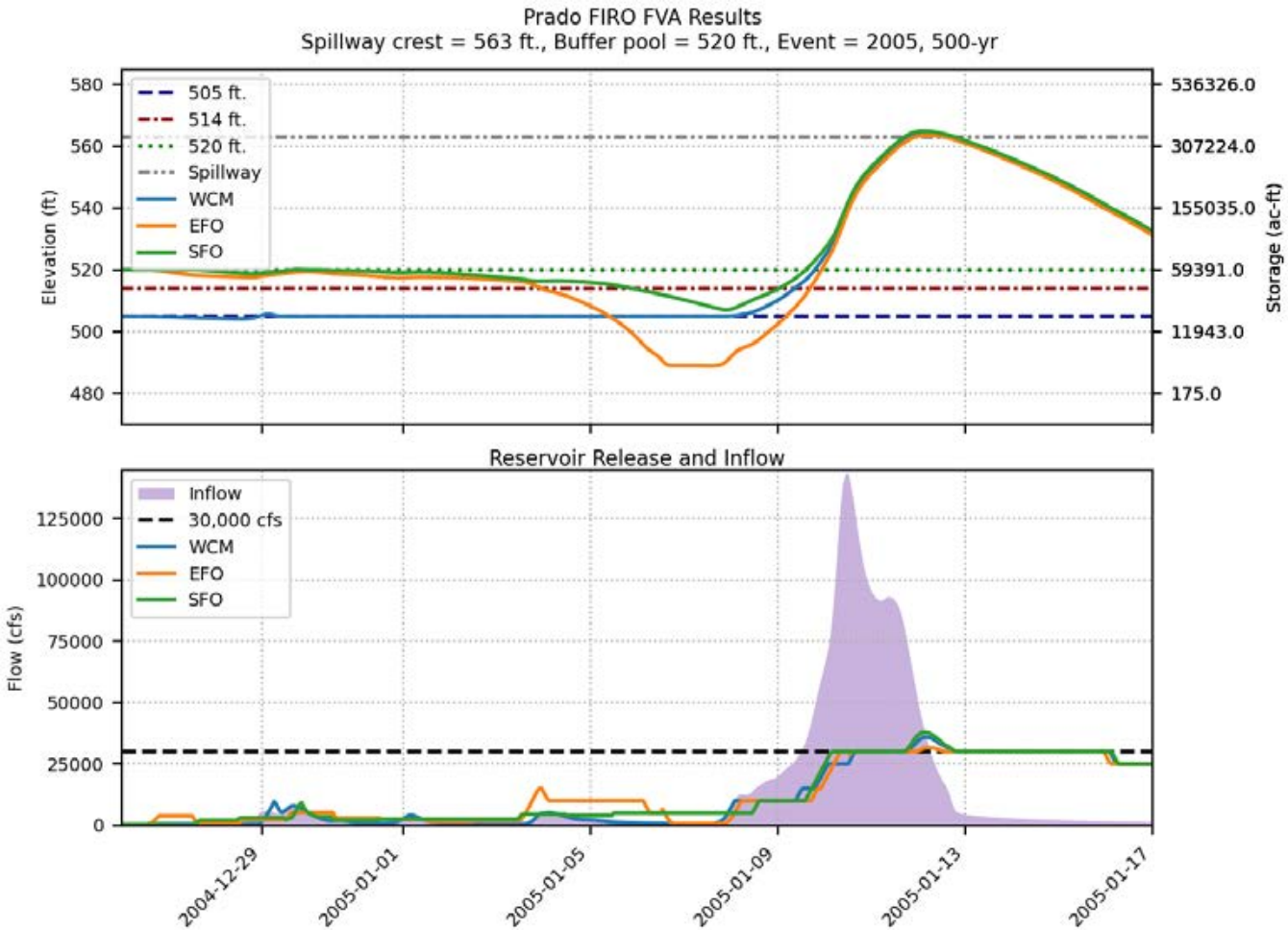
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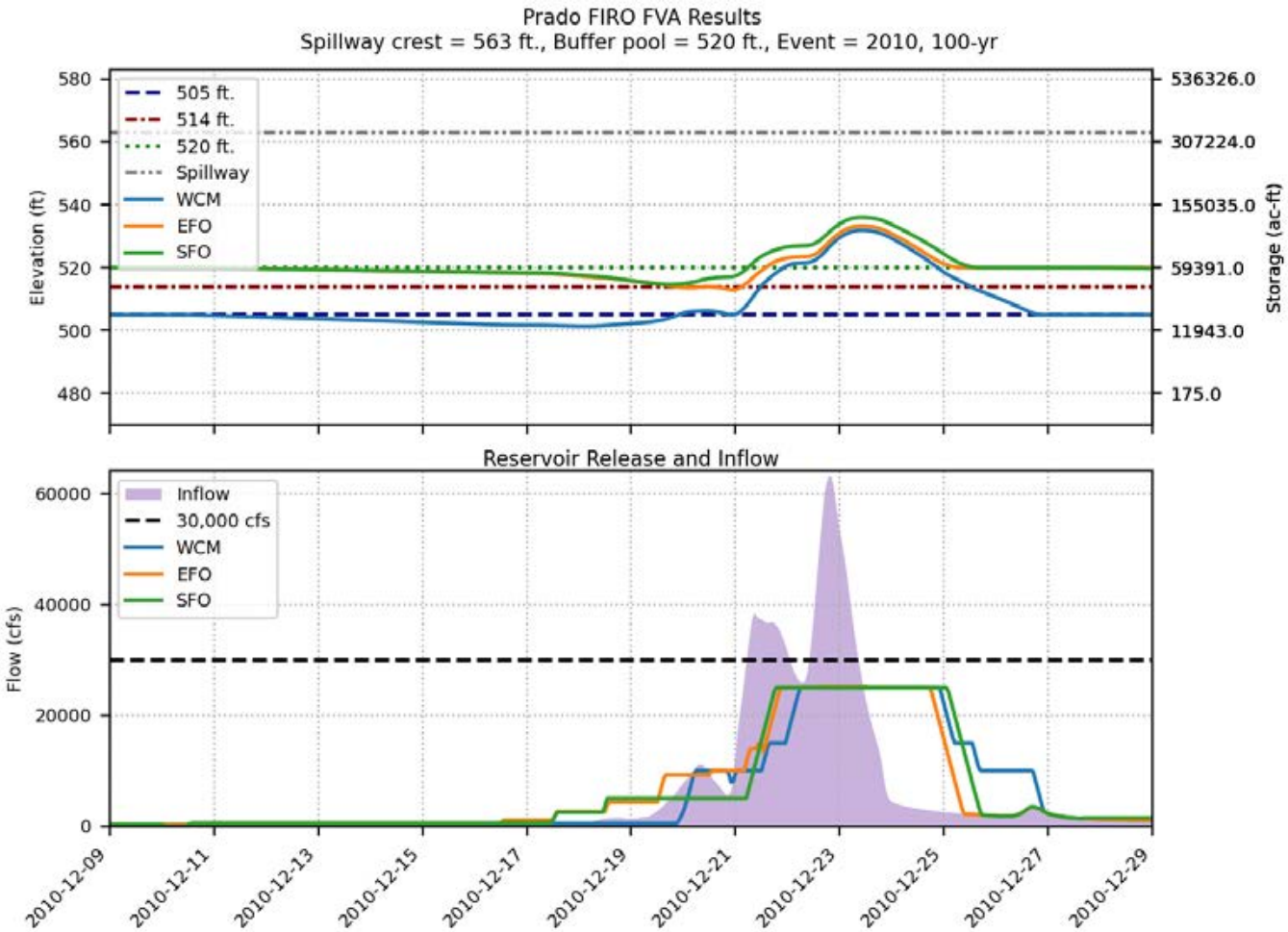
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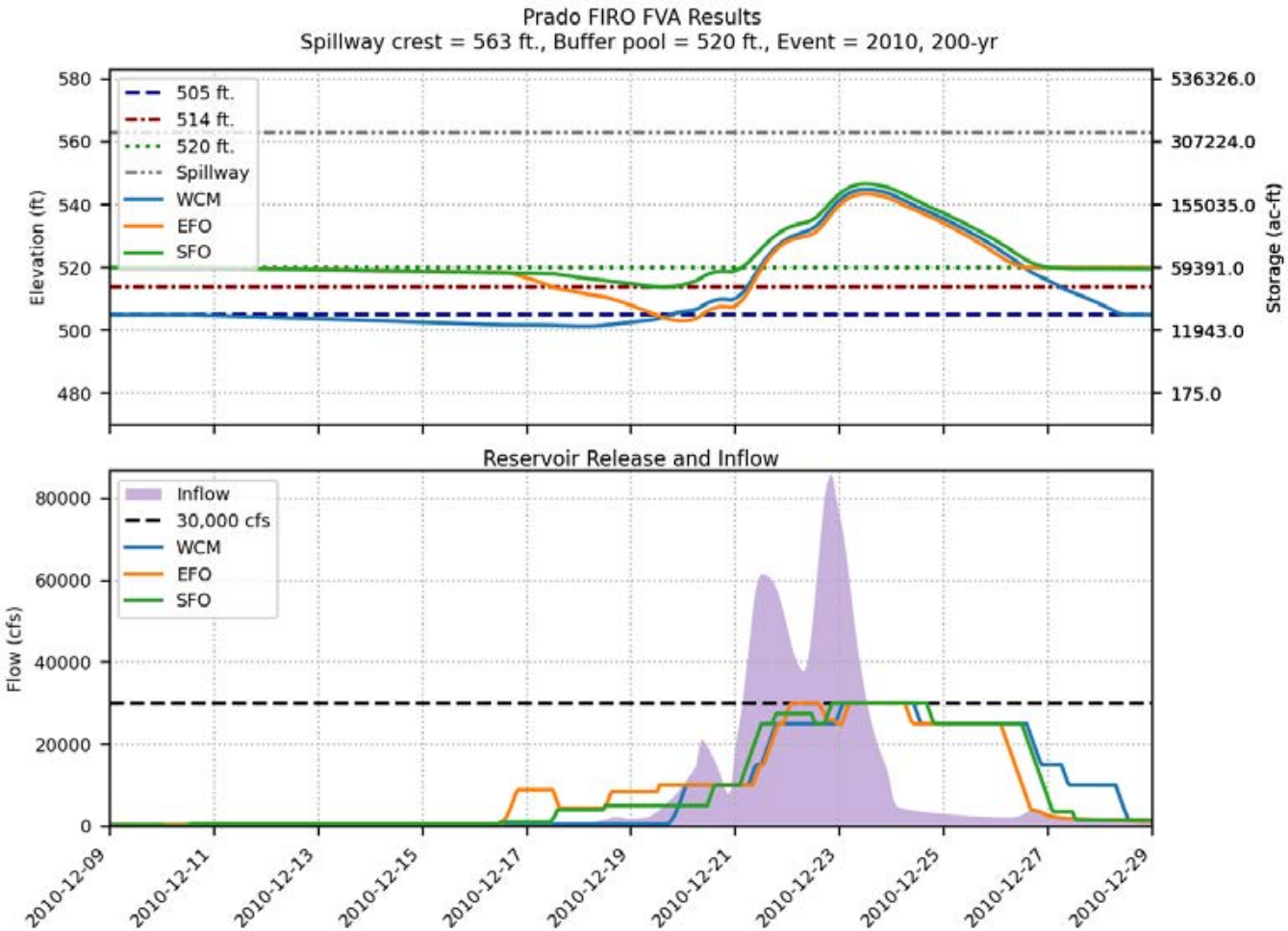
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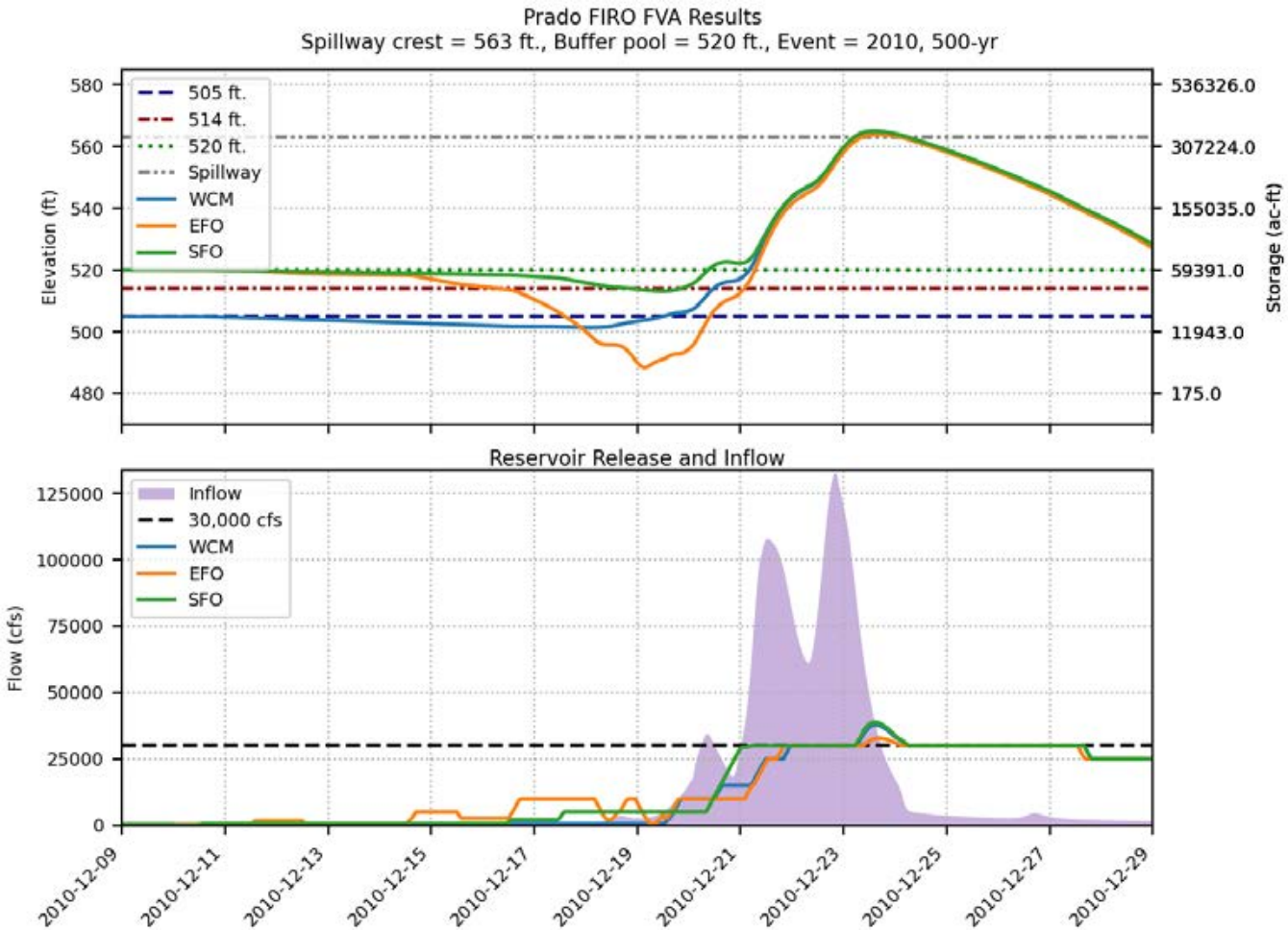
Prado FIRO FVA Results
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Appendix C—Observational Studies and Research (Section 6)

C.1 Soil Moisture Stations

C.1.1 Introduction and Background

An initial observational network evaluation was completed as part of the FIRO Prado PVA. Results from the initial network evaluation were used to inform the surface meteorology and soil moisture network enhancement strategy developed as part of the FVA. There are 27 high-quality precipitation gauges in the Santa Ana River watershed utilized by the California-Nevada River Forecast Center (CNRFC) for forecasting (Figure C-1). The majority of these precipitation gauges are located below 750 meters in elevation (Figure C-2).

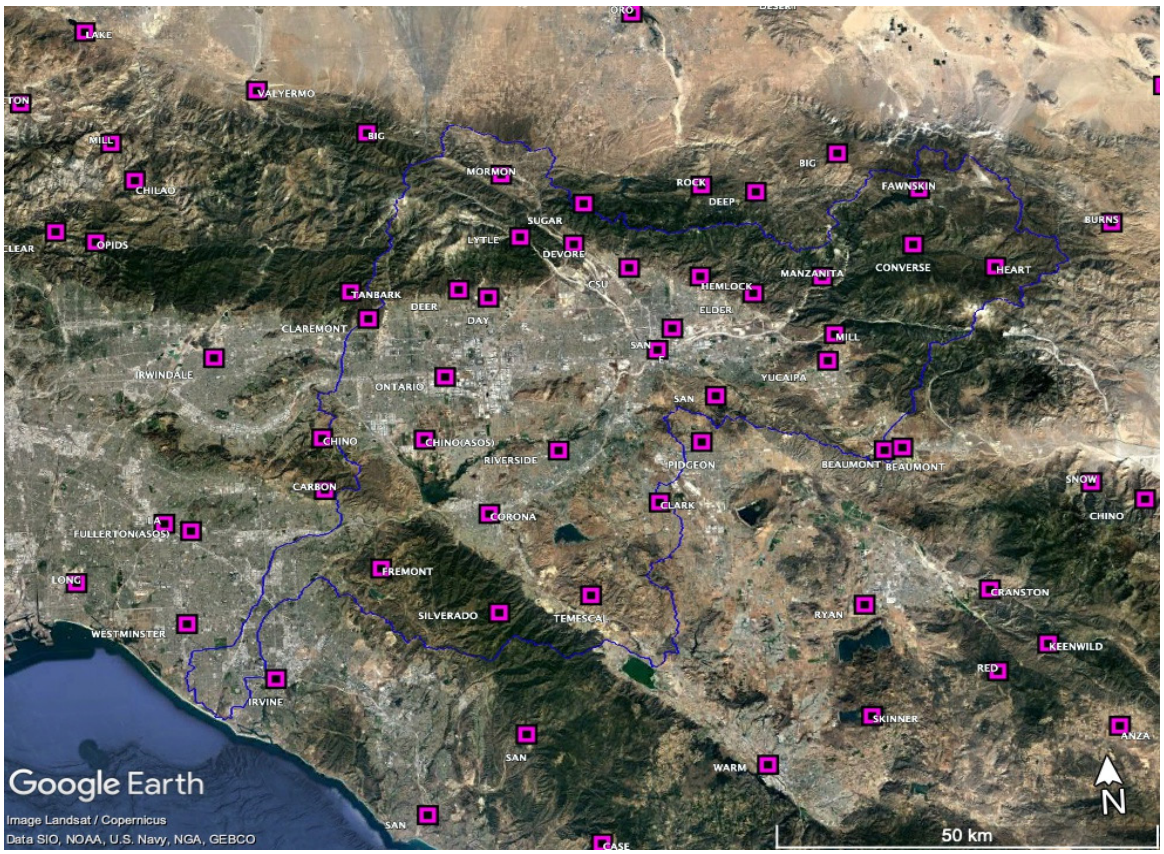


Figure C-1. The precipitation gages used by CRNFC (pink squares) in the Santa Ana watershed (outlined in blue).

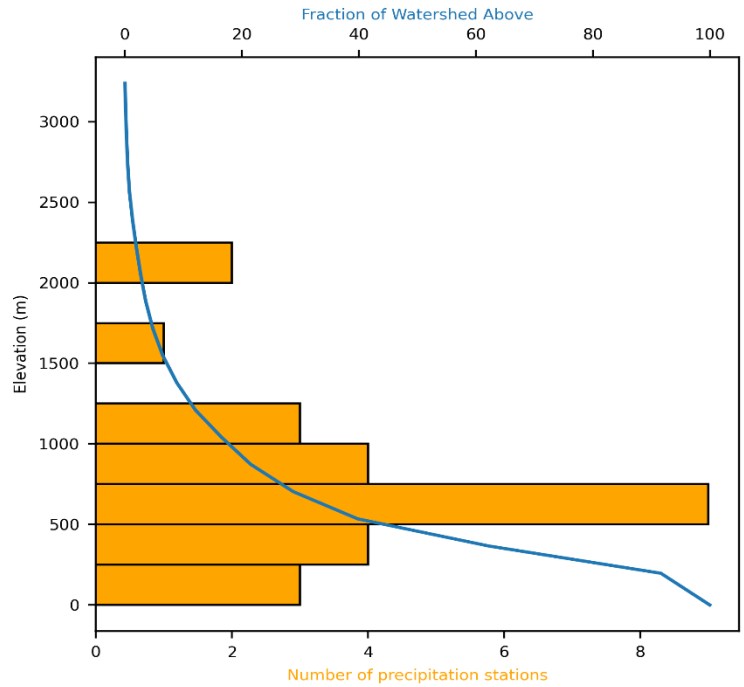


***Figure C-2**. The distribution of precipitation gages throughout the watershed binned by their elevation (yellow bars) and the hypsometric curve or the fraction of the total area of the watershed above the elevation (blue line) (for more info on the hypsometric curve see Section C.1.2.2).*

There are no pre-existing soil moisture stations within the Santa Ana River watershed boundary. Five stations were planned to begin a network. More stations may be required to enhance FIRO benefits in the future, which will be determined through regular observation network evaluations.

C.1.2 Methods

The locations for the surface meteorological and soil moisture stations recommended in the Prado FIRO PVA were selected with the overarching goal of getting representative samples from as much of the watershed as possible. First, we conducted a k-means cluster analysis. This analysis used input physical and hydroclimatic properties that are physically related to soil moisture variability and organized them into discrete clusters. This analysis was done within the area of the Santa Ana River basin over which the Gridded Surface/Subsurface Hydrologic Analysis model (GSSHA) is being run (see Figure 6.1 in the main document). Clusters identified in the analysis were used to select locations for five funded soil moisture stations representative of the discrete physical (elevation, slope, soil type) and hydroclimatic properties found in the Santa Ana River watershed. Cluster analysis methodology is detailed in Section C.1.2.3.

In addition to the cluster analysis, input was solicited from project partners to ensure that the soil moisture station locations selected in the cluster analysis would provide useful observations for the hydrology and verification research groups as well as have the highest potential to support operational needs in the future when the period of record is long enough. This support may also include assimilation into next-generation hydrologic models.

A soil map developed by ERDC gives a broad generalization of soil substrate for groups of soil types, and each combined soil group (referred to as soil index numbers) is associated with specific values for qualities including infiltration, storage capacity, parent material, and depth to bedrock. These soils data are a combination of both the State Soil Geographic (STATSGO) and Soil Survey Geographic Database (SSURGO) soil databases. The GSSHA model being developed for the Prado Dam study watershed used the soil index values representing each of 8 different soil types with the associated infiltration and surface roughness parameters. The different soil types with the greatest sensitivity to runoff and infiltration parameters was also considered in selecting the location of the soil moisture stations. Two of the five stations are placed each in the 2 soil types with the greatest sensitivity to the infiltration and runoff parameters. Results from the initial run of the GSSHA model informed the selection of sites within soil index areas containing the greatest runoff generation. See Section 6.4 for more information on the GSSHA model implementation in the Santa Ana River watershed. GSSHA is a fully distributed, physical-process-based, gridded hydrologic numerical tool suitable for engineering analysis and design that simulates the hydrologic response of a watershed subject to given hydrological and atmospheric inputs (USACE 2020).

C.1.2.1 Watershed Hypsometry

Since our area of interest is a smaller section of the Santa Ana River watershed that is used by the GSSHA model, we calculated a hypsometric curve for this area alone (Figure C-3). Equal elevation intervals were sampled (n = 20) from the 30 m DEM and reclassified as vector polygons. The structure of the hypsometric curve suggests a mature stage of denudation, where most of the model basin area is at lower elevation and would be dominated by fluvial or alluvial processes in natural conditions (Strahler 1952). The station locations are all in the lower elevation zones because to date as a result of limitations in obtaining access agreements. Future additional soil moisture stations are planned for higher elevation areas of the Santa Ana Basin. A map of the different soil types is shown in the Appendix.

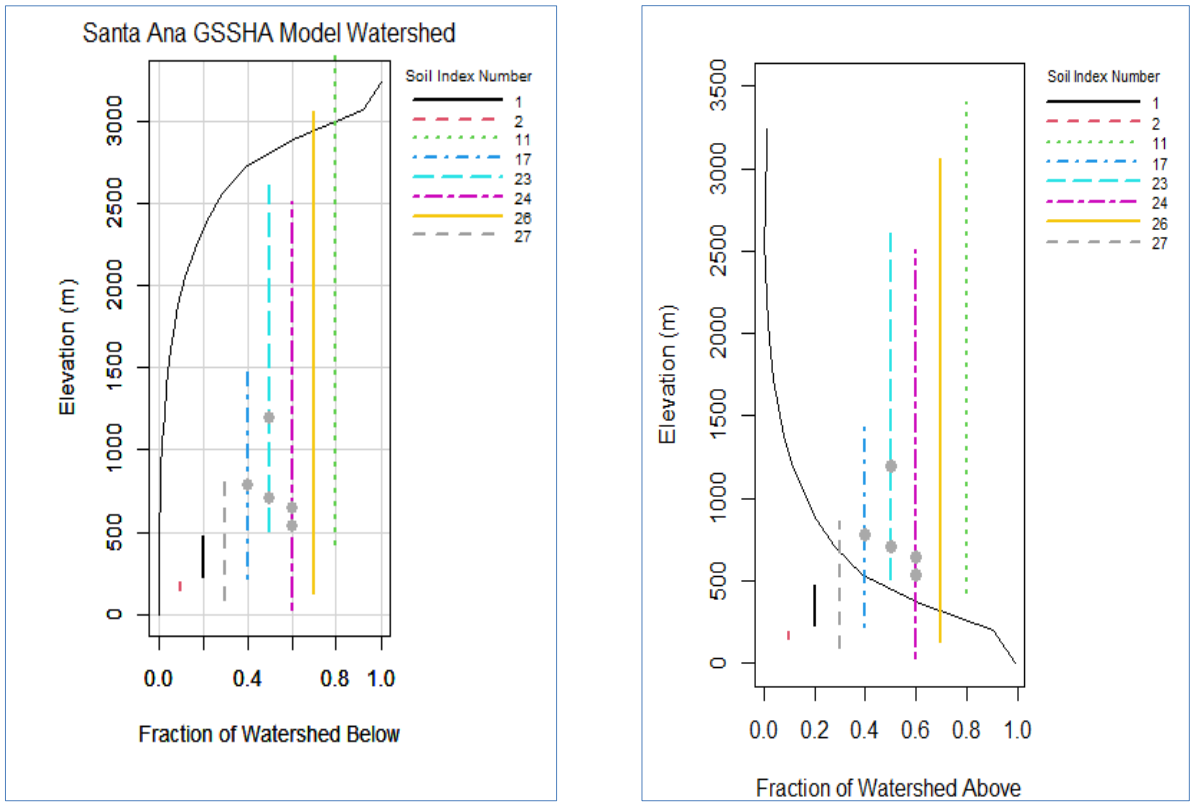


Figure C-3. *Hypsometric curve of the GSSHA model boundary for the Santa Ana River watershed showing the fraction of the watershed below elevation. Vertical lines show the elevation range of each soil group type that exists within the model boundary (soil index), ordered from smallest elevation range to largest range from left to right. The points represent the elevations of the sites selected for surface meteorology stations in the soil indices of interest to the GSSHA modeling.*

C.1.2.2 Cluster Variables

The variables used in the cluster analysis were selected based on analysis of multiple characteristics, input from ERDC and other stakeholders, and previous studies utilizing k-means cluster analysis to optimize soil moisture station locations. The k-means cluster analysis algorithm identifies groupings in datasets and organizes them into clusters based on similarities of various features (MacQueen, 1967, Sumargo, 2020, Curtis et al. 2019). In total, 8 variables were considered which represent critical factors modulating soil moisture patterns. Of these eight variables, temperature, precipitation, and snowpack are directly correlated with elevation. Therefore, those three variables were excluded from the analysis. This choice was made to reduce the possibility of overweighting elevation-related variables in the analysis. The remaining 5 variables were used in the k-means cluster analysis (Table C-1). 1) Topography impacts soil development, the gravimetric interactions of soil and water, and particle size. A 30 m digital elevation model (USGS National Map Viewer 2019) is included in the cluster analysis, and was also used to calculate 2) slope and 3) aspect. 4) Soil type is represented by Polaris probabilistic soil dataset (Chaney, et al., 2016). 5) Evapotranspiration potential is included using NDVI to represent vegetation cover. Vegetation cover can increase evapotranspiration and intercept precipitation before it reaches the soil.

Table C-1. Watershed variables for cluster analysis to determine Prado FIRO soil moisture station locations.

Variable	Resolution	Description	Source
Elevation	30 m	30 m resolution grid cells Digital Elevation Model	USGS 2019; https://apps.nationalmap.gov/downloader/
Aspect	30 m	30 m resolution derived from DEM; 360° Directional grid cells	USGS 2019; https://apps.nationalmap.gov/downloader/
Slope	30 m	30 m resolution derived from DEM; Slope angle degree grid cells	USGS 2019; https://apps.nationalmap.gov/downloader/
Polaris Probabilistic soil	30 m	30 m resolution probabilistic soil type	USGS; Chaney et al., 2016; https://pubs.er.usgs.gov/publication/70170912
NDVI	30 m	30 m resolution grid cells; Composite of "greenest" values over the region from WY2020, green reflectance of vegetation anomaly (z-score)	Landsat 8 (Didan 2021); https://lpdaac.usgs.gov/products/mod13q1v061/ (change to GEE)

C.1.2.3 Cluster Analysis

The k-means clustering algorithm (MacQueen, 1967) assigns number values to cluster types. The variables were normalized using mean normalization (Equation 1) to have matching ranges of 0-100 to ensure that variables with different ranges are not weighted differently. The normalization was applied to all of the variables in the cluster analysis following Sumargo, 2020, where a is the new minimum, b is the new maximum, x is the original dataset, and x' is the rescaled dataset. Grid cells were converted to point features with the standardized value and used to conduct the cluster analysis. All raster and shapefiles were projected to EPSG: 26911, NAD83/UTM zone 11 in meter coordinates for consistency, and all datasets used in the analysis are 30 m grid data. The point features sampled every 30 m grid cell from all of the datasets to create an array of 30 m point data with the five variable values as well as geographic coordinates for each point.

$$\text{Eq 1: } x' = a + \frac{(x - \min(x)) \times (b - a)}{\max(x) - \min(x)}$$

The cluster analysis considered 2-30 clusters on the 5 variables defined in Table C-1. In order to determine the optimal number of clusters to use, we calculated the within group sum of squares (Figure C-4). By comparing the difference in the within group sum of squares (Figure C-4), we find that after 10 clusters the difference in within group sum of squares is greatly

reduced and there is only a 2% difference between 10 and 12 clusters. Thus 10 clusters adequately capture the variability in the watershed considering the quantities we identified.

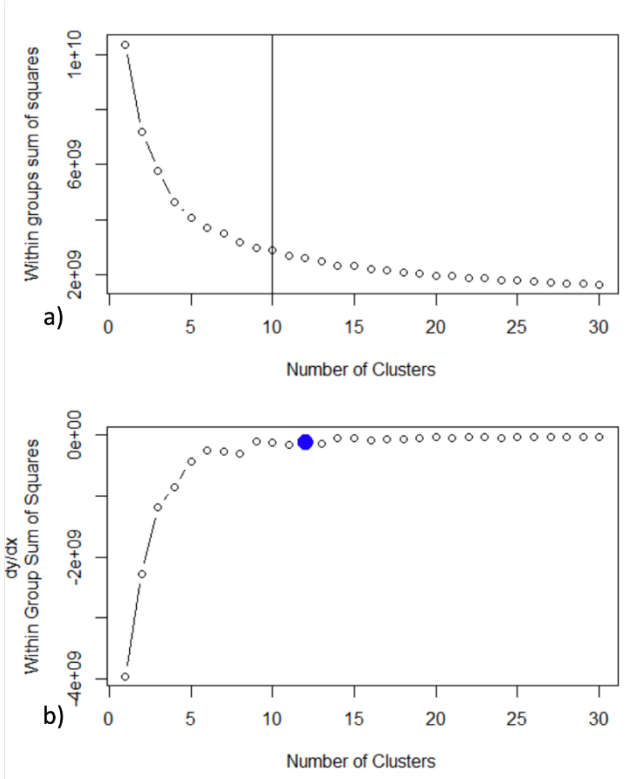


Figure C-4. *Within group sum of squares (WSS) for different numbers of clusters in the analysis. b) First order derivative of WSS with cut off point determined by curvature analysis (blue marker).*

After determining the most effective number of clusters, we next assessed the characteristics of the clusters. We looked at how the clusters were distributed spatially throughout the area of interest (Figure C-4), and calculated how much of the area of interest was covered by each group (Table C-2).

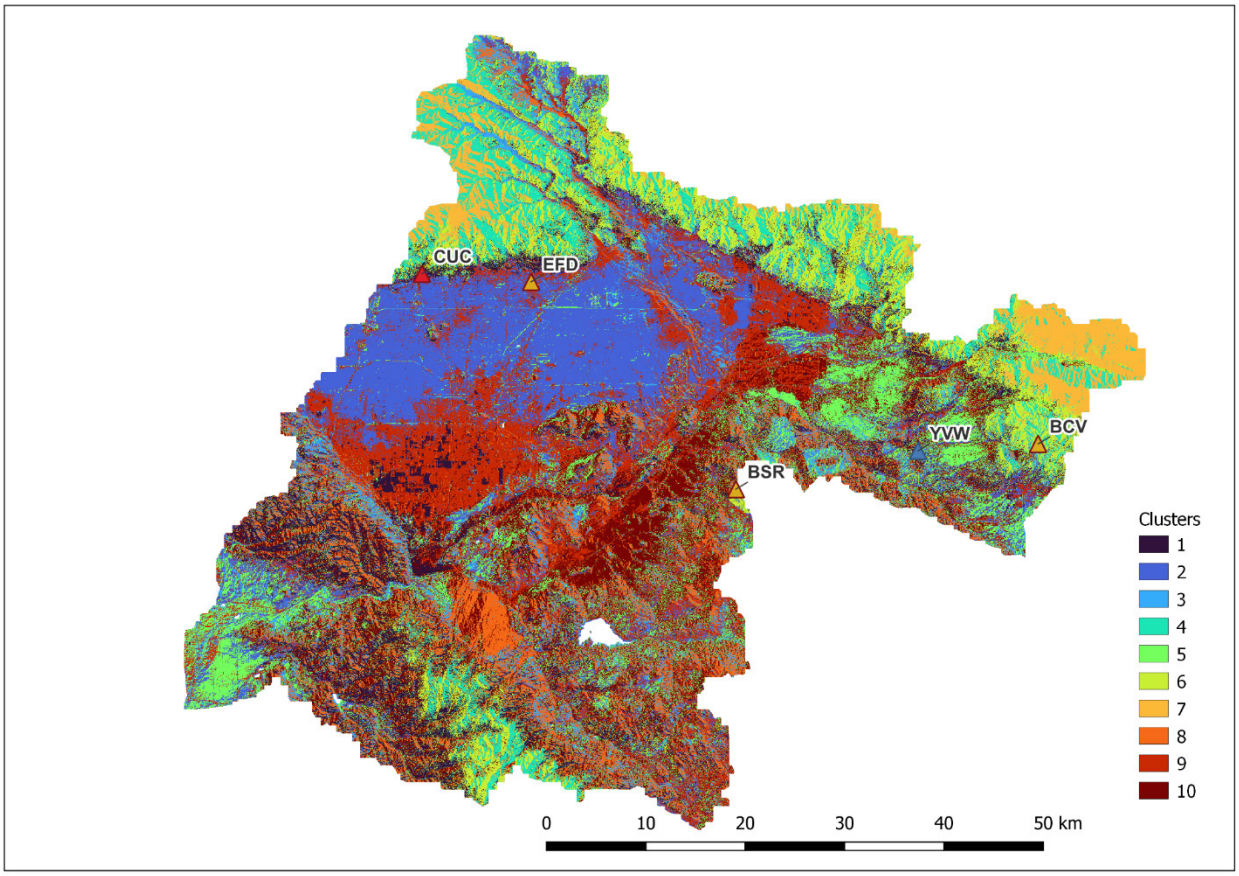


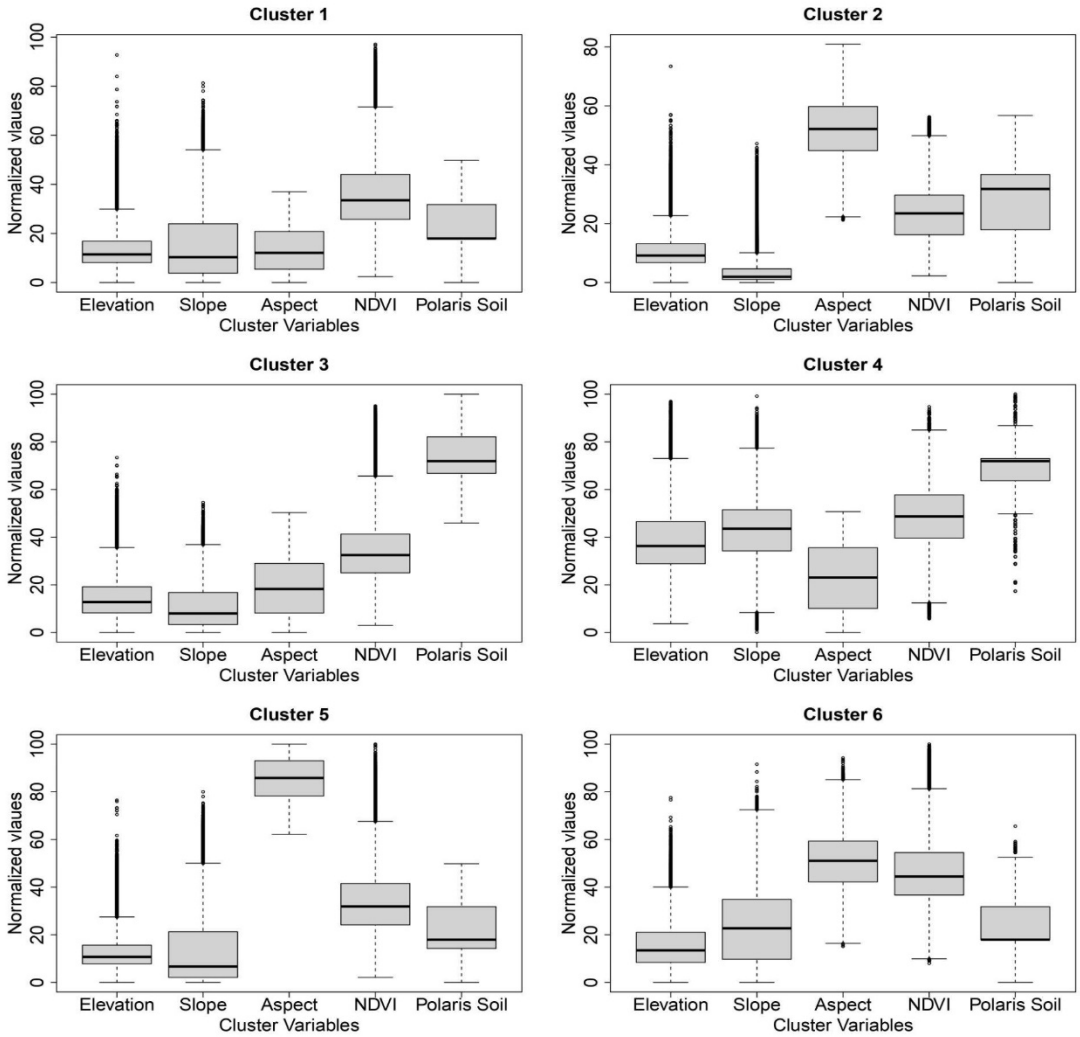
Figure C-5. *Map of clusters with stations site selected (yellow triangles) in the GSSHA watershed boundary.*

Table C-2. *Percent of watershed identified in each cluster.*

ID	Pixel Count	Percent
1	363017	8.78
2	716422	17.34
3	270445	6.54
4	288117	6.97
5	419845	10.16
6	359873	8.71
7	174610	4.23
8	402063	9.73
9	589571	14.27
10	548747	13.28
Total	4132710	100

We assessed the overall characteristics of the different clusters based on the characteristics of interest that we used to organize them (Figure C-5). The highest elevation cluster is Cluster 9,

while 4 and 7 are mostly in mid-elevations, and the rest are low. NDVI values are fairly similar across clusters, with Clusters 4, 6, and 7 showing ~10% higher values than the others. Slope and aspect are both relatively higher in Clusters 7 and 9. Other distributions of cluster values can be found below.



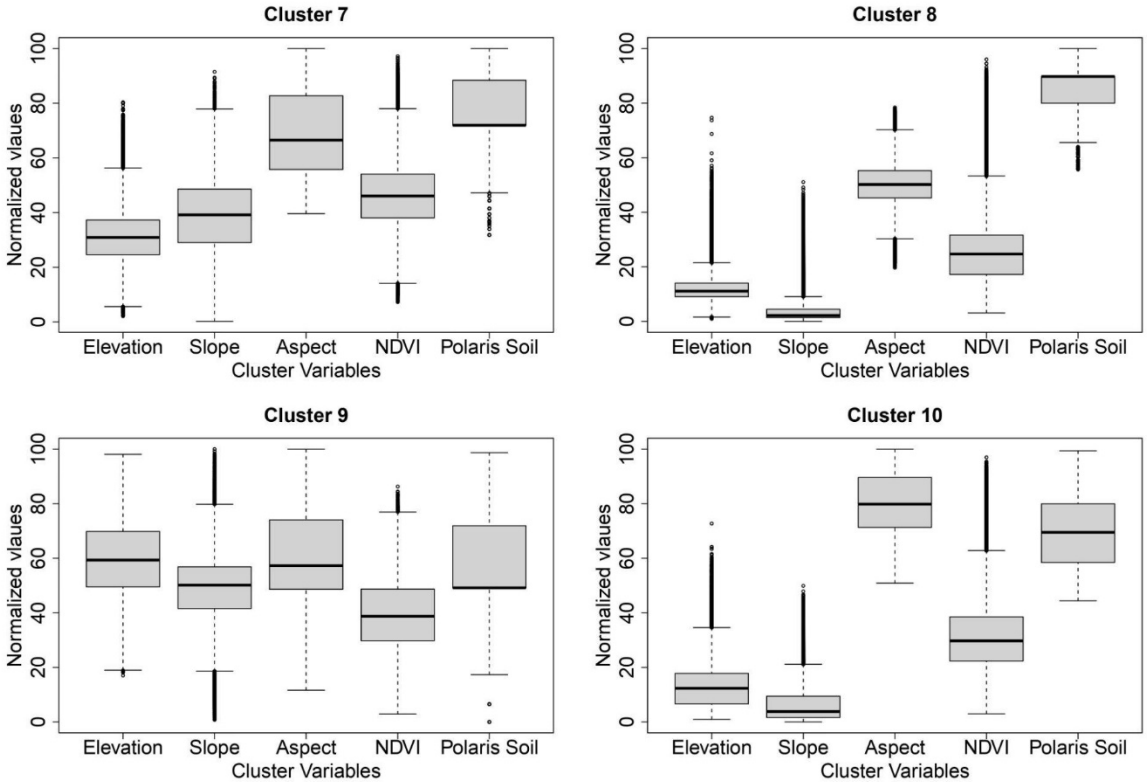


Figure C-6. Box and whisker plots of the 5 variables in each cluster. The dark horizontal line is the median, the edges of the box are the upper and lower quartiles, the dotted lines are the whiskers, the whisker ends are the upper and lower extremes, and the dots are outliers.

C.1.3 Results

Based on the cluster analysis (Section C.1.2.3), discussions with GSSHA modelers and other project partners, the following locations were selected for the five new soil moisture and surface meteorological stations for support of Prado FIRO. These stations span 5 of the clusters described above (Table C-3). One station was installed in November 2022 (see Figure C-5 for metadata) and the remaining four stations are planned for Summer 2023 deployment. The existing station data are received remotely via cell modem hourly. Data collection happens every 2 minutes. Data are housed at the CW3E website; NOAA HMT; MesoWest; and CDEC.

Table C-3. Station characteristics of the locations selected in the model watershed.

StationID	Latitude	Longitude	Elevation ft	Cluster IDs	Soil Index	Soil Type	SoilDescription
BCV	34.0174	-116.96	4050	5	23	ToF	Tollhouse sandy loam, 30 to 50 percent slopes
YVW	34.0074	-117.092	2100	1	24	SaD	San Emigdio sandy loam, 9 to 15 percent slopes
BSR	33.9629	-117.286	2590	4	17	RtF	Rockland
CUC	34.173	-117.632	2460	9	23	DnG	Trigo family-Lithic Xerorthents, warm complex, 50 to 75 percent slopes
EDS	34.157	-117.508	1690	2	24	SpC	Soboba stony loamy sand, 2 to 9 percent slopes

C.1.4 Station Metadata

Station Name: Yucaipa Valley
Station Code: YVW
Station Type: SMOIL
Latitude: 00
Longitude: 11 0 1
Telemetry: Cellular

Figure C-7. Picture of the installed Yucaipa soil moisture station (YWV).

Site Description: The station is located north of Yucaipa Valley Water District wastewater treatment facility, on the facility property, outside of the gated facility. It is in a small valley drainage, approximately 110 ft north of a concrete retention pond that is surrounded by a black metal fence. There is a rip rap drainage directly adjacent to the black fence. North of the site is the drainage head (Figure C-7), and east and west of the site are hillsides connected to the drainage head. The drainage flows south of the site into the rip rap drainage and ultimately into the valley where the treatment facility is located. The soil type is described as SaD: San Emigdio sandy loam, 9 to 15 percent slopes. Measured slope is approximately 10 percent. Observed soil down to 1m appears very homogeneous, with little stratification, consisting of sandy loam. Soil horizons were difficult to distinguish.

Weather Station Equipment Description:

- **Monument type:** Tripod
- **Data logger:** CR1000X
  - **Data logger S/N:** 29845
  - **Pakbus Address:** 27
- **Pyranometer:**
  - **Pyranometer S/N:** 380497
  - **Pyranometer height:** 222 cm
- **Anemometer:**
  - **Anemometer S/N:** WM185171
  - **Anemometer height:** 267 cm
- **Soil moisture sensor:** Stevens Hydraprobe
  - **Soil moisture SDI12 Address', S/Ns, Depths:**
  - **Address 1:** SN: 279269; Depth- 5
  - **Address 2:** SN- 279275; Depth- 10 cm
  - **Address 3:** SN- 279267; Depth- 15 cm
  - **Address 4:** SN- 279274; Depth- 20 cm
  - **Address 5:** SN-
  - **Address 6:** SN- 279273; Depth- 100 cm
- **Barometer:** Vaisala
- **SN:** T110828
- **Tipping bucket:**
  - **Height:** 167 cm
  - **On tripod or free-standing:** free-standing
- **Comms:** Airlink RV55
  - **Cellular Carrier:** Verizon

C.1.5 References

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C.2 RadMets

C.2.1 RadMet Outages

Data tables separating out the data outages at the Radar Meteorologic stations.

Table C-4. *Number of total time steps vs the number of missing time steps*

Station	Total Time Steps	Num Missing Time Steps	% Missing Time Steps
CAT	4354560	57657	1.32%
SOD	9184320	1472268	16.03%

Table C-5. *Number of missing time steps binned by quantitative precipitation estimate*

Station	0mm	0-10mm	10-20mm	10-20mm	30-40mm	40-50mm	50-60mm
CAT	56016	1334	159	148	0	0	0
SOD	1335527	119442	14520	2726	0	0	0

Table C-6. *Percent of missing time steps binned by quantitative precipitation estimate (eg of all the missing values, what percent occurred when quantitative precipitation estimate is at that amount)*

Station	0mm	0-10mm	10-20mm	10-20mm	30-40mm	40-50mm	50-60mm
CAT	97.15%	2.31%	0.28%	0.26%	0.0%	0.0%	0.0%
SOD	90.71%	8.11%	0.99%	0.19%	0.0%	0.0%	0.0%

C.3 Radiosondes

C.3.1 Radiosonde summaries

C.3.1.1 7 November 2022 Event

The CW3E team conducted soundings to sample the atmospheric river that impacted California in early November. We launched radiosondes from four separate locations in and near FIRO watersheds. Below is a table of the launching details for each site. Data collected via the launches can be found on the CW3E Sounding Google Drive.

Launch Location	Latitude	Longitude	Start Time (UTC)	Last Launch (UTC)	Number of Sondes Deployed
USBOD	38.3	-123.1	07 Nov 2022 00Z	10 Nov 2022 00Z	19
USYUB	39.2	-121.5	07 Nov 2022 00Z	9 Nov 2022 00Z	18
USSIO	32.8	-117.2	08 Nov 2022 06Z	9 Nov 2022 06Z	9
USOD	34.1	-117.1	08 Nov 2022 00Z	8 Nov 2022 21Z	8

In addition to launches every three hours during the AR, Bodega Bay and Marysville included extra launches to sample a narrow cold frontal rainband and Marysville included an additional late launch to capture a vorticity strip (additional information on page 2). The team is also very excited to add an additional launch location in the Santa Ana Watershed, near our permanent instrument installation at Seven Oaks Dam, which will allow us to learn more about AR structure and evolution in southern California to support FIRO Prado goals. The data from these launches were assimilated into several global numerical weather prediction models. This storm was additionally sampled by the Air Force 53rd Weather Reconnaissance Squadron C-130 as part of ARRecon.

An extra sounding was launched at Maryville at 4 PM on 9 November (00 UTC 10 November), well after atmospheric river conditions had ended over the region, to capture a vorticity strip in the backside of the trough that was governing the evolution of the atmospheric river over California. This trough was also forecast to impact the evolution, location, and intensity of Hurricane Nicole as it recurved and underwent extratropical transition over the Eastern Seaboard, leading to impacts across the eastern United States several days later.

Thanks to the CW3E launching teams: Ava Cooper, Benji Downing, Chad Hecht*, Ethan Morris, El Knappe*, Hart Wanetick, Hillary Beckmeyer, Kerstin Paulsson, and Lili Gilmore. (*primary authors of this report)

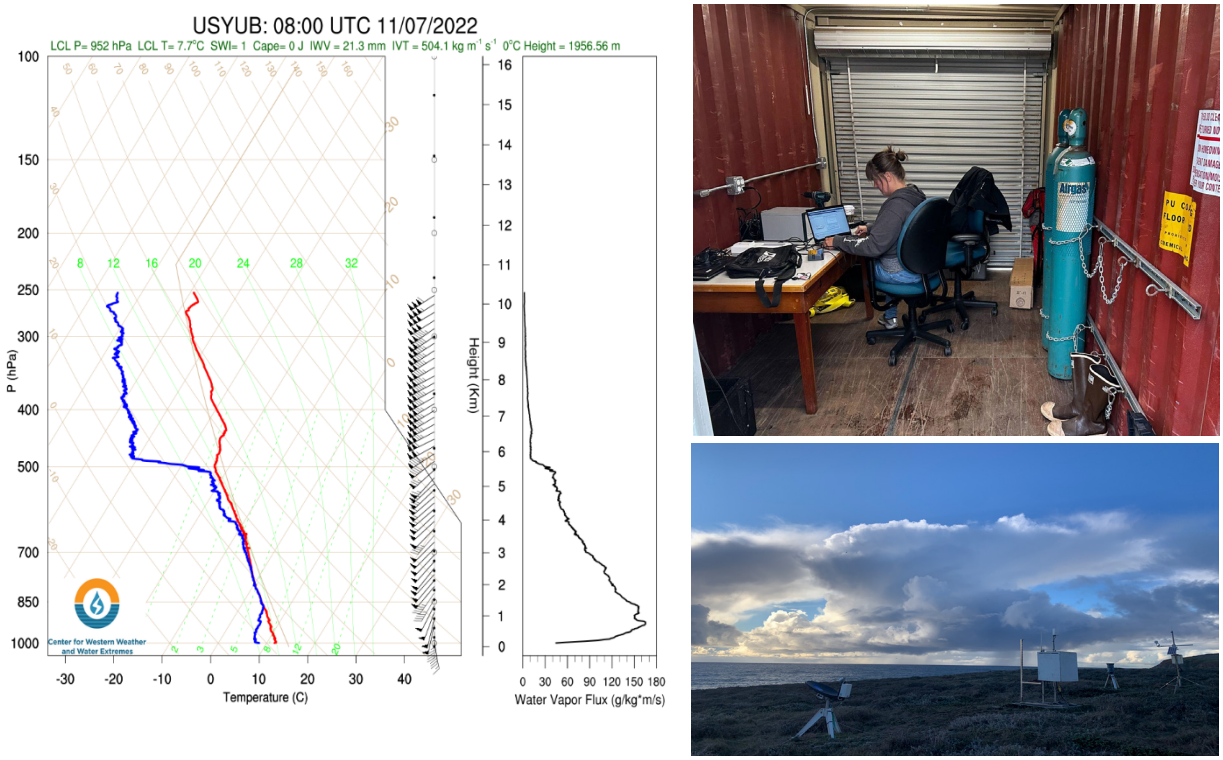
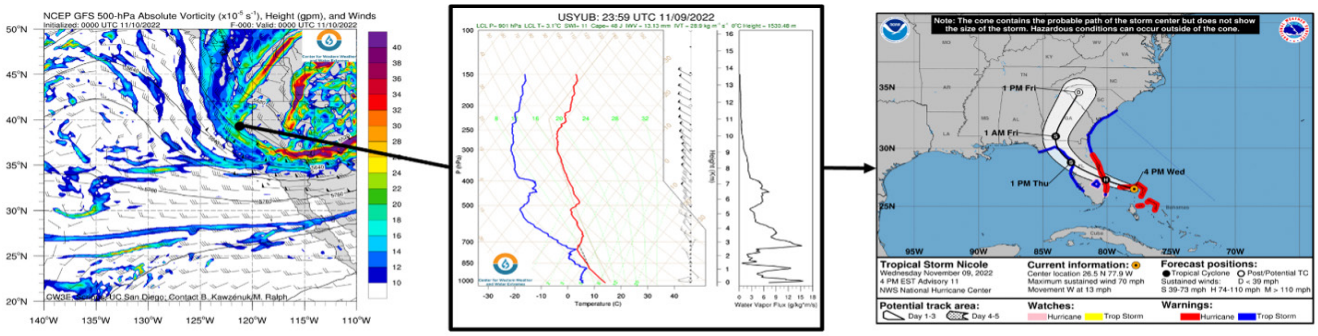


Figure C-8. *(left) Highest IVT for this storm recorded at the Marysville launch location. These figures are created for each launch and can be found in the Drive folder, linked above, under the launch location and within the Skew-T folder. (right top) H. Beckmeyer monitoring radiosonde deployments at the new launch location of Seven Oaks Dam. (right bottom) Between launches at Bodega Bay, team members visited CW3E surface meteorological site, BBY, to perform standard maintenance.*



(*Left*) GFS Analysis of 500-hPa Geopotential Heights and Absolute Vorticity highlighting the location of the launch in the backside of the trough and within the strip of higher absolute vorticities, (*Middle*) Skew-T from the extra launch, (*Right*) Cone of Uncertainty forecast from the National Hurricane Center highlighting the recurvature of Hurricane Nicole over the Eastern U.S.

C.3.1.2 11 - 16 January 2023 Events

Immediately following the tail end of an atmospheric river event sampled by the CW3E team between January 4-10, the team re-deployed the following morning to sample the continued parade of atmospheric river events impacting the US West Coast. For California, already facing elevated streamflows and high soil moisture levels, the importance of sampling this event, and future atmospheric river events, increases with flood risk. The CW3E team followed the storm intensity as it migrated, initially launching radiosondes from two northern California locations,

Bodega Bay (USBOD) and Marysville (USYUB), and then from southern California at the Seven Oaks Dam (USSOD) launch site. The table below provides launching details for the three sites.

Launch Location	Latitude	Longitude	Start Time (UTC)	End Time (UTC)	Number of Sondes Deployed
USBOD	38.3	-123.1	11 Jan 2023 15Z	14 Jan 2023 21Z	24
USYUB	39.2	-121.5	13 Jan 2023 21Z	14 Dec 2023 21Z	8
USSOD	34.1	-117.1	14 Jan 2023 12Z	16 Jan 2023 18Z	19

Figure C-9. *(left) Integrated Vapor Transport (IVT) forecast for the one of the ARs that impacted the US West Coast in mid-January. (middle left) A helium-filled meteorological balloon prior to launch at USSOD. (middle right) L. Katz and family friend ready to release a radiosonde from USBOD. (right) Highest IVT for this storm recorded at USSOD. These figures are created for each launch and can be found in the Drive folder, linked below, under the launch location and within the Skew-T folder.*

At USSOD, CW3E team members noticed radiosondes terminating at lower atmospheric elevations than usual. To investigate a potential atmospheric ice-layer limiting radiosonde heights, the team released larger meteorological balloons to give the radiosonde an extra push. When the larger balloons terminated at similar heights, the team hypothesized the problem to be a weak GPS signal through the canyon. However, sondes from this launch station still provide useful data. Data collected via the sondes were assimilated into several global numerical weather prediction models and can be found on the CW3E Sounding Google Drive. This storm was additionally sampled by the Air Force 53rd Weather Reconnaissance Squadron C-130 and the NOAA G-IV as part of ARRecon. Thanks to the CW3E launching teams: Chad Hecht, El Knappe, Benjamin Downing, Lisa Katz*, Ethan Morris, and Hart Wanetick. (*primary author of this report)

C.3.1.3 24 February 2023 Events

CW3E conducted soundings to sample an atmospheric river that impacted California beginning February 23rd, 2023. CW3E staff launched radiosondes (Figure C-10 1a and 1c) from USCAT

(Catalina) and USSOD (Seven Oaks Dam). Below is a table of the launching details for each site. Data collected via the launches can be found on the CW3E Sounding Google Drive.

Launch Location	Latitude	Longitude	Start Time (UTC)	Last Launch (UTC)	Number of Sondes Deployed
USCAT	33.4	-118.5	24 Feb 2023 12Z	25 Feb 2023 18Z	12
USSOD	34.1	-117.1	24 Feb 2023 12Z	25 Feb 2023 18Z	11

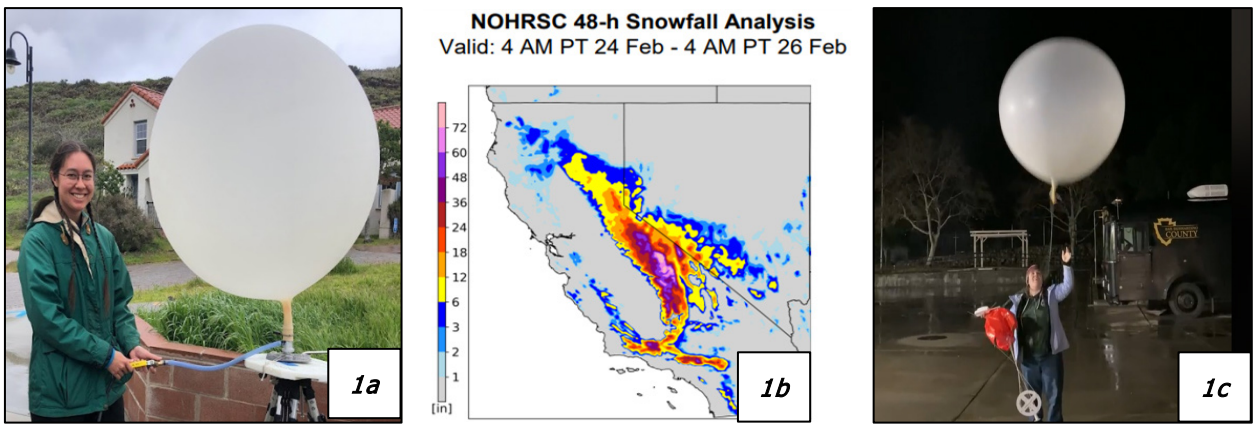


Figure C-10. (1a) S. Burnett inflates a balloon prior to launch at USCAT (1b) National Gridded Snowfall Analysis (NOHRSC) estimate of snowfall totals valid 4 AM PT 24 Feb - 4 AM PT 26 Feb (1c) N. Mascioli launches a radiosonde at USSOD

In addition to launches every three hours during the AR, hourly high frequency soundings were conducted at USCAT to sample a narrow cold frontal rainband (NCFR) (additional information on page 2). This AR was characterized by heavy precipitation (2.52 in at Seven Oaks Dam) combined with very low freezing levels and ample moisture which allowed for snow in low-elevation locations that rarely see snow accumulations (Figure C-10 *1b*). More information about this AR can be found in the CW3E event summary. Data from these launches were assimilated into several global numerical weather prediction models. This storm was also sampled by the Air Force C-130 as part of ARRecon.

High frequency soundings were performed at USCAT from 10 PM on 24 February (0600 UTC 25 February) through 2:30 AM on 25 February (1030 UTC 25 February) to capture a NCFR (figure 2b) as the atmospheric river made landfall in Southern California. The Highest IWV and IVT values at USCAT were ~24mm and ~577 kg m-1 s-1, respectively, which coincided with the passage of the NCFR around 0645 UTC (10:45 PM PT). The freezing level height was ~2150 m (~7,050 ft). A Skew-T plot, as shown in figure 2a, graphically visualizes data gathered from radiosonde launches. Figure C-11 (2a) shows vertical profiles of temperature, wind, and moisture on a skew-T diagram. In the left panel, temperatures in Fahrenheit are shown along the x-axis, with the red line indicating the air temperature, and the blue line indicating the

dewpoint temperature. Lines of constant temperature go from the bottom of the plot towards the upper right, hence the term skew-T. The left y-axis shows atmospheric pressure in hectopascals and the right y-axis shows height above ground in kilometers. Wind barbs showing wind speed and direction are shown along the right hand side of the plot. For this sounding, strong low level winds were out of the south-southeast, and veered to a southwesterly direction with height. This clockwise turning of the wind with height indicates warm air advection from the south and lift in the atmosphere. It can also signify the passage of a cold front. This is clearly evident by the NCFR passing over the sounding location at this time. The right panel shows the vertical profile of water vapor flux and indicates the mass of water vapor moving across the radiosonde sensor per meter per second. On this plot, the largest water vapor flux is in the lowest 1km of the atmosphere, indicating the height of the atmospheric river.

Thanks to CW3E staff El Knappe, Hart Wanetick, Sarah Burnett, Anna Wilson, Shawn Roj, Nora Mascioli, and Garrett McGurk* for their efforts as part of the launch teams at USCAT and USSOD (*primary author of this report).

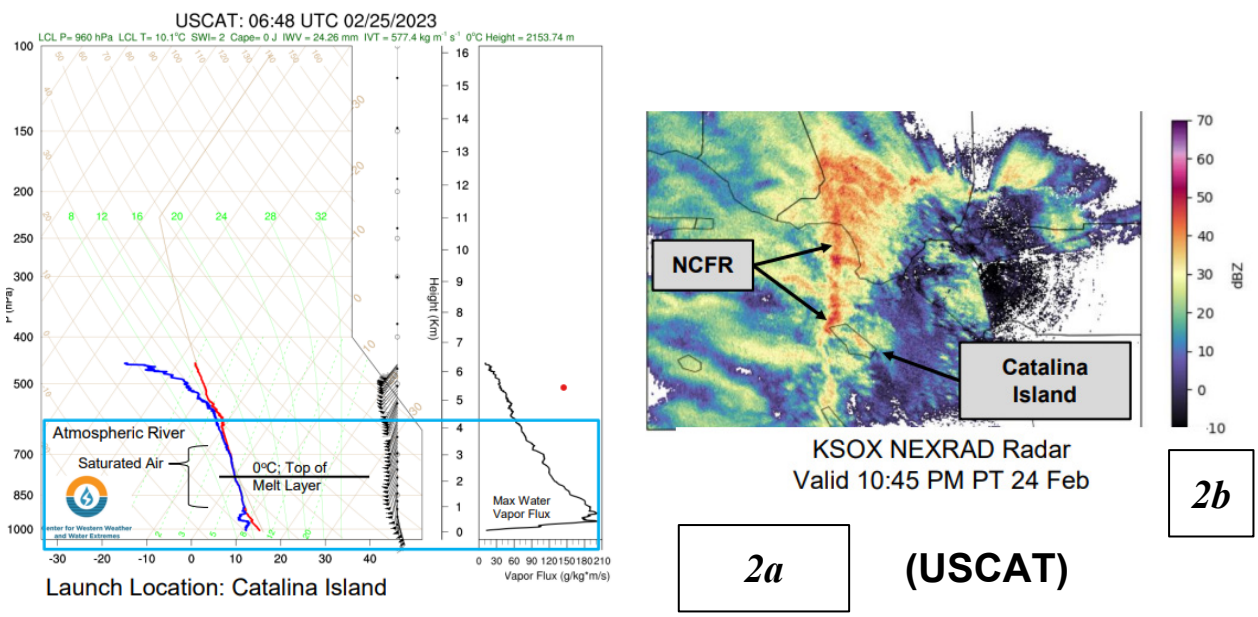


Figure C-11. (2a) USCAT Skew-T plot from the 0600 UTC 2/25/2023 launch showing the highest IVT recorded during this event at 577 km m-1 s-1 and a relatively low freezing level of 2153 meters. (2b) Santa Ana Mountain Radar NEXRAD Station KSOX showing the NCFR as it makes landfall in Southern California

C.3.1.4 9-15 March 2023 Events

Two atmospheric river events that occurred in California over a six-day period in March were sampled by the CW3E field team through a series of radiosonde balloon launches at four different locations within the state: starting at Northern California locations Bodega Bay (USBOD) and Marysville (USYUB), followed by southern California locations Catalina Island (USCAT) and Seven Oaks Dam (USSOD) to capture the progression of the storms. Data collected via the launches can be found on the CW3E Sounding Google Drive.

Launch Location	Latitude	Longitude	Start Time (UTC)	End Time (UTC)	Number of Sondes Deployed
USBOD	38.3	-123.1	09 Mar 2023 15Z	15 Mar 2023 03Z	22
USYUB	39.2	-121.5	09 Mar 2023 18Z	15 Mar 2023 03Z	21
USSOD	34.1	-117.1	10 Mar 2023 06Z	15 Mar 2023 18Z	27
USCAT	33.4	-118.5	10 Mar 2023 03Z	15 Mar 2023 15Z	27

These storms were significant, bringing up to AR3 conditions to the state, resulting in heavy precipitation, destructive flooding, strong winds, as well as high elevation freezing levels. The radiosondes launched during this period helped characterize both AR events, observing conditions with integrated vapor transport (IVT) levels as high as 900 kg $m^{-1}s^{-1}$ and integrated water vapor (IWV) levels as high as 37.22 mm. Balloons were typically traveling in the E / NE direction from all launch locations. Notable readings from each launch location are listed in the table below. This storm was also sampled by an Air Force C-130 as part of ARRecon.

	First AR				Second AR			
Launch Location	Max IVT (kg $m^{-1}s^{-1}$)	Max IWV (mm)	Max 0°C height(m)	Min 0°C height(m)	Max IVT (kg $m^{-1}s^{-1}$)	Max IWV (mm)	Max 0°C height(m)	Min 0°C height(m)
USYUB	900.3	29.26	3097.02	1312.82	707.2	27.78	2822.52	2111.87
USCAT	766.3	37.22	3642.53	3283.90	564.7	35.88	3426.14	2851.58
USBOD	747.8	29.73	3131.22	1319.26	635.9	28.38	3080.05	1955.67
USSOD	445.4	28.48	3931.73	2960.28	359.4	26.73	3151.88	2615.59

Thanks to CW3E staff Anna Wilson, Kerstin Paulsson, Natalie Contreras, Kate Lord, Sarah Burnett, El Knappe, Hart Wanetick*, Lisa Katz, Reagan McKinney, Ali Wolman, Ethan Morris, Tien-Yiao Hsu, and Adolfo Lopez Miranda for their efforts as part of the launch teams (*primary author of this report).

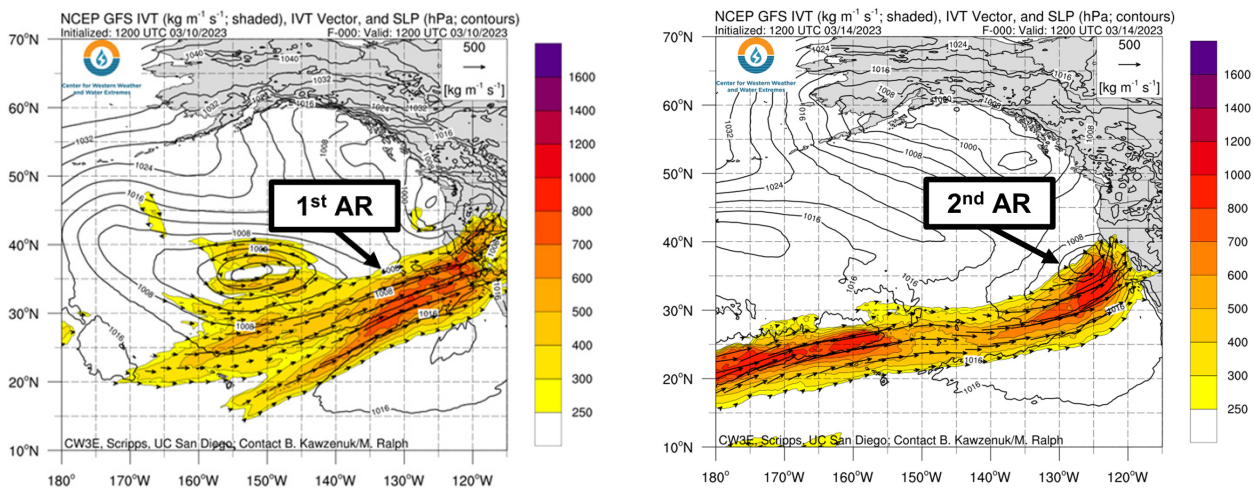


Figure C-12. *(left) IVT forecast plot for 1st AR event; (right) IVT forecast plot for 2nd AR event*

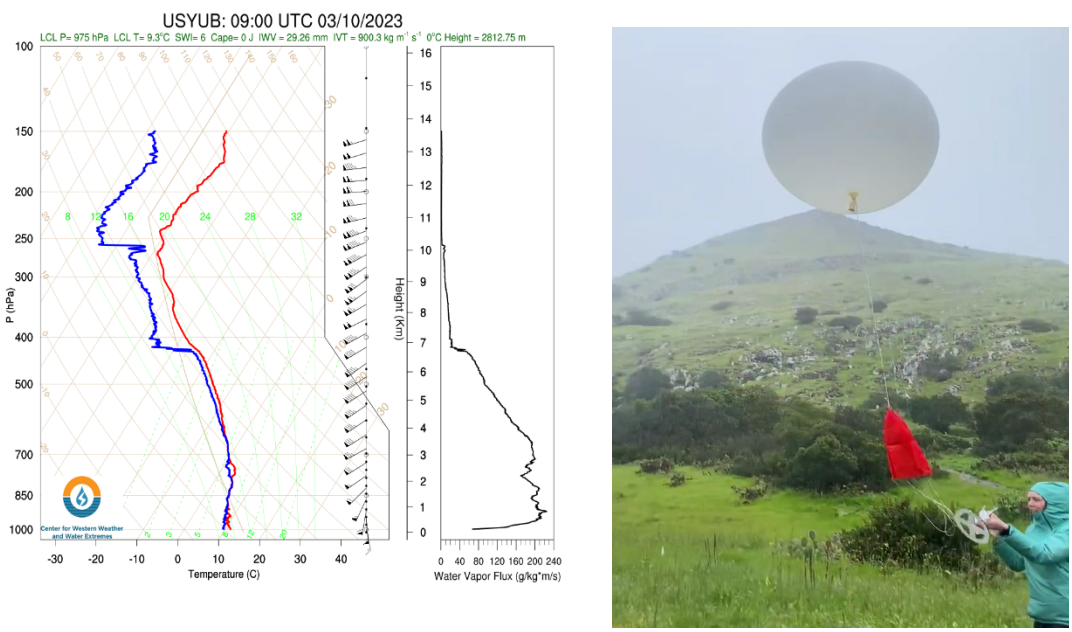


Figure C-13. *(left) Skew-T plot of launch from USYUB showing max IVT sampled during 1st AR, (right) Balloon launch from USCAT*

C.4 Computer Vision Stream Gaging

C.4.1 FIRO Prado Santa Ana River Flow Monitoring Introduction

The Prado FIRO PVA identified key locations along the Santa Ana River for improved flow monitoring to maximize FIRO benefits. The two locations identified in the PVA were selected to improve inflow and outflow monitoring at Prado Dam in support of model calibration and development and operations. USGS operates stream gages upstream and downstream of Prado Dam on the Santa Ana River (SAR). However, USACE LA District Reservoir Regulations reports that they do not currently utilize observations from the USGS Prado Dam streamgage as flows do not align with Prado Dam release gate rating curve flows. Both existing USGS sites present operational challenges when utilizing traditional flow monitoring techniques. Prado FIRO provided an opportunity to explore emerging flow monitoring technologies as a solution to monitor flows in these difficult-to-monitor locations.

The Center for Western Weather and Water Extremes (CW3E) and Orange County Water District (OCWD) worked with Xylem Inc. during the FVA period to develop a monitoring approach for Prado inflow and outflow utilizing emerging streamflow monitoring technologies. Xylem Inc.'s research and development group worked with the School of Civil Engineering at the University of Queensland, Australia to develop a image velocimetry device capable of overcoming challenges associated with traditional streamgaging methods. The technology, which Xylem has branded Computer Vision Stream Gaging (CVSG), captures stereo camera footage of the water surface, which is analyzed to estimate water level, surface velocities, and gauged discharge. The system utilizes a cloud architecture that allows for remote management of device configurations, automated data processing, and integration of internal and external data sources (Hutley et al., 2022).

C.4.2 Computer Vision Stream Gaging at Prado Dam

The USGS gage on the Santa Ana River below Prado Dam (USGS 1107400) is important for Prado Dam and OCWD recharge operations as flows recorded at the streamgage are representative of outflow from the dam. A station description and channel surveys can be accessed using this link. The streamgage is located in a concrete-lined trapezoidal channel reach of the Santa Ana River approximately 850 m downstream from Prado Dam. The USACE Los Angeles District (LAD) reports that the rating curve at this location is inaccurate, especially when comparing flows associated with known flood control releases from Prado Dam. Flood control releases from Prado Dam are important to monitor correctly for dam operations and downstream users including OCWD (Ralph et al., 2021). Collaboration with the USGS Redlands Field Office following PVA findings confirmed that flows in the 350-1200 cfs range are difficult to gage with traditional gaging equipment due to inadequate depth and flow conditions. The challenges associated with accurately measuring flows utilizing traditional acoustic gaging methods at the station may account for the discrepancies between flows observed at the Prado Dam release gates and the USGS streamgage.

The existing USGS streamgage station below Prado Dam was supplemented with the installation of a CVSG system (CW3E station code SAP). Additional streamflow observations facilitated by the installation of a CVSG unit provided a non-contact solution to collect velocity measurements at stages unsuitable for traditional gaging techniques. Streamflow observations collected by CVSG are available in near-real time for research and operational uses (see Figure C-14 for

example data). Collocating the CVSG with existing USGS instrumentation allowed for validation of CVSG against existing USGS ratings and manual discharge measurements (e.g., Figures in Section C.4.3).

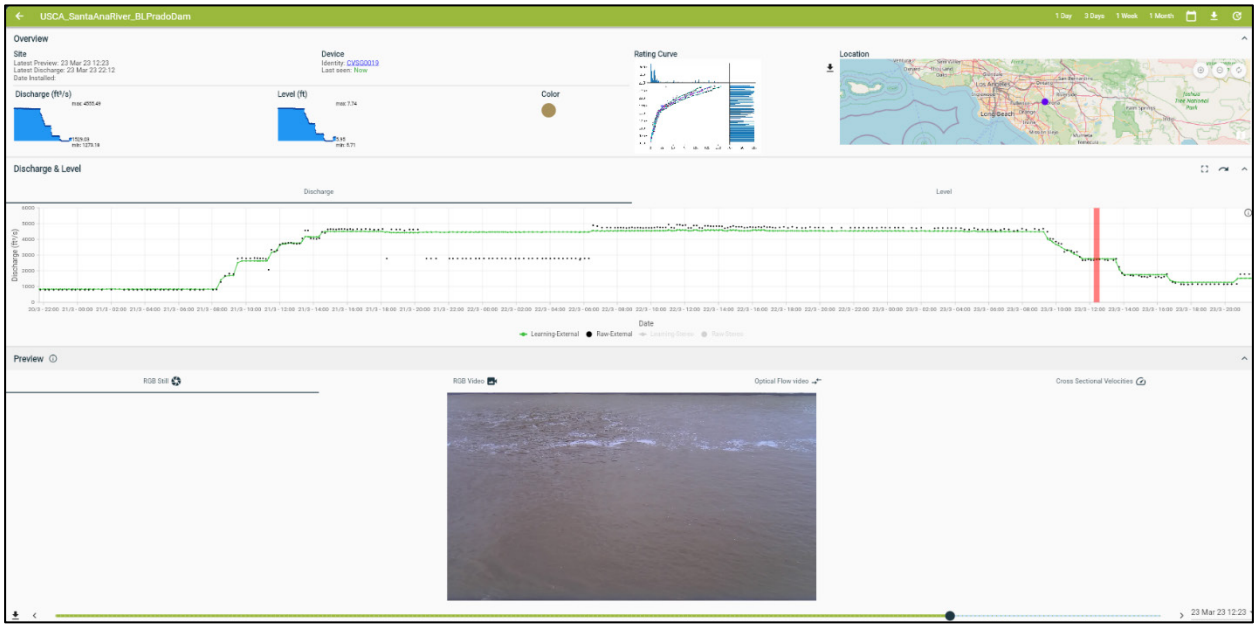


Figure C-14. Observations from SAP are available in near real-time on a dashboard developed by Xylem Inc. and the University of Queensland Australia School of Civil Engineering

C.4.3 Santa Ana Prado (SAP) CVSG Preliminary Analysis

At the time of FVA writing, preliminary analysis of the CVSG unit indicated that the technology was performing well under most flow conditions. Peer-reviewed studies using the technology at various stations have shown the computer vision stream gaging approach to be within 15% RMSE of traditional acoustic gauging methods (Hutley et al., 2022. Preliminary analyses of observations collected between August 2022 and March 2023 at SAP resulted in a 19.5% RMSE between flow estimated by CVSG and acoustic gauging performed by USGS personnel (e.g., as in Figure C-18) at the station. Additionally, the rating curve developed by CVSG is constantly being updated with each new velocity measurement collected by the device. The result of this process is a continually evolving rating curve which is fitted to the latest measurements at all the observed water levels for the station (Hutley et al., 2022). A full analysis of CVSG flow data will be conducted post-FVA

As of March 2023, the adaptive rating curve developed by CVSG differed at several stages from the USGS rating curve. In general, flow from CVSG is lower than predicted by the USGS rating curve at nearly all stages (Figure C-15 and Figure C-17). The most significant differences are in the 300 cfs to 1400 cfs range where the USGS rating curve is known to contain inconsistencies. However, USGS field measurements more closely align with the USGS rating curve at these flow rates. A more detailed analysis of CVSG will be completed post-FVA to allow for adequate time to collect additional observations. If deemed appropriate, USGS rating curve adjustments will be made based on CVSG observations.

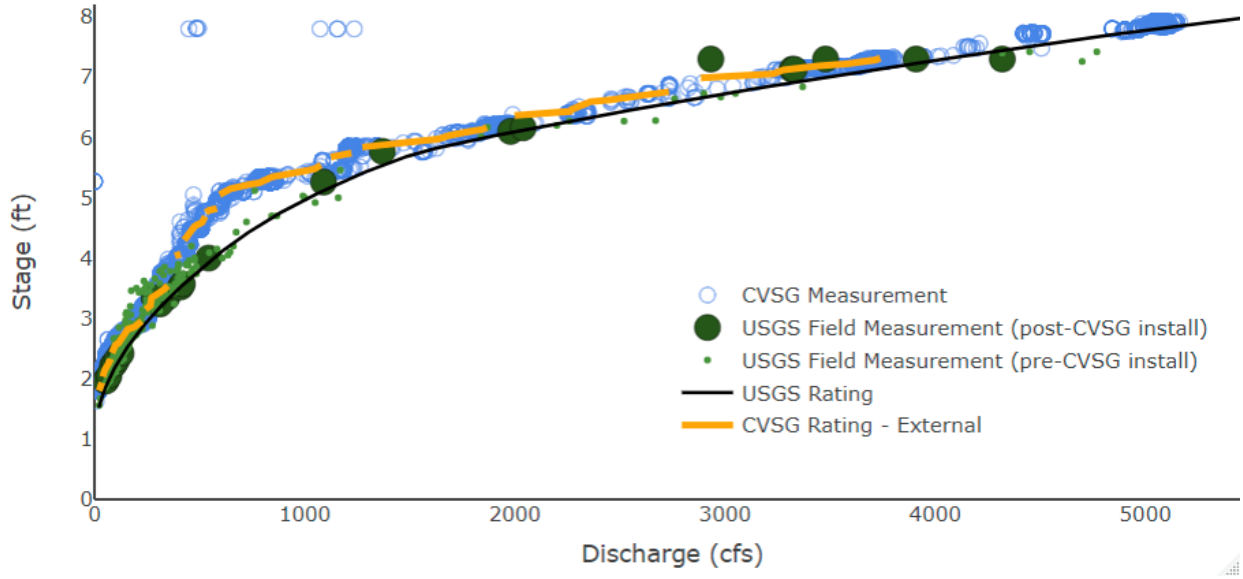


Figure C-15. CVSG measurements and rating curve vs USGS field measurements and rating curve 0-5500 cfs

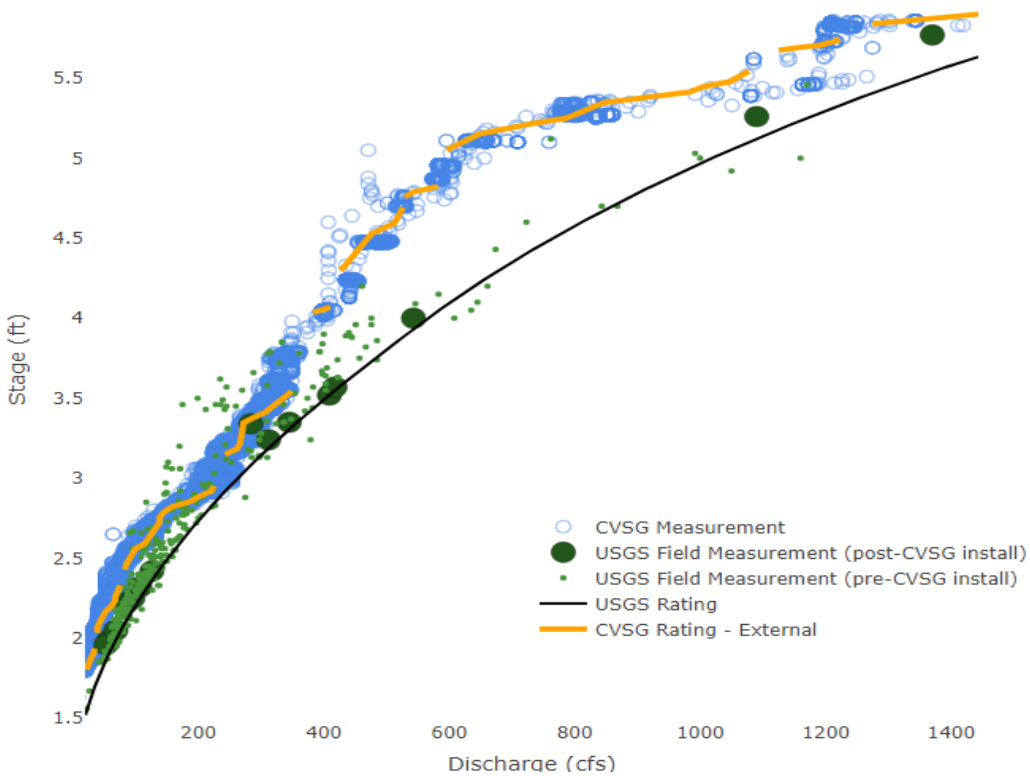


Figure C-16. CVSG measurements and rating curve vs USGS field measurements and rating curve 0-1500 cfs

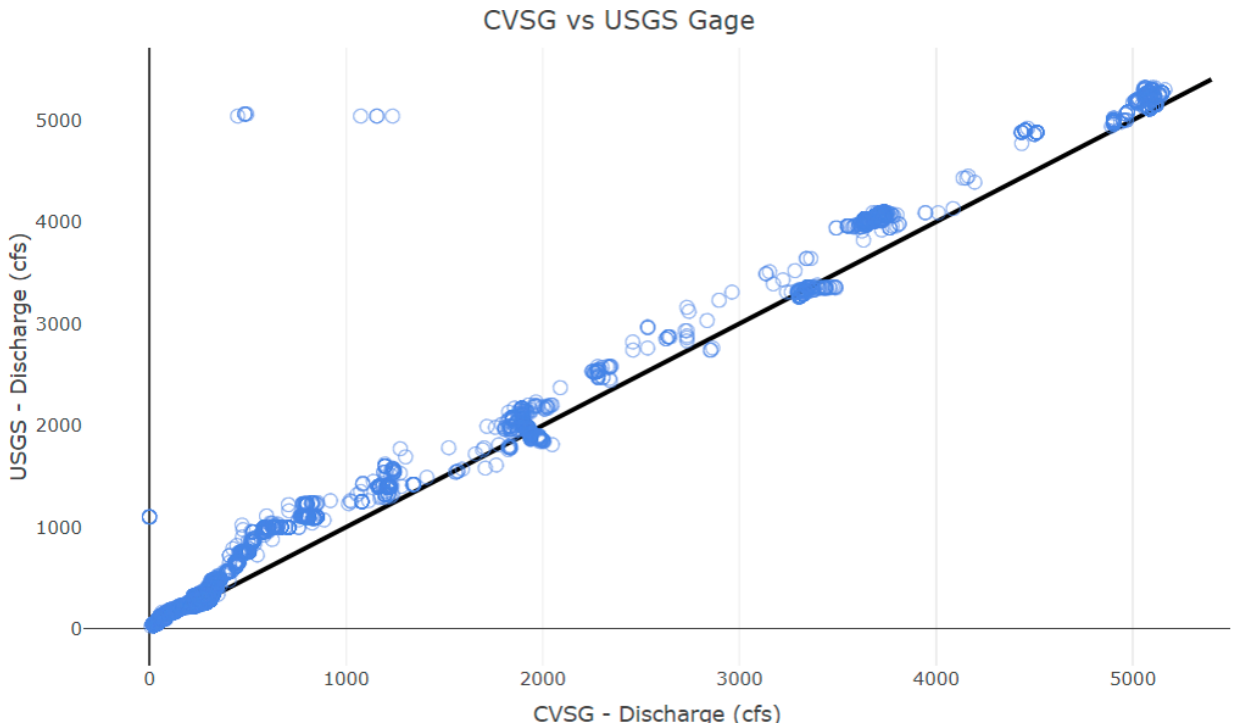


Figure C-17. *Identity line plot of CVSG flow measurements vs USGS rating curve flow data*

Figure C-18. *USGS staff performing ADCP field measurements at SAP.*

USGS staff routinely perform field measurements at SAP using traditional acoustic gaging methods (Figure C-18). The field measurements collected by USGS were used for verification of velocity and discharge measurements collected by CVSG. CVSG measurements were generally within 20% difference of manual discharge measurements collected from the same time (Figure C-19).

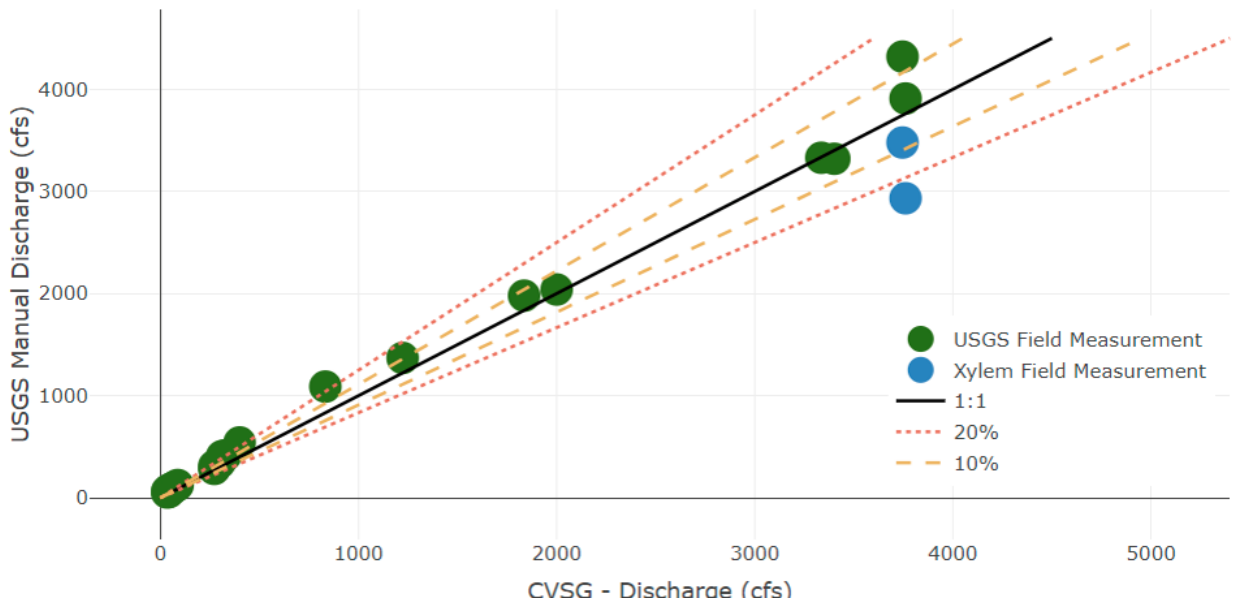


Figure C-19. *Identity line plot of CVSG measurements vs USGS and Xylem adjusted field measurements*

USGS field measurements were performed during a 4000 cfs flood control release in January 2023 following a series of AR's that impacted the region (Figure C-20). Upon further inspection of the ADCP measurements, Xylem engineers elected to change the depth measurement method utilized by the ADCP to better reflect the channel profile. This decision was supported by USGS staff who manage the data for the USGS station at the SAP site. Changing the depth measurement method resulted in lower measured discharge (Figure C-19 and Figure C-20). For the final analysis of CVSG technology, a deeper look into historical acoustic gaging measurements will be conducted to see if these measurements need to be adjusted. Adjusting historical manual discharge measurements may result in a rating curve shift that more closely aligns with the rating curve developed with CVSG technology.

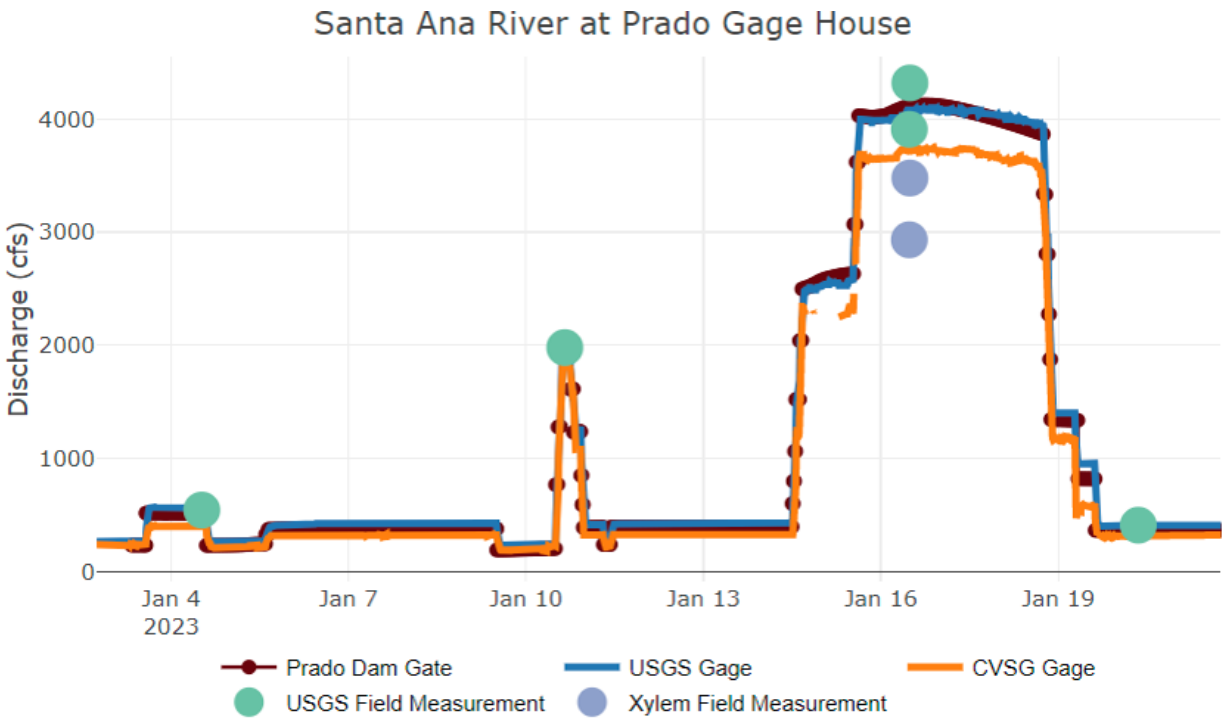


Figure C-20. *USGS field measurements and flow data, Xylem adjusted field measurements, CVSG measurements, and Prado Dam flow data during January 2023 Prado Dam flood control releases.*

C.4.4 Santa Ana Prado (SAP) Station Preparation

Prior to installation, a security enclosure was fabricated to deter vandalism attempts at the USGS Prado gage house. The general steps are as follows:

1. Mount CVSG device inside the security enclosure using Xylem provided baseplate and bushing spacers. (Figure C-21) (Baseplate CAD files available in ancillary files)
2. Attach CVSG device and IR illuminator to the angle aluminum. (Figure C-22)
3. Attach Xylem-provided mast mounting hardware to angle aluminum. (Figure C-22)
4. Install solar and IR illuminator cable feed-throughs on the security enclosure. (Figure **C-23**)
5. Connect CW3E fabricated antenna connectors to CVSG. Connect antenna connectors to antenna feed-throughs and antennas (Figure C-24)
6. Mount CVSG, security enclosure, solar panel, and IR illuminator on 1.5” mast. (Figure **C-26**)

Figure C-21. *(left) CW3E field engineers E. Morris and A. Lopez-Miranda secure CVSG base mounting hardware (right) base hardware with bushing spacers installed.*

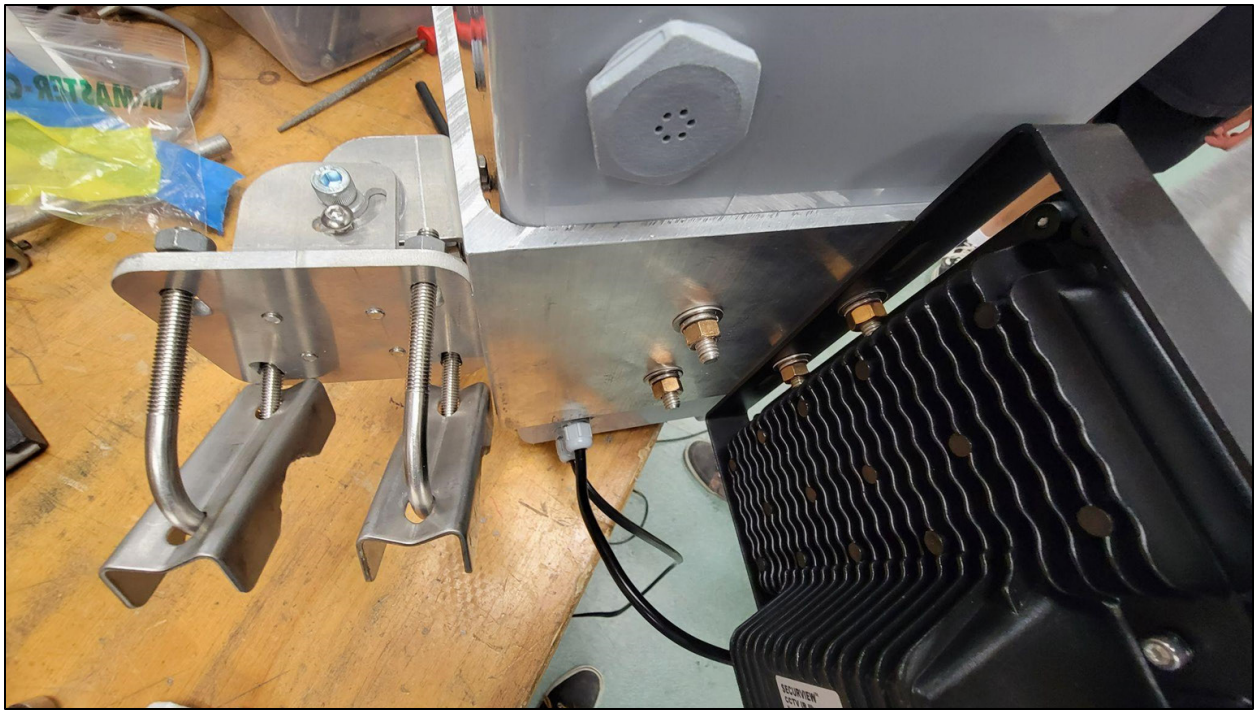


Figure C-22. *Security enclosure mount, mast bracket, and IR illuminator mount*

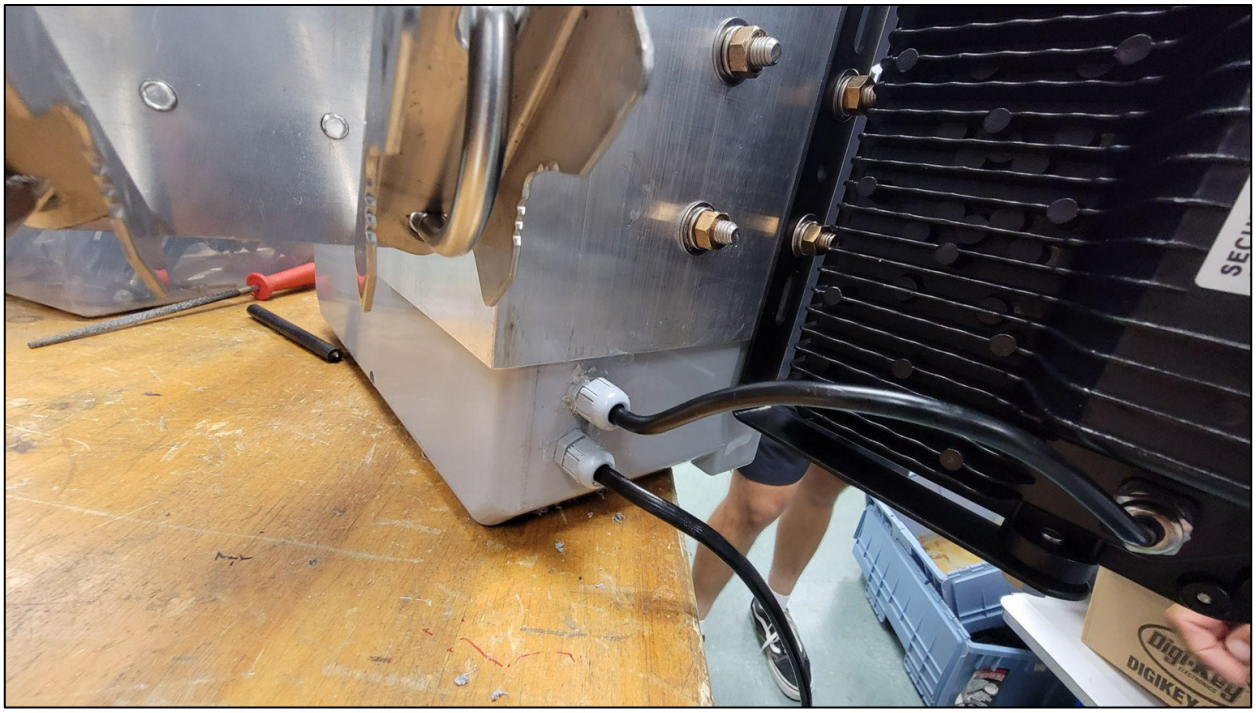


Figure C-23. *Solar and IR illuminator cable feed-throughs*

Figure C-24. *(left) CW3E fabricated antenna connectors connected to CVSG (right) Antenna connectors connected to antenna feed-throughs and antennas.*

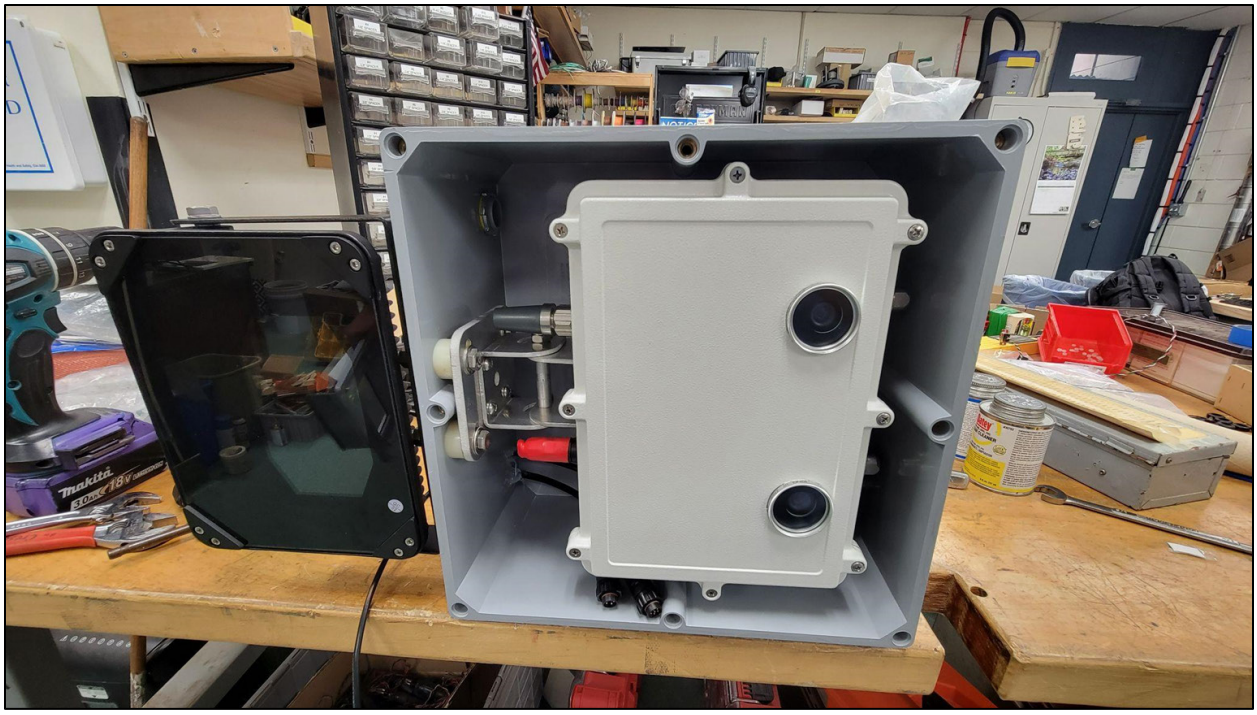


Figure C-25. *CVSG external weather and security enclosure with faceplate removed.*

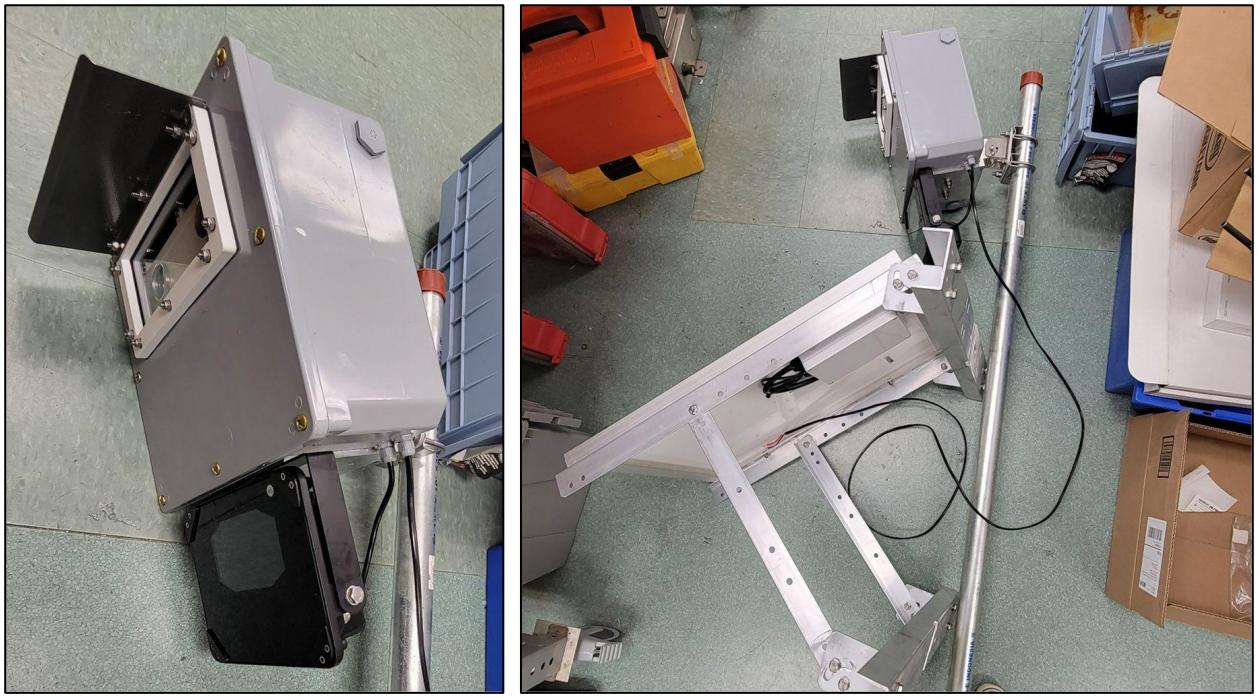


Figure C-26. *CVSG, security enclosure, security enclosure faceplate, solar panel, and IR illuminator test fit to 1.5" mast.*

C.4.5 Santa Ana Prado (SAP) Station Installation

Installation steps are as follows:

1. Attach strut channel to USGS gage house (Figure C-27) with ⅜” concrete anchors. (Figure C-28)
2. Secure 1.5” mast to strut channel using conduit clamps. (Figure C-28)
3. Attach CVSG, security enclosure, IR illuminator, and solar panel to the 1.5” mast using U-bolts. (Figure C-29)
4. Power on the camera and attach the security enclosure faceplate to the security enclosure (Figure C-30)
5. Adjust camera angle using real-time preview in the CVSG android application. (Figure C-31)
6. Install guylines to minimize wind shake during high-wind events. (Figure C-32 and Figure C-33)

   *Security enclosure faceplate was removed on November 17th, 2022 to minimize droplet distortion (Figure C-30).

Figure *C-27*. *USGS gage house below Prado Dam (1107400) before station installation*

Figure C-28. *Strut channel was attached to the USGS gage house using ⅜″ concrete anchors. Conduit clamps were used to attach the mast to the gage house strut channel.*

Figure C-29*. CVSG, security enclosure, IR illuminator, and solar panel were attached to the 1.5″ mast using U-bolts.*

Figure C-30. *(left)). Security enclosure faceplate installed on CVSG. (right) Security enclosure faceplate removed November 17th, 2022 to minimize droplet distortion.*

Figure C-31. *CVSG looking down towards the Santa Ana River below Prado Dam.*

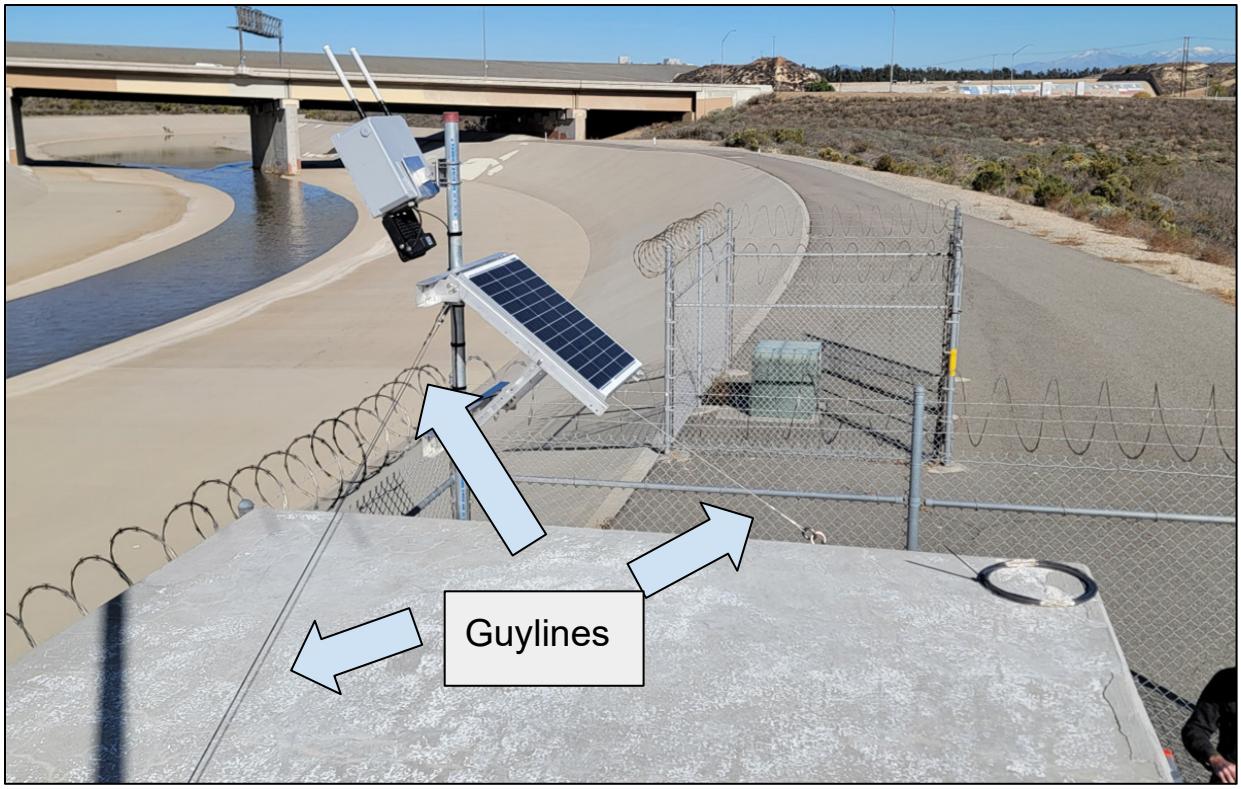


Figure C-32*. Guylines were installed in November 2022 to minimize mast movement in high winds.*

Figure C-33. *Guylines attached to CVSG mast.*

C.4.6 Santa Ana Prado (SAP) Station Description

Site Description: Computer vision stream gage collocated with the USGS stream gage at Santa Ana below Prado Dam. The site is located on a 1.5" mast, with the camera angle pointed perpendicular to the channel 26.43° at a height of 387 cm. The camera mast is attached to the USGS gage house which is surrounded by a barbed wire fence.

Gage type: CVSG
CVSG Model: Prototype
Height: Base of enclosure 0 cm
Camera angle: Per endicular to channel 2 downward an le
Service provider: Verizon
Installation Date: 22 Au ust 2022

C.4.7 Santa Ana Prado (SAP) Station Engineering Drawings

CVSG and security enclosure CAD files can be accessed using **this link.**

As-built channel drawings can be accessed using **this link.**

Each critical component of the environment around the station is illustrated in Figure C-34 and Figure C-35. Labeled items are explained in Table C-7.

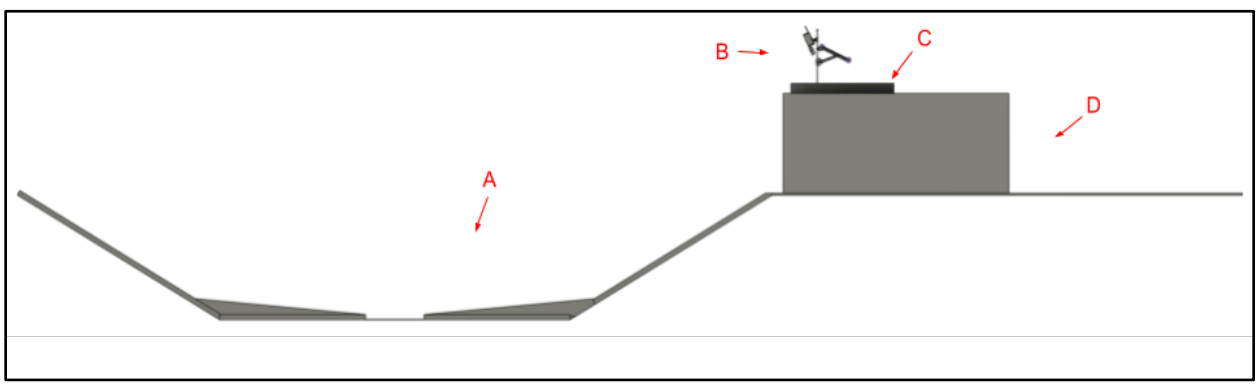


Figure C-34. Santa Ana River at Prado Dam stream cross section looking upstream (labels defined in Table C-7).

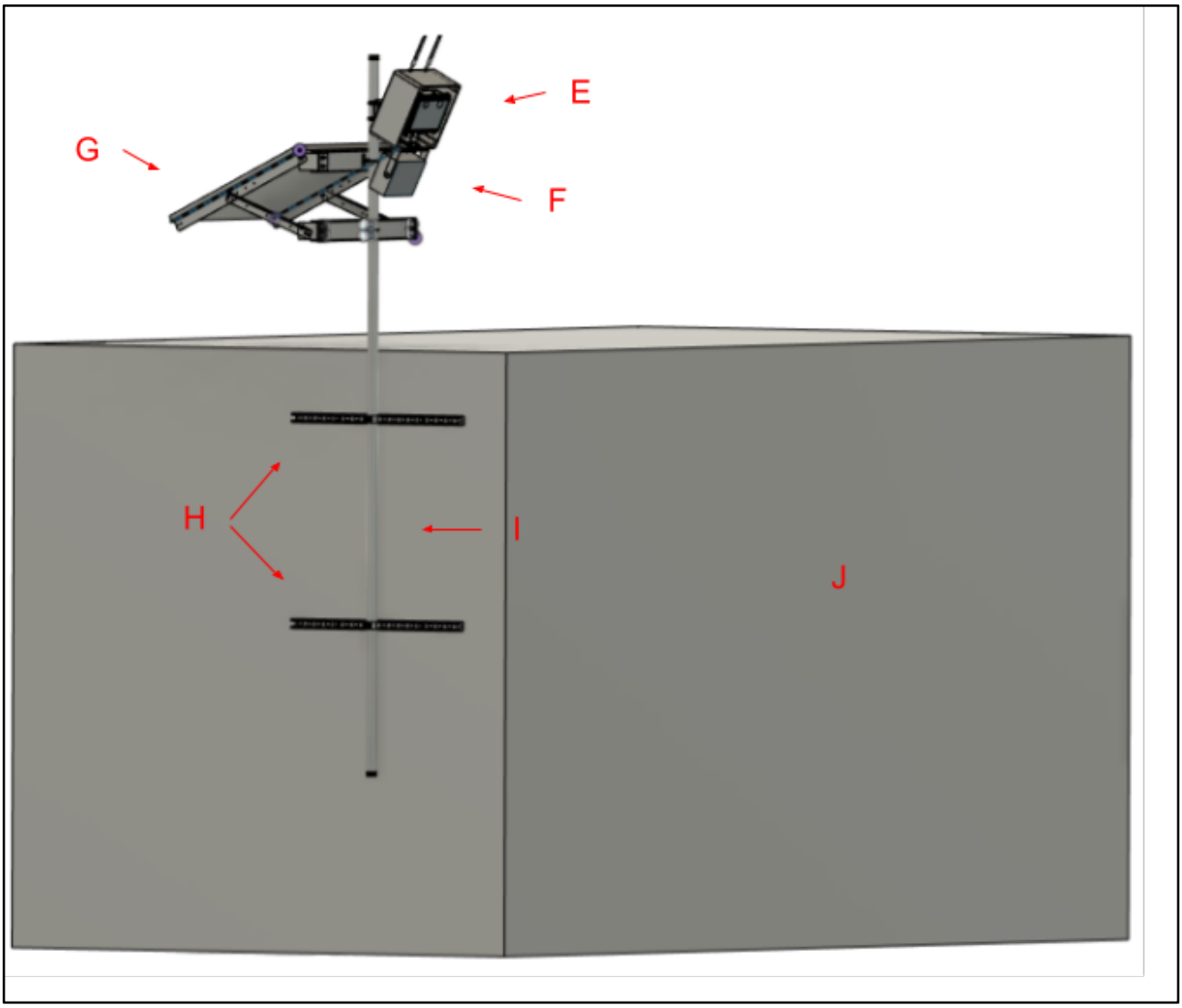


Figure C-35. *USGS Gage House with CVSG device installed (labels defined in Table C-7).*

Table C-7. *Labels for Figure C-35 and Figure C-36.*

Label	Component or Part	Details/Specifications
A	SAP Channel	Link to USGS channel survey
B	CVSG, Mast, Infrared Illuminator, Solar Panel	CVSG is mounted inside of an enclosure. The infrared illuminator is fastened directly under the enclosure. The enclosure is angled 26.43° downwards using a custom bracket assembly and L bracket Solar Panel mount and bracket assembly are fastened to mast with U-Bolts

Label	Component or Part	Details/Specifications
C, J	Prado Gage House	9.3ft x 16ft x 8.8ft (l x w x h)
D	Perimeter Fence	30.5ft x 19ft x 8ft (l x w x h)
E	CVSG	Camera angle: 26.43 degrees Height: 387 cm (12.7 ft) Enclosure: 13in x 13in x 6-3/4in Link to Enclosure
F	Infrared Illuminator	12 x Standard 850nm wavelength infrared LEDs 170m infrared distance Narrow 30° beam angle IP66 rated weather resistance for outdoor use Link to Infrared Illuminator
G	Solar Panel, Mount	Solar Panel: 50W with Victron Charge Controller Solar panel angle 38.9 Link to Mount
H	Strut Channel	Bottom strut height= 77in Top strut height= 101.25in Strut Channel length = 17in Link to strut channel
I	Mast	1-1/2 in. x 10 ft. Galvanized Steel Pipe Link to Mast

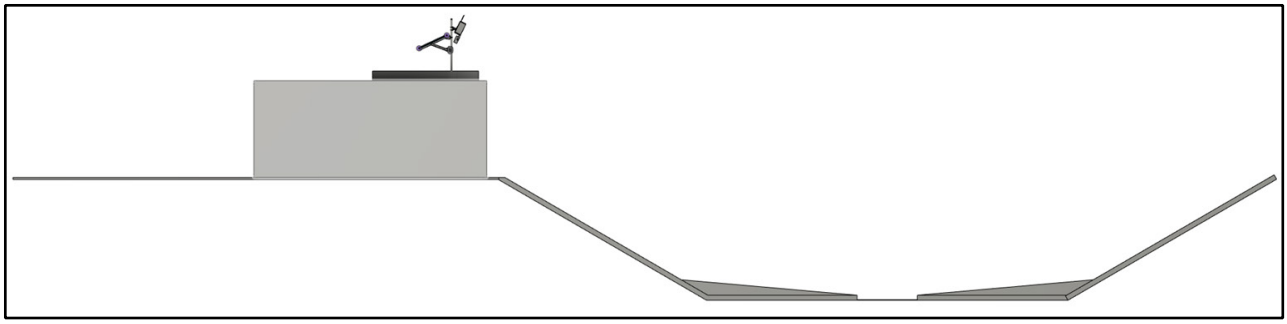


Figure C-36. Santa Ana River at Prado Dam stream cross-section looking downstream.

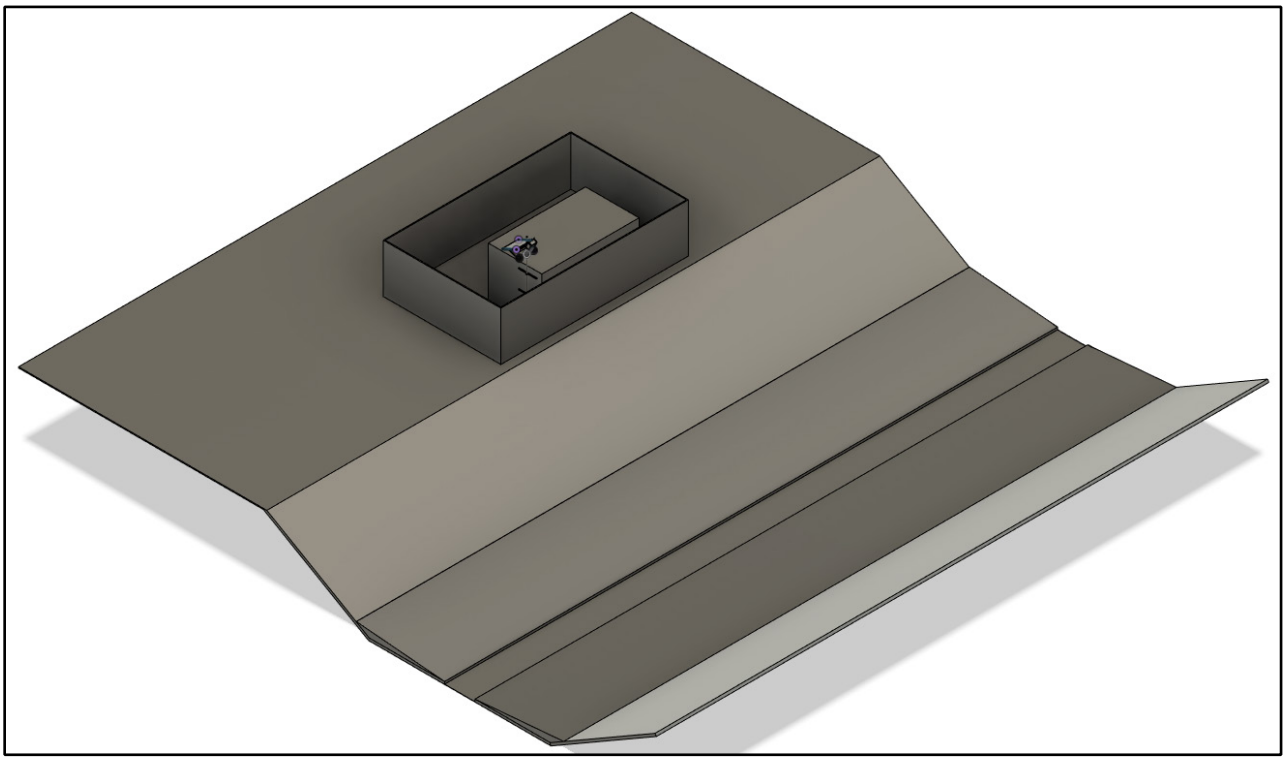


Figure C-37. Santa Ana River at Prado Dam stream cross-section oblique view.

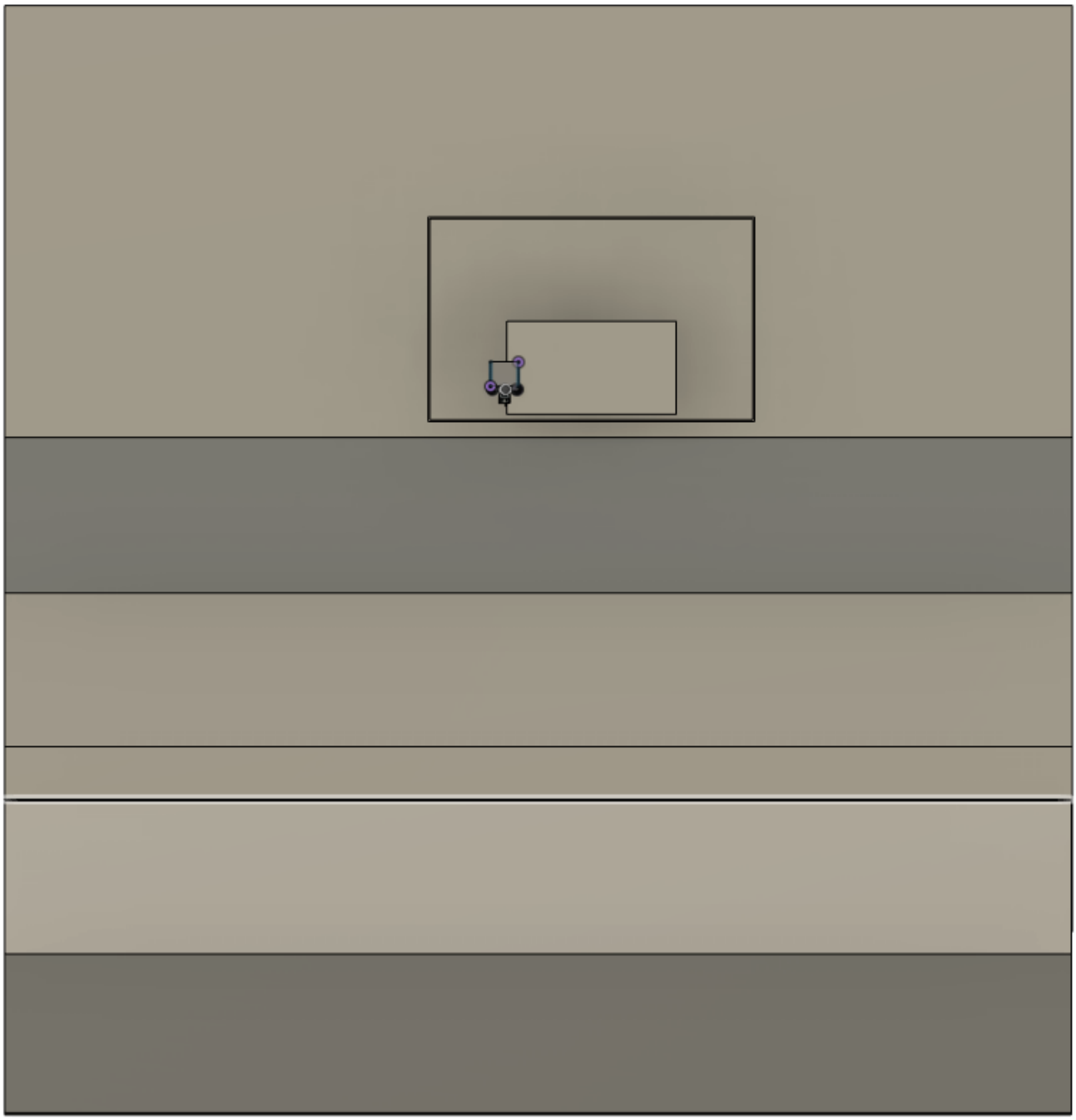


Figure C-38. Santa Ana River at Prado Dam stream cross section overhead view.

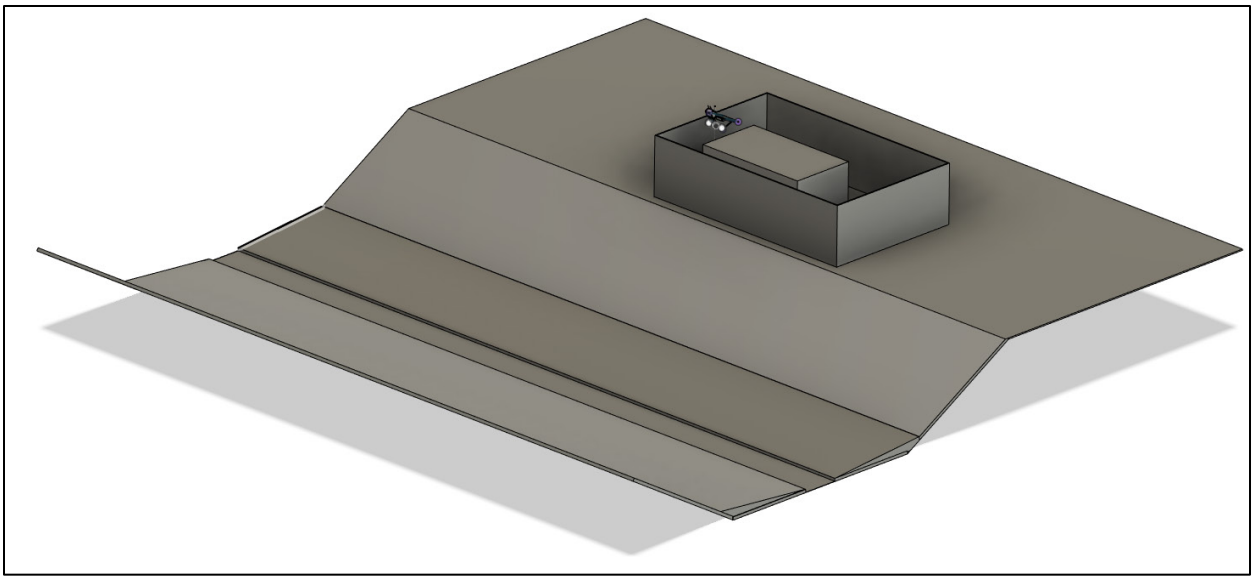


Figure C-39. Santa Ana River at Prado Dam stream cross section oblique view.

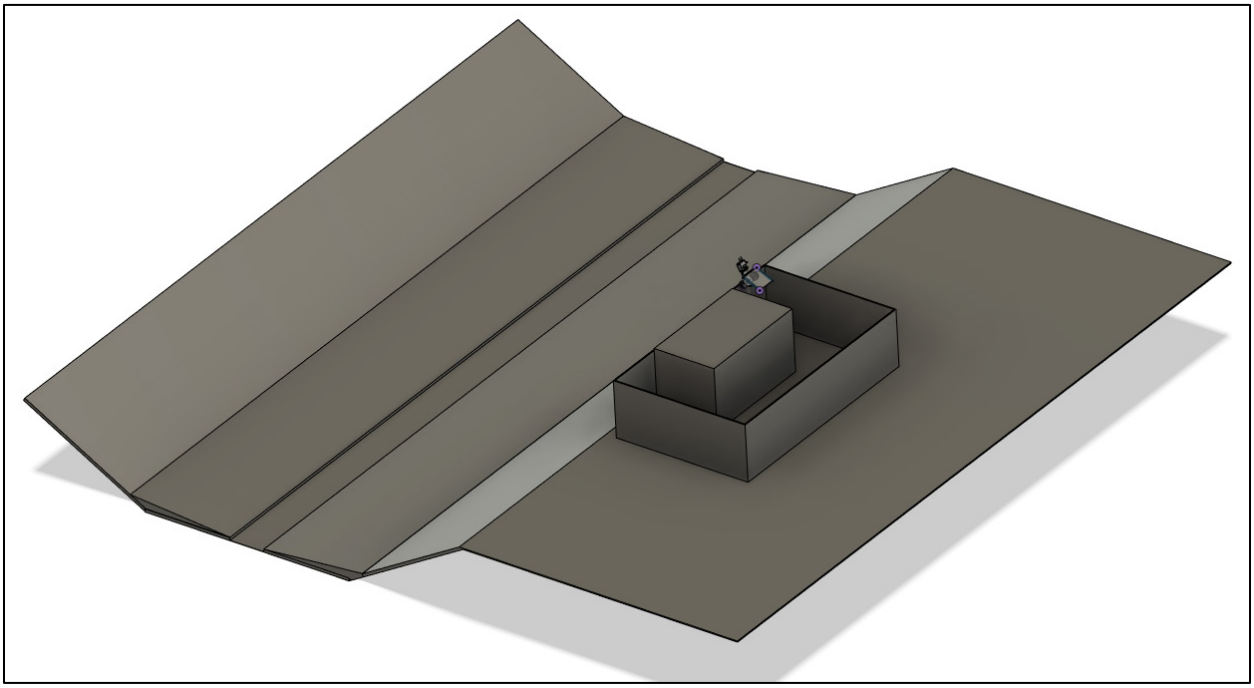


Figure C-40. Santa Ana River at Prado Dam stream cross-section oblique view.

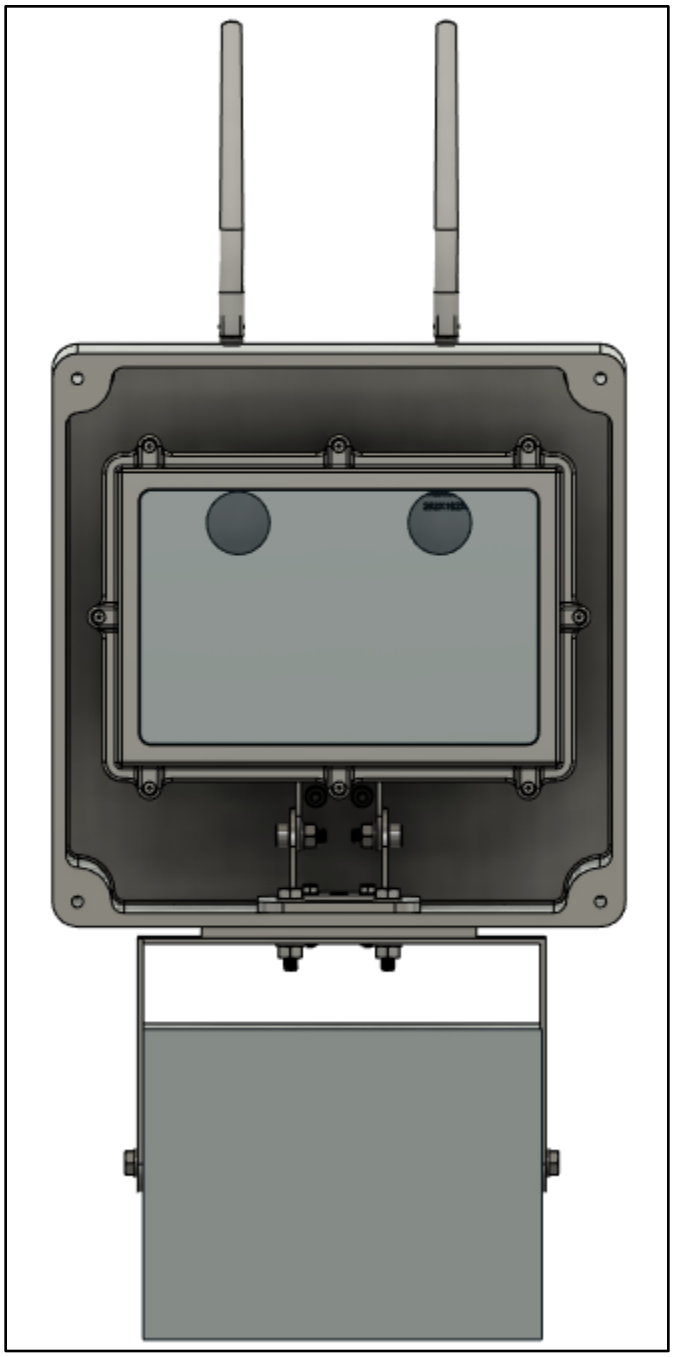


Figure C-41. CVSG device mounted in security enclosure with IR illuminator affixed shown in faceplate removed configuration.

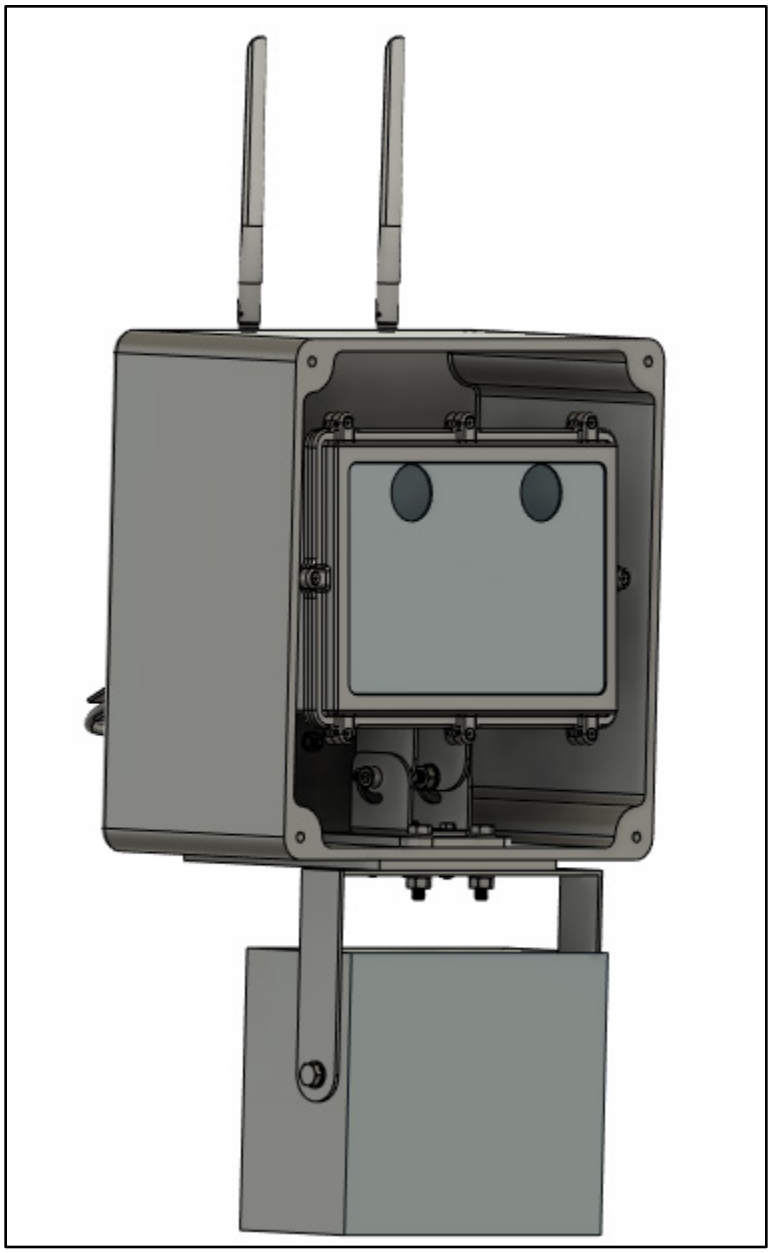


Figure C-42. CVSG device mounted in security enclosure with IR illuminator affixed shown in faceplate removed configuration.

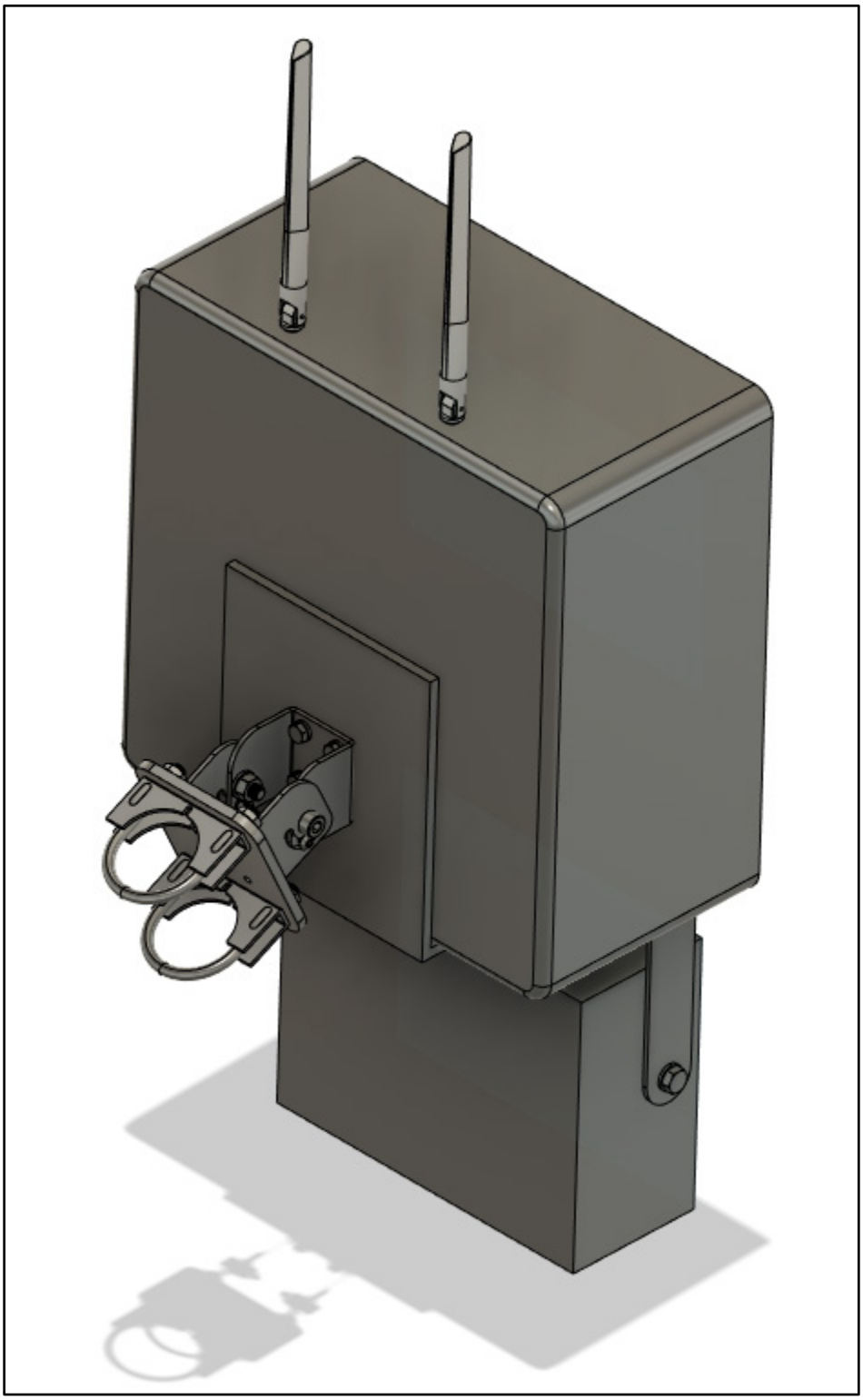


Figure C-43. CVSG device mounted in security enclosure with IR illuminator affixed.

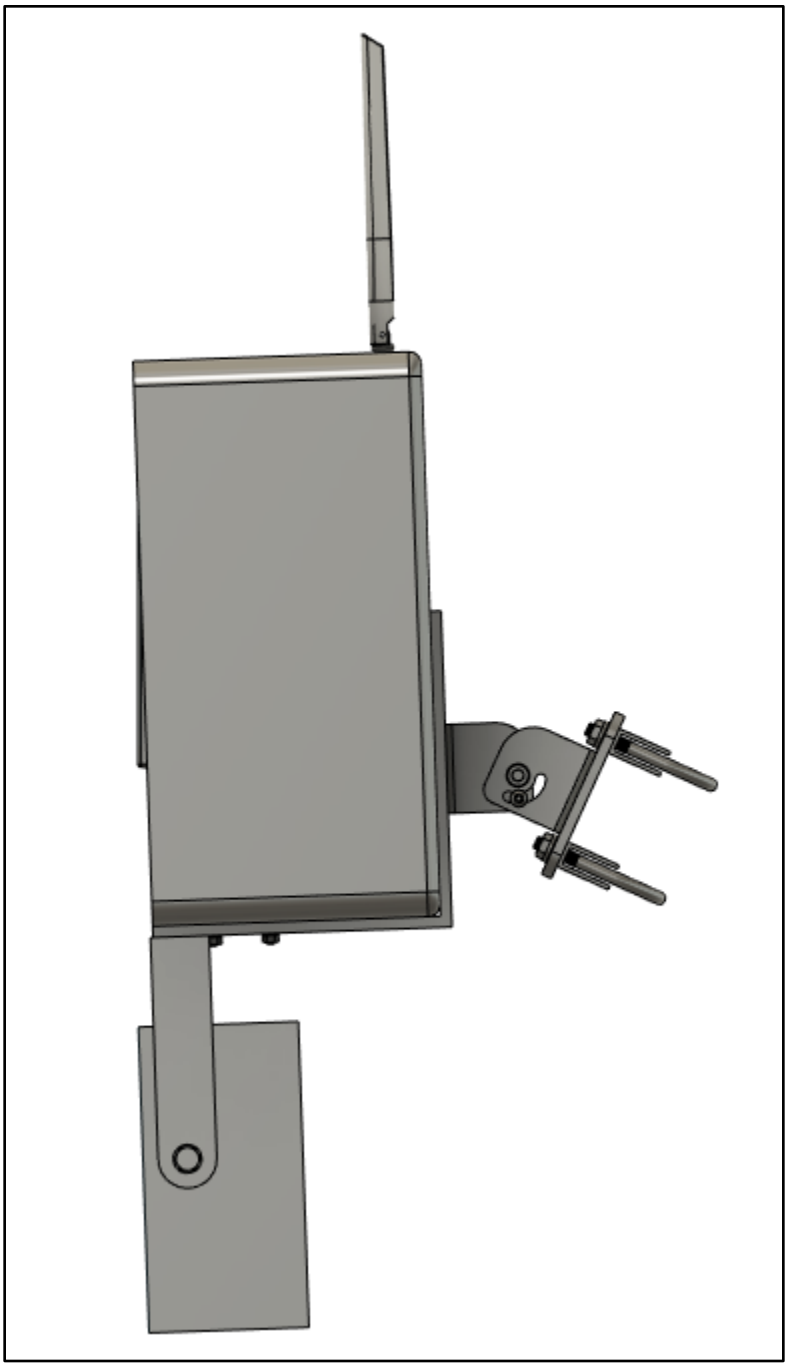


Figure C-44. CVSG device mounted in security enclosure with IR illuminator affixed.

C.4.8 Prado Inflow Monitoring

The Prado FIRO SC adjusted the timeline for inflow monitoring enhancements above Prado Dam to account for the research and development of emerging flow monitoring technologies. The computer vision stream gaging approach used below Prado Dam is being developed as an approach to monitor Prado Dam inflow. Three locations (USGS MWD, Hamner bridge crossing, and USGS E Street) have been identified as potential reaches on the Santa Ana River for Prado inflow monitoring on the Santa Ana River. Enhanced Prado Dam inflow monitoring will be completed post-FVA. A finalized version of the statistical assessment performed in Section C.4.3 will be completed in Summer 2023 to determine whether and how much the rating curve was improved using CVSG technology at SAP. Results from the statistical analysis will be used to determine if the technology is suitable for improving rating curves at the locations described in the remainder of this section.

C.4.8.1 MWD Crossing

The MWD Pipeline Crossing Gage (USGS 11066460) on the Santa Ana River is in Riverside County, California (33.9686111, -117.447500) and reflects a drainage area of 852 square miles. USGS measures stage from the bridge crossing, about 50 feet above the river during low flows, where the logger also resides. Stage has been recorded at this stretch of the river since 1985, with adjustments to the exact location or technology about every 10 years. Current instrumentation (in place since 2005) consists of a Design Analysis H-3611 radar sensor (Figure C-49) and Design Analysis H-522+ data logger with GOES transmitter.

Control conditions in this stretch of the Santa Ana River are unstable throughout the full range of stage due to heavy vegetation, stream braiding, sand transport, and high velocities (Figure C-45 through Figure C-48). These characteristics contribute to channel instability, debris pileups, washouts, and rapid changes in the streambed elevation. Some of these changes can occur directly below the radar, creating confounding measurements. Low-flow manual velocity measurements can be made by wading in a section just downstream of the gage. Medium- to high-flow measurements must be made from the pipeline catwalk and require three technicians. Records at MWD Crossing are considered fair to poor by USGS (Ralph et al., 2021).

Figure C-45. *MWD Pipeline crossing downstream view.*

Figure C-46. *MWD Pipeline crossing downstream view.*

Figure C-47. *MWD Pipeline crossing downstream view.*

Figure C-48. *MWD Pipeline crossing downstream view.*

Figure C-49. USGS Design Analysis H-3611 radar sensor installed at MWD Pipeline crossing.

C.4.8.2 Hamner Ave

The Hamner Ave bridge (33°56'46.8"N 117°33'30.1"W) crosses the Santa Ana River in Norco, California. Flow measurements have been collected at this location since 2016 by Scheevel Engineering for Orange County Water District. Reports from Scheevel Engineering indicate that flows are primarily confined to the main channel with minimal overtopping even at relatively high flows. A total of fourteen flow measurements have been performed, with two measurements taken during storm flows and twelve at baseflow. Construction on a new bridge with pedestrian access began in 2021 (Figure C-50). Construction had not been completed at the time of Prado FVA document development, however, the pedestrian walkway may provide a suitable location for CVSG installation. Riprap, rocks placed to stabilize the channel banks, was installed during the initial stages of construction Figure C-51). If the riprap remains installed, this will provide a stable cross section to collect streamflow measurements. This site has been considered as an alternative to the MWD crossing site proposed in the Prado PVA.

Figure C-50. *Proposed design for new Hamner Ave Bridge (a) 3D view and (b) aerial view.*

Figure C-51. *(a) Google streetview capture showing Santa Ana River Channel before the new bridge and riprap were installed. (b) Google streetview capture showing Santa Ana River Channel and new bridge construction from the old bridge. Note riprap installed on channel banks.*

C.4.8.3 E Street

USGS 11059300 is located in San Bernardino (34°03'57.8"N 117°18'01.9"W) 0.4 mi downstream from E Street Bridge, 0.4 mi upstream from Warm Creek, 1.2 mi downstream from San Timoteo Creek, 2.8 mi south of San Bernardino, and 26 mi downstream from Big Bear Lake (Figure C-52). USGS instrumentation includes a Sutron Satlink 3 datalogger and Sutron steady rate bubbler located inside of the gage house (Figure C-53). Low-flow measurements lower than 100 cfs can be made in the low-flow concrete channel with fair to good accuracy (Figure C-54). Wading measurements below 500 cfs can be made safely at any cross-section, although depths are shallow and velocities high. Very high flow measurements are made from a bridge crossing upstream via a vehicle crane. Records at E Street are considered poor. This site has been evaluated as an alternative to the MWD Crossing location. The distance from the USGS gage house to the channel is at the upper limit of the CVSG device utilized below Prado Dam.

Figure C-52. *USGS E Street Satellite view.*

Figure C-53. *(a) USGS gage house looking towards SAR channel. (b) USGS gagehouse view from channel bank.*

Figure C-54. *(a) USGS E Street low-flow channel downstream view. (b) USGS E Street low-flow channel bubbler. (c) USGS E Street low-flow channel looking upstream.*

C.4.9 References

Hutley, N. R., Beecroft, R., Wagenaar, D., Soutar, J., Edwards, B., Deering, N., ... & Albert, S. (2022). Adaptively monitoring streamflow using a stereo computer vision system. EGUsphere, 1-38.

Ralph, F. M., Woodside, G., Anderson, M., Cleary-Rose, K., Haynes, A., Jasperse, J., Sweeten,J., Talbot, C.,Tyler, J.,Vermeeren, R. (2021). Prado Dam Forecast Informed Reservoir Operations Preliminary Viability Assessment. UC San Diego. Retrieved from https://escholarship.org/uc/item/13091539

Appendix D—Meteorological Studies and Research (Section 6)

D.1 Additional Details on the landfalling AR Climatology

Analysis of landfalling ARs influencing the Santa Ana River watershed and Prado basin leveraged the hourly European Centre for Medium Range Weather Forecasting (ECMWF) ERA5 dataset to calculate the AR scale following the methodology of Ralph et al. (2019) at 33.5N, 118W near Irvine, California (Figure D-1). The climatology of landfalling ARs for water years (WY) 1960-2023 (through February 2023) contains an average annual frequency of 3.7 ARs and a standard deviation of 2.8 ARs. A majority (86%) of landfalling ARs in Southern California contain an AR scale rank of AR1 or AR2; very few achieve a rank of AR3 or higher.

Landfalling ARs are most common during the cool-season months of December, January, and February (DJF) with an average monthly frequency less than 0.8 per month per year, or 2.2 per year during the whole DJF period. These landfalling ARs are primarily associated with IVT directions that are southwesterly like the AR4 in February 2019; however, both westerly and southerly IVT directions are also common. The few easterly IVT directions are actually not landfalling ARs; the methodology also picks up nearby warm-season tropical cyclones such as Tropical Storm Kay that impacted southern California during September 2022.

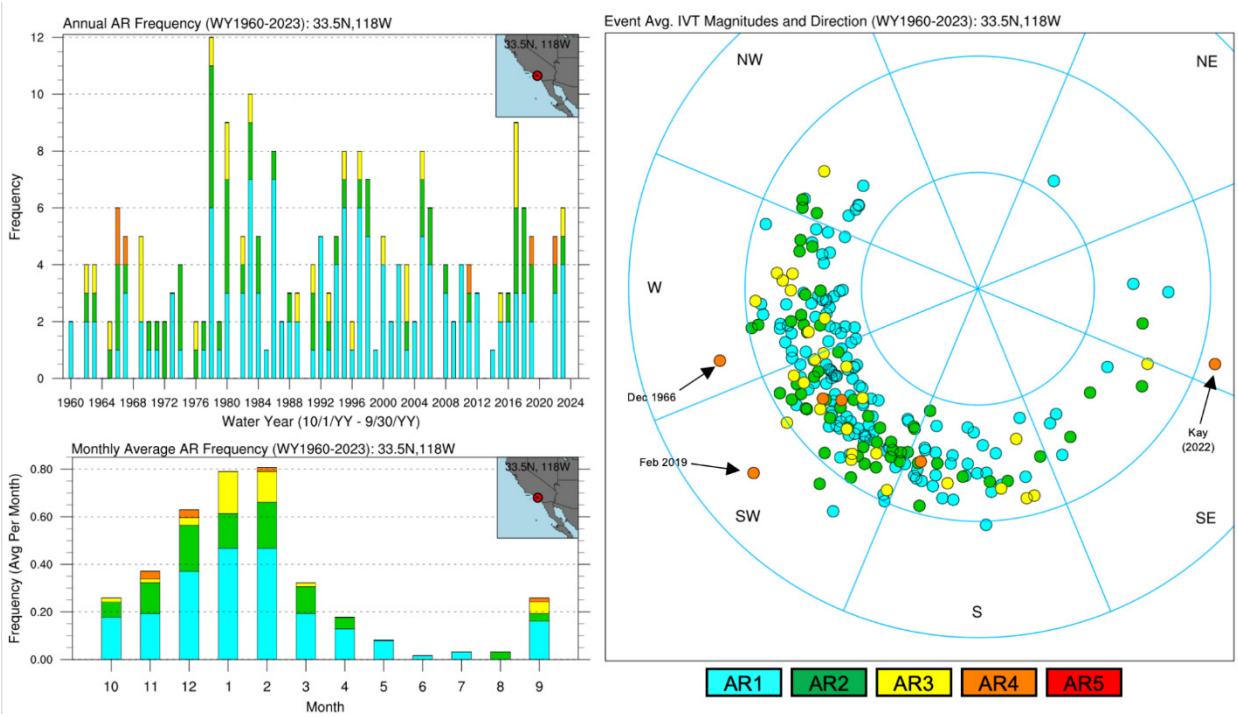


Figure D-1. *Climatology of landfalling ARs at Prado based on Ralph et al. (2019) AR scale using integrated vapor transport (IVT) magnitude (left two panels by year and month) and average storm IVT magnitude and direction (right panel). Climatology is based on ECMWF ERA5 dataset for water years 1959 through present. Note that WY23 is current through 28 Feb 2023.*

D.1.1 References

Ralph, F. M., M. Dettinger, J. J. Rutz, J. M. Cordeira, L. Schick, M. Anderson, C. Smallcomb, and D. Reynolds, 2019: A scale to characterize the strength and impacts of atmospheric rivers. *Bull. Amer. Met. Soc.,* 100, 269–289.

D.2 Additional Details on the AR and Precipitation Catalog

An extended (~12-year) catalog of precipitation, atmospheric river characteristics, and forecast verification statistics over the Santa Ana River watershed was developed to further the understanding of the mechanisms that lead to precipitation and how it is forecast. Daily mean-areal Stage-IV precipitation observations within the HUC-8 boundary of the Santa Ana River watershed serves as the foundation of the catalog while several atmospheric river related observations (derived from ERA5 Reanalysis) are provided, such as:

- Daily Mean IVT Magnitude and Direction
- Daily Maximum IVT Magnitude and Direction
- Atmospheric River Scale

Forecast information and statistics are included in conjunction with the observations listed above in order to contextualize and identify systematic sources of error as a function of lead time and physical process. Daily mean-areal quantitative precipitation forecasts from the California-Nevada River Forecast Center and West-WRF were calculated for lead-times up to five days identifying days and lead times that exhibited the largest and smallest forecast errors. In addition to precipitation forecasts, several variables and statistics were calculated from West-WRF data for atmospheric river characteristics, such as daily mean and maximum IVT magnitude and direction. The Method for Object-Based Diagnostic Evaluation (MODE) tool was utilized to identify landfall position error of atmospheric rivers and the role these errors played on the forecast of precipitation.

In summary, this overarching catalog serves as a meteorological reference for the Santa Ana River watershed and the phenomena that can lead to extreme precipitation, over/under forecasts, short lead times, etc. The data within this catalog was utilized to perform several of the analyses presented in this FVA and will continue to provide information for studies and analyses in the future.

Date	Watershed_Precip	Watershed_STD_DEV	Lower_MAP	Lower_Pct	Upper_MAP	Upper_Pct	AVG_IVT	AVG_IVT_Direction	Max_IVT	Max_IVT_Direction	ARscale
20190214	97.73	33.1	79.08	20.3	134.57	34.54	722.6	228.7	1000.9	224.2	4
20211224	62.31	34.16	43.75	17.62	92.1	37.09	447.7	235.2	686.5	230.4	2
20211214	59.87	35.22	44.31	18.57	83.34	34.92	362.9	218.3	622.4	214.8	1
20190117	59.16	35.29	38.47	16.31	83.6	35.45	345.1	238	469.3	253.8	1
20180109	51.94	21.44	33.02	15.95	77.28	37.33	390	193.8	584	186.9	2
20170123	49.53	21.72	36.06	18.27	66.91	33.89	353	240.9	803.8	231.3	3
20140228	49.49	23.21	33.41	16.94	70.88	35.94	400.9	204	623.3	203.5	1
20230101	45.54	-9999	27.71	15.27	70.69	38.95	298.5	243.6	511.4	220.5	1
20221108	44.23	-9999	26.75	15.17	65.65	37.23	321.3	220.7	517.7	212.2	1
20161216	42.99	19.82	32.87	19.19	59.2	34.55	493	241.4	627.2	234.8	2
20170120	42.8	16.28	31.6	18.52	62.93	36.89	279.4	254.3	530.8	241.1	1

Figure D-2. *An example of the information provided within the catalog for the largest precipitation days over the Santa Ana River watershed.*

D.3 Additional Details on Linking ARs to Precipitation in the Santa Ana Watershed

D.3.1 Summary

- Over the Santa Ana Watershed, most days during the "cool and wet" season (Oct–Apr) are dry, and of days with precipitation (26%), most are not very meaningful (>0.25"; 6%).
  - Days with > 1.00" are truly exceptional (1.5%).
- The largest precipitation events over the Santa Ana Watershed occur predominantly under AR conditions (IVT > 250) with the direction of maximum daily IVT from the south-southwest (180-240 degrees).
- Values of daily maximum IVT < 250 tend to yield relatively few large daily precipitation totals (>1.00") and values of daily maximum IVT > 500, while very rare, tend to deliver the largest events.

D.3.2 Discussion

For the Santa Ana Watershed and storage behind Prado Dam, the climatology of precipitation during the cool season can be summarized as a majority of dry days (75%) a minority of wet days (precipitation > 0.00"; 25%), and a very small minority of meaningfully wet days (precipitation > 0.25", 6%), with both the probability and amount of precipitation increasing as a function of increasing IVT. This can be visualized via Figure D-1, which shows PoP > 70% and average daily precipitation > 0.25" once maximum daily IVT is in the 300-350 range. Once the 450-500 range is reached, PoP is nearly 100% with a few exceptions and average daily precipitation increases rapidly. However, caution is advised with only 35 days within this range or above. Additionally, the 700-750, 800-850, and 1000-1050 ranges each only contain 1 event.

The precipitation climatology of the Santa Ana Watershed is also heavily influenced by the direction of the daily maximum IVT (Figure D-2). Moving in a counterclockwise direction, few days feature a maximum IVT direction from the south (150-210 degrees), but this number increases rapidly in toward the westerly direction (~270 degrees) before dropping off slowly to the northwest (300+ degrees). Precipitating days follow a roughly similar pattern, but do make up a larger percentage of days, and hence produce a higher PoP (near or exceeding 50%), from the south-southwest direction (170-220 degrees). Average daily precipitation is maximized ~10 degrees counterclockwise of PoP, in the range of 180-230 degrees.

Since most precipitation occurs under AR conditions (i.e., IVT > 250), it is useful to revisit the previous analysis based on maximum daily IVT direction but only consider days with a maximum IVT > 250 (Figure D-3). Moving in a counterclockwise direction, few days feature an average IVT direction from 150-180 degrees, but this number increases rapidly toward a maximum near 240 degrees before decreasing toward more westerly and then northwesterly directions. Precipitating days follow a fairly similar pattern, but begin to make up a smaller percentage of days, and hence produce a lower PoP, for directions counterclockwise from about 240 degrees and more so after about 290 degrees. Perhaps most striking is the average daily precipitation, which generally approaches or exceeds 0.50-0.75" from 150-240 degrees and decreases rapidly in the counterclockwise direction from there.

A final graphical picture of the relationships between precipitation and both the daily maximum IVT magnitude and direction is presented in Figure D-4. The relationship between precipitation and daily maximum IVT magnitude is visually apparent – linear and polynomial trendlines explain 35.6% and 49.2% of the variance, respectively (not shown). Notably, large precipitation totals (> 1.00") are observed across the watershed, the daily maximum IVT magnitude is almost always > 250. But note that there are also many IVT > 250 events that do not produce large (> 1.00") or even meaningful (>0.25") precipitation totals. Similarly, the relationship between precipitation and daily maximum IVT direction is equally apparent – almost all precipitation events > 1.00" occur with a maximum IVT direction between 180 and 270 degrees and most of these are clustered with the range from 200 to 240 degrees.

In summary, over the Santa Ana Watershed, most days during the "cool and wet" season (Oct–Apr) are dry, and of days with precipitation (25%), most are not very meaningful (>0.25"; 6%). Days with > 1.00" are truly exceptional (1.4%). This short analysis shows that the largest precipitation events over the Santa Ana Watershed occur predominantly under AR conditions (IVT > 250) with the direction of maximum daily IVT from the south-southwest (180-240 degrees). Values of daily maximum IVT < 250 tend to yield relatively few large daily precipitation totals (>1.00") and values of daily maximum IVT > 500, while very rare, tend to deliver the largest events.

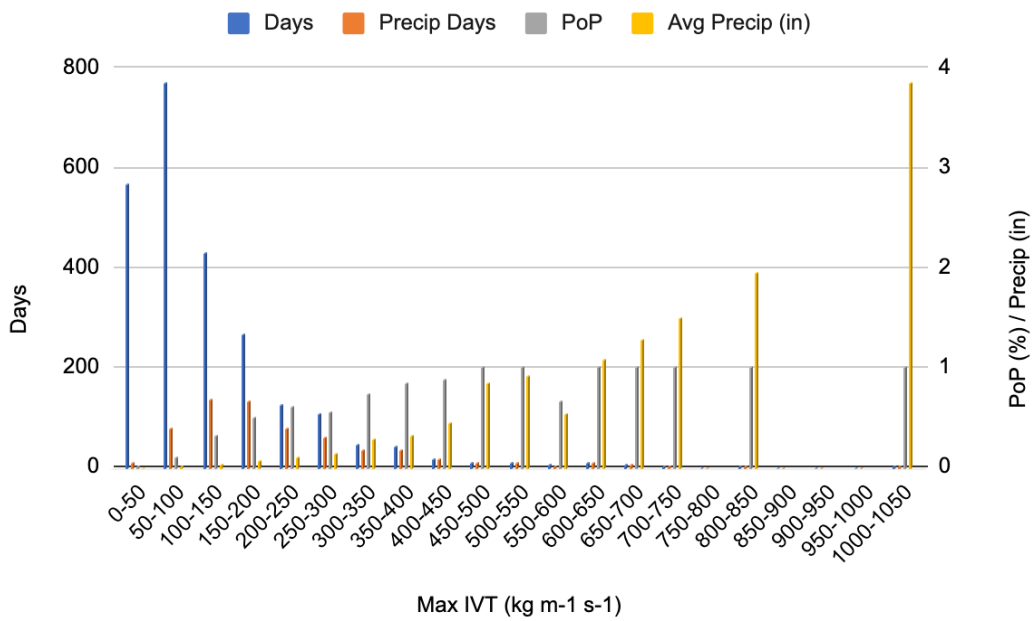


Figure D-3. *The number of days (blue), days with precipitation (orange), probability of precipitation (PoP; gray), and average daily precipitation (yellow) as a function of daily maximum IVT for cool season (Oct–Apr) days during the period Oct 2010 – Jan 2023. Note that the maximum value for PoP is 1; a PoP of 0.45, for example, represents a 45% chance of precipitation.*

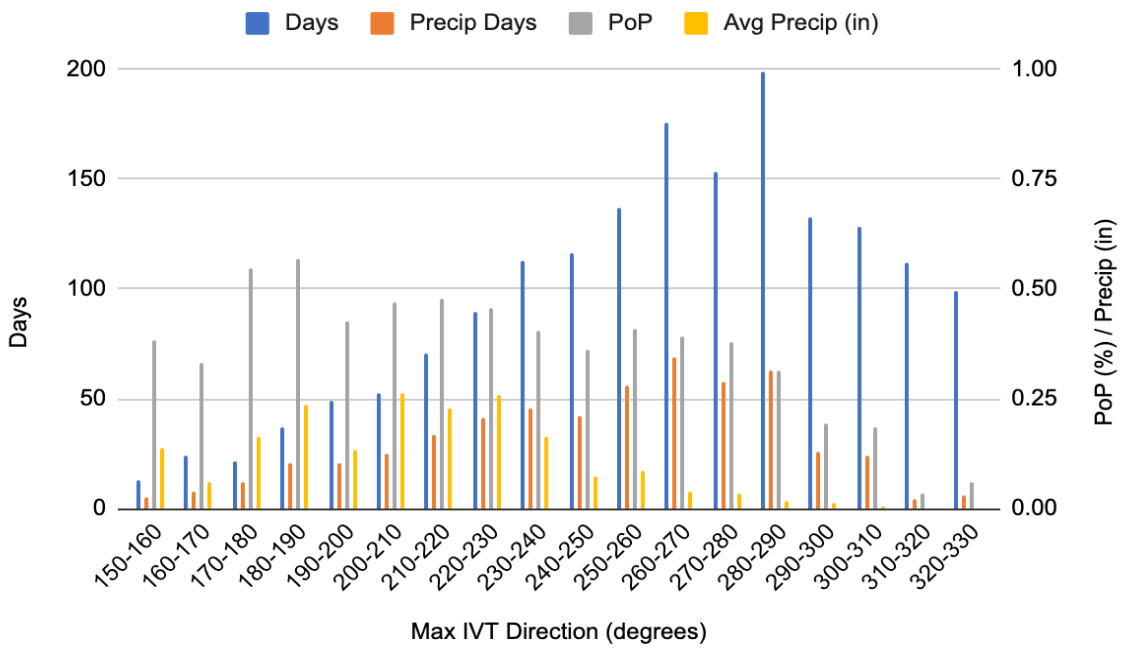


Figure D-4. *The number of days (blue), days with precipitation (orange), probability of precipitation (PoP; gray), and average precipitation (yellow) as a function of direction of the maximum daily IVT for cool season (Oct–Apr) days during the period Oct 2010 – Jan 2023. Note that the maximum value for PoP is 1; a PoP of 0.45, for example, represents a 45% chance of precipitation.*

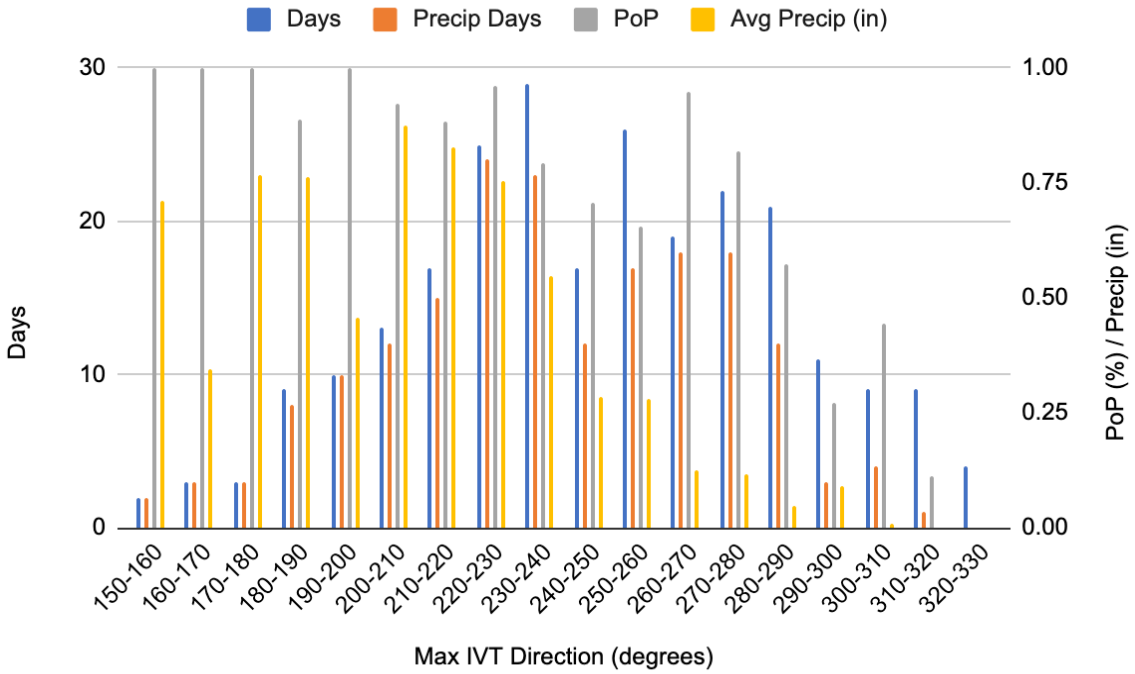


Figure D-5. *As in Figure D-4, but only for days with daily maximum IVT > 250.*

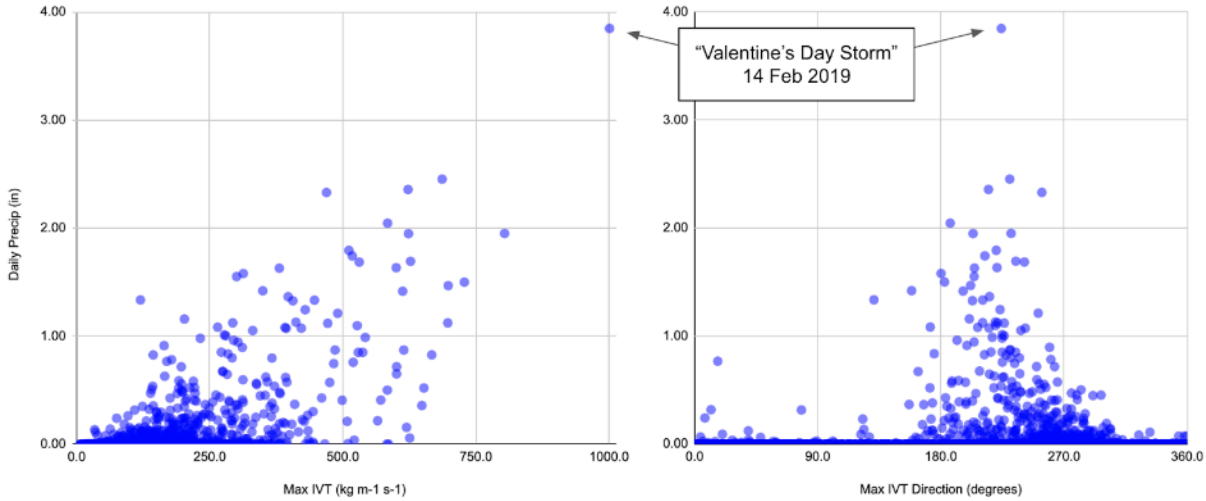


Figure D-6. *Scatter plots of daily precipitation vs. a) maximum daily IVT and b) direction of the maximum daily IVT. The "Valentine's Day Storm" of 14 Feb 2019 over California is highlighted.*

D.4 Additional Details on Orographic Precipitation in the Santa Ana River watershed

The Santa Ana HUC8 watershed features complex topography that influences the spatial distribution of precipitation. Portions of three mountain ranges lie within the watershed, including the Santa Ana Mountains in the south, which run parallel to the coast (northwest-to-southeast orientation) and have a maximum elevation < 6,000 feet, and the San Gabriel and and San Bernardino Mountains in the north, which are both part of the broader west-to-east running Transverse Ranges and have maximum elevations > 10,000 feet. The following analysis will explore the relationship between topography, synoptic-scale moisture transport, and precipitation in the Santa Ana watershed.

The orographic distribution of precipitation was investigated by comparing the observed precipitation (i.e., Stage IV QPE) in the lower 25% and upper 25% hypsometry of the Santa Ana watershed. The lower and upper quartile elevations of the watershed were determined by regridding a high-resolution (1 arc-minute) global relief dataset (ETOPO1; Amante and Eakins, 2009) to match the 4-km Stage IV QPE grid. Stage IV grid cells in the upper 25% of the watershed are primarily concentrated in the San Gabriel and San Bernardino Mountains (Figure D-7). As is typical in regions of complex terrain, annual precipitation generally increases with elevation in the watershed.

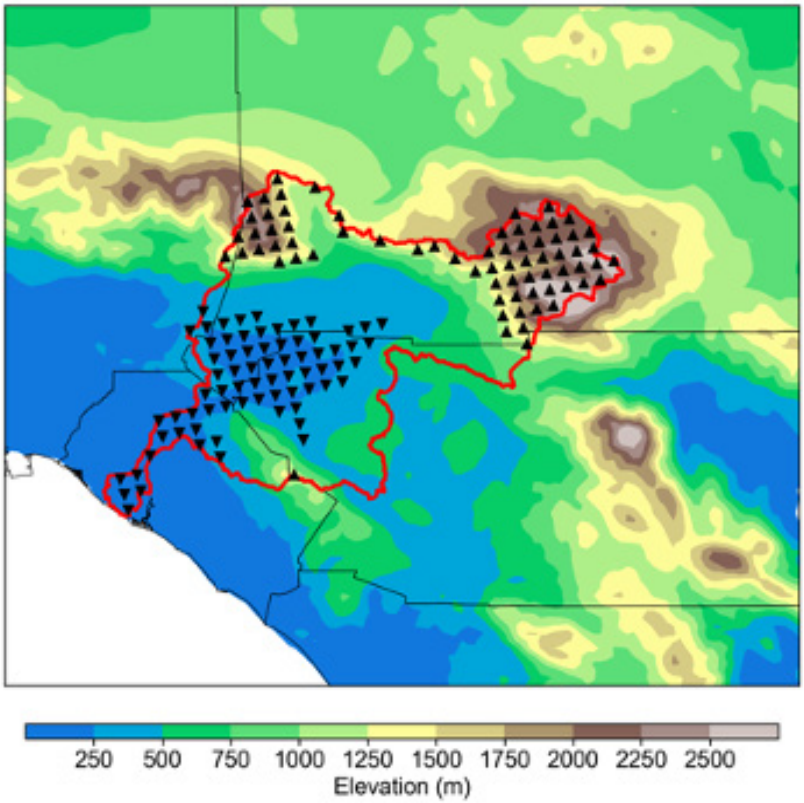


Figure D-7. *Map showing elevation (shaded) and the boundary of the Santa Ana HUC8 watershed (red contour). Stage IV grid cells located in the lower (upper) 25% of the watershed are denoted by downward-pointing (upward-pointing) triangles.*

During the 11 water years (WYs) spanning 2012-2022, the annual MAP in the upper and lower portions of the watershed was 455 mm (17.9 inches) and 223 mm (8.8 inches), respectively. Overall, 37% of the total precipitation fell in the upper 25% of the watershed, whereas only 18% of the total precipitation fell in the lower 25% of the watershed. The annual percentage contributions from the upper and lower portions of the watershed are anti-correlated, i.e., years with higher contribution from the lower portion of the watershed are characterized by lower contribution from the upper portion of the watershed (Figure D-8). The orographic precipitation ratio (defined as the ratio of MAP in the upper 25% of the watershed to MAP in the lower 25% of the watershed) varies from year-to-year, with a minimum value of 1.8 in WY 2015, and a maximum value of 2.7 in WY 2018.

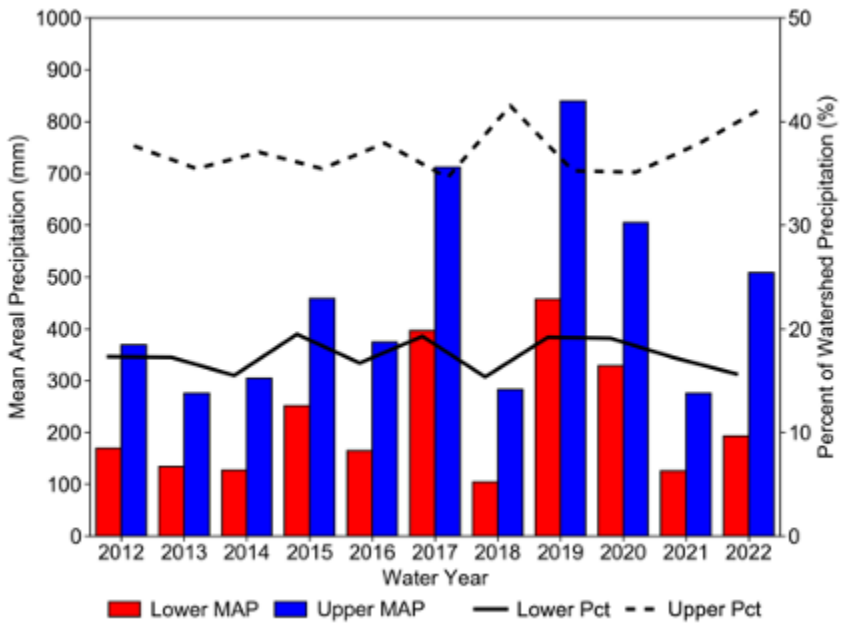


Figure D-8. *Time series showing total MAP in the lower (red bars) and upper (blue bars) portions of the Santa Ana watershed during WYs 2012-2022. Solid (dashed) line represents the percent of total WY precipitation that fell in the lower (upper) portion of the watershed.*

Previous research has shown that the Transverse Ranges help focus precipitation on days with enhanced low-level water vapor flux, especially when the low-level vapor flux has a southerly-to-southwesterly orientation (Oakley et al., 2017; Ricciotti and Cordeira, 2022). Assuming upslope moisture flux is maximized at some angle x, we can estimate the upslope component of 925-hPa vapor flux by multiplying the 925-hPa vapor flux magnitude by the cosine of the difference between the 925-hPa vapor flux direction and x ($\cos(\Delta)$). If the difference exceeds 90°, it is assumed that there is no upslope moisture flux component. Similar to Ricciotti and Cordiera (2022), we find the strongest relationship between projected daily mean 925-hPa vapor flux at 33.5°N, 118°W (coastal Orange County) and daily MAP in the Santa Ana watershed when the 925-hPa vapor flux direction is from the southwest. The correlation between 925-hPa vapor flux and precipitation strengthens if we exclude days during the warm season (May-Sep), when synoptic-scale moisture transport has limited relevance.

The upslope component of daily mean 925-hPa vapor flux explains as much as 63% of the variance in cool-season (Oct-Apr) daily MAP, with the highest correlation observed for a direction of 210° (Figure D-9; top panel). Low-level vapor flux is especially important on days

when AR conditions (i.e., IVT ≥ 250 kg m^{-1} s^{-1}) are present along the coast of Southern California. If we only consider days during Oct-Apr with AR conditions, the upslope component of daily mean 925-hPa vapor flux explains as much as 78% of the variance in daily watershed MAP (Figure D-9; bottom panel). Despite the strong relationship between low-level vapor flux and watershed precipitation on daily time scales, the direction of low-level vapor flux does not appear to modulate the relative orographic distribution of precipitation within the watershed. No correlation was found between cos(Δ) and orographic precipitation ratio.

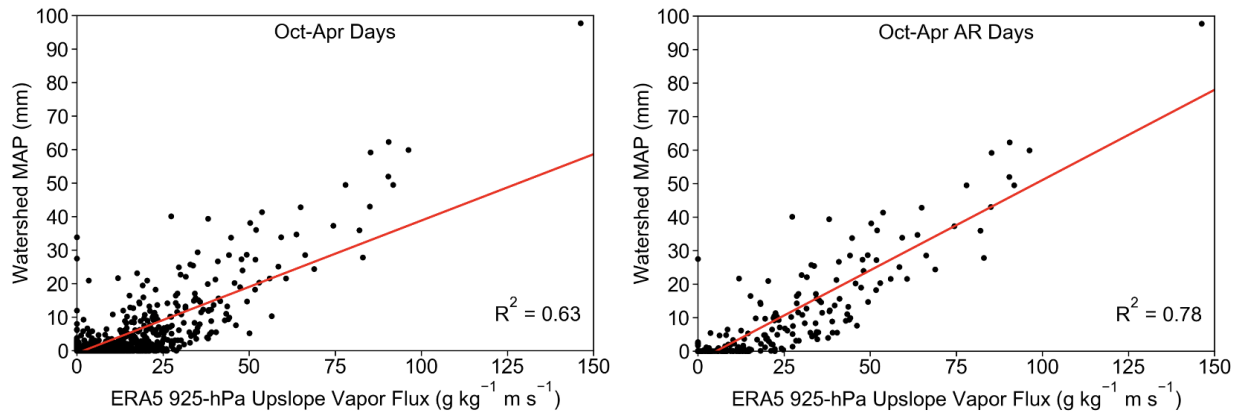


Figure D-9. *Scatter plots showing the upslope component of the daily mean 925-hPa vapor flux vs. daily watershed MAP for all Oct-Apr days (top) and Oct-Apr days with AR conditions (bottom) during WYs 2012-2022.*

D.4.1 References

Amante, C. & Eakins, B. W. (2009). ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis. *NOAA Technical Memorandum NESDIS NGDC-24*. National Geophysical Data Center, NOAA. doi:10.7289/V5C8276M

Oakley, N. S., Lancaster, J. T., Kaplan, M. L., & Ralph. F. M. (2017). Synoptic conditions associated with cool season post-fire debris flows in the Transverse Ranges of southern California. *Natural Hazards*, **88**, 327–354. doi: https://doi.org/10.1007/s11069-017-2867-6

Ricciotti, J. A., & Cordeira, J. M. (2022). Summarizing relationships among landfalling atmospheric rivers, integrated water vapor transport, and California watershed precipitation 1982–2019, *Journal of Hydrometeorology*, **23**, 1439-1454. doi: https://doi.org/10.1175/JHM-D-21-0119.1

D.5 Additional Details on Precipitation Intensity in the Santa Ana River watershed

D.5.1 Data and Methods

A climatology of hourly precipitation observations was gathered for seven ASOS/AWOS stations distributed across the Santa Ana watershed for a period between 10/1/2011 and 1/31/2023. The hourly data was then used to calculate the daily maximum precipitation rate and the daily precipitation totals for each day during the period of record with greater than 1 valid hourly observation. Hourly station precipitation observations were analyzed for each AR event during the period of record by isolating the observed precipitation between the start hour and end hour reflected in the Prado AR Catalog.

D.5.2 Research Questions

1. During the cool season, what percent of daily maximum precipitation rates at stations in the Santa Ana watershed occurred on No AR vs AR days? (Figure D-1)
2. During the cool season, what percent of daily maximum precipitation rates at stations in the Santa Ana watershed occurred on No AR days vs AR Like vs AR days? (Figure D-2)
3. During the cool season, what percent of daily precipitation totals at stations in the Santa Ana watershed occurred on No AR vs AR days? (Figure D-3)
4. During the cool season, what percent of daily precipitation totals at stations in the Santa Ana watershed occurred on No AR vs AR Like vs AR days? (Figure D-4)
5. During landfalling ARs within the period of record, on average what percent of the total AR hours was precipitation observed at each station in the Santa Ana watershed? (Figure D-5)
6. For the hours where precipitation was observed during ARs, on average what percent of hourly precipitation rates exceeded the 90th percentile value of all hours of observed precipitation? (Figure D-6)
7. For the hours where precipitation was observed during ARs, on average what percent of hourly precipitation rates exceeded the cool season 90th percentile value of all hours of observed precipitation? (Figure D-7)

Analysis of Daily Maximum Precipitation Rate and Daily Precipitation Total (1, 2, 3, 4)

- As the maximum daily precipitation rate at stations in the watershed increases from (0-2.5] mm to (10.0-12.5] mm, the percent of those rates which did not occur on AR days decreased from 91% to 43%, while the percent which occurred on AR days increased from 9% to 57%. (Figure D-10).
- When you subset the No AR days into explicitly No AR and AR Like days, you can combine the percentages associated with the AR Like and AR days. As the maximum daily precipitation rate at stations in the watershed increases from (0-2.5] mm to (10.0-12.5] mm, the percent of those rates which did not occur on AR days decreased from

71% to 29%, while the percent which occurred on AR Like and AR days increased from 30% to 71%. (Figure D-11).

- As the daily precipitation total at stations in the watershed increases from (0-10] mm to (40-50] mm, the percent of those rates which did not occur on AR days decreased from 91% to 58%, while the percent which occurred on AR days increased from 9% to 42%. (Figure D-12).
- When you subset the No AR days into explicitly No AR and AR Like days, you can combine the percentages associated with the AR Like and AR days. As the daily precipitation total at stations in the watershed increases from (0-10] mm to (40-50] mm, the percent of those rates which did not occur on AR days decreased from 69% to 25%, while the percent which occurred on AR Like and AR days increased from 31% to 75%. (Figure D-13).

As both daily maximum precipitation rates and daily precipitation totals increase, the likelihood they were not associated with an AR decreased, and the likelihood they were associated with an AR increased. This inverse relationship demonstrates that ARs are more frequently associated with the highest daily maximum precipitation rates and daily precipitation totals at stations in the Santa Ana watershed.

Analysis of AR Precipitation Duration and Intensity (5, 6, 7)

- As AR intensity increases from AR1-2 to AR3-5, the average percent of the total AR duration with observed precipitation across all stations in the watershed decreases from 47% to 31%.
- As AR intensity increases from AR1-2 to AR3-5, the average percent of hourly rainfall rates greater than or equal to the 90th percentile of all hourly rainfall rates at all stations in the watershed increases from 30% to 44%.
- As AR intensity increases from AR1-2 to AR3-5, the average percent of hourly rainfall rates greater than or equal to the **cool season** 90th percentile of all hourly rainfall rates at all stations in the watershed increases from 30% to 43%.
- The broad conclusion which can be drawn from this analysis is that although there are less rainy hours during stronger ARs, the likelihood that there is high intensity precipitation during those rainy hours is higher.

Figures Follow on next page

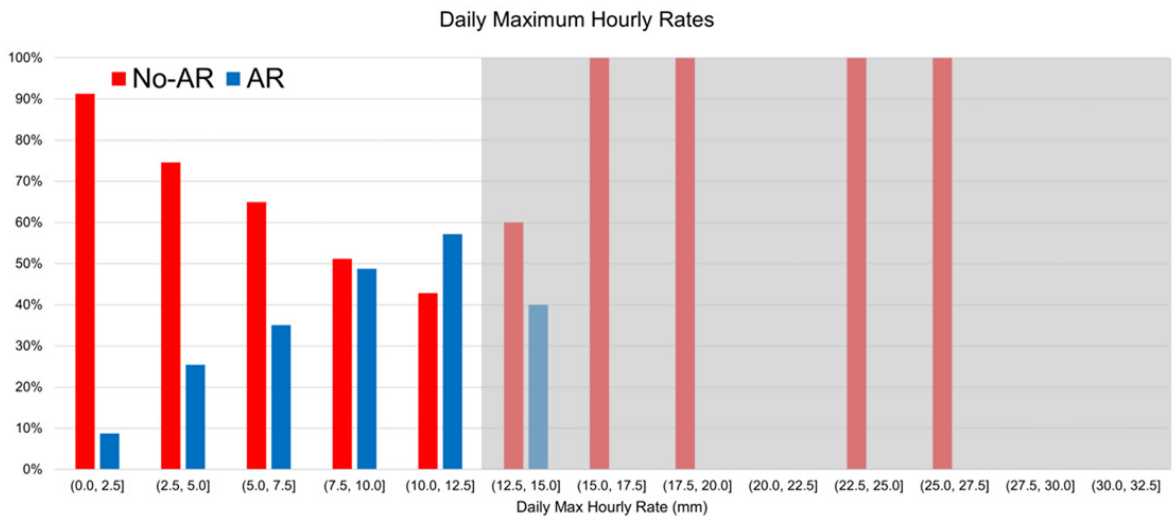


Figure D-10. *A histogram of the percent of daily maximum precipitation rates greater than zero which occurred on AR (blue) and No-AR (red) days during the cool season (Oct–Mar) across all stations between Oct 2011 – Jan 2023. Gray shaded region indicates sample size below 10 occurrences during the period of record.*

Method: For days in the cool season, divide the number of daily maximum precipitation rates in each histogram bin which occurred on No AR days and AR days by the total number of days with a daily maximum precipitation rate within each histogram bin.

	No-AR	AR
(0.0, 2.5]	91%	9%
(2.5, 5.0]	75%	25%
(5.0, 7.5]	65%	35%
(7.5, 10.0]	51%	49%
(10.0, 12.5]	43%	57%
(12.5, 15.0]	60%	40%
(15.0, 17.5]	100%	0%
(17.5, 20.0]	100%	0%
(20.0, 22.5]	0%	0%
(22.5, 25.0]	100%	0%
(25.0, 27.5]	100%	0%
(27.5, 30.0]	0%	0%
(30.0, 32.5]	0%	0%

	No-AR	AR-Like	AR	Total
(0.0, 2.5]	1187	344	146	1677
(2.5, 5.0]	138	120	88	346
(5.0, 7.5]	38	51	48	137
(7.5, 10.0]	8	13	20	41
(10.0, 12.5]	6	3	12	21
(12.5, 15.0]	3	0	2	5
(15.0, 17.5]	1	0	0	1
(17.5, 20.0]	1	0	0	1
(20.0, 22.5]	0	0	0	0
(22.5, 25.0]	1	0	0	1
(25.0, 27.5]	2	0	0	2
(27.5, 30.0]	0	0	0	0
(30.0, 32.5]	0	0	0	0

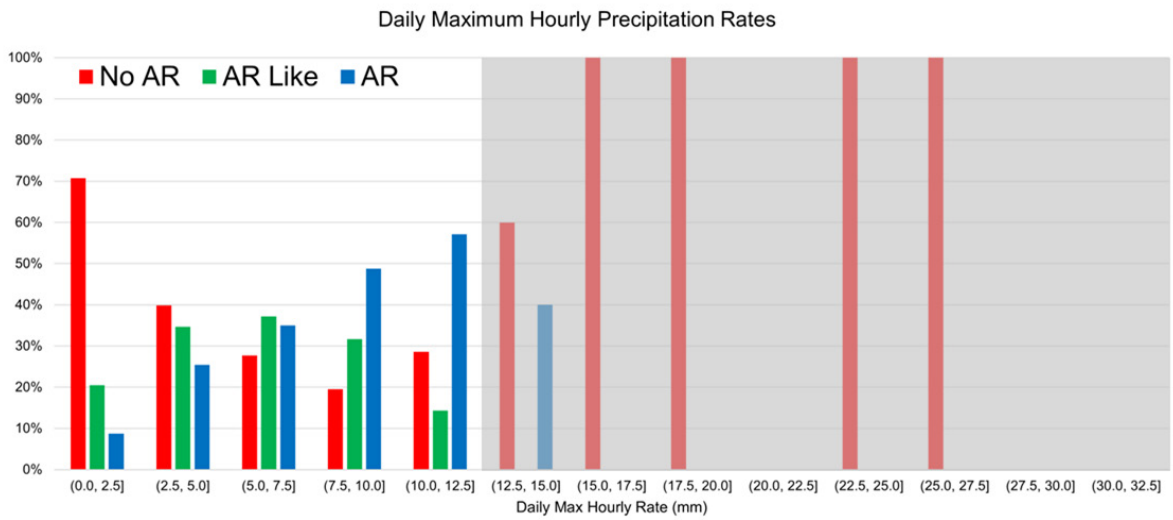


Figure D-11. *As in Figure D-1, but further subsetting the original No AR days to explicitly "No AR" days (No AR in catalog, Max IVT < 250)(red) and "AR Like" days (No AR in catalog, Max IVT ≥ 250). Gray shaded region indicates sample size below 10 occurrences during the period of record.*

Method: For days in the cool season, divide the number of daily maximum precipitation rates in each histogram bin which occurred on No AR days, AR Like days, and AR days by the total number of days with a daily maximum precipitation rate within each histogram bin.

	No AR	AR Like	AR
(0.0, 2.5]	71%	21%	9%
(2.5, 5.0]	40%	35%	25%
(5.0, 7.5]	28%	37%	35%
(7.5, 10.0]	20%	32%	49%
(10.0, 12.5]	29%	14%	57%
(12.5, 15.0]	60%	0%	40%
(15.0, 17.5]	100%	0%	0%
(17.5, 20.0]	100%	0%	0%
(20.0, 22.5]	0%	0%	0%
(22.5, 25.0]	100%	0%	0%
(25.0, 27.5]	100%	0%	0%
(27.5, 30.0]	0%	0%	0%
(30.0, 32.5]	0%	0%	0%

	No-AR	AR-Like	AR	Total
(0.0, 2.5]	1187	344	146	1677
(2.5, 5.0]	138	120	88	346
(5.0, 7.5]	38	51	48	137
(7.5, 10.0]	8	13	20	41
(10.0, 12.5]	6	3	12	21
(12.5, 15.0]	3	0	2	5
(15.0, 17.5]	1	0	0	1
(17.5, 20.0]	1	0	0	1
(20.0, 22.5]	0	0	0	0
(22.5, 25.0]	1	0	0	1
(25.0, 27.5]	2	0	0	2
(27.5, 30.0]	0	0	0	0
(30.0, 32.5]	0	0	0	0

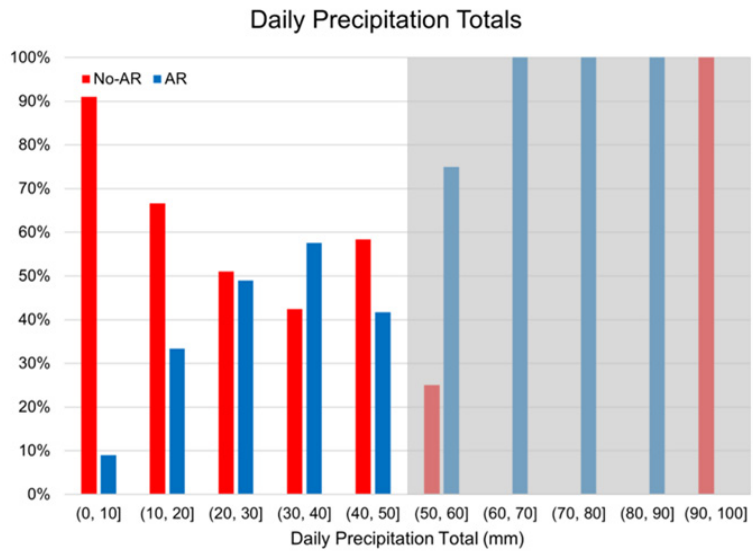


Figure D-12. A histogram of the percent of daily precipitation totals greater than zero which occurred on AR (blue) and No-AR (red) days during the cool season (Oct–Mar) across all stations between Oct 2011 – Jan 2023. Gray shaded region indicates sample size below 10 occurrences during the period of record.

Method For days in the cool season, divide the number of daily precipitation totals in each histogram bin which occurred on No AR days and AR days by the total number of days with a daily maximum precipitation rate within each histogram bin.

	No-AR	AR
(0, 10]	91%	9%
(10, 20]	67%	33%
(20, 30]	51%	49%
(30, 40]	42%	58%
(40, 50]	58%	42%
(50, 60]	25%	75%
(60, 70]	0%	100%
(70, 80]	0%	100%
(80, 90]	0%	100%
(90, 100]	100%	0%

	No-AR	AR Like	AR	Total N
(0, 10]	1305	408	169	1882
(10, 20]	59	71	65	195
(20, 30]	10	39	47	96
(30, 40]	6	8	19	33
(40, 50]	3	4	5	12
(50, 60]	1	1	6	8
(60, 70]	0	0	1	1
(70, 80]	0	0	3	3
(80, 90]	0	0	1	1
(90, 100]	1	0	0	1

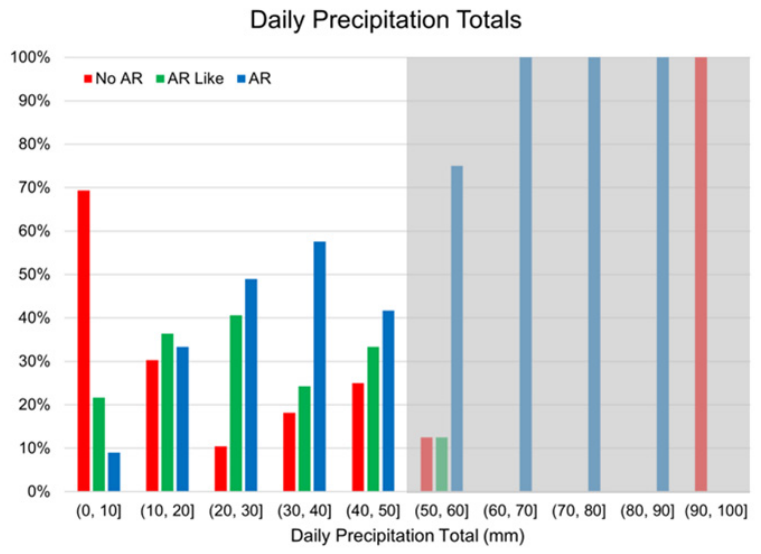


Figure D-13. *As in Figure D-3 but further subsetting the original No AR days to explicitly "No AR" days (No AR in catalog, Max IVT < 250)(red) and "AR Like" days (No AR in catalog, Max IVT ≥ 250). Gray shaded region indicates sample size below 10 occurrences during the period of record.*

Method For days in the cool season, divide the number of daily precipitation totals in each histogram bin which occurred on No AR days, AR Like days, and AR days by the total number of days with a daily maximum precipitation rate within each histogram bin.

	No AR	AR Like	AR
(0, 10]	69%	22%	9%
(10, 20]	30%	36%	33%
(20, 30]	10%	41%	49%
(30, 40]	18%	24%	58%
(40, 50]	25%	33%	42%
(50, 60]	13%	13%	75%
(60, 70]	0%	0%	100%
(70, 80]	0%	0%	100%
(80, 90]	0%	0%	100%
(90, 100]	100%	0%	0%

	No-AR	AR Like	AR	Total N
(0, 10]	1305	408	169	1882
(10, 20]	59	71	65	195
(20, 30]	10	39	47	96
(30, 40]	6	8	19	33
(40, 50]	3	4	5	12
(50, 60]	1	1	6	8
(60, 70]	0	0	1	1
(70, 80]	0	0	3	3
(80, 90]	0	0	1	1
(90, 100]	1	0	0	1

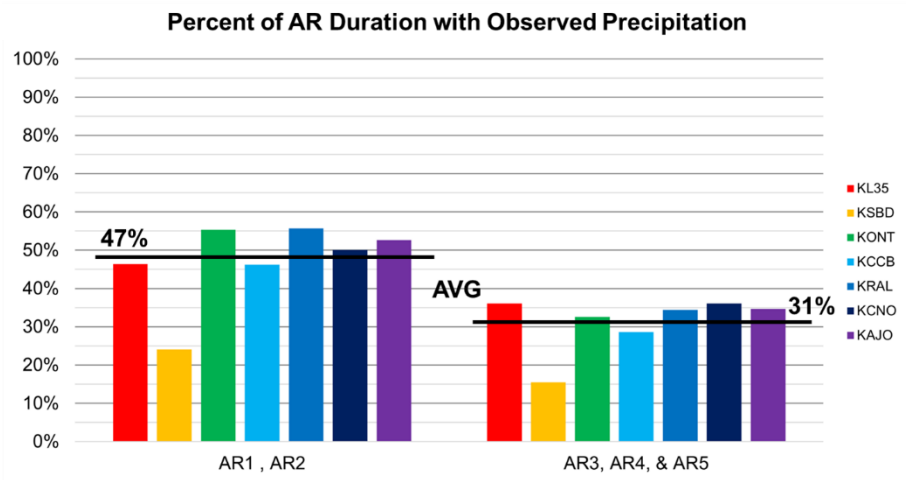


Figure D-14. The percent of hours during ARs with rain observed at one of seven stations in the Santa Ana watershed, subset by weak (AR1, AR2) and strong (AR3, AR4, AR5) ARs. The thick black line represents the average value across all stations. (Hours with Precip Observed divided by Hours of AR Duration , averaged across AR1 AR2 and AR3 AR4 AR5 events)

Method: Divide the number of hours with precipitation >0 by the total number of AR hours, then average these values for AR1, AR2 and AR3, AR4, AR5 bins at each station. The black line is the average of the values across all stations (columns).

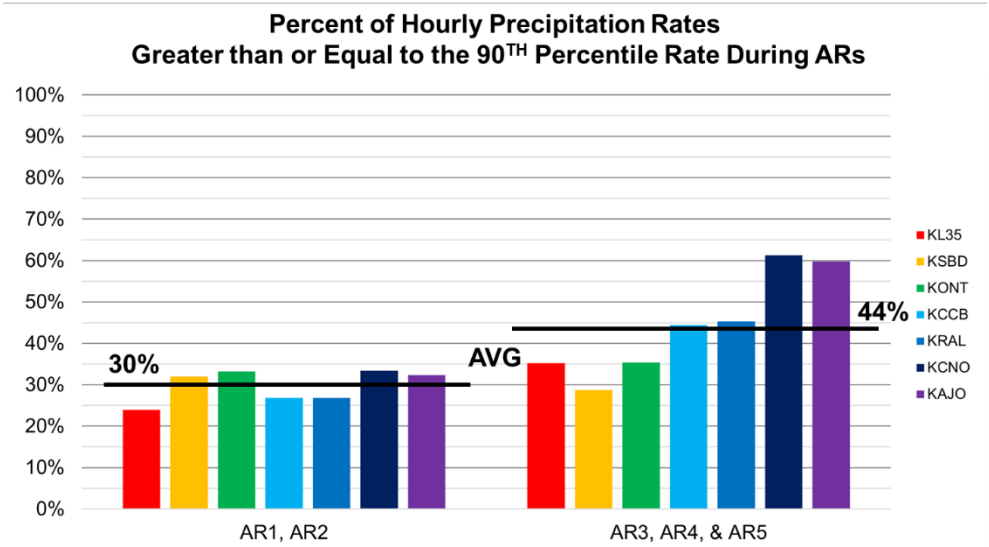


Figure D-15. The percent of the previously defined rainy hour observations at each station which exceeded the 90th percentile value for hourly precipitation observations at a given station. The thick black line represents the average value across all stations. (rainy hours during AR >= 90th percentile threshold / rainy hours during AR , averaged across AR1 AR2 and AR3 AR4 AR5 events)

Method: Divide the number of hours with precipitation observations >= to the 90th percentile precipitation rate during an AR by the number of hours with precipitation observations > 0 during the AR, then average the values for AR1, AR2 and AR3, AR4, AR5 bins at each station. The black line is the average of the values across all stations (columns).

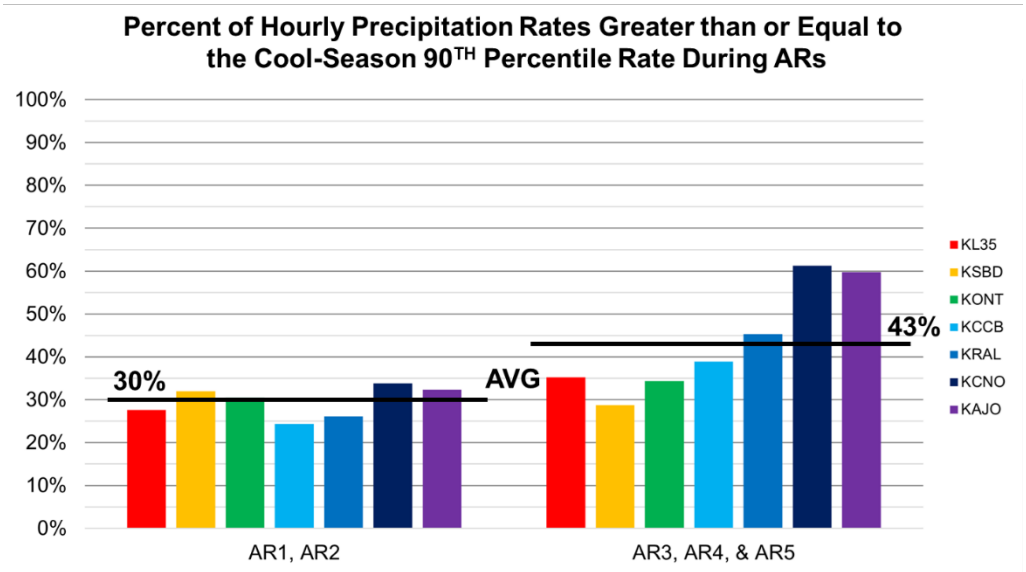


Figure D-16. *As in Figure D-6, but percent of hours greater than or equal to the cool season 90th percentile hourly rain rate for each station. The thick black line represents the average value across all stations. (rainy hours >= cool season 90th percentile threshold / rainy hours , averaged across AR1 AR2 and AR3 AR4 AR5 events)*

Method: Divide the number of hours with precipitation observations >= to the cool season 90th percentile precipitation rate during an AR by the number of hours with precipitation observations > 0 during the AR, then average the values for AR1, AR2 and AR3, AR4, AR5 bins at each station. The black line is the average of the values across all stations (columns).

D.6 Additional Details on Diagnostic tools that provide guidance on the influence of key storm mechanisms in forecast models

While extreme precipitation over the Santa Ana River watershed is predominantly governed by atmospheric rivers, additional meteorological mechanisms can impact the characteristics, distribution, and forecast performance of precipitation within atmospheric rivers (e.g., narrow cold-frontal rainbands, cutoff lows, etc.). Forecast diagnostics were developed to provide insight into the potential likelihood for such meteorological phenomena that can cause high-intensity precipitation, large-scale precipitation that is not tied to orographic features, and upstream events that may introduce forecast uncertainty downstream.

For example, two-dimensional Peterssen frontogenesis is now included in the suite of high-resolution West-WRF diagnostics to assist in identifying favorable environments for the development of narrow cold-frontal rainbands and, therefore, high-intensity precipitation. NCFRs generally form and intensify in the vicinity of a strengthening (frontogenetic) cold front and recognizing the potential for these features at longer lead-times will provide essential decision support for an ARs range of impacts.

- Additional forecast diagnostics were developed from NCEP Global Forecast System data, including:
- Two-dimensional Pettersen Frontogenesis and Temperature advection for the purposes described above. (Figure D-17)
- Potential vorticity, 250-hPa wind speeds, and irrotational winds to assist in identifying upstream events that can lead to forecast uncertainty over California (Figure D-18)
- 700-hPa Q-Vector and Q-Vector convergence to identify regions where synoptic-scale conditions are favorable for precipitation that is not tied to upslope moisture flux

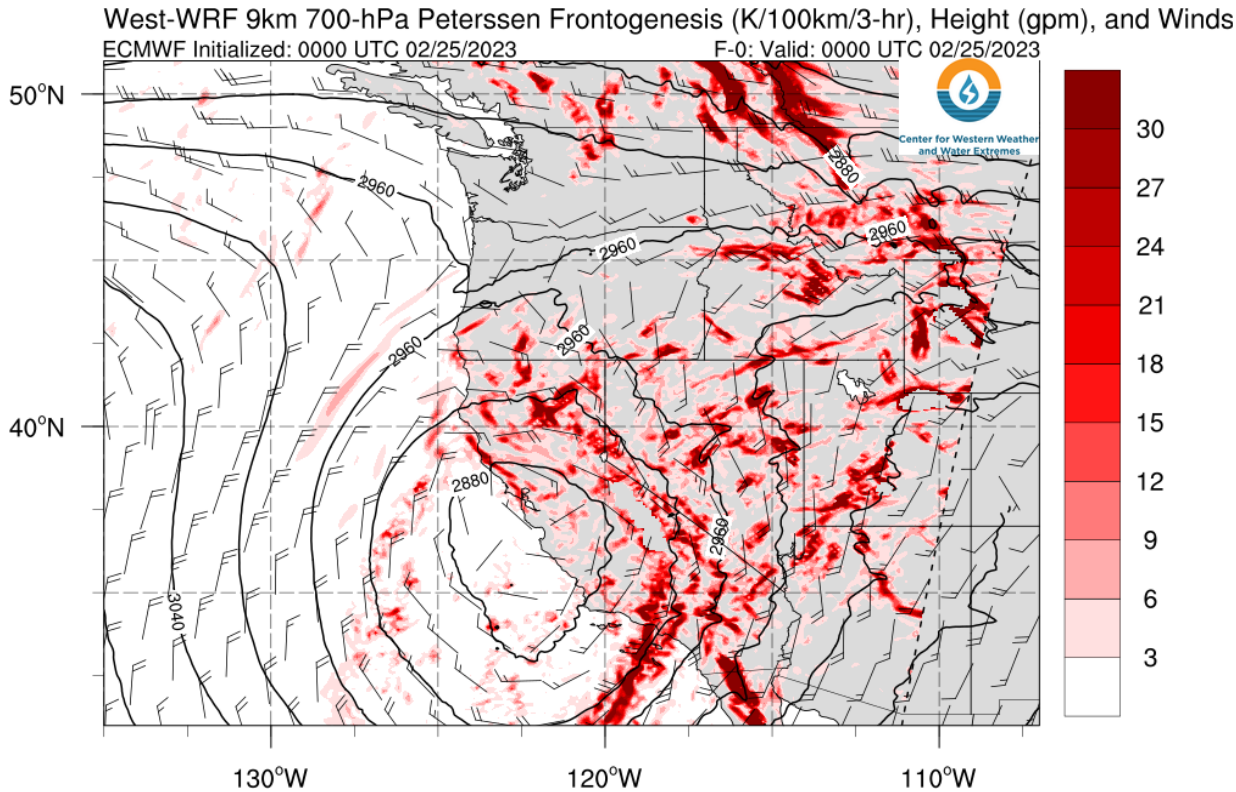


Figure D-17. *Example forecast image of ECMWF West-WRF two-dimensional Pettersen frontogenesis (shaded; K/100km/3-hr) for the Atmospheric River that impacted Southern California on the 25th of February 2023.*

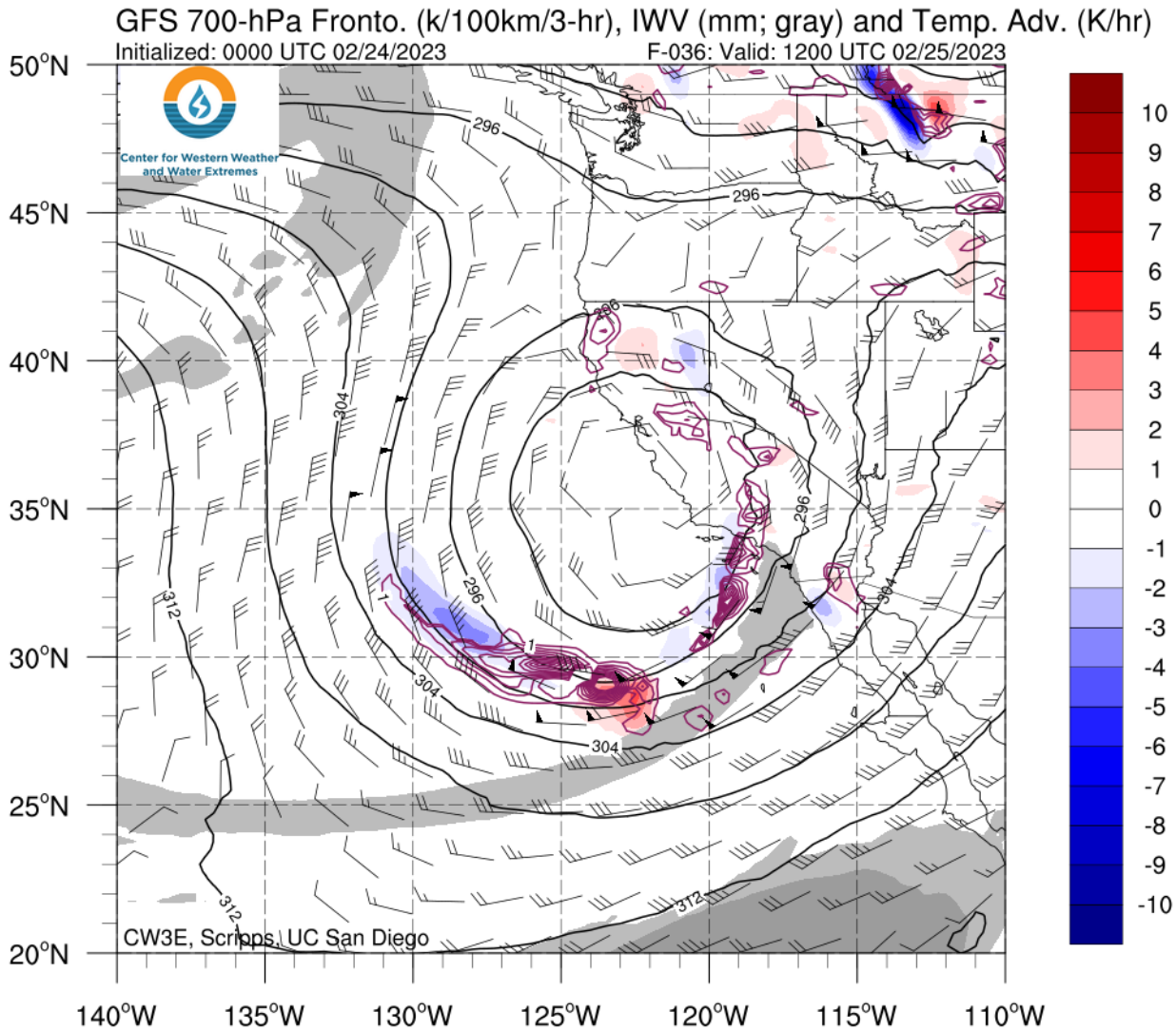


Figure D-18. Example forecast image of GFS two-dimensional Pettersen frontogenesis (purple contour; K/100km/3-hr), temperature advection (color shade; K/hr), geopotential height (dam; black contour), and integrated water vapor (mm; gray shade) for the Atmospheric River that impacted Southern California on the 25th of February 2023.

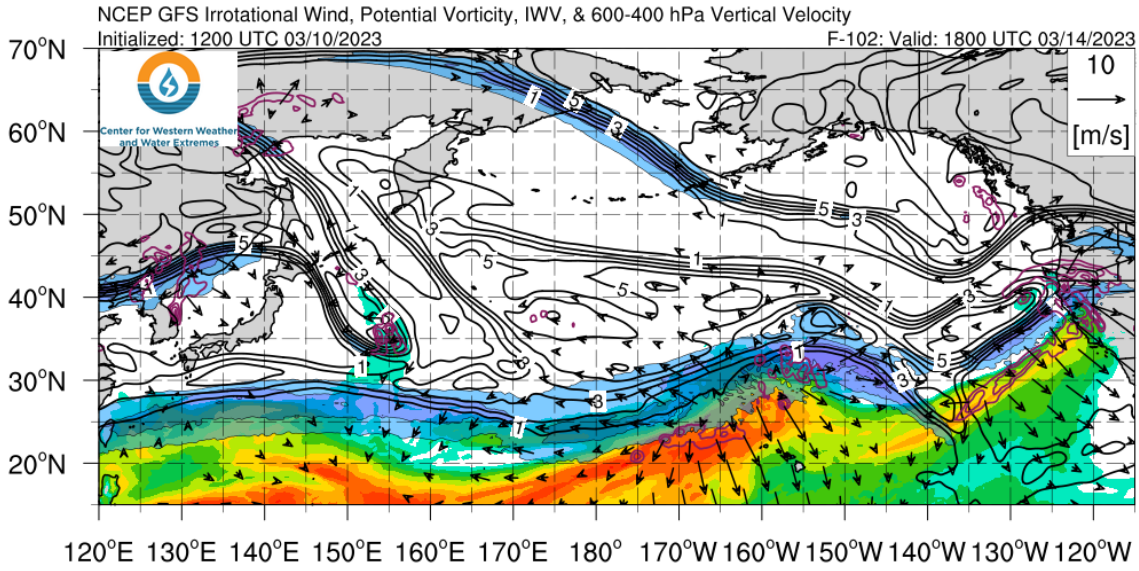


Figure D-19. *Example forecast image of GFS 250-hPa potential vorticity (pvu), 250-hPa wind speed (m/s), 300–200-hPa layer average irrotational wind vectors (m/s), and integrated water vapor (mm) for the atmospheric river that impacted California on the 14th of March 2023.*

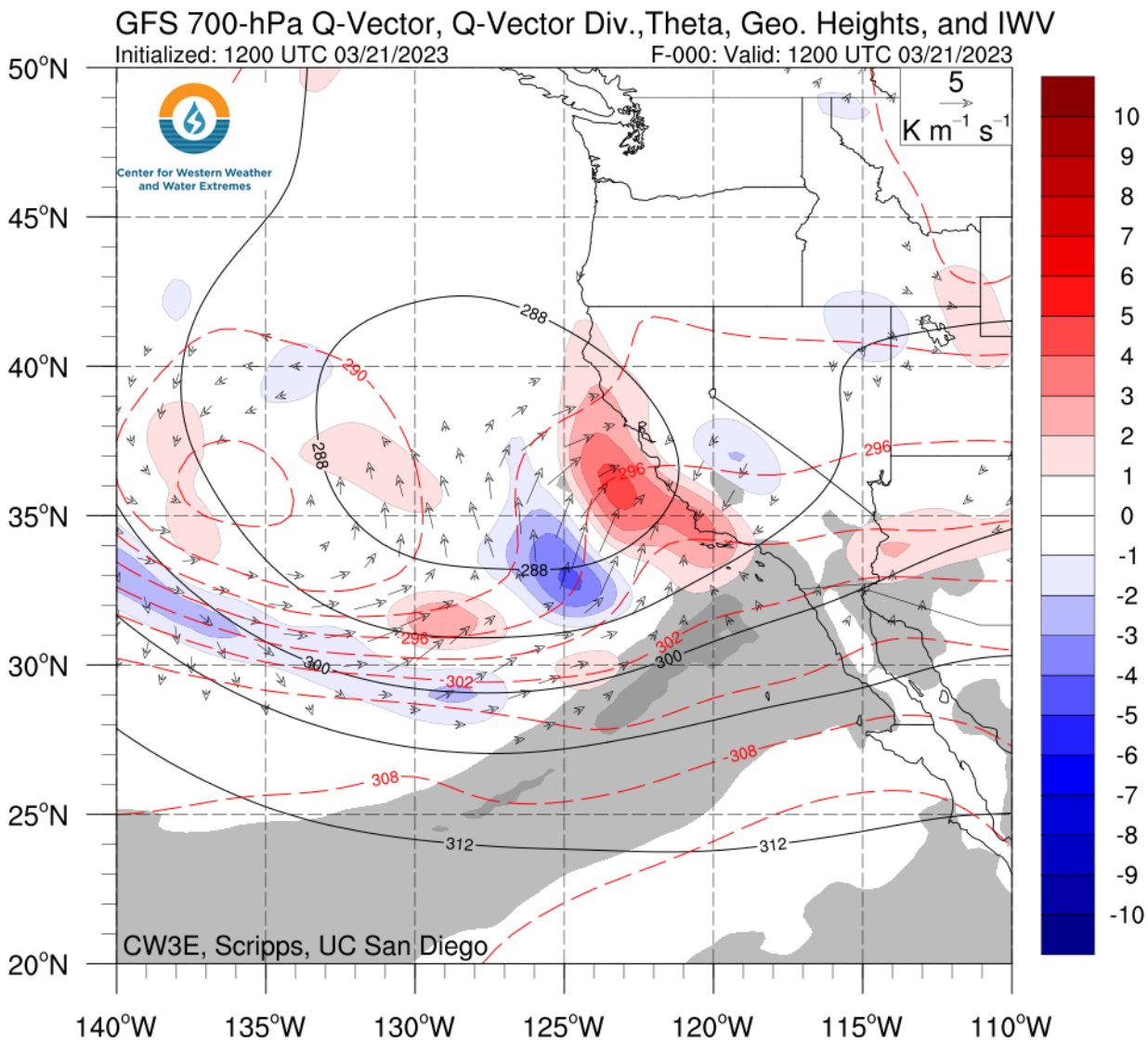


Figure D-20. *Example forecast image of 700-hPa Q-Vectors (vector 10^{-7} Pa m^{-1} s^{-1}) , Q-Vector Convergence (10^{-12} Pa m^{-2} s^{-1}), potential temperature (K; red contour), geopotential height (dam; black contour), and integrated water vapor (mm, gray shading) for the atmospheric river that impacted Southern California on the 21st March 2023.*

D.7 Additional Details on AR Recon Program and data assimilation in Numerical Weather Prediction

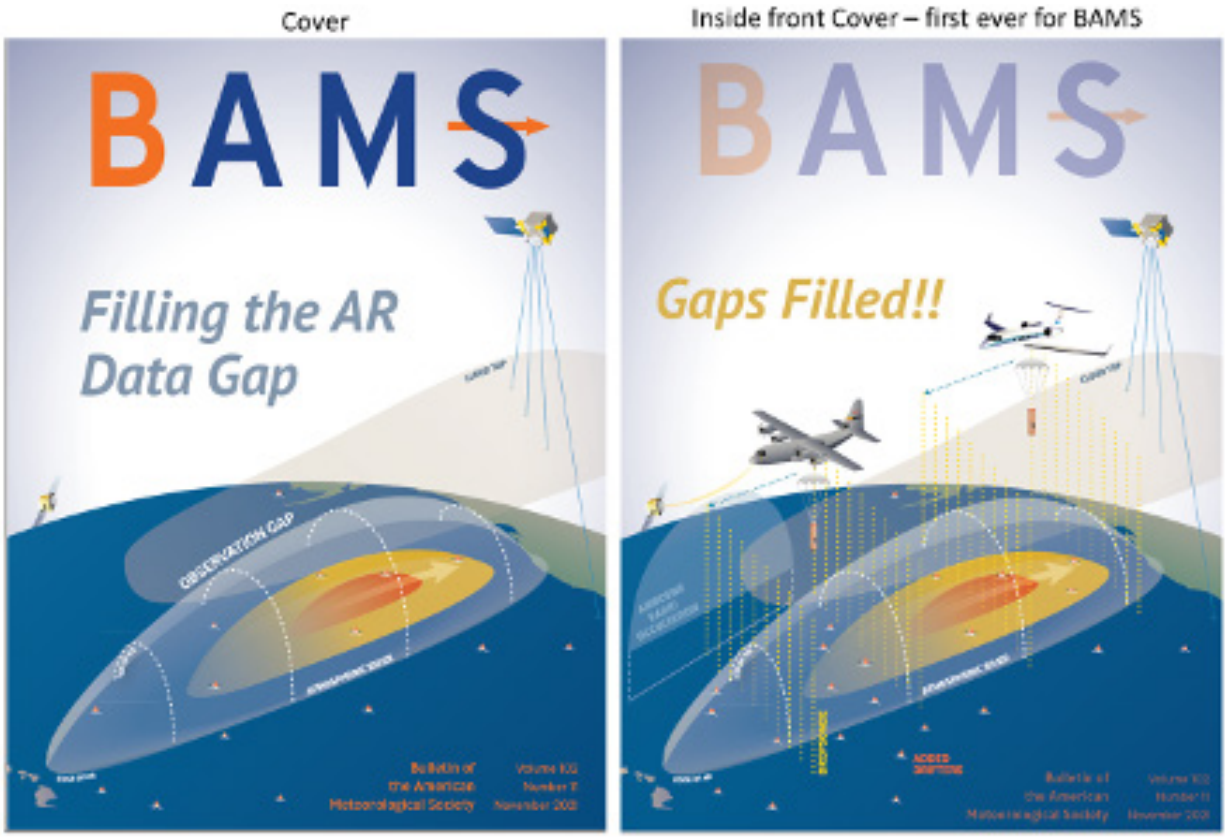


Figure D-21. *The cover of the Bulletin of the American Meteorological Society illustrates how AR Recon fills observation gaps directly upstream of coastal watersheds like the Santa Ana (Zheng et al., 2021b).*

ARs are the primary drivers of both flooding and water resources in the west. Improving the forecast accuracy of ARs can further enhance the benefits of FIRO at Prado Dam. One of the main sources of forecast error and uncertainty is the AR and nearby conditions offshore, which represent a critical gap in the standard observation network that AR Recon addresses (Figure **D-21**). Global weather models operated by the NWS, US Navy, and EU (among others) assimilate AR Recon data with demonstrable evidence that collected observations improve representation of ARs over the North Pacific, improve forecasts of precipitation downstream over western North America, and provide both complementary and additive benefits to satellite-derived data collection techniques. Specific results regarding the impacts of data collected by AR Recon on forecasts published in peer reviewed literature are listed below:

- AR Recon dropsonde per observation impact is more than double that of the individual observations in North American Radiosonde network, with *global* reduction in forecast error per flight comparable to the entire North American Radiosonde network (Stone et al., 2020).

- AR Recon dropsonde observations are crucial in identifying model deficiencies, including elucidating biases in temperature, humidity, and water vapor flux dispersiveness within ARs in the ECMWF IFS model (Lavers et al., 2020).
- AR Recon dropsonde observations improve the three-dimensional structure of ARs and water vapor transport in ECMWF model forecasts (Lavers et al., 2018).
- AR Recon dropsonde observations improve atmospheric forecasts by a greater contribution per observation than that of an individual satellite instrument. Heavy rainfall forecasts are better when assimilating both dropsonde and satellite radiance observations (Sun et al., 2022).
- AR Recon dropsonde observations reduce overall errors in AR water vapor flux and inland precipitation at forecast lead times from 1 to 6 days, with largest improvement of inland precipitation forecast skill associated with back-to-back flights every other day (Zheng et al., 2021a).
- AR Recon observations improve geographical distribution of forecasted precipitation at lead times of ~3 to 5 days by 5-15% over full western US and by 10-20% over Pacific Northwest and Northern California when dropsonde data is assimilated into the NCEP Operational Global Forecast System model (Lord et al., 2022a).
- AR Recon observations improve atmospheric river, wind, humidity and precipitation forecasts over the U.S. West Coast by improving low-altitude moisture fields (Lord et al., 2022b.

D.7.1 References

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D.8 Additional Details on High-resolution probabilistic precipitation forecasts and data visualizations

The development and implementation of the 200-member West-WRF ensemble is a significant milestone to CW3E's ability to provide near real time forecast information and allows for additional probabilistic forecast capabilities. CW3E developed a suite of forecast products utilizing the West-WRF ensemble output to produce percentile based and probabilistic forecasts of Atmospheric Rivers, Integrated Vapor Transport, the AR Scale, precipitation, snowfall, wind, temperature, and atmospheric moisture.

One such example displays the probability of 24-hour precipitation to be greater than 3 inches (Figure D-22). This format of map is available for multiple variables, domains, and accumulation times ranging from 15-minutes to 72-hours for lead times up to 7-days. Similar maps are also produced for a percentile based forecast to allow the user to see the full spread of ensemble members and forecasted extremes.

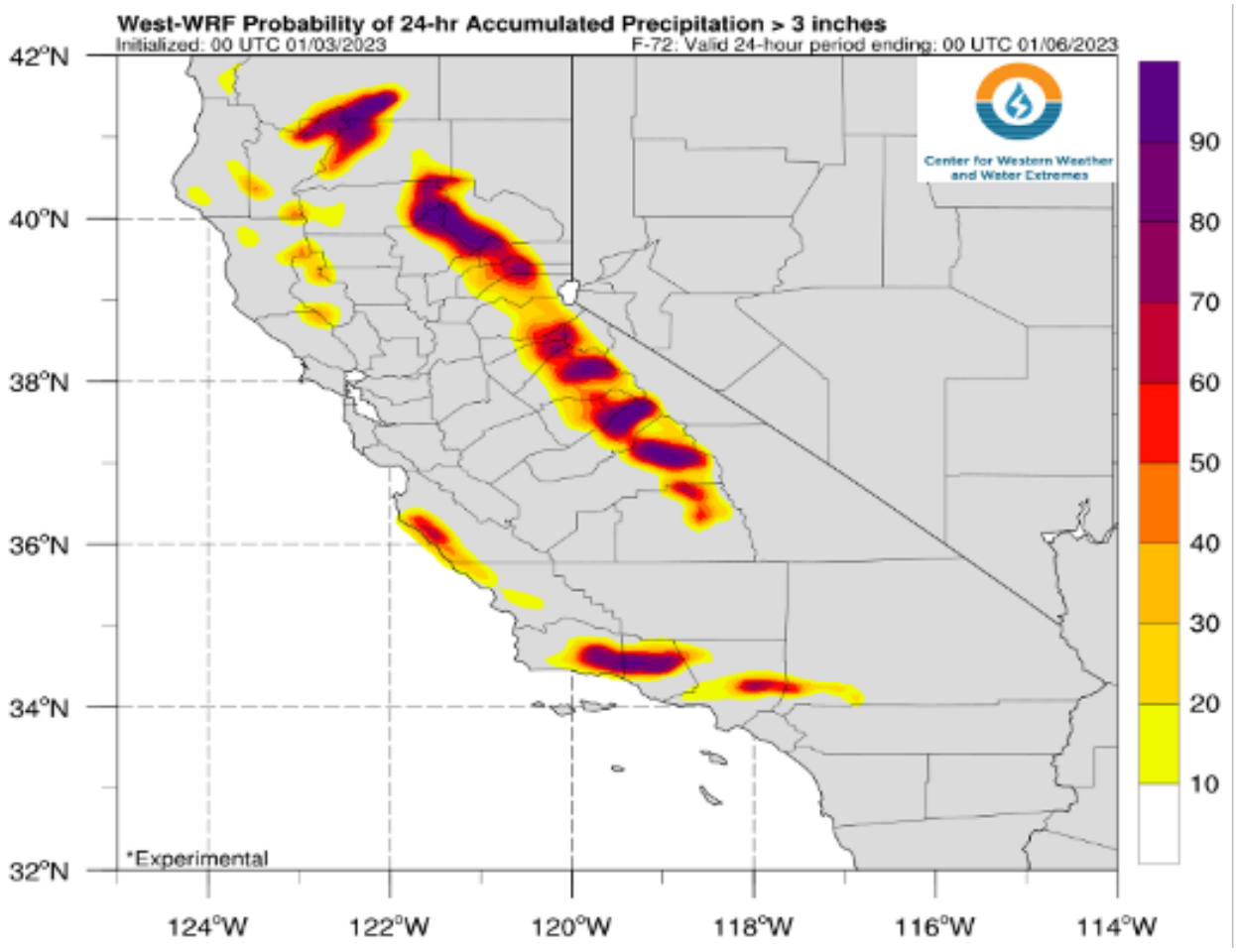

Figure D-22. *West-WRF forecast of the probability of 24-hour precipitation to be greater than 3 inches. Probability is calculated by the number of ensemble members predicting QPF to be greater than 3 inches during the 24-hour period. Model initialized 00 UTC 3 January 2023, forecast valid 00 UTC 5-6 January 2023.*

Probabilistic forecasts for specific locations have also been developed displaying the AR Scale, precipitation, snowfall, temperature, and wind speeds. These products display a time series of the chosen variable, forecasts from each ensemble member, as well as a probabilistic forecast of various thresholds being exceeded (Figure D-23). In addition to these new tools several existing tools previously deployed using global numerical weather models have been adapted and designed to display the West-WRF ensemble including the CW3E AR Landfall tool, IVT plume diagrams, and multiple AR Scale diagnostic tools. All products are available online at https://cw3e.ucsd.edu/west-wrf_ensemble/.

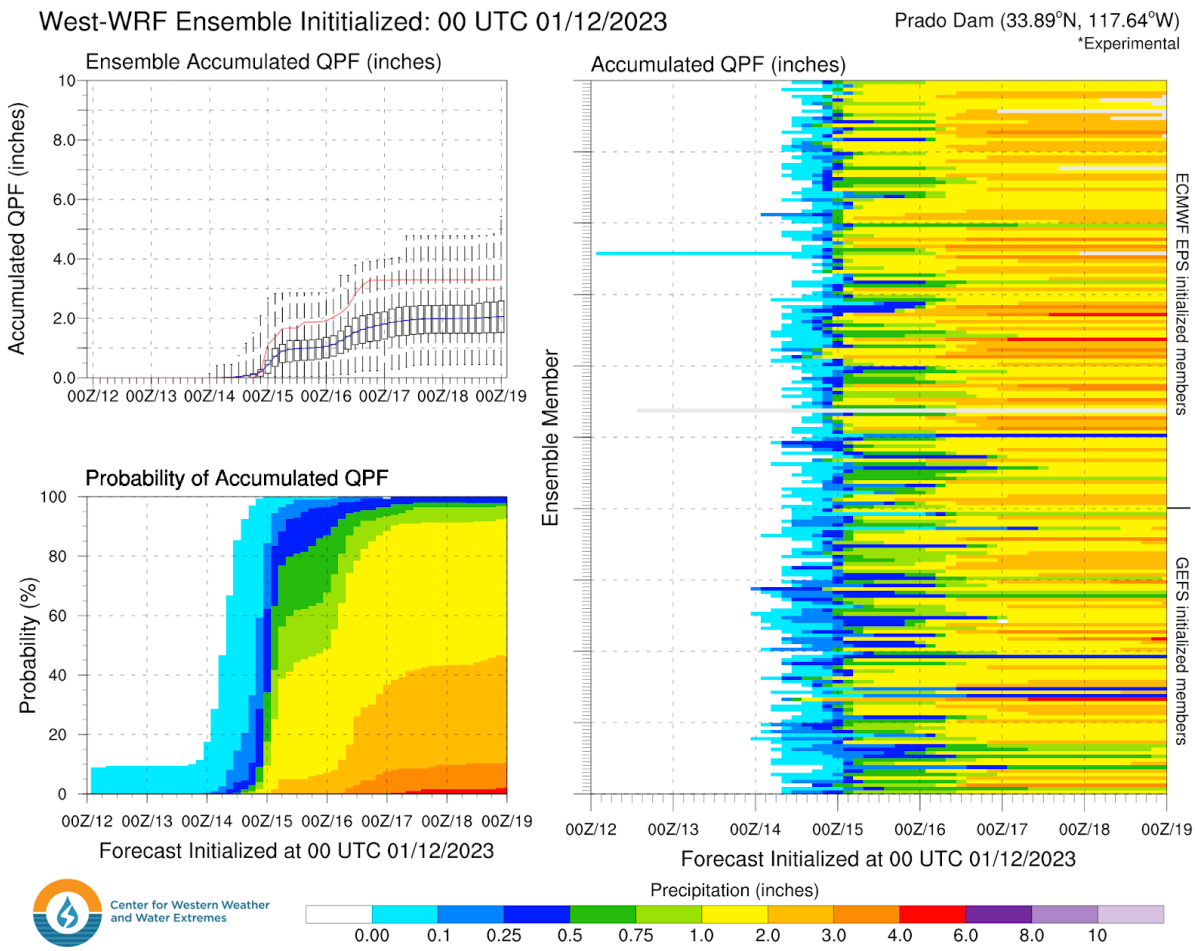

Figure D-23. *West-WRF 24-hour QPF for Prado Dam initialized 00 UTC 12 January 2023. Top left: Box plot of 24-hour QPF for lead times up to 7 days. Bottom left: Probability of 24-hour precipitation to be greater than various thresholds (according to color bar) calculated by the number of ensemble members predicting QPF over each threshold. Right: 24-hour QPF from each West-WRF ensemble member (y-axis) colored according to scale.*

In Figure D-23, the red line in the upper left represents the gauge observations of 3-hourly precipitation from the site near Prado Dam. While the West-WRF ensemble mean (and much of the ensemble) under forecasts both waves of precipitation, the timing is consistent, and the observations fall within the ensemble spread. With ~3 inches of observed precipitation through the 2/12 00Z to 2/19 00Z period, the probability of this from the ensemble was around 10% (lower left plot). The corresponding Stage-IV observed accumulated precipitation for the period 1200 UTC 12-18 January 2023 and West-WRF 90th percentile precipitation accumulation are found in Figure D-24. The ensemble mean underestimates accumulation across most of Southern California and the Coastal Ranges to the north (not shown). The ensemble 90th percentile accumulated precipitation generally captures the maxima throughout Southern California. This analysis shows the benefits of an ensemble forecasting approach, as the observed precipitation at Prado Dam (gauge analysis) and Stage IV QPE across Southern California are represented as possible (albeit unlikely) model solutions, compared to a deterministic forecasting approach where the observations and QPE would likely not be captured in the model solution.

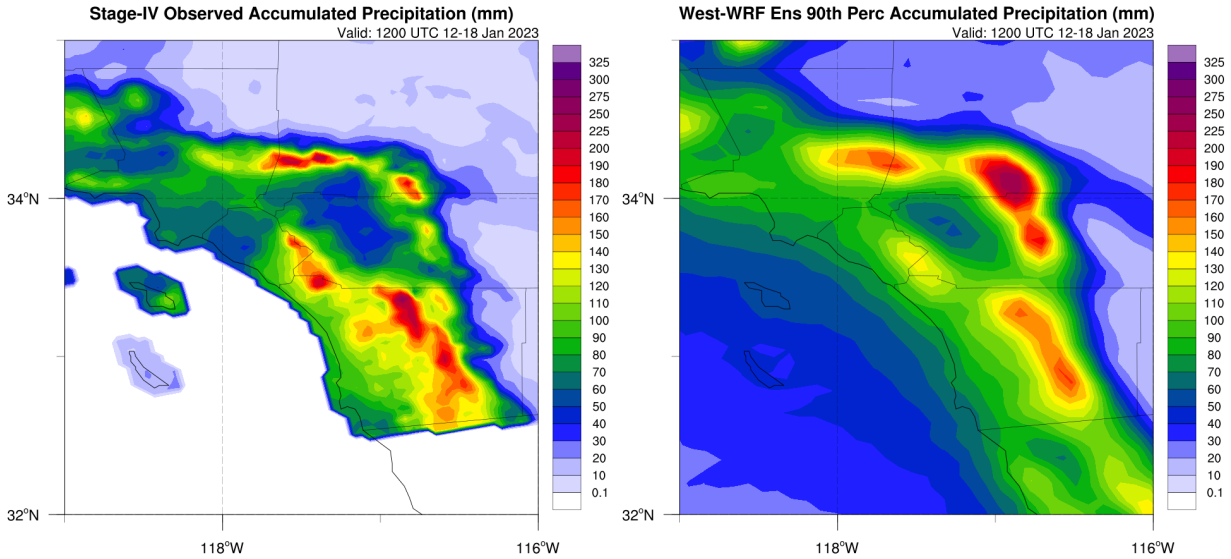

Figure D-24. *(left) Total precipitation (inches) for the period 1200 UTC 12-18 January 2023 from the Stage-IV precipitation dataset, and (right) West-WRF 90th Percentile Accumulated Precipitation (inches)*

D.9 Additional Details on Machine learning to improve reliable probabilistic predictions

The value of accurate precipitation forecasts cannot be overstated for California, which experiences uniquely high variability in precipitation governed by the presence or absence of a relatively small number of large storms, typically landfalling atmospheric rivers (ARs) in the winter months. Quantitative precipitation forecasts (QPFs) provide crucial information to water managers for mitigating urban, riverine, and flash flood risks. In addition, reliable precipitation forecasts have the potential to guide decisions related to reservoir, agricultural, and irrigation management.

In this context, forecasts from numerical weather prediction (NWP) models have a prominent role in informing better decision-making. NWP models are based on our best understanding of the dominant physical processes and the most advanced numerical procedures to integrate the equations describing atmospheric evolution. However, they are contaminated by errors in initial conditions, numerical approximations, incomplete understanding of underlying physical processes, and the inherent chaotic nature of the atmosphere.

A significant portion of NWP model errors can be recovered in a post-processing framework. Recent advancements in artificial intelligence (AI) and machine learning (ML) are enabling us to train algorithms that learn the dynamical model behavior over a historical period when predictions from the same model and observations of the quantity of interest are available. These algorithms can leverage the valuable information provided by NWP and learn a significant portion of their biases, resulting in improved forecasts and reliable uncertainty quantification.

CW3E has been developing state-of-the-art ML algorithms to improve predictions of extreme weather events over the Western U.S., with an emphasis on the prediction of integrated vapor transport (IVT) and precipitation associated with ARs.

D.9.1 Applying Deep Learning on CW3E's 34-year Deterministic West-WRF Reforecast dataset (Hu et al. 2023)

A deep learning architecture, Unet, has been applied for post-processing deterministic NWP predictions of precipitation and generating 0-5-day daily accumulated precipitation forecasts (Figure D-25). The novel deep learning framework was tested against state-of-the-art benchmark methods, including an Analog Ensemble, non-homogeneous regression, and mixed-type meta-Gaussian distribution. The Unet was found to outperform the benchmark methods at all lead times, as measured by Continuous Ranked Probability and Brier skill scores, while producing a reliable estimation of forecast uncertainty, as measured by binned spread-skill relationship diagrams. Additionally, the Unet was found to have the best performance for extreme events, i.e., the 95th and 99th percentiles of the distribution.

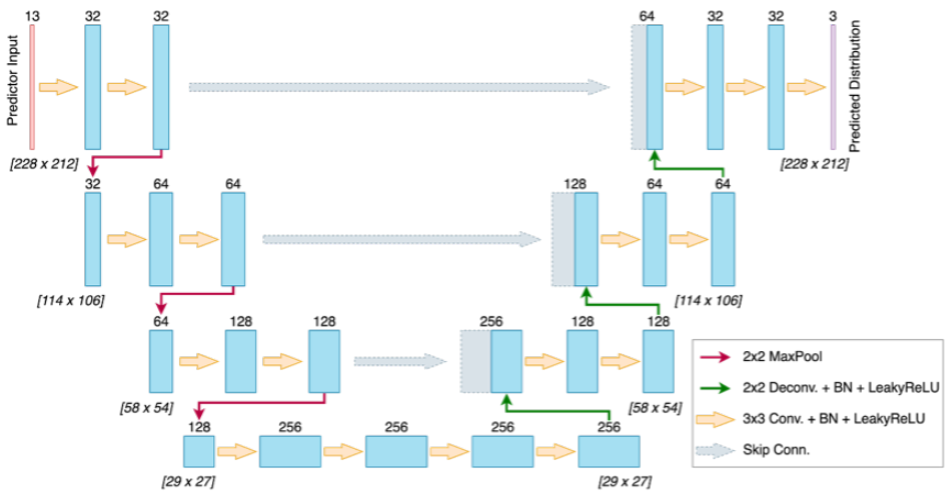

Figure D-25. Designed Unet Model Architecture.

For the intense wet period of Dec 2022-Jan 2023, during which a family of ARs affected the U.S. West, the performance of the Unet over the Prado basin is illustrated in Figure D-26 vis-à-vis dynamical models, e.g., GEFS, ECMWF, and the West-WRF, through a display of the Continuous Ranked Probability Score (CRPS). CRPS is an error metric, which calculates the area between the forecasted cumulative distribution function and the indicator function defined by the ground truth, with a **lower score indicating a higher accuracy**. For the period of assessment (12/30/22-1/16/23), the deterministic West-WRF model post-processed with deep learning (West-WRF + Unet) exhibits the lowest error score (4.36 mm) and outperforms the other three dynamical models.

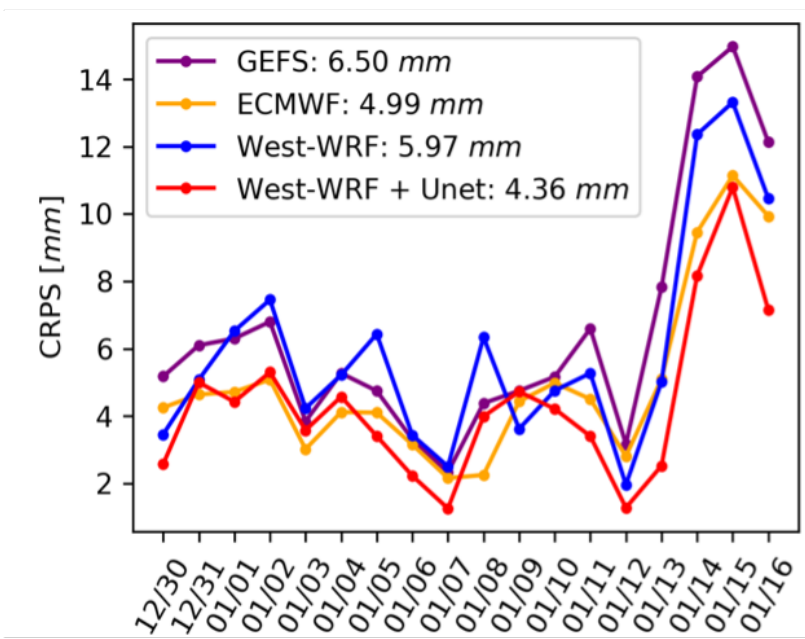

Figure D-26. Comparison of model skill over Prado Basin during Winter 2022-23.

D.9.2 Application of Deep Learning on CW3E's 200-member West-WRF NRT Ensemble

In this application, we utilize NWP outputs from the 200-member ensemble of a customized version of the Weather Research and Forecasting (WRF) model, named West-WRF, developed by CW3E that is run in near-real-time (NRT) forecast mode at 9-km resolution in support of decision making and scientific research of extreme weather events over the Western U.S. The deep learning application involves an Artificial Neural Network-Censored, Shifted Gamma Distribution model (ANN-CSGD; Ghazvinian et al. 2022) for generating post-processed, high-resolution, probabilistic precipitation forecasts for lead times up to 7 days.

The application of this deep learning technique improves the skill of the raw forecast (Figure D-27) as it maintains the high precipitation event probabilities while reducing the locational biases. Furthermore, the deep learning-based post-processed West-WRF forecast (shown in purple; Figure D-36) outperforms the ECMWF (shown in green) by ~15% when aggregated over the Prado basin for the period of assessment (Dec 2021 - Mar 2022), from lead time of 1 to 6 days.

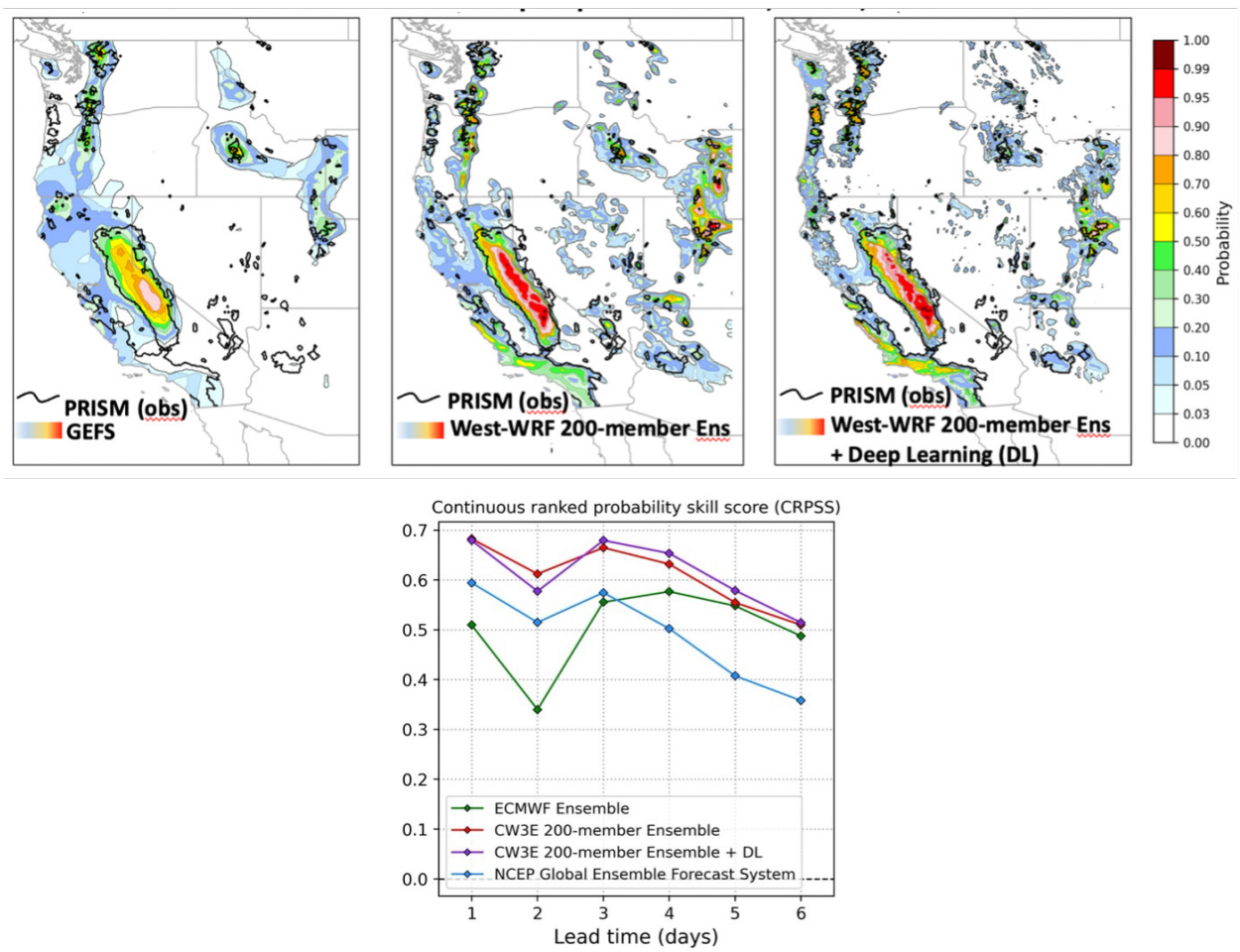

Figure D-27. *Skill Comparison among GEFS, West-WRF, and West-WRF+ML.*

D.9.3 References

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D.10 Report on Summarizing the skill of the AR Landfall Tool in GFS and ECMWF ensemble forecasts for southern California following the publication of Stewart et al. (2022)

A Report Evaluating the WY2017–2020 skill of the "AR Landfall Tool" in Southern California by Jason M. Cordeira, *Center for Western Weather and Water Extremes, UCSD/Scripps,* July 2022

D.10.1 Introduction

D.10.1.1 Motivation

Atmospheric Rivers (ARs) are long and narrow regions of enhanced integrated water vapor transport (IVT) that can influence the occurrence of precipitation-related high-impact weather events along U.S. West Coast such as floods and flash floods (e.g., Young et al. 2017). Landfalling ARs may also influence the occurrence of extreme wind events (Waliser and Guan 2017) and increase the likelihoods of shallow landslides and debris flows (Oakley et al. 2018). The potential for hazardous weather associated with landfalling ARs can be summarized by (1) National Weather Service-issued watches, warnings, and advisories (WWAs) where 60–90% of flood-related WWAs in the Western U.S. occur on days with cool-season landfalling ARs (Bartlett and Cordeira 2021) and (2) damage claims in the National Flood Insurance Program where ARs have caused an average of $1.1 billion in flood damages annually across the Western U.S. (Corringham et al. 2019). Due to the causal relationship between landfalling ARs and the potential for hazardous weather across the western US, reliable and skillful forecasts of landfalling ARs are critical to hazard preparation, risk mitigation, and water resources management (e.g., DeFlorio et al. 2018; Ralph et al. 2020; Cordeira and Ralph 2021).

D.10.1.2 Goal

The goal of this report is to summarize the cool-season skill of the European Centre for Medium-Range Weather Forecasts (ECMWF) Ensemble Prediction System (EPS) and the National Centers for Environmental Prediction (NCEP) Global Ensemble Forecast System (GEFS) model forecasts of enhanced IVT along the Southern California coast for water years (WY) 2017–2020 that is often observed during landfalling ARs. This report complements previous studies by Cordeira and Ralph (2021) and Stewart et al. (2022) that summarized model forecast skill along the North America West Coast and focused on a point in coastal Northern California at 38N, 123W near Bodega Bay. This report uses the data contained in these past studies and focuses on a point in coastal Southern California at 33N, 117.5W near Irvine at the outlet of the Santa Ana River.

D.10.1.3 Methods

The Stewart et al. (2022) study used 0.5° latitude × 0.5° longitude gridded forecast data along the west coast of North America (25°–55°N) from the GEFS and the EPS models verifying during October–April of WY 2017, 2018, 2019, and 2020. Data were primarily collected from The Interactive Grand Global Ensemble (TIGGE) database at ECMWF with additional details regarding collection of forecast data provided within Cordeira and Ralph (2021) and Stewart et al. (2022). The forecast data include what fraction of the 20 (GEFS) and 50 (EPS) ensemble members contained forecast IVT magnitudes ≥250 kg m^{-1} s^{-1} (i.e., the probability of IVT

magnitudes ≥250 kg m^{-1} s^{-1}; P_{250}) and compares those values to the IVT magnitude at verification. The probability of IVT magnitudes ≥250 kg m^{-1} s^{-1}, or as it's referred to in this study as P250, can be depicted along the North American coastline as a function of forecast lead time in what is known as the "AR Landfall Tool" (Cordeira et al. 2017). An example of the AR Landfall Tool ahead of the February 2019 landfalling AR is shown in Fig. 1.

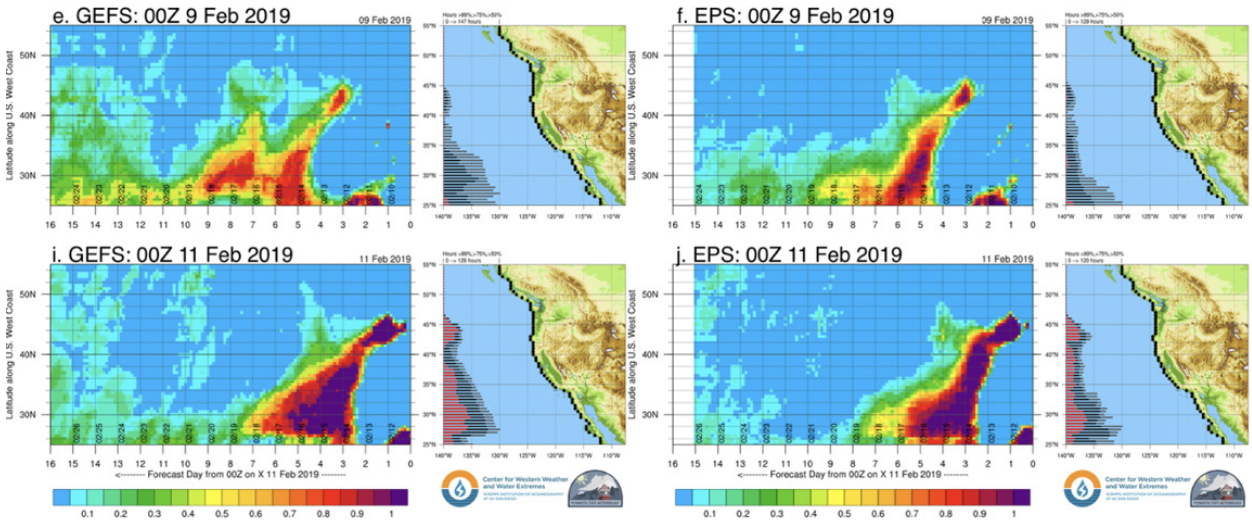

Figure D-28. Selected forecasts of the coastal ensemble probability of IVT magnitude ≥250 kg m^{-1} s^{-1} (shaded according to scale) initialized daily at 0000 UTC on 9 and 11 February 2019 for the (left) GEFS model out to 16 days and (right) EPS model out to 15 days. Coastal latitudes are shown in the right-most panels of each image and topography is shaded every 100 m using a blue-green-brown-white color scale. The gray, black, and red bars in these panels represent the number of hours that probability values exceed 75, 90, and 99% and are not used in this study. These panels (e, i, f, and j) are cropped from Figure D-28 of Stewart et al. (2022).

Verification of P_{250} and the AR Landfall tool in Stewart et al. (2022) followed the methodology of Cordeira and Ralph (2021) and is defined as the 0-h ensemble-mean IVT magnitude forecast from each ensemble. In this way, the model forecasts were scored against themselves in lieu of comparing each model forecast to an independent reanalysis (e.g., the EPS forecasts are verified against the EPS 0-h ensemble mean). Note that forecast skill in this study was analyzed every 12 hours as opposed to every six hours as in Cordeira and Ralph (2021) given the 12-hour availability of the 0-h EPS ensemble-mean IVT magnitude forecasts. There were four upgrades to the EPS and zero upgrades to the GEFS model system during the period of study (see Table 1 of Stewart et al. 2022). The subsequent comparisons of the two model systems in their study and in this report should emphasize that while overall model skill remained constant for the GEFS, it may have improved for the EPS. In other words, variability in skill in the EPS may not be attributed to meteorology alone and their study and in this report therefore assessed the "operational" skill of the models.

As in Cordeira and Ralph (2021), forecast skill in Stewart et al. (2022) was assessed using a four-outcome contingency table of whether P_{250} forecasts exceeded a percentage threshold e , 0 and whether a verification time contained IVT ma nitudes 2 0 m^{-1} s^{-1}. The success ratio, probability of detection (POD), and equitable threat score (ETS) are calculated

from the contingency table at different lead times which are complemented by reliability diagrams and the Brier skill score (BSS). Descriptions of each skill metric is provided in context with the results in the next section.

D.10.1.4 Previous work by Stewart et al. (2022)

Analysis of dProg/dt for the GEFS and EPS P_{250} forecasts prior to verification times with IVT ma nitudes 2 0 m^{-1} s^{-1} in coastal regions of northern California (38°N, 123°W) indicated that EPS P_{250} forecasts provided ~1-day of additional lead-time guidance for situational awareness over the GEFS at lead times of 6–10-days. Reliability of all P_{250} forecasts from the EPS and GEFS models at 38ºN demonstrated that the P_{250} forecasts at leads times through ~9 days were on average reliable; however, the EPS was overall more reliable than the GEFS at lead times >9 days. The EPS had higher forecast skill with success ratios that were 0.10 to 0.15 higher than the GEFS at lead times >6 days for P_{250} thresholds of 2 and 0 , and days for P_{250} threshold with similar differences for P_{250} 0 as a function of latitude alon the west coast of orth America When accountin for success via random chance, the TS values su ested that differences between the PS and FS P_{250} forecasts largely arise for P_{250} thresholds 2 and 0 for leads times between –8 days at 38ºN and are more widespread at different lead times elsewhere along the coast for P_{250} 0 The TS difference is lar est alon the coast of re on and Washin ton where AR fre uency is hi hest, su estin that the FS may attribute at least some of its s ill in this re ion to random chance and its lac of s ill to false alarms

The event-based skill analysis demonstrated that the POD for both models was largely similar at 38ºN with (1) improvements in POD for P_{250} prior to more intense events as compared to less intense events and (2) minor latitudinal variations favoring higher POD in the EPS along the coast of Washington and Oregon and higher POD in the GEFS along the coast of Mexico. The BSS illustrated that the EPS contained higher skill at lead times of ~6–10 days than the GEFS in forecasting events and non-events at 38ºN. The BSS of the EPS was also higher than the GEFS by ~0.10 for most locations along the West Coast of North America at lead times >1 day, and for a given BSS value, the EPS led the GEFS by ~0.5 days at lead times of 3–5 days and by ~1.0 days at lead times of 5–10 days. Overall, the EPS and GEFS P_{250} forecasts contained largely similar skill at lead times <6 days and >10 days, whereas the EPS contained better skill at lead times of ~6–8 days at 38ºN. These lead times do vary by latitude, but overall favored the EPS. Given the largely similar POD values, yet differences in success and ETS, it appeared the EPS provides more skillful P_{250} forecasts owing to a lower false alarm ratio in Northern California.

The results of Stewart et al. (2022) were applied to forecasts of landfalling ARs to enhance situational awareness, and applications such as FIRO (Ralph et al. 2019). In coordination with FIRO, forecasts within a 3–5-day lead time are typically used to determine the likelihood and strength of an upcoming AR and its precipitation, which support decisions on how best to manage water within a FIRO-supported reservoir. Their study suggested that both the EPS and GEFS P_{250} forecasts provided on average similar measures of skill for periods of enhanced IVT associated with a landfalling AR at leads times <6 days and were likely equally useful in this decision-making process. However, the EPS P_{250} were on average more likely to provide better guidance at lead times >6 days, potentially in supporting decisions as to whether a second event is likely at longer lead times. This result was supported by the BSS of P_{250} forecasts at leads times – days that indicated that the PS rovides more s illful robabilistic forecasts

than the FS for both events with IVT ma nitudes 2 0 m^{-1} s^{-1} and non-events with IVT magnitudes <250 kg m^{-1} s^{-1}.

D.10.1.5 Summary of Results focusing on Southern California

Forecast characteristics and reliability

For all the cool-season WYs examined in this report, 117 of 1698 (~6.9%) and 121 of 1698 (~7.1%) 12-hour times (i.e., initializations) verified with IVT magnitudes ≥250 kg m^{-1} s^{-1} at 33ºN, 117.5ºW for the EPS and GEFS, respectively (Figure D-29). These values are ~10 percentage points lower than in Northern California at 38ºN (i.e., this result iterates the well-known fact that ARs are not as likely in southern California as compared to northern California). The difference in the number of verification times indicates that each model is verified against a slightly different but overwhelmingly similar set of events. WY17 contained most of the verification times (>50 in each model), while WY18, WY19, and WY20 contained ~25–50% fewer verification times meeting the minimum IVT magnitude criteria in this study.

	All Verification Times			WY2017			WY2018			WY2019			WY2020		
Model	All	Verif	[%]	All	Verif	[%]	All	Verif	[%]	All	Verif	[%]	All	Verif	[%]
GEFS	1698	121	7.1%	424	55	13.0%	424	26	6.1%	424	24	5.7%	426	16	3.8%
EPS	1698	117	6.9%	424	51	12.0%	424	24	5.7%	424	26	6.1%	426	16	3.8%

Figure D-29. *Number of verification times and verification times with IVT magnitudes ≥ 250 kg m^{-1} s^{-1} during the study period and during each WY for the EPS and GEFS at 33N, 117.5W*

The frequency of P_{250} forecast values ≥50% and ≥75% in each model as a function of lead time are approximately the same as the frequency of event times with IVT magnitudes ≥250 kg m^{-1} s^{-1} at short lead times and decreases as lead time increases (Figure D-30). The lower frequency of P_{250} forecast values ≥50% and ≥75% at longer lead times suggests under-forecasting that would be consistent with a lower POD at longer lead times. Alternatively, the frequency of P_{250} forecast values ≥25% is higher than the frequency of event times with IVT magnitudes ≥250 kg m^{-1} s^{-1} at leads times out to ~8–10 days. The large frequency of P_{250} forecast values ≥25% at these lead times suggests the potential for over-forecasting that would be consistent with a lower success ratio and higher false alarm ratio. This result at 33N is similar to results across northern California at 38N.

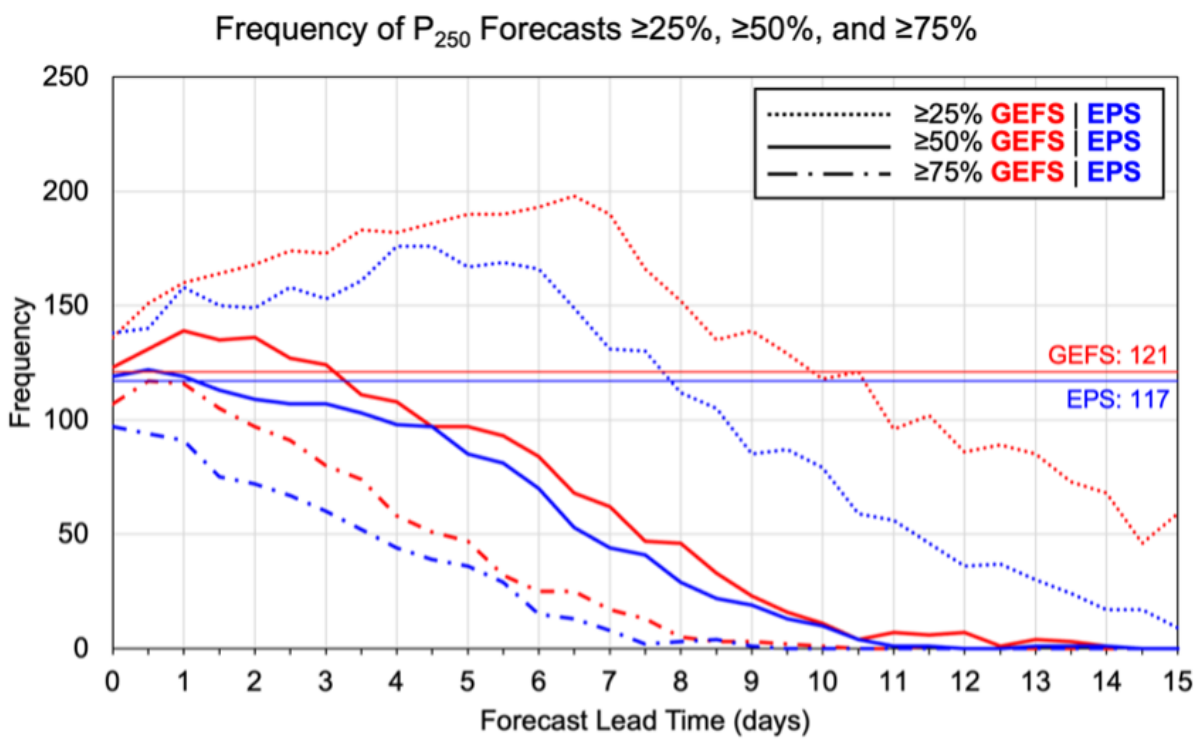

Figure D-30. *Frequency of the GEFS (red) and EPS (blue) P_{250} forecasts ≥ 25%, ≥ 50%, and ≥ 75% for all forecasts verifying every 12 hours at 33°N, 117.5°W. The number of verifying times with IVT magnitudes ≥250 kg m^{-1} s^{-1} in each model is shown as thin black horizontal lines.*

The statistical consistency of the EPS and GEFS IVT magnitude forecasts for (1) all forecasts and (2) for all forecasts specifically prior to verifying times with IVT magnitudes of 250–500 kg m^{-1} s^{-1} at , 11 W is shown via a dis ersion dia ram of the avera e ensemble s read i e , ensemble member standard deviation and avera e root mean s uare error R S of the ensemble-mean IVT magnitude forecasts (Figure D-31). Note that these relationships are influenced by both the underlyin s ill of the model forecasts and characteristics of ensemble spread in model forecasts of non-normally distributed IVT magnitude that favors non-events over events by a factor of 10 1 (Figure D-29 The avera e of all forecasts li ely misre resents the statistical consistency of forecasts rior to events with IVT ma nitudes 2 0 m^{-1} s^{-1} by including many low-magnitude spread forecasts prior to events with IVT magnitudes <250 kg m^{-1} s^{-1} that outnumber the former by >10:1 (Figure D-29). The ensemble spread of forecasts solely prior to verifying times with IVT magnitudes of 250–500 kg m^{-1} s^{-1} is still not comparable to the average RMSE for both models for lead times through ~6 days (i.e., not adequately dispersive) and then becomes very under dispersive thereafter as the models become less skillful and spread saturates at ~100 (Figure D-31 (b)). This result contrasts with the statistical consistency of forecasts at 38N studied by Stewart et al. (2022) who found the model was at least consistent through 6 days. The gap between the RMSE and spread in the GEFS is larger than the gap in the EPS forecasts at almost all leads times and is largest for forecasts verifying with IVT magnitudes of 250–500 kg m^{-1} s^{-1} and at lead times of >6 days, suggesting that the smaller GEFS ensemble may be characteristically more under dispersive than the larger EPS ensemble. These results suggest that the ensemble spread is on average not large enough to capture the average RMSE of all forecasts and subsets of forecasts prior to events in both

models, which implies that both the EPS and GEFS are under-dispersive across all lead times in southern California.

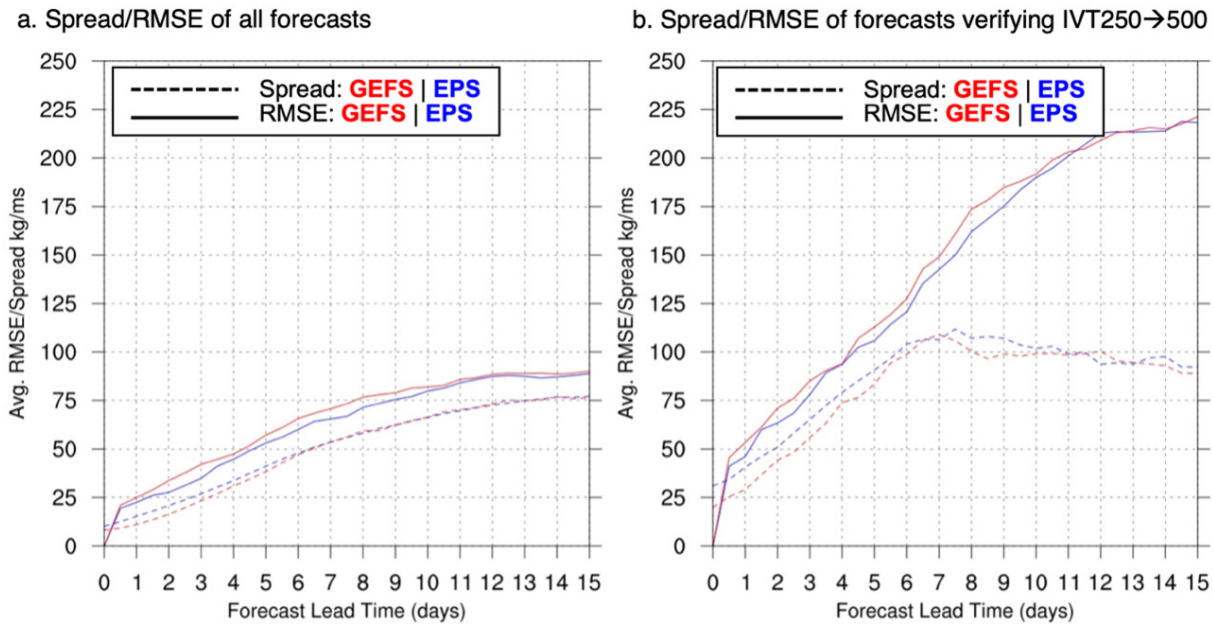

Figure D-31. The average ensemble spread and root mean square error (RMSE) of ensemble-mean IVT magnitude forecasts for (a) all times and (b) times verifying with IVT magnitudes of 250–500 kg m^{-1} s^{-1} for forecasts verifying every 12 hours. Solid lines represent the RMSE and dashed lines represent ensemble spread; (GEFS = red, EPS = blue).

dProb/dt

Analysis of the P_{250} forecast values as a function of lead time (dProg/dt) for the GEFS and EPS forecasts in each WY at 33ºN, 117.5ºW highlights both interannual, intraseasonal and inter-model variability (Figure D-32). For example, WY17 contained many forecasts with higher P_{250} than durin other water years owin to hi her AR activity Figure D-29 and Cordeira and Ral h 2021 that was common to both models When avera ed across all forecasts rior to verification times with IVT ma nitudes 2 0 m^{-1} s^{-1}, both the EPS and GEFS contain P_{250} values that increase relative to their model's climatology (here taken as the four-year average of P_{250}) at a lead time of ~10–12 days (Figure D-33; i.e., on average the ensemble is providing some measure of enhanced situational awareness relative to climatology 10 days prior to events). Forecasts increase above the following thresholds at the following lead times:

- Both models cross above the 25% P_{250} threshold at a lead time of ~8 days. This lead time is ~0.5 days shorter than the GEFS analysis for 38N near Bodega Bay and 1.5 days shorter than the EPS at 38N.
- Both models cross above the 50% P_{250} threshold at a lead time of ~4.5 days. This lead time is ~1 day shorter than the GEFS and EPS analyses for 38N near Bodega Bay.

- The EPS (GEFS) crosses above the 75% P_{250} threshold at a lead time of ~1.25 (1.75) days. These lead times are ~1 day shorter than the GEFS and EPS analyses for 38N near Bodega Bay.

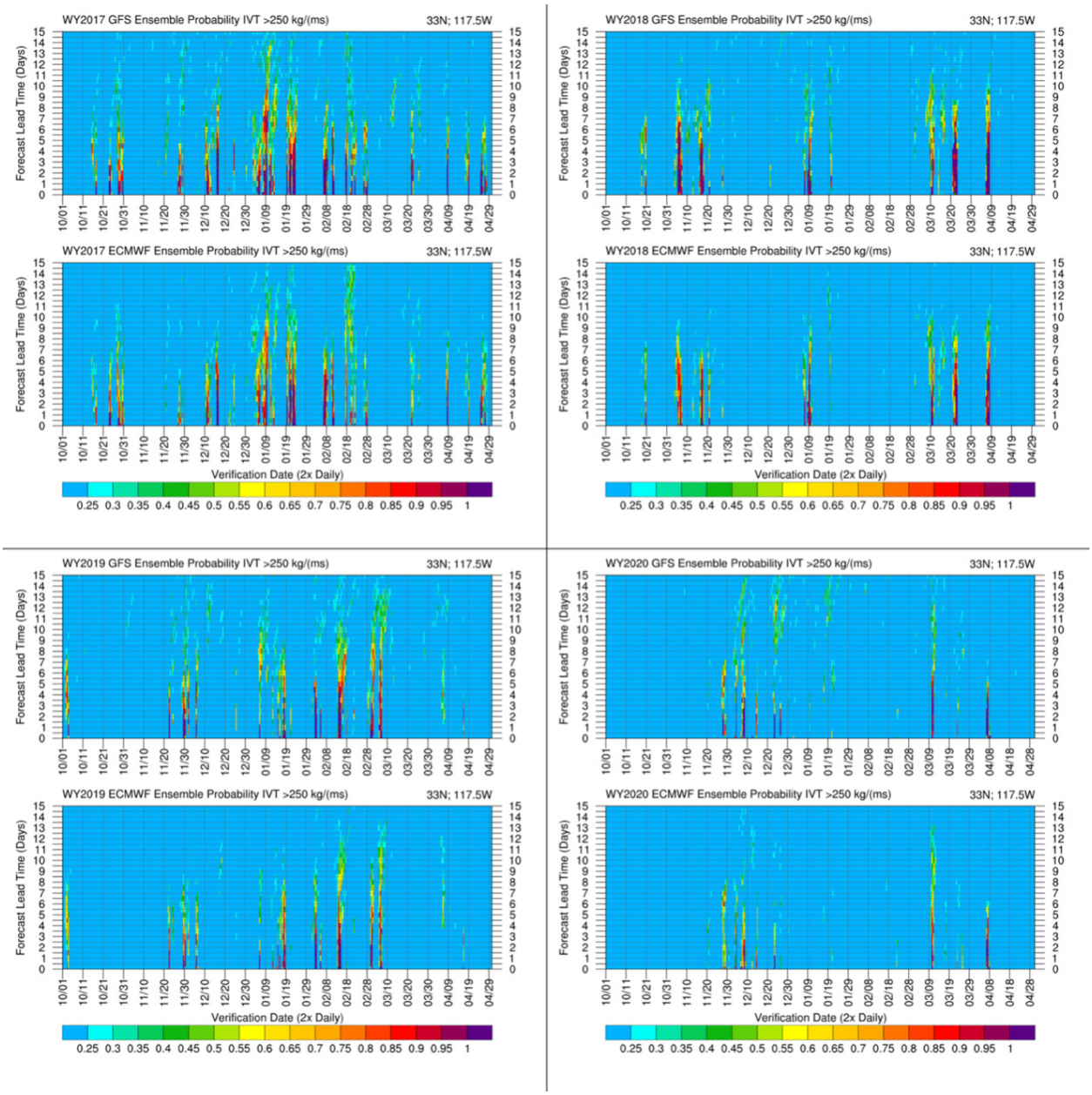

Figure D-32. *A forecast–lead-time illustration of the GEFS and EPS P_{250} (shaded according to scale) for verification times every 12 hours during WY17, WY18, WY19, and WY20 at 33ºN, 117.5ºW as labeled.*

For similar P_{250} thresholds, the EPS provides, on average, no additional advantage over the GEFS at lead times of ~6–10 days which is contrast to the analysis for 38N (the EPS led the GEFS by 1 day). At these lead times, the EPS at 38N is almost "2 days better" than the either the GEFS and EPS at 33N. The only lead times where one model contains significantly higher

P_{250} on average at 33N is at lead times of 0 to 2 days where the GEFS leads the EPS. Note that the dProg/dt analysis illustrating higher or lower P_{250} values prior to verifying events does not necessarily imply higher or lower skill given that higher P_{250} at a given lead time could result from random chance and/or be associated with a large false alarm ratio, which was suggested by Figure D-30. The results do, however, portend less utility in lead time prediction of ARs using probabilistic IVT forecasts and associated situational awareness at 33N as compared to 38N.

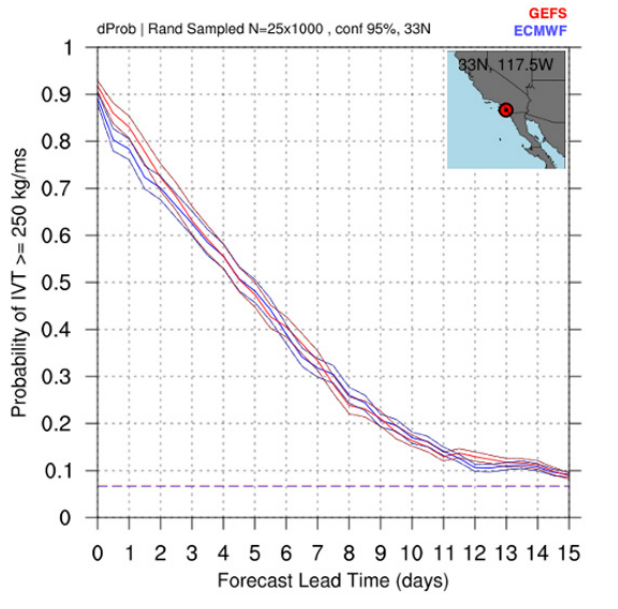

Figure D-33. *Forecast lead time change in the P_{250} forecast values (i.e., "dProg/dt") prior to verification times with IVT magnitudes ≥250 kg m^{-1} s^{-1} for the GEFS (red) and EPS (blue) for forecasts verifying every 12 hours at 33ºN, 117.5ºW. The solid line represents the mean while the dashed lines represent the 95th confidence level generated through 1000 random samples of 25-member populations of forecasts.*

Reliability

The reliability is a measure of the calibration of a probabilistic forecast; a forecast of 50% should verify 50% of the time. The short- and medium-range P_{250} forecasts at 33ºN, 117.5ºW are mostly reliable with GEFS P_{250} forecasts of 52–60% at lead times of 1–3, 4–6, and 7–9 days verifying 44%, 53%, and 52% of the time (Figure D-34 (a)) and EPS P_{250} forecasts of 52–60% verifying 45%, 54%, and 60% of the time (Figure D-34 (b)). The P_{250} forecasts at longer lead times are unreliable and less skillful in both models with P_{250} forecasts of 42–50% at lead times of 10–12 days verifying 31% of the time in the GEFS and 30% of the time in the EPS. These results are similar to results shown by Cordeira and Ralph 2021 (Figure D-34 (a)). The unreliable forecasts of the GEFS at longer lead times at 33N is similar to results shown at 38N; however, the EPS is more unreliable at longer lead times at 33N as compared to 38N. The reliability can only be measured with sufficient forecast sample size; there are very few or zero occurrences of high probability forecasts at long lead times. The sample size of forecasts is larger in the GEFS than in the EPS (see Figure D-30), but largely not reliable with most curves representing lead times out to 7 – 9 days all below the 1:1 reliable curve in the GEFS.

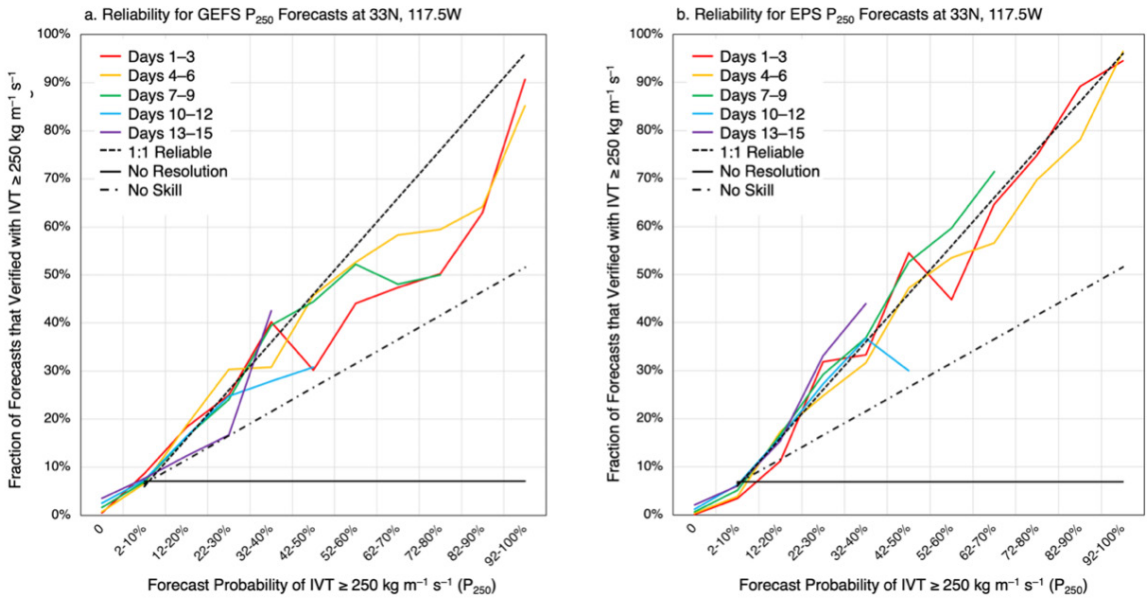

Figure D-34. *Reliability diagram for the (a) GEFS and (b) EPS P_{250} forecast at 38ºN, 123ºW for lead times of 1–15 days (colored solid lines) grouped by lead times of 3 days according to the legend. Values are only calculated if there were 10 or more forecasts to evaluate and forecast values are grouped into a 0% only bin and then in 10% bins thereafter. The black lines represent the no resolution (solid), no skill (dot-dash), and 1:1 reliability (dashed) for the latter 10 bins.*

Contingency Metrics (Success, POD, ETS, and Brier Skill Score; Figure D-35)

The success ratio identifies what fraction of P_{250} forecasts at or above a threshold of 0 verify with IVT ma nitudes 2 0 m^{-1} s^{-1}. The success ratio of the EPS is generally similar to or slightly larger than the success ratio of the GEFS for lead times out to 8 days (Figure D-35 (a)). Using P_{250} 0 , forecasts are correct 0- of the time at lead times of to days The PS does contain sli htly hi her success ratio values at lead times of 2 days and -8 days; however, the latter may be due to small sample size given the "jumpy" appearance of the data. These values are 0 10 less than the success ratio farther north at near Bode a Bay, CA For a iven success ratio value e , 0 , model forecasts in northern California lead forecasts in southern California by almost 3 days:

- 38N GEFS/EPS P_{250} ≥50%: 4 days / 5 days
- 33N GEFS/EPS P_{250} ≥50%: 1 day / 2.5 days

The probability of detection identifies what fraction of verification times with IVT magnitudes 2 0 m^{-1} s^{-1} were correctly forecast by P_{250} forecasts at or above a threshold of 50%. Both the EPS and GEFS contain very similar or identical probability of detection values on average as a function of lead time (Figure D-35 (b)). Approximately 50% of events are predicted at a lead time of 4.5 days using P_{250} 0 while only 2 of events are redicted at a lead time of days using P_{250} 0

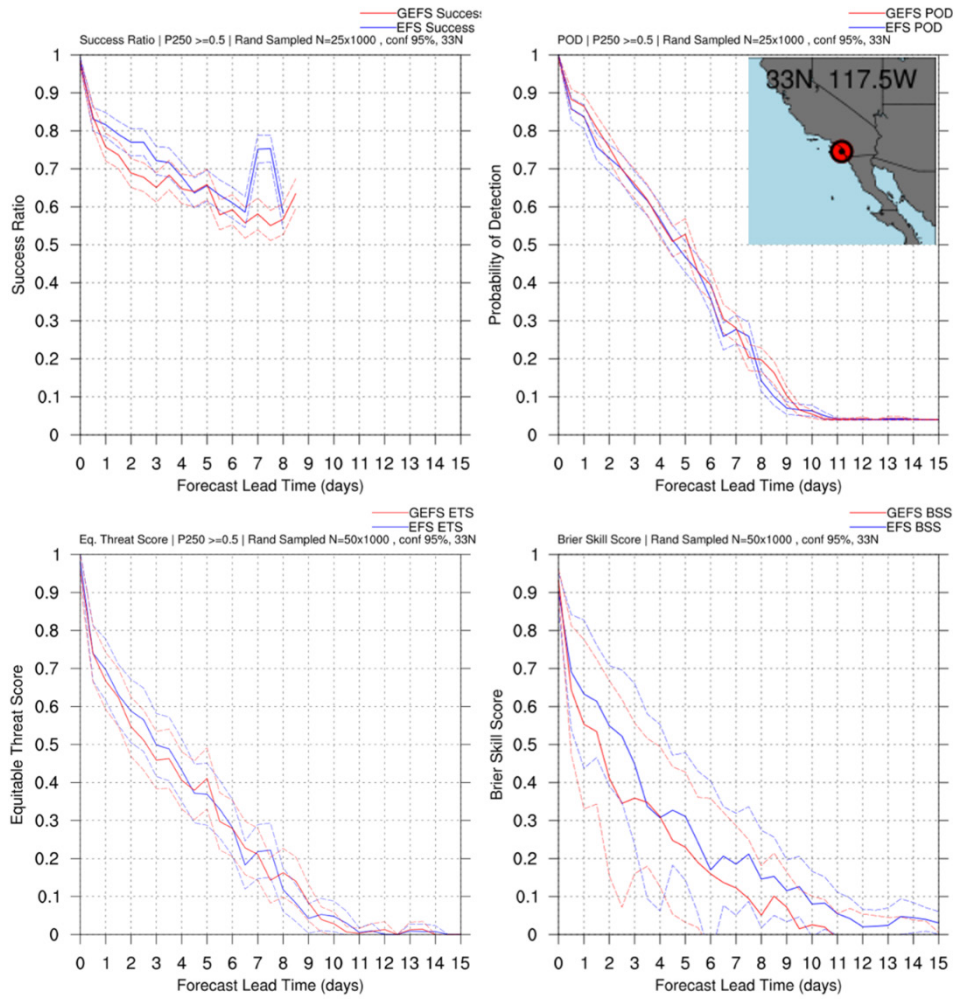

Figure D-35. *GEFS and EPS skill metrics at 33N, 117.5W for lead times every 12 hours out to 15 days for valid times between 0000 UTC 1 October 2016 through 1200 UTC 30 April 2020 for (a) success ratio, (b) probability of detection, (c) equitable threat score, and (d) Brier skill score. Solid lines represent the mean while the dashed lines represent 95th percent confidence levels for statistical significance generated through 1000 random samples of (a, b) 25-member and (c, d) 50-member populations of forecasts.*

The equitable threat score measures what fraction of observed and/or forecasted events were correctly predicted while also considering hits associated with random chance. Both the EPS and GEFS contain very similar or identical equitable threat scores on average as a function of lead time (Figure D-35 (c)). The equitable threat scores are ~0.4 at lead times of 4–5 days which is 0.10 lower than the location farther north at 38N. The similar values and lack of significant differences between the EPS and GEFS imply that the differences in the dProg/dt analysis and the success ratios were likely driven by random chance.

The Brier skill score assesses the relative skill of P_{250} forecasts as compared to reference climatology and includes both forecasts of events (i.e., large P_{250} values prior to times with IVT ma nitudes 2 0 m^{-1} s^{-1}) and non-events (i.e., small P_{250} values prior to times with IVT magnitudes <250 kg m^{-1} s^{-1}. The EPS on average contains a higher Brier skill score than the GEFS as a function of lead time (Figure D-35 (d)); however, the differences do not appear

statistically significant. In both models, the Brier skill score is ~0.3 at a lead time of 3 days and decreases below 0.1 at a lead time of 7–9 days. For comparison, the Brier skill score does not decrease to 0.3 and 0.1 in the EPS at 38N until a lead time of 8 days and 12 days, respectively.

D.10.2 References

For all references, please see Stewart et al. (2022): Stewart, B. E., J. M. Cordeira, and F. M. Ralph, 2022: Evaluating GFS and ECMWF ensemble forecasts of integrated water vapor transport along the U.S. West Coast. Wea. Forecasting. 37, 1985–2004.

D.11 Brief Report on December 2022 - January 2023 "Deep Dive" Lead-Time Prediction

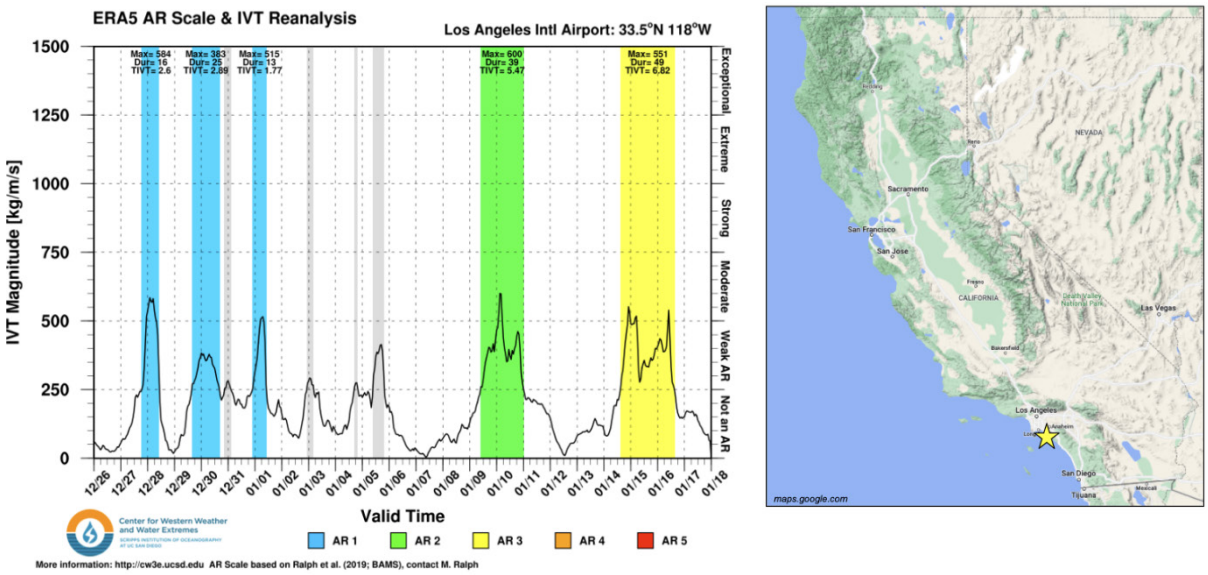

Figure D-36. Time series of IVT magnitude from 26 December 2022 through 17 January 2023 with individual landfalling ARs noted by AR scale (color) with information on their maximum intensity (IVT magnitude), duration (hours), and time-integrated IVT (10^7 kg/m) at 33.5N, 118W.

Southern California using IVT information at 33.5N, 118W (near Irvine)								
	Start	End	Max IVT ($kg\ m^{-1}\ s^{-1}$)	Duration (h)	AR Scale	Avg IVT Dir (deg)	tIVT ($10^7\ kg\ m^{-1}$)	Avg Z0C (m ASL)
AR #1	2022-12-27 1900 UTC	2022-12-28 1000 UTC	584.6	16	1	266	2.60	3655
AR #2	2022-12-29 1600 UTC	2022-12-30 1600 UTC	383.2	25	1	313	2.89	3363
AR #3	2022-12-31 2200 UTC	2023-01-01 1000 UTC	515.3	13	1	229	1.77	3115
AR #6	2023-01-09 1000 UTC	2023-01-11 0000 UTC	600.2	39	2	232	5.47	2961
AR #8 & #9	2023-01-14 1500 UTC	2023-01-16 1500 UTC	551.9	49	3	257	6.82	2391

Figure D-37. Information on the start time, end time, maximum intensity, duration, AR Scale, average IVT direction, time-integrated IVT, and average height of the freezing level.

Nine ARs made landfall in California from 26 December 2022 through 17 January 2023 (Figure D-36 and Figure D-37). Five of these landfalling ARs directly impacted southern California at a point near Irvine at 33.5N, 118W. Three of these ARs were AR1 rank according to the Ralph et al. (2019) AR Scale, one was an AR2, and one was an AR3. Additional details on these events can be found in Figure D-37.

Each of these landfalling ARs contained IVT magnitudes >250 kg/ms that could be traced in ensemble forecasts ahead of each event. These forecasts, colloquially known as the AR Landfall Tool, captures the ensemble odds of IVT magnitudes exceeding 250 kg/ms and presents that

information as a function of lead time and latitude along the U.S. West Coast. We can isolate each of those forecasts for a given location (i.e., at 33.5N) and assess how the forecasts "rolled forward" toward verification.

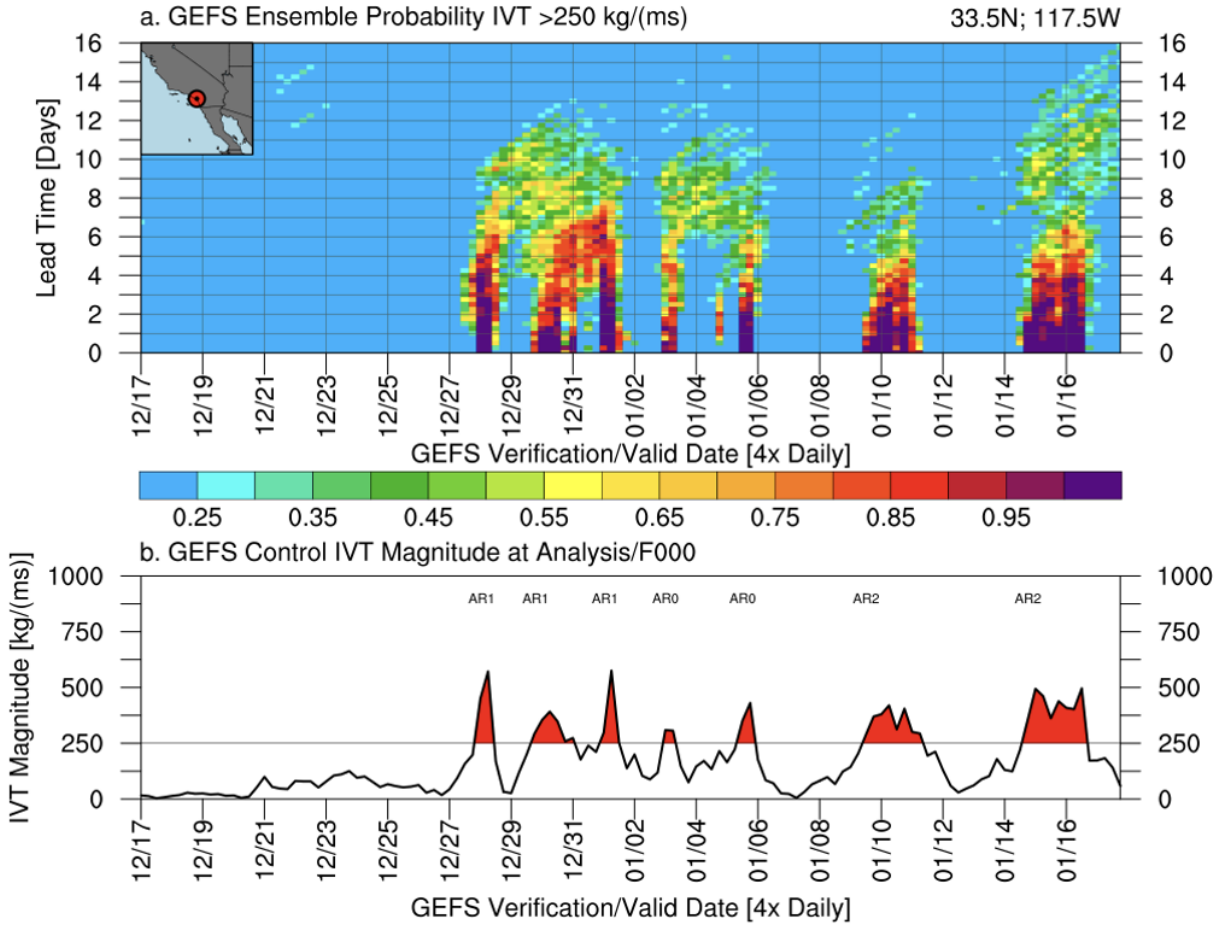

Figure D-38. *Lead time prediction of the ensemble odds of IVT magnitudes >250 kg/ms from the 30-member GFS ensemble at 33.5N, 117.W for late December 2022 through January 2023. Verification of IVT Magnitudes >250 kg/ms is shown in the lower panel.*

The assessment of lead-time prediction by the NCEP GFS ensemble model illustrates odds of AR landfall increasing to above 50% at various lead times across each system (Figure D-38). The earlier storms in late December featured odds >50% at lead times >8 days and odds >75% at lead times >6 days, with shorter leads for similar thresholds for storms in January. When summarized for each AR impacting southern California using the method of "when did the odds increase above 50% and stay above 50?", the average lead time prediction was 5.4 days with a range from just under 4 days to 7 days (Figure D-39). When summarized using a method of "when did the odds increase above 75%, but then stay above 50%?", the average lead time prediction for AR start was 3.6 days (range of 1.25 to 7.75 days), for the duration was 4.5 days (range of 3.2 to 5.8 days), and for the time of maximum IVT magnitude was 5.25 days (range of 4.25 to 6.25 days) (Figure D-40). On average, landfalling ARs using the AR Landfall Tool in

Southern California were reasonably well predicted and/or forecast with confidence 5-6 days in advance.

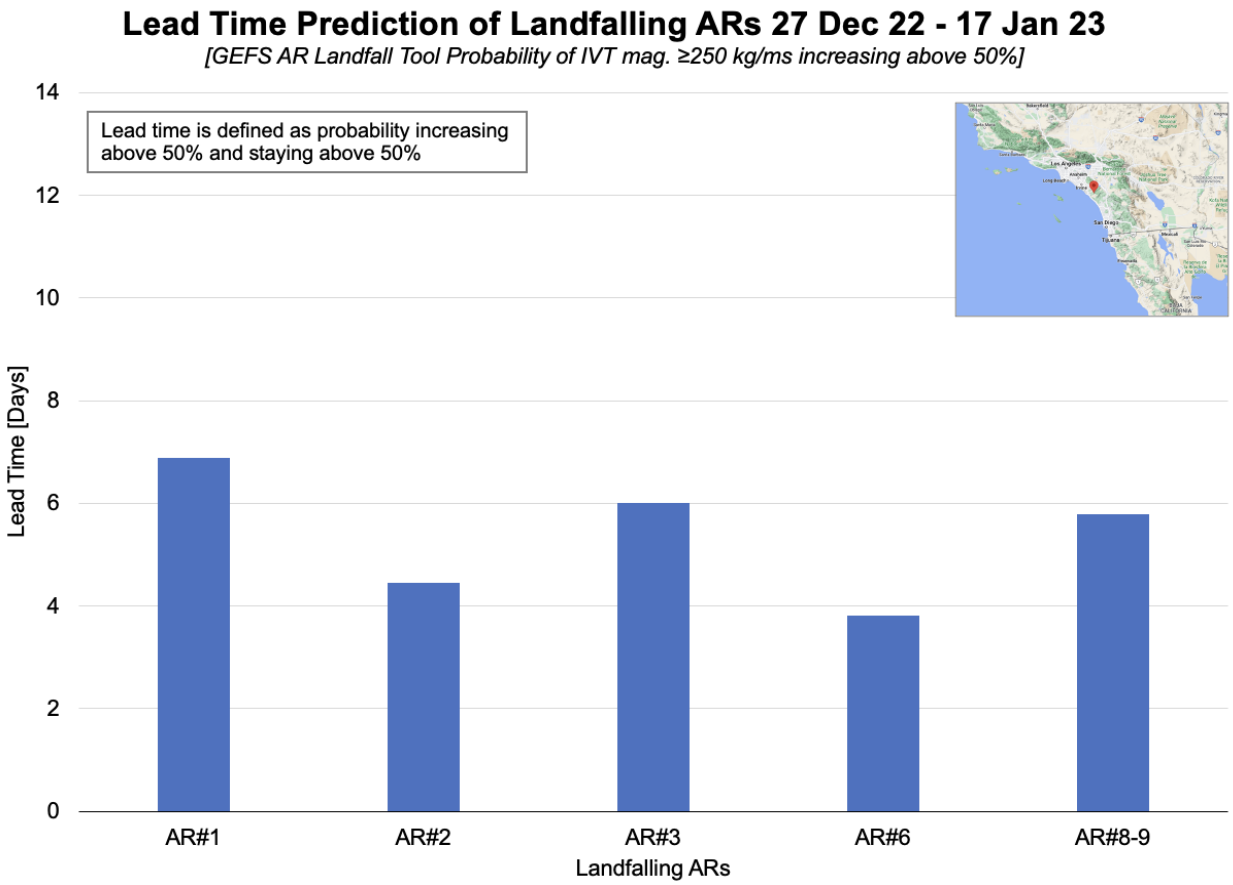

Figure D-39. *Average lead-time prediction for the duration of each AR impacting southern California based on "odds increasing above 50% and staying above 50%".*

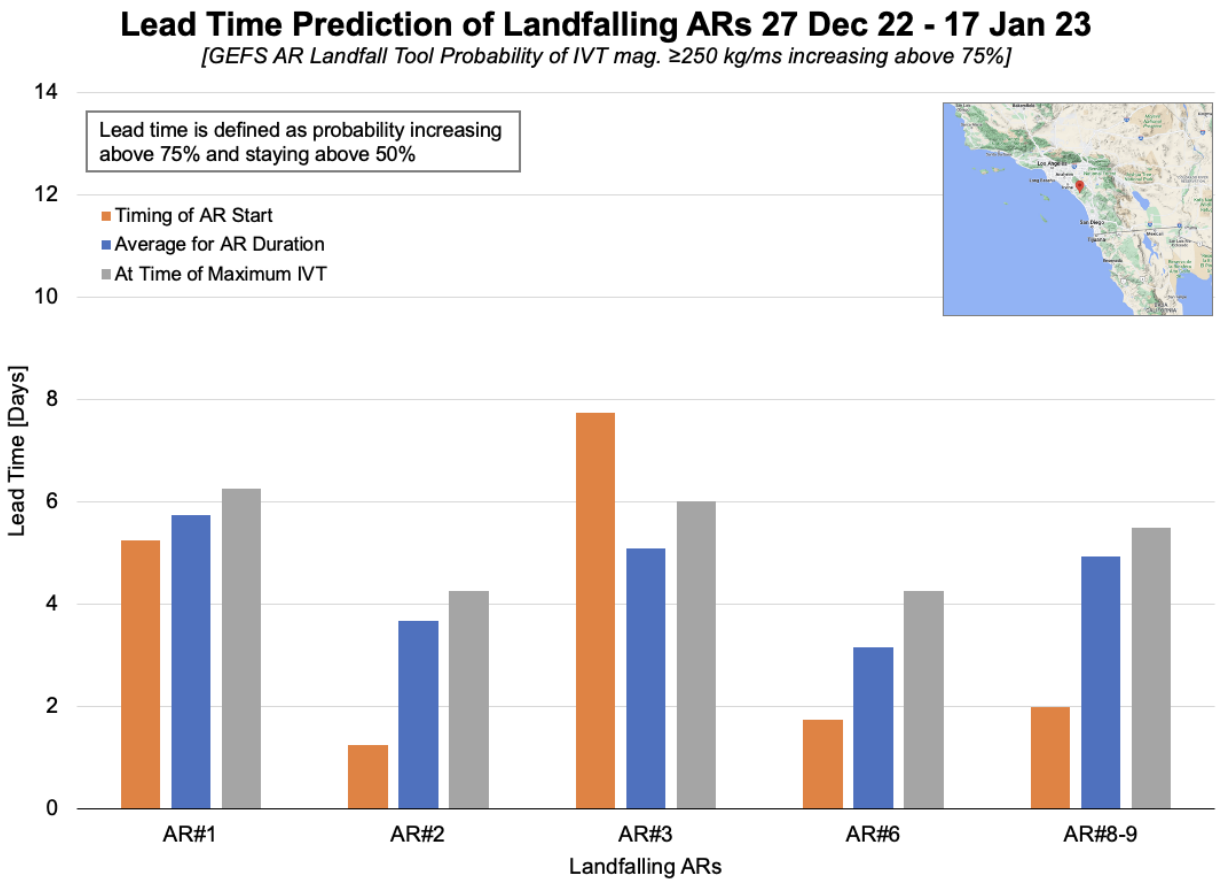

Figure D-40. *Average lead-time prediction for the duration of each AR (blue) along with timing of AR start (orange), and time of maximum IVT magnitude (gray) impacting southern California based on "odds increasing above 75% and staying above 50%".*

Appendix E—Environmental Studies and Research (Section 6)

Prado Basin Water Conservation and Habitat Assessment 2021-2022

Least Bell's Vireos and Southwestern Willow Flycatchers In Prado Basin of The Santa Ana River Watershed, CAn

Prado Basin Water Conservation and Habitat Assessment 2021-2022

Report to

U.S. Fish and Wildlife Service
Palm Springs Fish & Wildlife Office
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January 2023

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INTRODUCTION

Prado Basin contains the single largest forested wetland in coastal Southern California supporting an abundance and diversity of wildlife, including many listed and sensitive species. The Basin is located at the confluence of four of the watershed's largest tributaries where flood control, water management, and wildlife habitat requirements are balanced.

Water conservation in Prado Basin was built into the dam design and has been in operation at some level since construction was completed in 1941. The dam was constructed and operated by the US Army Corps of Engineers (Corps). In 1985, a hydrology and water conservation study of Prado Reservoir was prepared. In 1988, an analysis of the operation of Prado Dam for additional water conservation was conducted. In 1990, the water control plan was revised to raise the buffer pool from elevation 490 ft to 494 ft. The buffer pool allowed the water control manager to limit releases from Prado Dam and to coordinate with Orange County Water District (OCWD) to release water downstream at rates that facilitated OCWD's groundwater recharge activities. In 1993, the current springtime operation for water conservation at Prado Dam was approved which allowed the buffer pool elevation to increase from elevation 494 ft. to elevation 505 ft. during the non-flood season (March 1 to September 30). During the flood season (October 1 to February 28), the buffer pool in Prado Reservoir was at an elevation of 494 ft. until 2006 when the allowable winter season level was raised to 498 ft. Then in 2018, a 5-year deviation from the Dam Operation Plan was granted and water conservation could be allowed to an elevation of 505 ft year-round. In addition, the running average release rate of 500 cubic feet per second for outflows was reduced to 350 cfs to accommodate lowered percolation rates brought on by the hardening of the riverbed downstream. OCWD is currently working on a Feasibility Study with the Corps that would allow water conservation to an elevation of 505 ft. year-round and lowered release rates beyond the deviation timeframe.

It is the Corps' policy to balance the use of reservoir resources by conserving as much water as possible consistent with other operational, environmental, and fiscal constraints. The Corps regulation entitled Water Control Management states in its policy section (33 CFR 222.7, 6d) that the development and execution of water control plans will include appropriate consideration for efficient water management by the emphasis on water conservation as a national priority. The objectives of efficient water control management are to produce beneficial water savings and improvements in the availability and quality of water resulting from project regulation/operation. The Corps has been extremely cooperative in developing balanced resource use in the Prado Basin to conserve as much water as possible while ensuring an appropriate focus on flood control and other priority project functions consistent with Corps Regulations including environmental values.

Water conservation at Prado Dam maximizes the efficient use of local water resources. To reduce the need for expensive imported water supplies, OCWD has initiated several water-management projects to enhance groundwater supplies, including water conservation at Prado Dam. Although the Dam's primary operational function is for flood control, changes have occurred in the operation to allow water from the Santa Ana River to be held back during the flood and non-flood seasons. Slowing the release rates from the dam enables OCWD to recharge the stored flood pool into the groundwater basin downstream and wets a greater area of the flood plain for a longer time in the Santa Ana Canyon below the dam and in the Basin.

Getting water to elevation 505 ft and operating for water conservation with outflows well reduced from what they would be for flood control purposes only happens at the tail end of large storm events followed by clear weather with no major storms in the forecast. Generally, when there is enough inflow to get to 505 ft, there is significantly more than that and flood control always takes precedence. Dam maintenance and construction also take precedence over water conservation unless the work can be safely scheduled for a later date. If unfavorable weather is forecast, the water level is drawn down to an elevation of 490 ft. - 498 ft to accommodate anticipated inflow volume and ensure sufficient Basin capacity for flood control purposes.

Effects of the Operation of Prado Dam on Habitat

Prado Dam stops flood waters and sediment. The flood water is eventually released in a controlled manner but much of the heavier-grained sediment has built up over time with deposits as deep as 30 ft. or more locally in the Basin. One of the effects of this has been the shrinkage of the acreage in the water conservation pool areas (Table 1). The difference in Basin topography between 1989 and 2008 resulted in a loss of 349 acres below elevation 505 ft and a net loss of 152 acres to 556 ft (sediment deposition is not uniform). The water conservation pool is shrinking dramatically toward the dam over time due to ongoing sedimentation. Approximately 23% of the acreage and habitat located below elevation 505 ft in 1989 was above that elevation and out of the conservation pool area as of 2008. This outright loss of habitat acreage in the lower Basin is the single largest effect of the balanced operation of Prado Dam to date.

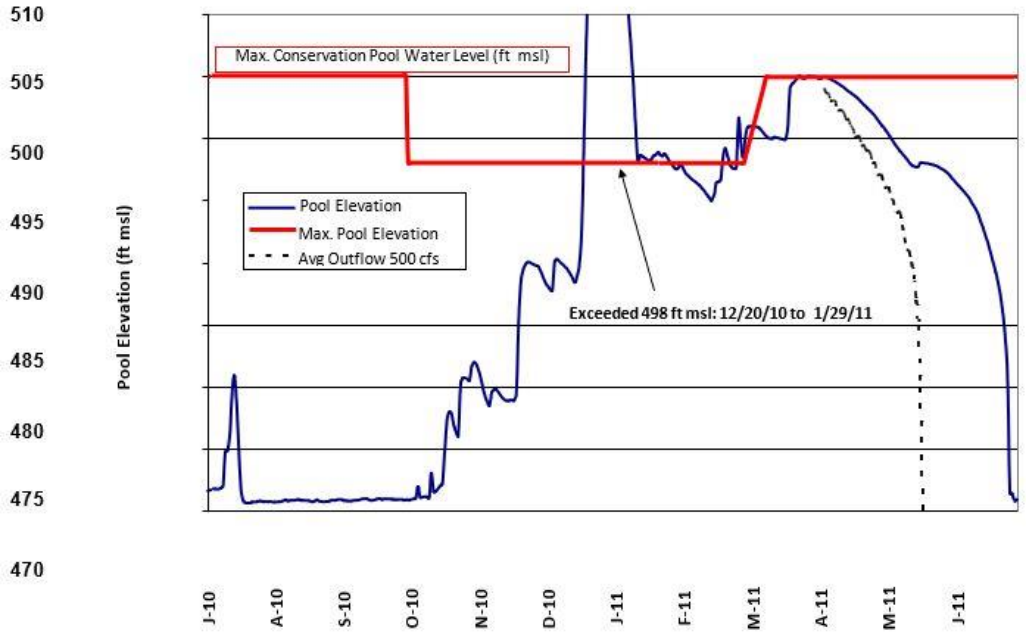
Table 1: Prado Acreage in the Conservation Pool Areas and Basin Comparing 1989 Elevations with 2008 Elevation Data

Data Year	Vertical Datum	Data Source	Elevation (FT)	Acreage	Acreage 1989-2008	Percent Lost
1989	NGVD 29	Corps	556	8933	-	-
1989	NGVD 29	Corps	505	2201	-	-
1989	NGVD 29	Corps	498	1508	-	-
2008	NGVD 29	Corps	556	8781	-152	2%
2008	NGVD 29	Corps	505	1852	-349	16%
2008	NGVD 29	Corps	498	1159	-349	23%
2008	NAVD 88	Corps	556	8433	-500	6%
2008	NAVD 88	Corps	505	1610	-591	27%
2008	NAVD 88	Corps	498	1126	-515	34%

Temporary habitat damage has also occurred at the lower elevations in Prado Basin because of prolonged inundation. Mule fat (*Baccharis salicifolia*) appears susceptible to 2– 3 weeks of inundation. Plants are killed or die back significantly. A high percentage of these sprout from the base but recovery after major dieback is often not complete enough to provide nesting habitat that year. Black willow (*Salix gooddingii)* survival of inundation is very high but if the foliage is submerged, it is lost after 3 – 7 days and unavailable for nest placement when the water recedes. Otherwise, the willow foliage nearest the ground is heavily used for vireo nest placement particularly where other shrubby riparian cover is limited in the lower-most Basin.

Habitat damage attributable to water conservation is complicated by the associated, initial prolonged inundation caused by flood control. For example, in the winter of 2010/2011 construction activity and facilities protection in and below Prado combined with flood control operations resulted in the highest inundation level on record in the Basin, 529.35 ft on December 23, 2010 (Figure 1). The water conservation pool was exceeded for 1 month and 9 days and substantial short-term damage was incurred by Mule fat stands on the Basin edge that had never been flooded before. Most of the Mule fat growing at and below water conservation elevations died back considerably and some patches appeared lost. Most of these patches, but not all, did recover slowly reaching a stature useful to riparian nesting birds by 2012 and after. Patches of Mule fat at the lowest elevations were the slowest to recover from crown sprout but some did not come back from the 2010/2011 submergence. Still, there are important, scattered patches of Mule fat in the lowest reaches of the Basin, but the total coverage of Mule fat below elevation 505 ft. is less than 2 acres and OCWD has planted 45 acres of Mule fat above 505 ft. compensating for any potential loss at a ratio of 20:1 or greater**.**

Figure 1: Prado Conservation Pool: FY10-11



Over the past 20 years water elevations at the conservation buffer pool have occurred between 498 ft. and 505 ft. fifteen times including this current water year. During that same period, the water elevation at the conservation buffer pool occurred at 505ft. and above 8 times. In 2004 the buffer pool was at 498 ft for 9 days in March and at 494 ft. for most of March; in 2005 the buffer pool was at 498 ft. for most of March and 505 ft. for most of April and for half of the month of July; in 2010 and 2017 the buffer pool was above 498 ft. through mid- March; in 2019 the pool stayed above 498 from mid-January through mid-April, and 505 intermittingly from mid-February through March; and in 2020, the pool stayed above 505 in April and above 498 until the end of May. In 2021 the pool stayed at or above 498 for 9 days.

Interestingly, four of the five highest counts of reported vireo territories all occurred during years when impounded stormwater was held behind the dam in 2004, 2005, 2010, 2019, and 2020. The prolonged presence of a flood pool and wetter conditions were associated with high vireo counts in part because of the extra foliage volume and insect food available under those conditions.

OCWD has funded and staffed wildlife management and habitat restoration activities focused upon endangered Least Bell's Vireos watershed-wide with the wherewithal provided by water conservation. These ongoing conservation activities have led to greatly increased habitat quantity and quality in the Prado Basin and throughout the watershed. The environmental management program will continue with ongoing water conservation behind Prado Dam. Currently, at the insistence of the Regulatory Agencies, a major focus of the funding for environmental work has been shifted to vegetation monitoring (see below).

WATER CONSERVATION 2020-2022

Except for 2017, 2019, and 2020 the winter seasons of 2012-2016, 2018, 2021, and 2022 were characterized by smaller rain events and very little habitat inundation. Rainfall totals at Prado dam for the past eleven precipitation years (July 1st to June 30th) were 9.09”, 8.00”, 4.56”, 10.95”, 8.74”, 15.77”,4.20”, 17.75”,13.96”, 5.13”, and 7.96”, respectively. See Table 2 for rainfall amounts and inundation durations from water years 1983/1984 to 2021/2022. During that same period, the Corps approved two deviations from normal operations for additional water conservation: on December 22, 201,6 a deviation to elevation 503.9 ft was approved; and on January 19, 20,17 a deviation to elevation 505 ft was also approved. The Corps approved permanent year-round water conservation to 505 ft. with the signing of the Record of Decision on June 6, 2022

On December 28, 2021, the pool reached a peak water surface elevation (WSE) of 503.44 ft. The maximum daily mean discharge during this period was 2,822 cfs recorded on December 29, 2021. Figure 2 shows the pool elevation for the period December 2021 – August 2022 (See also, Appendix A & B). As shown in Table 2, 18 days (n=274) were above the significant elevational band of 498’ compared to 9 days during the same period in 2020/2021.

Figure 2: Prado Dam Pool Elevation (ft) December 2021- August 2022

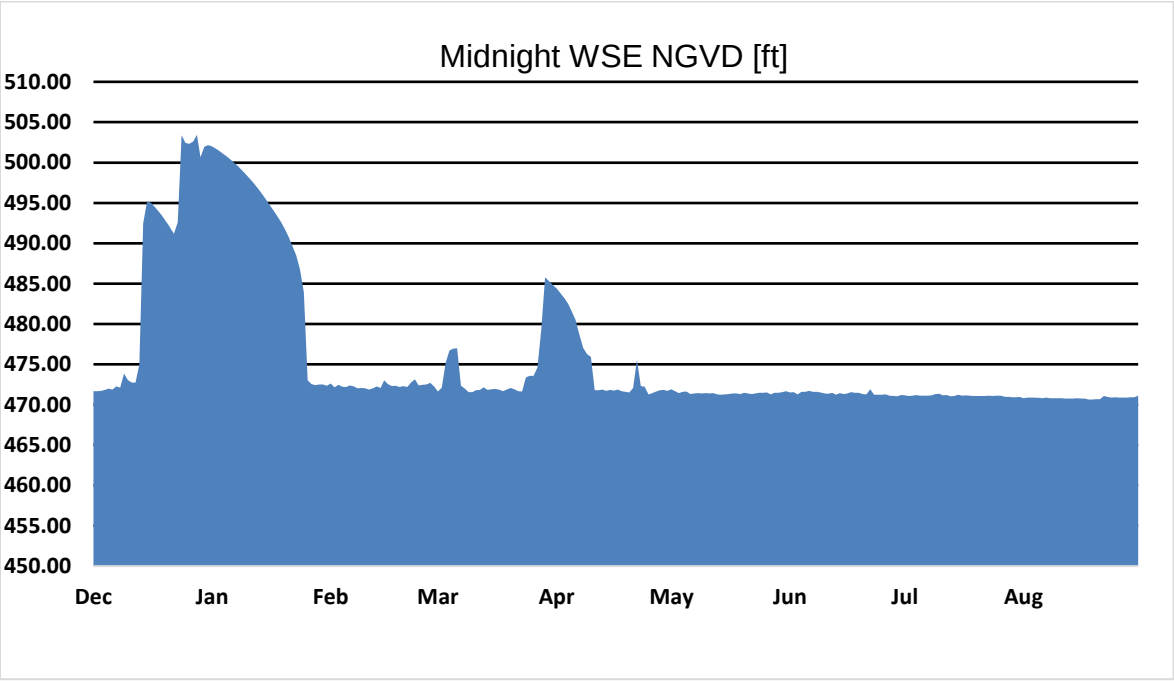


Table 2: Water Years and Inundation Duration 1983/1984 to 2021/2022

Water Year	Number of Inundation Days at Elevation:						Rainfall Totals
	485	490	494	498	504	505	
1983/1984	54	39	31	2	0	0	5.87
1984/1985	18	2	0	0	0	0	10.39
1985/1986	148	24	2	0	0	0	13.52
1986/1987	127	49	0	0	0	0	6.85
1987/1988	205	88	4	0	0	0	12.14
1988/1989	143	53	0	0	0	0	8.41
1989/1990	76	21	0	0	0	0	6.82
1990/1991	68	51	44	18	0	0	13.91
1991/1992	88	51	30	14	0	0	15.62
1992/1993	207	170	81	31	23	23	28.75
1993/1994	113	53	0	0	0	0	11.03
1994/1995	201	191	159	128	79	9	26.81
1995/1996	53	41	18	1	0	0	9.25
1996/1997	67	43	4	0	0	0	14.67
1997/1998	219	189	152	135	79	8	35.87
1998/1999	94	26	0	0	0	0	6.06
1999/2000	59	34	0	0	0	0	9.44
2000/2001	96	66	19	0	0	0	12.35
2001/2002	82	0	0	0	0	0	4.31
2002/2003	206	182	76	44	9	0	16.09"
2003/2004	141	99	42	11	0	0	10.04"
2004/2005	318	307	290	162	45	15	33.94"
2005/2006	240	172	102	81	7	2	11.28"
2006/2007	16	0	0	0	0	0	3.37"
2007/2008	102	85	64	7	0	0	9.07"
2008/2009	90	68	52	5	0	0	11.53"
2009/2010	161	120	95	34	9	8	18.12"
2010/2011	217	187	176	119	47	21	22.35"
2011/2012	78	52	16	0	0	0	8.71"
2012/2013	30	6	0	0	0	0	7.93"
2013/2014	34	21	13	3	0	0	5.24"
2014/2015	60	35	27	7	0	0	12.94"
2015/2016	43	24	15	8	0	0	5.97"
2016/2017	123	122	108	80	18	6	15.78"
2017/2018	12	8	2	0	0	0	4.20"

2018/2019	142	122	104	90	48	19	17.97"
2019/2020	169	154	130	95	28	21	13.94"
2020/2021	90	73	47	9	0	0	5.13"
2021/2022	44	39	25	18	0	0	7.96"

Color Coding for Days of Inundation

1-50	50-100	100-150	150-200
200-250	250-300	300-350	350-365

Color Coding
0 - 10"
10 - 15"
15.01 - 35"

EFFECTS OF WATER CONSERVATION ON LEAST BELL'S VIREO HABITAT AND POPULATION

Mitigation requirements for habitat damage due to water conservation were based historically upon the expected days of increased inundation of habitat below the pool elevation. So, 15.2 acres were determined to be the mitigation requirement for winter water conservation, or 13.8% of the 109.8 acres of habitat still requiring mitigation below 498 ft. The 13.8% is the ratio of average annual increased days of inundation divided by the current number of days of expected inundation, or 4 days/29 days. In 2012, only 94.6 acres remained un-mitigated below 498 feet based upon the historic habitat base; by 2008, those acres and habitat had been lost to sedimentation. Irrespective of the assessment method utilized or the size of the documentation effort, habitat suitability comes and goes and most of the habitat damage associated with inundation is temporary and ascribable to the much higher and longer inundation associated with flood control. Also, the vireos generally have not nested over standing water unless it pools after the nest is in use, but they do routinely forage in emergent vegetation, so the issue is the potential reduction of nest site location options, not outright or long-lasting habitat loss. However, in some years like in 2020, vireos nested abundantly over water. The lack of water has become the larger issue for vireos in southern California including Prado. Habitat viability including food abundance and availability have been hugely impacted by episodic drought cycles and reduced flows in the river.

We examined the distribution of vireo territories in the Basin to see if diminished habitat values at the lower elevations had led to reduced use of that habitat based on the number of occupied breeding territories (Table 3). Vireo occupation of the lower elevations fluctuated over time but did not appear to be greatly diminished except in the aftermath of high-water years in 2006 and 2012 at bean low elevation of 498 ft. Most territories are not majorly repositioned because inundated habitat supports great foraging opportunities, although nest locations might be moved higher or upslope.

Table 3: Elevational Distribution of Least Bell's Vireo Territories

Survey Year	1999	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Territories at 466-498' (Percent of Total)	58 (17%)	104 (23%)	149 (35%)	86 (19%)	132 (22%)	112 (19%)	36 (8%)	55 (13%)	65 (14%)	90 (17%)	79 (14%)	53 (10%)	63 (14%)	105 (19%)	114 (22%)	110 (21%)	127 (25%)	108 (20%)	170 (26%)	80 (13%)	118 (16%)	96 (16%)	110 (16%)
Territories at 498-505' (Percent)	46 (14%)	67 (16%)	63 (15%)	74 (17%)	86 (15%)	69 (12%)	64 (15%)	60 (14%)	79 (17%)	91 (17%)	104 (18%)	102 (20%)	103 (23%)	115 (20%)	100 (19%)	103 (19%)	89 (17%)	95 (17%)	110 (17%)	97 (16%)	156 (22%)	98 (16%)	111 (16%)
Territories at 466-505' (Percent)	104 (31%)	171 (39%)	212 (49%)	160 (36%)	218 (37%)	181 (30%)	100 (24%)	115 (27%)	144 (31%)	181 (34%)	183 (32%)	155 (30%)	166 (37%)	220 (39%)	214 (41%)	213 (40%)	216 (42%)	203 (37%)	280 (42%)	177 (30%)	274 (28%)	194 (32%)	221 (33%)
Territories Within 566' Elevation (Not Above River Road)	336	444	429	447	590	600	423	420	463	538	569	517	451	561	520	532	511	549	665	600	719	597	677

Reduced nesting cover quality could lead to reduced nesting success, but such effects are localized and negligible in that the overall success has resulted in the consistent increase in the Prado population brought about by ongoing management efforts funded by OCWD as part of the water conservation program.

Figure 3 depicts the upward trend in the total number of vireo territories from 2000 through 2022. Despite the presence of a flood pool at the start of five nesting seasons, the total number of territories has steadily increased. The trend dipped in 2021, perhaps due to the Airport Fire that burned 1,087 acres at the end of 2020. The resulting loss of habitat quality displaced many vireos to adjacent areas, presumably still in the watershed. It is also unknown what the upper limit might be in terms of vireo carrying capacity in the Prado Basin. Six hundred to 700 territories are a lot of vireos in 4,500 acres or less of riparian habitat.

Figure 4 depicts the distribution of vireos across the elevational gradient from 1999 through 2022. The percent of total vireo territories located within the lower elevational bands shows little variation between years regardless of the presence of a flood or conservation pool. This lack of movement indicates that most vireos returned to historical breeding territories even if the understory was partially or fully inundated at the start of a nesting season. Least Bell's Vireo productivity within the elevational bands is discussed in more depth in Appendix B.

Figure 3: Total Vireo Territories 2000-2022

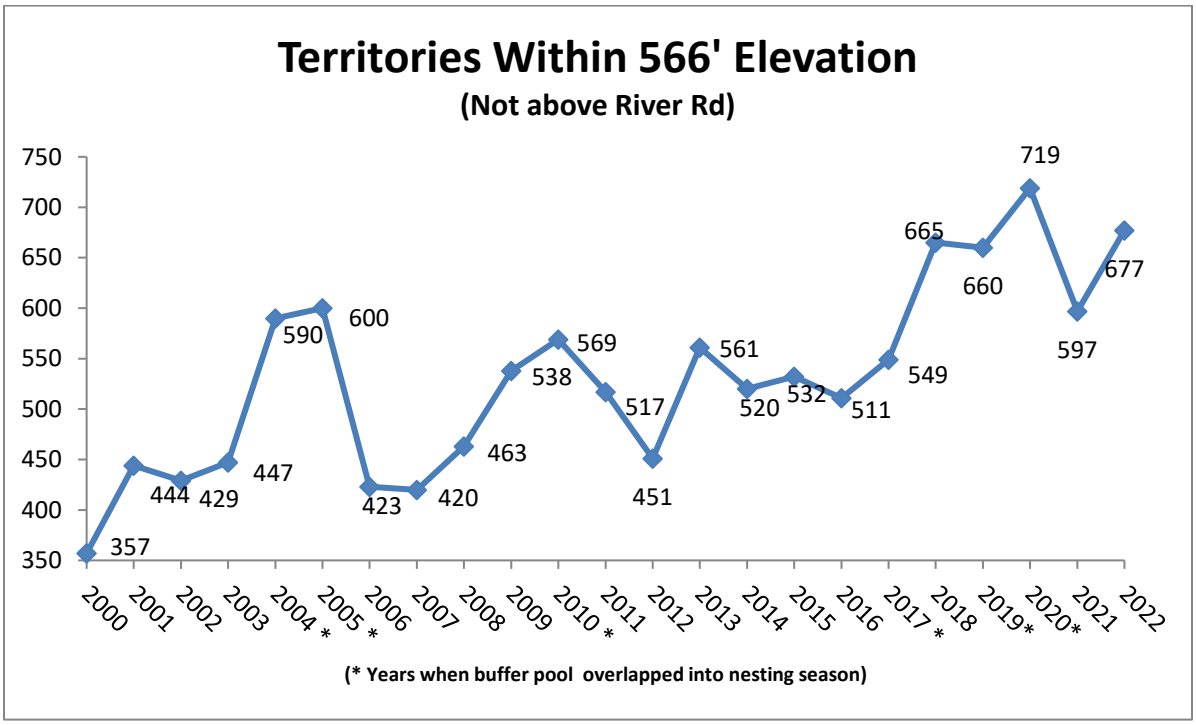
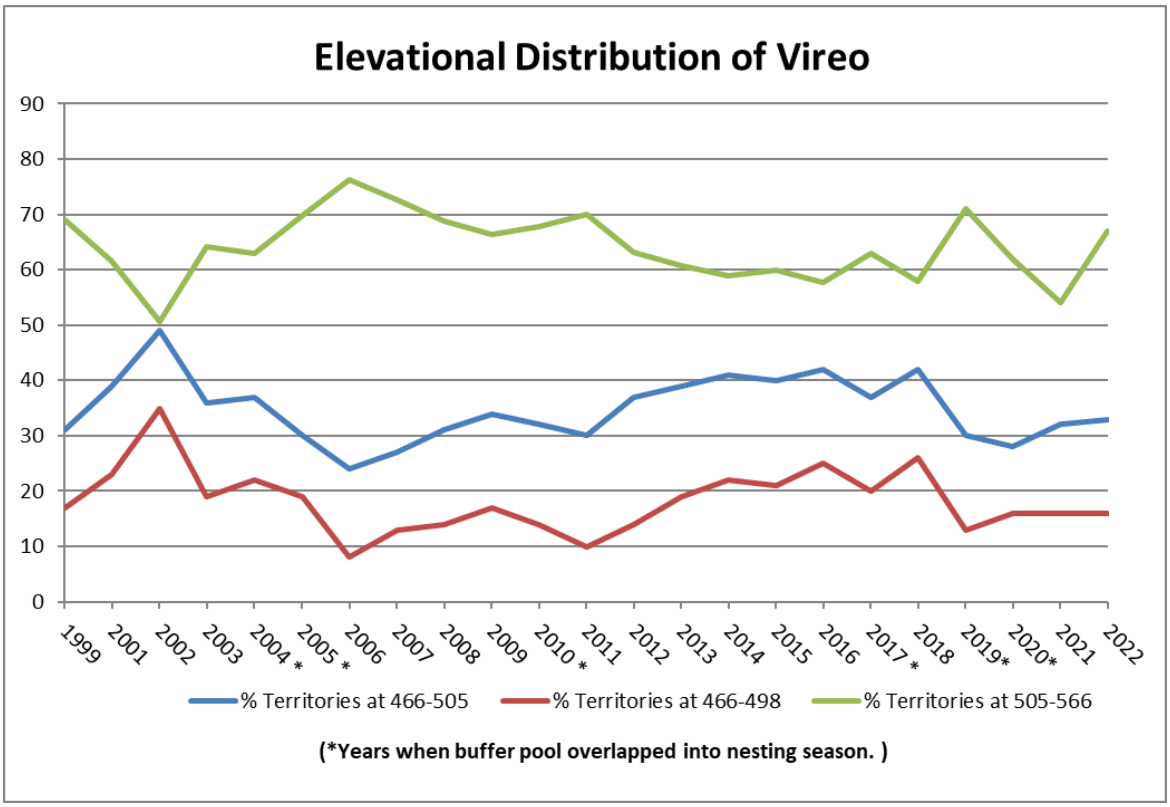


Figure 4: Elevational Distribution of Least Bell's Vireo Territories, 1999-2022



LEAST BELL’S VIREO PRODUCTIVITY DATA WITHIN WATER CONSERVATION ELEVATIONS

Least Bell’s Vireo is found and nests in a variety of different riparian habitat settings and water regimes. For the sake of this study, the Prado Basin has been divided into several different areas according to water conservation elevational zones. The elevational zones are each unique in their vegetative diversity and species complexity. The elevational zones include below 490’, 490-497’, 498-505’, and 505’ and above.

Searches and monitoring visits were conducted almost daily for Least Bell's Vireos in the Basin and environs from March until the last nest had fledged. All suitable riparian and transitional upland habitat was surveyed. All individual birds or pairs were noted during each visit to each section of the Basin. Data were taken on bird location, movement, behavior, food preferences, nest placement, sex, and age. Singing vireos were identified as males. Fledgling young were identified on the bases of their plumages, behaviors, and vocalizations.

Nests of the endangered birds were intrusively monitored, although great care was taken to minimize visits, scent cues for predators, habitat damage, trailing, and disturbance. Nests were located from a distance when possible and the contents were checked with a mirror. Data were taken on reproductive timing and success, cowbird parasitism, and depredation. Cowbird eggs were removed or replaced with infertile eggs and young cowbirds were removed. The eggs were taken with adhesive tape to avoid human contact with, and scent on the nest or contents. Nest monitoring was conducted as prescribed in memoranda and permits from the State and Federal wildlife agencies. However, no nest visits were conducted if 1) there was a chance of inducing a nest "explosion" or premature departure by nestlings; 2) approaching the nest would result in habitat destruction or trailing, or 3) no additional significant information or benefit to the occupants would result from the visit.

Nest height was recorded, and unsuccessful nests were carefully examined for signs of parasitism or other disturbance. Nests were assumed depredated if all eggs or unfledged young were destroyed or removed. Cowbird parasitism events were classified as such only if a cowbird egg(s) or pieces were found in, or below, the affected nest.

Using GIS software all vireos and nests were categorized by location into the basin elevational zones. Separated into the elevational zones the nest data were analyzed per each zone. The nest data included nesting substrate and the ground cover/ understory species present at the nest site. Dominant and subdominant species of ground cover were determined at each nest site within 3 meters of the Vireo nest. The average height of the dominant ground cover was determined. The height of each nest was also measured.

2022 Observations

The first returning male vireo was detected on 17 March. By 31 March, 156 male vireos had been detected and an additional 242 male vireos were found by 15 April this season. The first female vireo was detected on 25 March, with 87 found by 15 April. The first nest of the 2022 season was likely completed before 31 March. Nestling young were first observed on 14 April and the first fledgling on 3 May. The last nest of the season was completed on or about 30 June. Vireos had departed the Basin by about 20 September 2022, when only one male could be found. Six hundred seventy-seven males, 327 females, and 570 fledged young were detected in the Prado Basin in 2022.

Nesting Below 490' Elevation

This elevation zone is characterized by water-dependent plant species' including a tree canopy and abundant ground cover. The tree canopy is dominated by Black Willow and a sublayer of water-dependent herbaceous perennials and annuals. The most common understory species in this zone are Cocklebur (*Xanthium strumarium*), and Spearscale (*Atriplex triangularis*). There are few woody species besides Black Willow, so this zone is characterized by a sparse middle understory layer. This is the smallest in the extent of the elevation bands with 540.5 acres and many of these acres are comprised of open space, and monotypic stands of cocklebur.

The vireos in this zone are found in the island patches of Black Willows and the habitat fringes near the dam. Thirty-seven territories, and 13 nests were documented within this zone (Table 4). Eight (62%) of these nests were successful, and 2 of them were depredated. The average clutch size was 2.8 and a total number of 25 fledglings were produced in this zone. Black Willows were used as the nesting substrate for 100% of the nests, with an average nest height of 44" (Table 5). The most dominant and commonly occurring groundcover species at the nest sites in this zone was Spearscale (Table 6). Eight of the nests are bare ground/leaf litter/deadfall under and around them.

Nesting at 490'-497'

As in the lower elevations, vegetation is characterized by water-dependent plant species with tree canopy and abundant herbaceous ground cover. The tree canopy is dominated by Black Willow with a ground cover of water-dependent herbaceous perennials and annuals. The understory layer is more diverse compared to the lower elevations with the emergence of additional herbaceous understory species such as Beggers Ticks, Stinging Nettle, Lamb's Quarters, Grape, White Sweet Clover, and some Perennial Pepperweed. Mule fat was present in small numbers. The most common understory species' is Spearscale, but Cocklebur is still present in the wetter years. This elevational band comprised 585.1 acres of habitat.

The vireos in this zone are found in the heart of the Black Willow Forest. Seventy-three territories, and 16 nests were documented in the 490-497' belt (Table 4). Eight (50%) of these nests were successful, six nests were depredated. The average clutch size was 3.0 and a total of 22 fledglings were produced in this zone. Black Willows were the most common nesting substrate with 88% of the nests placed therein with an average nest height of 50" (Table 5). The most dominant and commonly occurring groundcover species was Spearscale at 8 nest sites and bare ground/leaflitter/deadfall was prevalent at 4 nest sites (Table 6).

Nesting at 498'-505'

Although vegetative diversity is partly dependent on water availability, this next higher zone is often the most diverse in Prado Basin. Many of the water-dependent species become less common in this zone, particularly during dry years, but woody perennials such as Mule fat are common. The tree canopy is dominated by Black Willow but Cottonwood, and Arroyo Willow adds to the canopy diversity. The understory is herbaceous with species such as Perennial Pepperweed, Nettle, Lambs Quarters, and Hemlock. Grape is also abundant in this zone. This elevational band comprises 675.1 acres.

One hundred eleven territories, and 39 nests were documented within this zone (Table 4). Nineteen (49%) of these nests were successful, seventeen were depredated. The average clutch size was 2.7 and a total number of 48 fledglings were detected in the 498-505' zone. Black Willows were the most common nesting substrate for 64% of the nests, with an average nest height of 42" (Table 5). The most dominant and commonly occurring groundcover category was Bareground/leaflitter/deadfall at 19 nesting sites with Perennial Pepperweed at 6 nest sites (Table 6).

Nesting Above 505'

This zone is characterized by localized diversity but also large tracts of land that only become flood irrigated during high rainfall years. Plant diversity is higher closer to the Santa Ana River and tributaries due to higher groundwater. Mule fat is the most common plant species encountered in this zone and it often provides both canopy and understory value. The tree canopy is equally shared by Black Willow, Cottonwood, and Arroyo Willow. Black Willows are most concentrated near the perennial waterways. The understory consists of herbaceous species such as Perennial Pepperweed, Nettle, and Hemlock. Following an average to above average rainfall year, many nonnative annuals including annual grasses dominate the understory. This is also the elevational zone where woody native perennials become common including California Rose (*Rosa californica*), and California Blackberry (*Rubus ursinus*). This is the largest of the elevational bands encompassing 8,486 acres between 505' and 566'.

Within this zone 456 territories (67% of all territories), and 133 nests were documented (Table 4). Ninety-eight (74%) of these nests were successful and 29 nests were depredated. The average clutch size was 2.9 and 300 fledglings were produced at 505-566' in 2022. Mule fat was the most common nest support for 32% of the nests, followed closely by Black Willow for 25% of all nests (Table 5). The average nest height was 42". The most dominant and commonly occurring groundcover category was Bareground/leaflitter/deadfall at 83 sites with Perennial Pepperweed dominating the understory at 31 nest sites (Table 6).

Santa Ana River Watershed

The watershed data was collected and provided by the Santa Ana Watershed Association and includes territories upstream, and downstream of the Prado Basin. These territories extend up into the tributaries including those tributaries found in Orange County. These sites are typically classified as a riverine riparian habitat with pockets of marsh wetlands.

Watershed-wide vireo detections outside of the Prado Basin included 1,393 territories, and 408 nests of which 203 (55%) were successful and 128 were depredated. The average clutch size was 3.4, and a total number of 1,005 fledglings were documented. The average height of these nests was 39" above the ground.

Discussion

Vireos in the lowest elevations of the Prado Basin often build nests further from the ground than nests built further from the dam, but in 2022 the nest heights were similar throughout. The height above the ground at which nests are built is influenced by the presence of water in some years and by nesting substrate preference in all years. The vireos in the lower elevations of the Basin nest predominantly in Black Willows that may or may not have near-ground foliage depending upon the pool elevation and pool retention time, quite different than circumstances at higher elevations. Both the presence and height of an inundation pool and the timing of warmer weather determine the presence or absence of near-ground willow cover at the time that vireos are searching for nest sites. Despite slightly too much higher nest heights, the vireos in the lowest elevations have had success rates like those observed at the higher elevations.

The comparable nesting heights across elevations in 2022 were due partly to ongoing drier conditions and the associated lack of an inundation pool at the time of vireo nest site selection. Differences in nesting success across elevational bands are complicated by smaller sample sizes in the lowest elevations within smaller acreages. The average success rate of all Prado vireo was 66% compared to the 55% observed in the rest of the watershed.

The watershed data excluding Prado reflects the diversity of habitat and lack of seasonal inundation of the riverine habitat. The watershed nest height in 2022 averaged 39" which is consistent with vireo nest heights reported in the literature. The average nest height in Prado Basin for 2022 was 43" which is lower than the 2021 average nest height of 52". This disparity reflects the dynamic nature of habitat in a flood control basin with its everchanging water regime. During dry years the habitat components leaf out and grow just as they would elsewhere in those parts of the watershed not influenced by the effects of water retention.

Water availability also influences the overall productivity of the Least Bell's Vireo in the Prado Basin. When water is available the habitat quality is improved, and productivity increases with greater foliage volumes and food production. Under drier conditions in 2022, the average number of vireo fledglings remained high but the average clutch size was slightly lower than in previous years, both in the Prado Basin and in the watershed outside the Basin.

Table 4: Least Bell's Vireo Nesting Data – Prado Basin 2022

Elevation Zone	# Territories	# Nests	# Successful Nests	Parasitized Nests	Depredated Nests	Success Rate	Avg. Nest Height (Inches)	Avg. Clutch Size	# Fledglings	Avg # of Fledges
<490	37 (5%)	13 (7%)	8	1	2	62%	44"	2.8	25	3.1
490-497	73 (11%)	16 (8%)	8	0	6	50%	50"	3	22	2.8
498-505	111 (16%)	39 (35%)	19	0	17	49%	42"	2.7	48	2.5
>505	456 (67%)	133 (66%)	98	3	29	74%	42"	3	300	3.1
Totals - All Areas	677	201	133	4	54	66%	43"	2.9	395	3
Watershed (SAWA)	1393	408	203	21	128	55%	39"	3.4	1005	2.7

Table 5: Least Bell's Vireo Nesting Substrate - Prado Basin 2022

Plant Species	Elevation Below 490'	Elevation 490-497'	Elevation 498-505'	Elevation Above 505'	Total
Black Willow (Salix gooddingii)	12 (92%)	14 (88%)	25 (64%)	34 (25%)	85 (42%)
Mulefat (Baccharis salicifolia)			2 (5%)	42 (32%)	44 (22%)
Arroyo Willow (Salix lasiolepis)			2 (5%)	24 (18%)	26 (13%)
Southern California Grape (Vitis girdiana)	1 (8%)	1 (6%)	7 (17%)	7 (5%)	16 (8%)
Black Elderberry (Sambucus nigra)				7 (5%)	7 (3%)
Tamarisk (Tamarix ramosissima)				1 (<1%)	1 (<1%)
Narrowleaf Willow (Salix exigua)				1 (<1%)	1 (<1%)
Eucalyptus sp.		1 (6%)	1 (3%)		2 (1%)
Fremont Cottonwood (Populus fremontii)				3 (2%)	3 (1.5%)
Olive (Olea europaea)				1 (<1%)	1 (<1%)
Castor Bean (Ricinus communis)			1 (3%)		1 (<1%)
Common Sunflower (Helianthus annuus)			1 (3%)		1 (<1%)
Arizona Ash (Fraxinus velutina)				3 (2%)	3 (2%)
Pacific Willow (Salix lucida)				2 (1%)	2 (1%)
Red Willow (Salix laevigata)				2 (1%)	2 (1%)
Box Elder (Acer negundo)				1 (<1%)	1 (<1%)
Chinese Elm (Ulmus parvifolia)				1 (<1%)	1 (<1%)
California Pepper (Schinus molle)				1 (<1%)	1 (<1%)
Himalayan Blackberry (Rubus armeniacus)				1 (<1%)	1 (<1%)
Giant Reed (Arundo donax)				2 (1%)	2 (1%)
Total Nests	13	16	39	133	201

Table 6: Dominant Groundcover Encountered at Least Bell's Vireo Nest Site - Prado Basin 2022

Plant Species	Elevation <490'	Elevation 490-497'	Elevation 498-505'	Elevation >505'
Bareground/Leaflitter/Deadfall	8	4	19	83
Castor bean (Ricinus communis)			1	
Poison Hemlock (Conium maculatum)			1	7
Black Mustard (Brassica nigra)			1	1
Stinging Nettle (Urtica dioica L. Ssp holosericea)			2	2
Non-Native Grasses	1			
Perennial Pepperweed (Lepidium latifolium)		1	6	31
Spearscale (Atriplex prostrata)	3	8	4	1
Common Sunflower (Helianthus annuus)	1	1	2	1
Horseweed (Erigeron canadensis)		1		
Caterpillar Phacelia (Phacelia cicutaria)				3
Curly Dock (Rumex crispus)				1
White Nightshade (Solanum Americanum)			1	
Himalayan Blackberry (Rubus armeniacus)				3
Wild Radish (Raphanus sativus)				1
Milkweed sp. (Asclepias)		1		
Dominant Feature	Elevation <490'	Elevation 490-497'	Elevation 498-505'	Elevation >505'
Vegetated	5	12	18	51
	38%	76%	49%	38%
Deadfall/Leaflitter/Bareground	8	4	19	83
	62%	24%	51%	62%
Average Substrate Height	21"	27"	25"	25"

OTHER FACTORS AFFECTING HABITAT HEALTH IN THE PRADO BASIN

Polyphagous Shot Hole Borer

Bird nesting habitat is under siege in the Basin by a threat much weightier than temporary inundation. In the spring of 2016, District biologists first observed the Basin's trees, especially arroyo and black willows, die off in a patchwork. The cause of mortality was later confirmed to be Polyphagous shot hole borers (PSHB) (*Euwallacea sp*.) and *Fusarium* dieback (FD) (*Fusarium euwallaceae*), pest-disease complex. Although PSHB certainly arrived before the spring of 2016, there was no obvious destruction before then. In 2022, PSHBs were detected locally throughout the Basin but a singular widespread die-off of trees has still not reoccurred. In the patchwork areas hit hardest by the infestation, many trees have either died or in most cases crowns sprouted after the upper branches had died back. Crown sprouting, as observed in several of the specimen black and arroyo willows in the Basin, allows most of the trees to persist. The sprouts even provide suitable bird nesting habitat.

Although the bulk of the forest has been able to withstand wholesale tree loss the dieback and crown sprouting has resulted in a reduction of canopy height in many areas. The lack of canopy has been mitigated in many areas as previously damaged trees have had substantial regrowth into the upper canopy. Loss of canopy and native understory have negatively impacted many bird species, including the vireo. Surveys into the deeper parts of the forest have yielded evidence that PSHB is present in these areas but has not resulted in large die-offs or significant dieback. PSHB spread and visible damage appeared to lessen during 2020, 2021, and 2022 seasons. PSHB is an on-ongoing concern and although the infestation seems to be expanding slower, there are currently no viable large-scale control methods. Forest changes will continue to be monitored and recorded as riparian patches regenerate following episodes of dieback.

Drought, Ground Water, and Reduced Surface Flows

The depth of groundwater and surface flows from the Santa Ana River and tributaries are essential to healthy tree, and shrub growth as well as the recruitment of young plants. When surface flows decrease the wet gradient that exists between the groundwater and surface flows begins to retreat. If this gradient diminishes greatly, young trees and shrubs will not persist beyond the rainy season. Under wetter conditions, this gradient will fall slowly allowing plants to match their root growth with the retreat of the moisture gradient. If the gradient drops too quickly due to reduced flows in the waterways or a reduction in groundwater levels due to pumping, plants cannot adapt quickly enough and will decline, possibly perishing.

Longer periods of drought have also become a persistent threat to habitat viability in the Prado Basin. As groundwater levels drop, so does the recruitment of tree species in the interior of the Basin. In upslope areas of the basin, shallow-rooted species such as Black Willow have declined leading to the recruitment of the more drought-tolerant willows, particularly Mule fat. Mule fat can typically grow roots to a depth of 10-12 ft compared to Black Willow with root depths of only 6-8 ft. or less. As dry conditions persist, even Mule fat will decline especially with further drops in the water table.

In the lower elevations, drought years often give young willows a chance to recruit when inundation pools diminish. A lot of recruitment has taken place from 2012 to the present due to consistent yet shorter inundation events. Water tables at these lower elevations remain high even during drought years. This recruitment contributes to the overall "creep" of the forest as conditions allow for trees to encroach on areas that had previously been vegetated but were damaged by extreme inundation events, intense fires, and insect damage.

In 2022 habitat decline continued at higher elevations due to below-average rainfall. Dry conditions contributed to scarce plant understory and were reflected in stressed trees and shrubs. The dry conditions in the upper elevations of the flood plain also led to the poor tree and shrub recruitment by species such as Mule fat. The presence of a modest inundation pool at the lowest elevational zones allowed for increased vegetative growth there, expressed in the canopy of the Black Willow Forest.

In 2015, 8 groundwater monitoring wells were installed across the Prado Basin at different elevational zones. These drive points were situated in locations where there would be no influence from perennial surface water near the wetlands or conveyance channels. In 2021 these 8 temporary wells were replaced by 10 permanent wells installed to a shallow depth of 17 feet. Nine additional wells were installed in 2022 at 5 locations (Figure 5). Most of the wells are shallow, but 4 of the wells were installed to a depth of 48-50 feet.

Monthly monitoring from 2016-2022 revealed that groundwater levels have steadily dropped at most well sites except those located deeper in the forest where groundwater is replenished by the inundation pool. The recent declines have persisted at higher elevations even during wet years. The northernmost wells have experienced the most dramatic groundwater decline as shown in the hydrographs for PD9, 10, 11, and PD12 (Figures 6-7). Monitoring wells PD13, and PD14 show seasonal modulations with a slight decline overall (Figure 7). Wells located in the center of the Basin with little influence from the channels and wetlands show declining water levels with drought. Well PD16 in contrast shows little change due to its location in the inundation area where the hydraulic gradient between surface and groundwater is present for much of

the year (Figure 8). The monitoring wells graphed in figures 8-10 are newer wells with no historical data, but trend lines will become clearer with additional sampling over time.

Past and future effluent reductions, groundwater pumping, increased stormwater capture at upstream locales, and extreme droughts will present challenges in maintaining a healthy forest. Maximizing flood irrigation when available will be key to the long-term health of the forest and dependent wildlife populations in the Prado Basin.

Figure 5: Location of Groundwater Monitoring Wells in Prado Basin

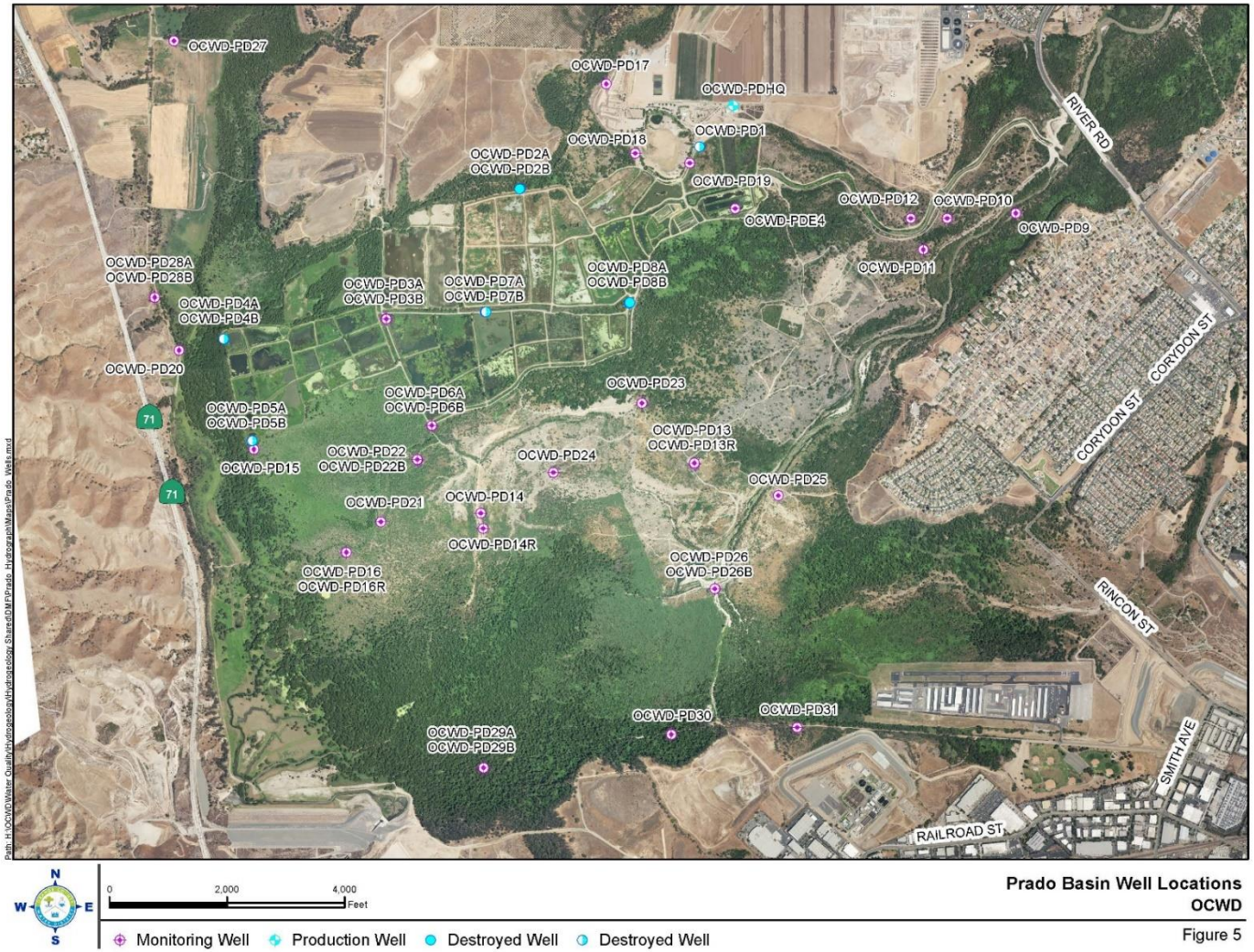


Figure 6: Prado Basin Groundwater Levels

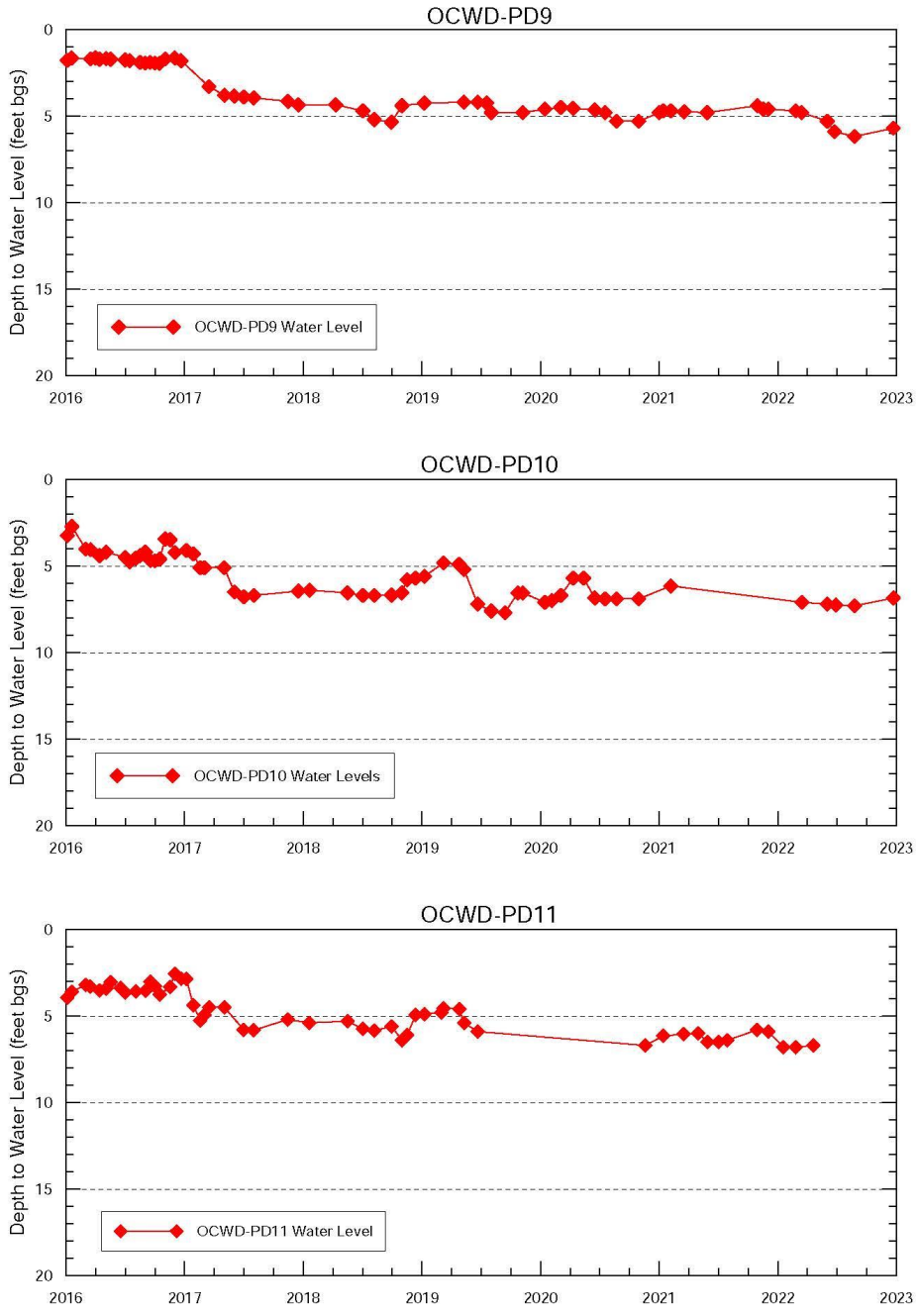


Figure 7: Prado Basin Groundwater Levels

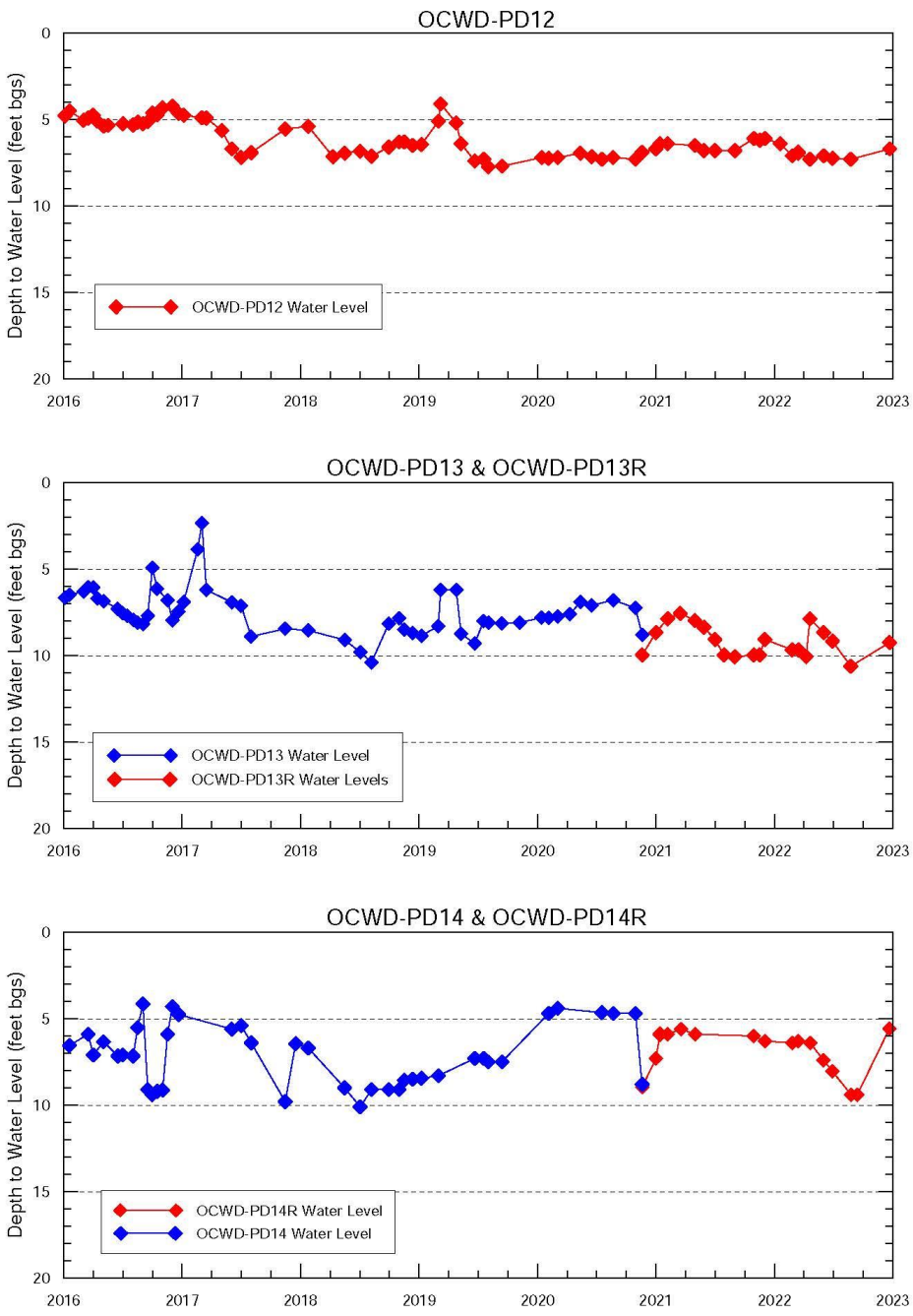


Figure 8: Prado Basin Groundwater Levels

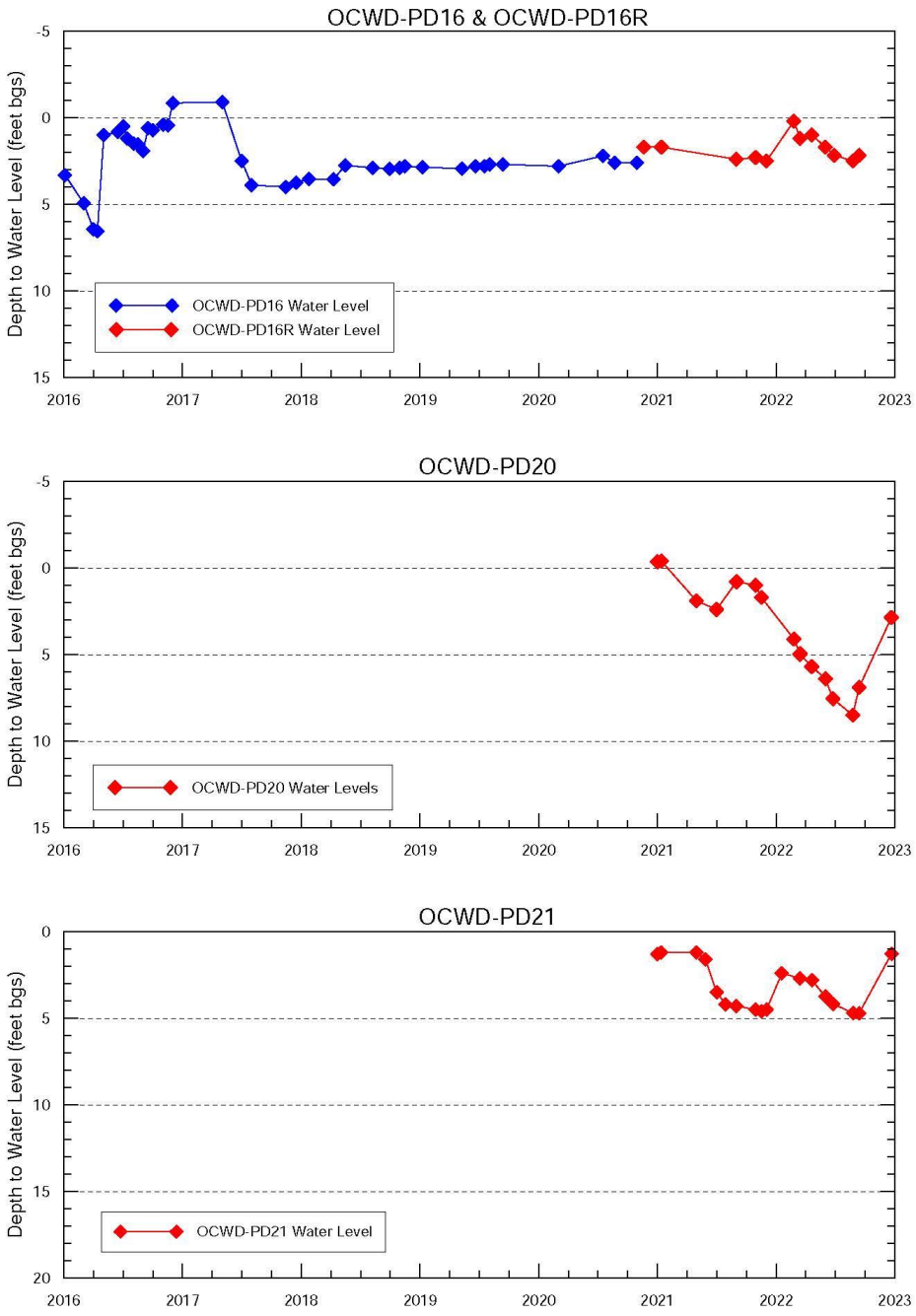


Figure 9: Prado Basin Groundwater Levels

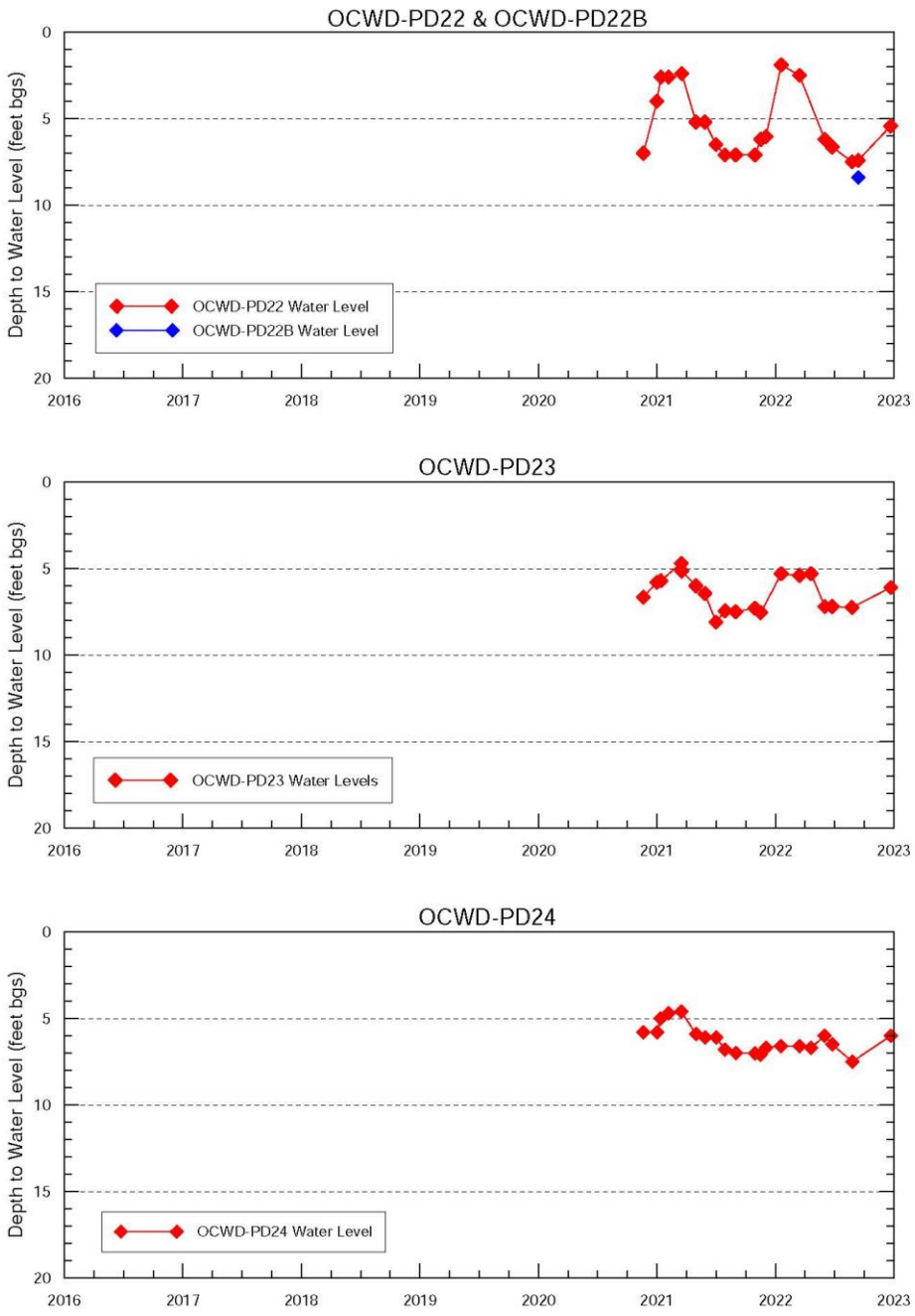
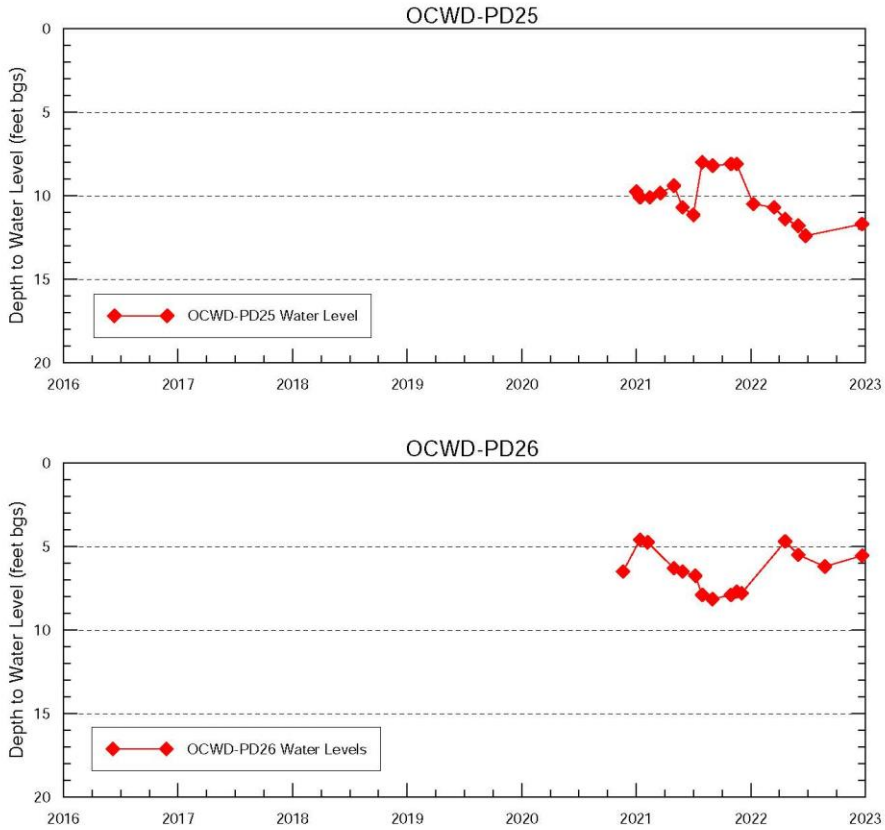


Figure 10: Prado Basin Groundwater Levels



Past Fire Events in the Prado Basin

Fire is emerging as the largest potential inimical factor affecting habitat and species in the Prado Basin; its effects on habitat health are extremely detrimental, even catastrophic with increasing frequency. Homeless encampments, periodic droughts, reduced water availability due to sinking groundwater, and the growth of nonnatives such as Arundo have combined to create conditions conducive to big fires. A significant percentage of the basin's native riparian values and species will be lost over time, if nothing meaningful is done to reduce the frequency and size of future fires.

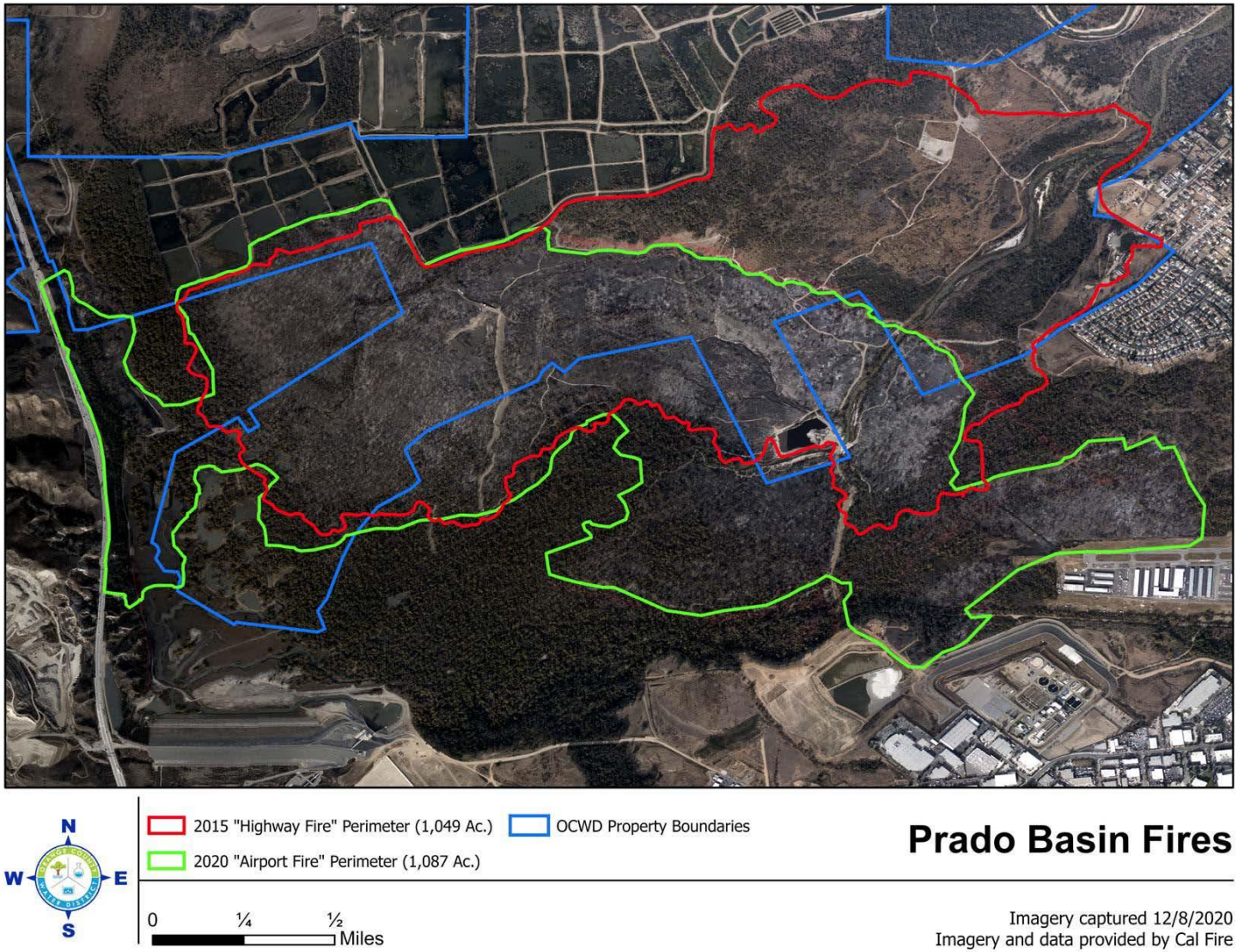
Drier conditions carried the April 2015 Highway Fire that burned 1,049 acres. The footprint of the fire spanned the groundwater elevational gradient causing the intensity of the burn to vary across the affected land. The most destructive area of the burn occurred in a large patch of black willow forest mixed with Giant Reed (*Arundo donax)*. The trees in this area showed signs of water stress before the fire. The intermix of giant reeds added fuel and helped carry the fire. Many Black Willows that burned in the hottest areas of the fire did not survive. These hot spots have been colonized by invasive non-natives, predominantly Perennial Pepperweed, which is deeply rooted enough to establish abundantly across the basin where willows no longer can. In contrast, areas that burned quickly, and with lower intensity, rebounded more quickly. Well-watered Black Willows and Mule fat near the water channels crown-sprouted quickly thus providing nesting habitat and refuge for wildlife, some during the following season.

In December 2020 a second fire burned across the lower Prado Basin. The Airport fire burned 1,087 acres over much the same footprint as the 2015 fire. As in 2015, the fire followed and burned hotter through the Arundo patches. Fortunately, much of the Arundo had previously been removed and the fire was concentrated in the Arundo mulch, containing it to the lowest vegetation layers. Observations in 2021 confirmed that tree death was minimal and regrowth in the form of crown sprouting was noted throughout the burn footprint and many of the willows survived the fire. This regrowth continued in 2022 facilitating the return of many bird species including Least Bell's Vireo (Figures 11 and 12). Figure 13 shows the footprint of both fire events.

Figure 11: Black Willows Burned – Post Airport Fire 12/14/2020

Figure 12: Black Willow Regrowth - Post Airport Fire 9/29/2022

Figure 13: Prado Fire Maps



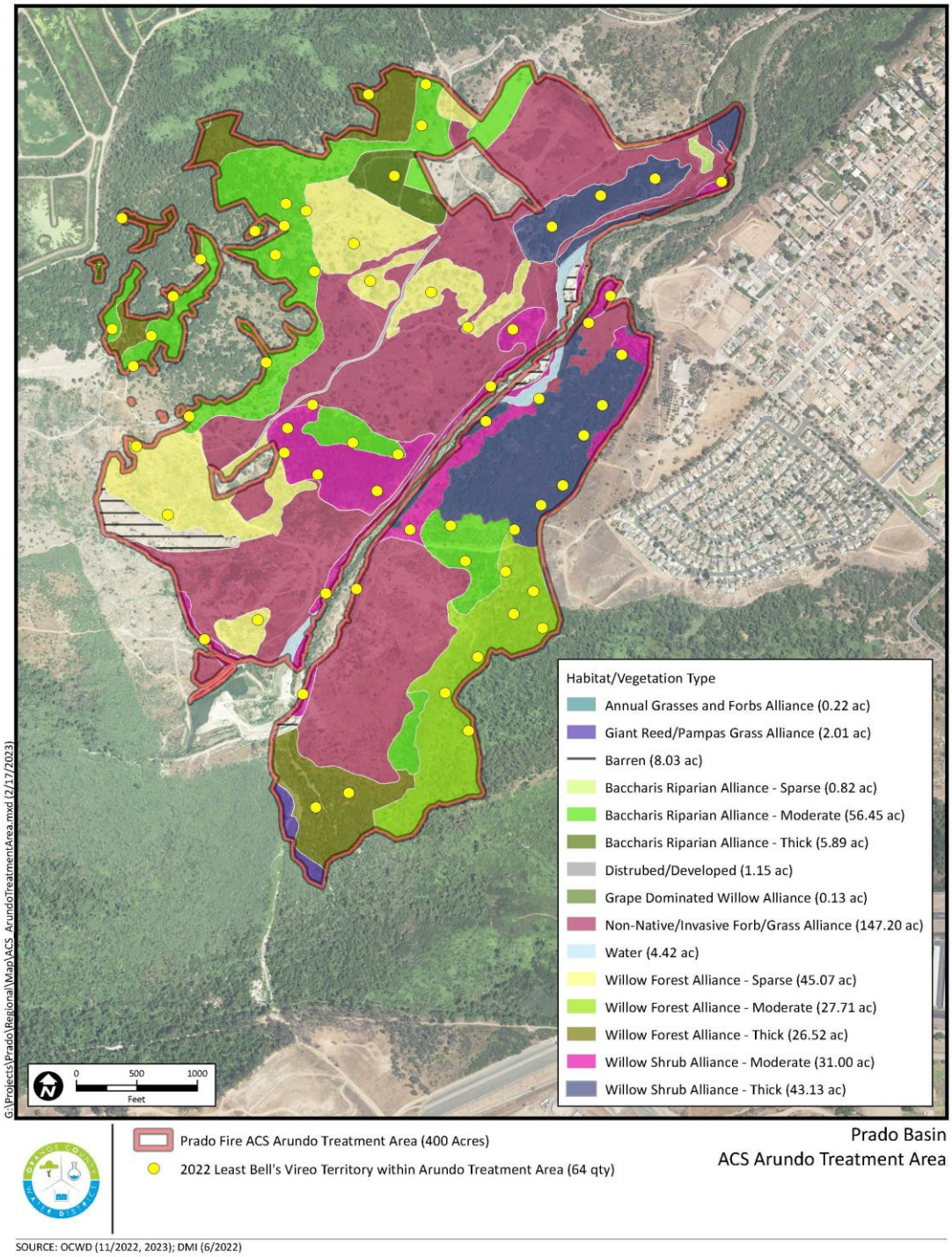
Preemptive Habitat Restoration with Giant Reed Control on the Highway Fire Site

The removal of Giant Reed, *Arundo donax* from this designated site in Prado Basin began on Orange County Water District property following the “Highway Fire” which burned over 1,000 acres in April 2015 (Figure 14). The fire consumed and was largely fueled by hundreds of acres of Arundo. Immediately following the fire, Arundo regrowth was rampant and the OCWD Board approved the funding to treat the regrowth and monitor habitat recovery on 400 acres. ACS was contracted to treat the Arundo and other non-natives for a duration of 5 years concluding in May 2020. Parts of this parcel were burned a second time in December 2020 and additional Arundo treatment has been ongoing with grant funding. The District’s goal in this preemptive work has been to establish riparian values upfront that could act to offset, if needed any potential habitat losses over time due to District activities in the Prado Basin due to Water Conservation or other projects.

The vegetational composition of this parcel has been monitored and surveyed to quantify natural recruitment and the development of viable habitat. Results to date have been encouraging with the generation of hundreds of acres of early successional scrub and forest stands in a mosaic across the landscape interspersed with more open but weedier ground. Baccharis Riparian, Willow Forest, and Willow Shrub types now make up 237 acres of this site, providing suitable habitat for 64 Least Bell’s vireo territories in 2022 where there were none in 2015 following the fire. The additional open, patchy, weedier remaining 163 acres consist of non-native forbs, grasses, barren ground, disturbed sites, and water. Some acreage was lost during storm events, becoming part of the river channel. Additional acreage of viable habitat may be generated over time but likely would require weeding, planting, and other measures to ensure success.

A small piece of the restored habitat on the Preemptive Habitat Restoration Site was set aside and dedicated to offset any potential habitat damage associated with the activities on the Sediment Demonstration Project site (FWS-WRIV-09B0192-18F0101, Formal Section 7 Consultation for the Five Year Planned Deviation to the Prado Dam Water Control Plan and Sediment Management Demonstration Project in the Prado Basin, Riverside County, California issued by the U.S. Fish and Wildlife Service on July 11, 2018).

Figure 14: 400 Acre Arundo Treatment, Preemptive Habitat Restoration Site



DOCUMENTING CHANGES IN RIPARIAN VEGETATION OVER TIME

Plant cover in the riparian community of the Prado Basin has been photographed and measured to establish baseline conditions and any changes over time associated with water conservation. The different methodologies pursued to monitor habitat health include aerial flights; the stacked cube method of estimating plant cover from ground to canopy top; observations of vegetation at vireo nesting sites; and camera monitoring stations including timelapse.

Monitoring Vegetation with Photographs

Habitat health can be influenced by increased inundation, drought conditions, insect infestation, fire, and other forest-altering events. Most monitoring sites included mixed mule fat and black willow riparian woodlands. Mule fat is a perennial evergreen and will not defoliate unless under stress. Black willow is the dominant species of riparian tree in the Basin and is winter deciduous. These willows can endure long periods of inundation and may not show signs of degradation for many years, necessitating long-term monitoring. The photographs yield visual documentation of varying conditions over time relative to pool size as it pertains to water conservation and flood control. Figure 15 shows the locations of our canopy and understory photo stations.

Canopy Photo Stations

Perimeter monitoring stations are situated at higher elevations to overlook habitat potentially affected by inundation due to water conservation and flood control. Nine stations are located along the edges of the basin (Figure 15). These stations give a panoramic view of the habitat within many elevational zones. The images taken focus on the tree canopy but also capture the adjacent shrub and ground cover layers. Each station consists of a permanent stake in the ground that has been GPS-ed to mark the site. Photos are taken while standing directly in front of the stake. There are typically three visits to the photo stations during the year depending on access. The first round of photos is taken during January-February to document possible inundation events. The second visit happens in spring when temperatures are rising and many species, including the willows, are coming out of dormancy. The spring visit is generally well-timed with peak bird nest initiation. A third visit takes place in late summer when any decrease in habitat cover would be most evident. This visit coincides with annual vegetational surveys using the stacked cube method of estimating plant cover at various heights above ground to compare with data taken in other seasons and years.

The following photo sets are in areas that are often inundated during the wet season (Figures 16-19). The spring and summer visits are used to show habitat growth and decline during the past 5 seasons. The photos display the benefits of flood irrigation during wet years and decline during dry years. The spring visits show that willows in the basin typically exhibit strong re-growth from previous inundation events. The August

visit is typically an indicator of a bad versus good rain year since tree canopy decline is often not seen until the summer months when surface water is absent and groundwater levels have dropped.

The 2018 photos indicate the decline and dieback in the willow canopies due to drought, heat, and damage from shot hole borers. Between the 2010/11 and 2017/18 rain seasons, there were 6 years with below-average rainfall and 5 years of extreme drought. Infrequent rainfall provided some relief, but sequential dry years contributed to the habitat decline that was seen in 2018. The numerous drought years did allow younger willow trees to recruit and persist at the lower elevations. In 2019 the forest canopy was showing signs of recovery and in 2020 the forest grew exceptionally after two successive years of decent rainfall (17.97”, 13.94”). In 2021 and 2022, the forest canopy remained healthy in the lower elevations, but some decline was noted in the summer. This was due to the low rainfall, 5.13” in 2021 and 7.87” in 2022, which supported only scarce understory growth and caused a noteworthy decline in the habitat at the higher elevations. Habitat at the lower elevations was not as drought-stricken the past two years because of a meager inundation pool in the late winter to early spring.

Figure 15: Prado Basin Photo Monitoring Stations

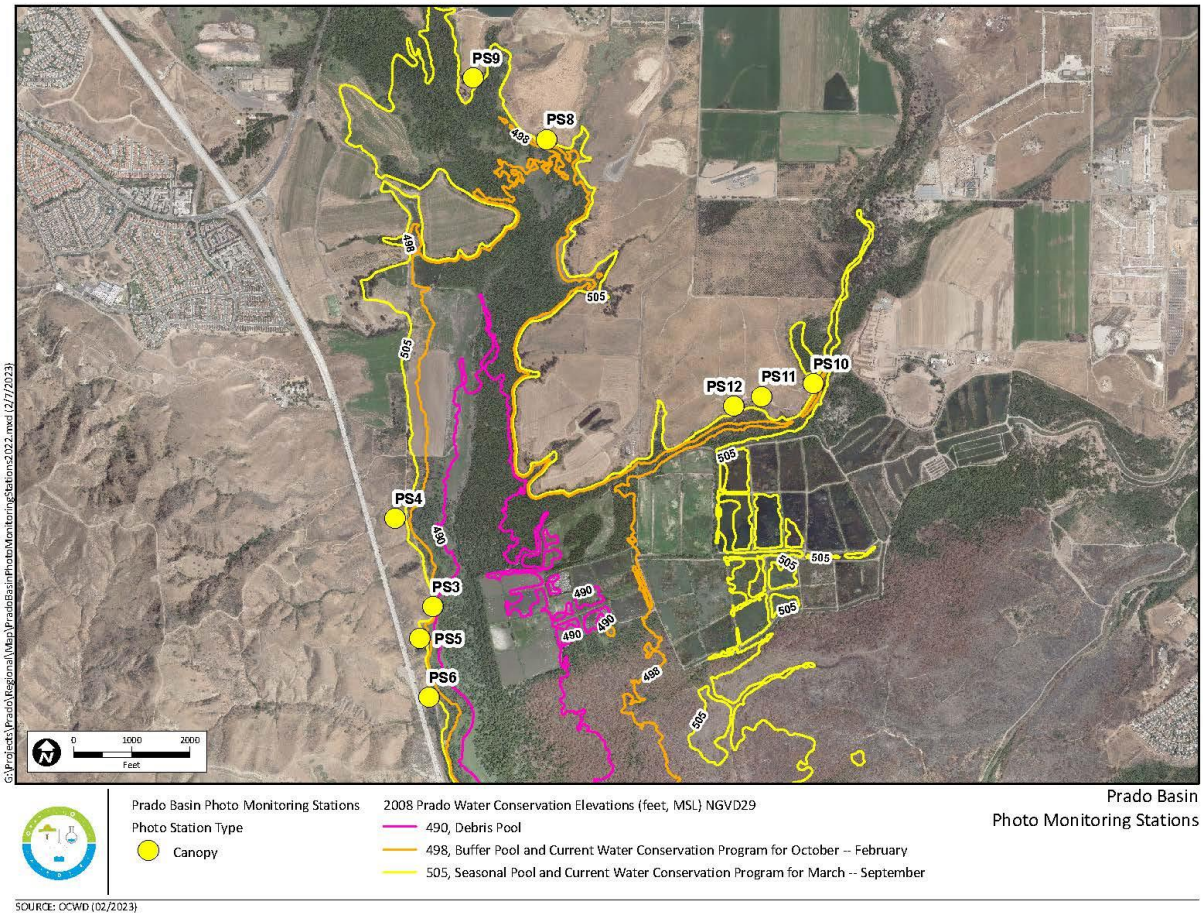


Figure 16: Canopy Photo Station #3 2018-2022

May 2018

August 2018

June 2022

August 2022

Figure 17: Canopy Photo Station #8 2020-2022

May 2018

August 2018

June 2022

August 2022

Figure 18: Canopy Photo Station #9 2018-2022

May 2018

August 2018

June 2022

August 2022

Figure 19: Canopy Photo Station #11 2018-2022

May 2018

August 2018

June 2022

August 2022

Remote Monitoring Using Drones

Vegetational transects were flown with drone-mounted cameras to document habitat health. A contractor, HANA Resources flew transects to collect thermal photographs and calculate foliage types and conditions, using temperature in part, down to the pixel level. From 2018 to 2022 HANA Resources, Inc. (HANA) provided the Orange County Water District (OCWD) with vegetation studies of two legs of a transect (*Chino Creek Leg 1 505 Northeast, and Chino Creek Leg 2 505 North*), conducted to assess plant health for the OCWD Prado Flood Control Basin Plant Assessment Project (Figure 20).

HANA Resources' plant growth health measurement and prediction system utilizes drone-captured images to measure the current growth and condition of plant stands. The system involves a drone flight along a pre-determined path, capturing images that are patched together to analyze plant cover health along the transect. The captured

images may include both high-resolution multispectral images and high-resolution aerial images. The imagery data are processed to create an orthmosaic image of the land cover, within which each pixel comprising the image is analyzed with the Normalized Difference Vegetation Index (NDVI). NDVI quantifies vegetation, and measures the difference between the near-infrared (reflected by vegetation) and red bands (absorbed by vegetation) of the electromagnetic spectrum, as follows:

$$NDVI=(NIR-RED)/(NIR + Red).$$

Resulting values range from -1 (Red) to +1 (Green), where -1 is equivalent to surface water and +1 represents dense vegetation. Dirt roads, and building surfaces typically show values closer to 0. The flights typically take place in the months of June, and August. June is key to showing growth following inundation events and to capturing the vegetation used by Least Bell's Vireos during the period that they are foraging for nestlings. The August flight and analysis are timed to match the data collection period using the stacked cube method.

Figure 20: HANA Resources' Flight Transects

North East 512 Leg

This deep forest leg starts near the dam and cuts through the lowest portion of the riparian forest which gets some degree of inundation during each rainy season. This leg was lengthened this year to include an additional 0.33 miles of forest as it transitions into an Arundo removal site. The regular inundation along this leg typically facilitates a high score for vegetation health and cover in the canopy layer but often delays herbaceous growth in the understory. The green portions in sections 1-6 on the map indicate that most of the leg is very healthy (Figure 21). Table 7 shows the acreage and cover percentage of the three vegetation layers. The tree layer is the most productive of these classes with 16.05 acres represented as very healthy with a 36.51 cover percentage. The shrub layer also rated high in the very health category with 12.58 acres and 28.63 coverage. Trees with a shorter stature are often included in the shrub category. Under a thick tree canopy, the herbaceous layer is often poorly measured with only 5.67 acres represented and 12.90 percent coverage. Depending on the timing of the flight and inundation pool size there can be an abundance of understory vegetation in this part of the forest, or the growth can be delayed until the inundation pool recedes.

North 505 Leg

This leg of the transect has changed dramatically over the study years, as the *Arundo donax* that once covered most of the leg was removed in 2020 and then the Airport fire burned through here in December 2020. This leg straddles the 505' elevation which is infrequently inundated. In 2022 this transect was shortened by .23 miles so as not to include the wetlands which were often represented as open water but could contain cattail/bulrush depending on the time of year. As seen in figure 22 sections 1-4 includes large amounts of inanimate or dead, expressed as yellow and red on the map. The proportionally large amount of inanimate or dead recorded is due to the presence of unhealthy Arundo, chipped Arundo, roads, and open areas created during the Arundo removal. Many of the existing trees in this area burned during the previous fire but many now have resprouted and are growing rapidly.

As expected, the inanimate/ dead layer dominates this leg with 7.74 acres and 38.84 percent coverage (Table 7). The shrub layer only registered 1.64 acres and 8.23 percent coverage in the very healthy category. The tree category contributed 1.61 acres and 8.08 percent coverage in the very healthy category. The herbaceous layer was the smallest contributor with only .59 acres, and 2.97 percent coverage. The lack of herbaceous layer is partially due to the lack of sufficient rainfall during the 2021-22 rain year.

This year's analysis provides baseline data for a relatively dry year to compare with subsequent years since the NE leg was lengthened slightly and the N leg was shortened to no longer include wetland ponds.

Figure 21: Northeast Transect Leg – NDVI

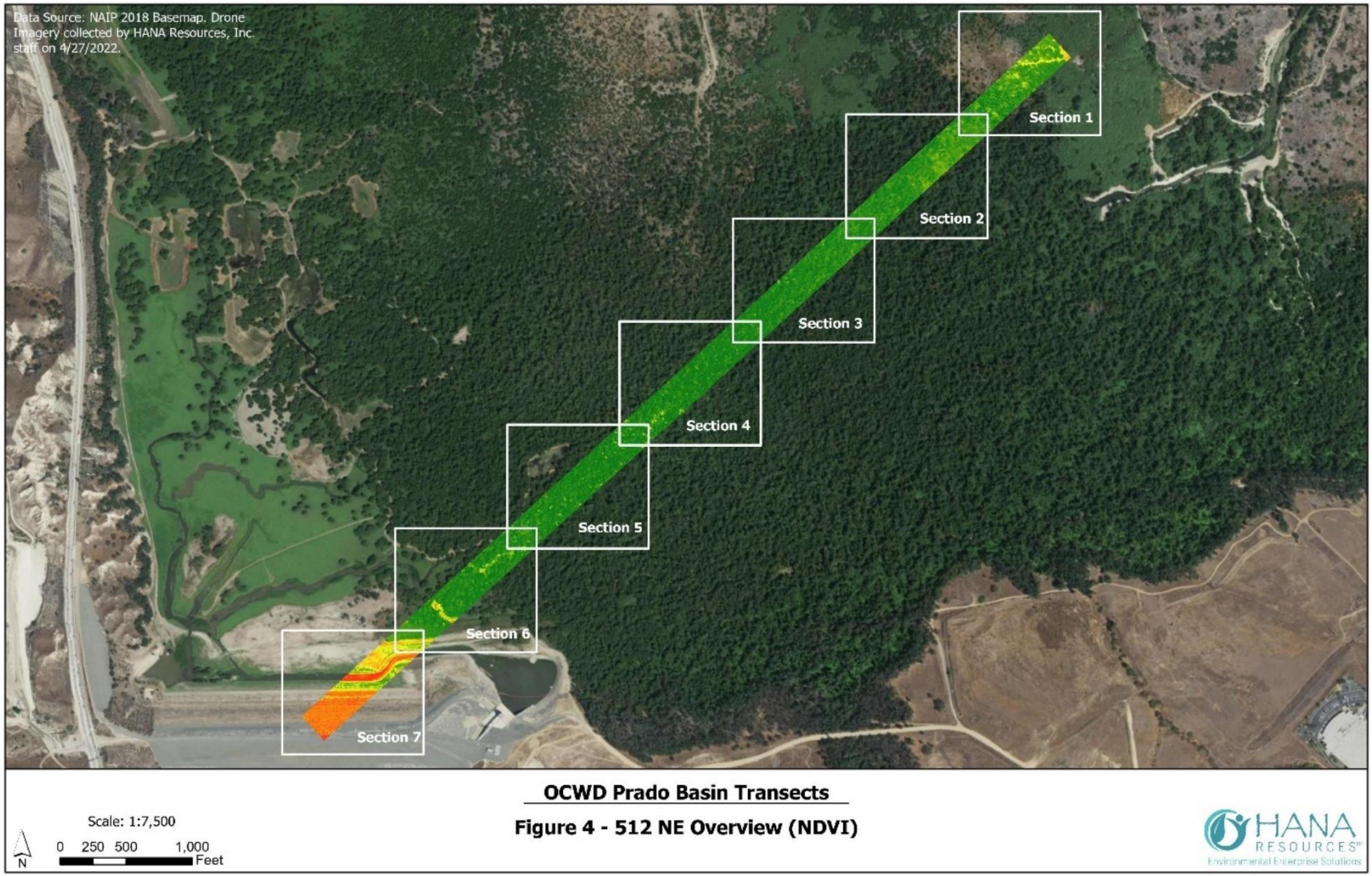


Figure 22: East Transect Leg – NDVI

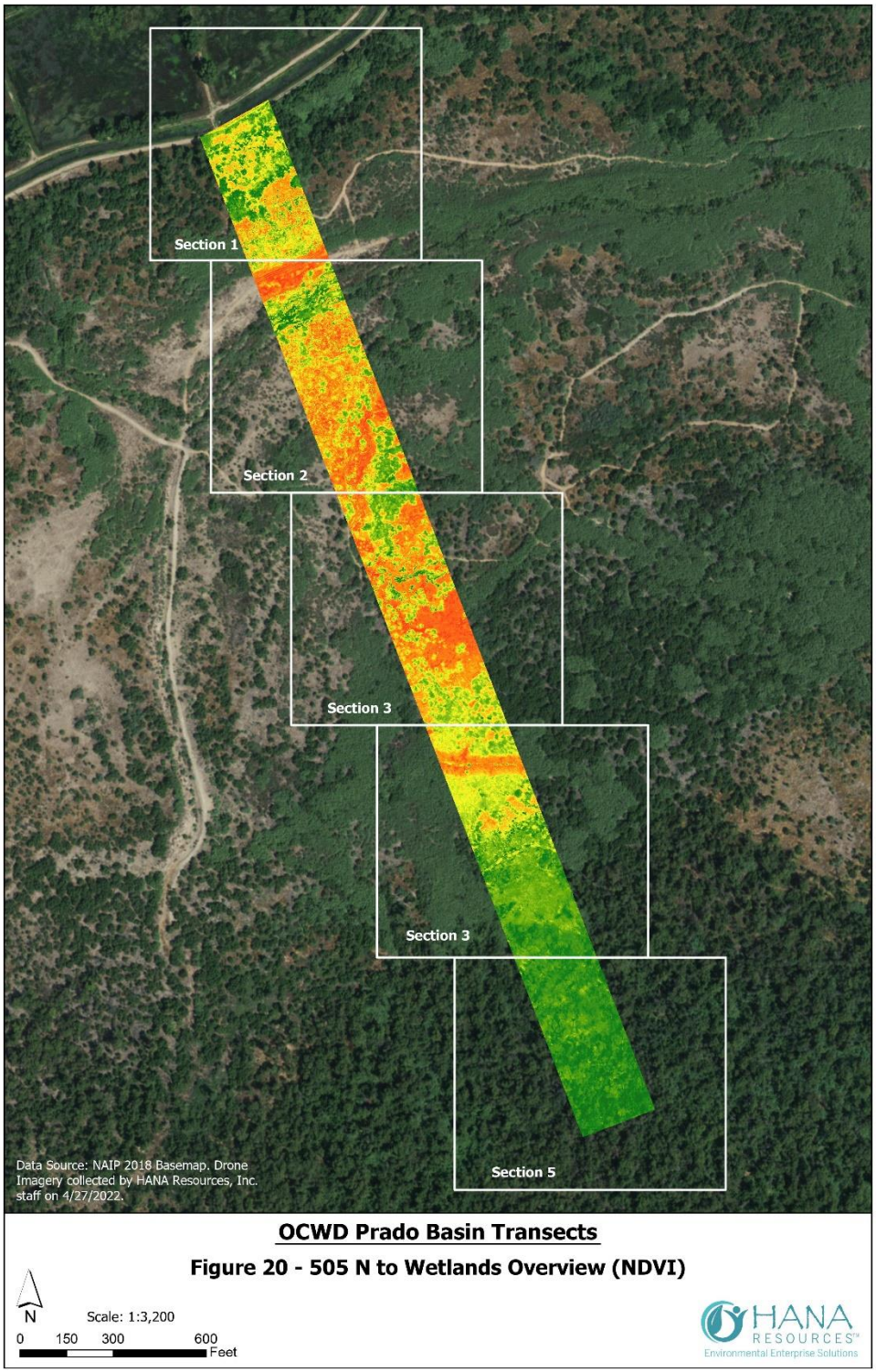


Table 7: Plant Health Assessment Calculations by Layer

Transect ID	Layer	Veg Type	Acreage	% Cover
512 North East	Herb	Very Healthy Veg > .66	5.67	12.90
		Healthy Veg < .66 and > .33	1.60	3.64
		Unhealthy Veg 0 < .33	1.00	2.26
	Shrub	Very Healthy Veg > .66	12.58	28.63
		Healthy Veg < .66 and > .33	1.89	4.30
		Unhealthy Veg 0 < .33	0.34	0.76
	Tree	Very Healthy Veg > .66	16.05	36.51
		Healthy Veg < .66 and > .33	0.73	1.67
		Unhealthy Veg 0 < .33	0.03	0.08
		Inanimate/Dead	4.06	9.25
		Total	43.95	100.00
505 North to Wetlands	Herb	Very Healthy Veg > .66	0.59	2.97
		Healthy Veg < .66 and > .33	1.49	7.45
		Unhealthy Veg 0 < .33	1.81	9.06
	Shrub	Very Healthy Veg > .66	1.64	8.23
		Healthy Veg < .66 and > .33	2.84	14.26
		Unhealthy Veg 0 < .33	1.40	7.02
	Tree	Very Healthy Veg > .66	1.61	8.08
		Healthy Veg < .66 and > .33	0.78	3.89
		Unhealthy Veg 0 < .33	0.04	0.20
		Inanimate/Dead/Water	7.74	38.84
		Total	19.94	100.00

Remote Sensing Using Aircraft and LiDAR Technology

Stillwater Sciences was contracted by Orange County Water District (OCWD) to conduct a Pilot Study to explore the use of LiDAR (Light Detection and Ranging, also known as Airborne Laser Mapping) in assessing the structure and health of riparian vegetation and associated wildlife habitat in Prado Basin. This study focused on testing the use of LiDAR data collected by a commercial vendor in July 2020 in (1) assessing the structure of riparian vegetation, and (2) comparing it with field-based, labor-intensive methods currently used to link vertical vegetation structure with potential suitability as nesting habitat for the endangered least Bell's vireo (*Vireo bellii pusillus*).

OCWD conducts field-based vegetation studies in the lower Prado Basin using the stacked cube methodology developed by Barbara Kus of the United States Geological Survey (USGS). Stacked cube field protocols involve estimating vegetation cover within a sequence of stacked 2x2x1 meter cubes visualized from the ground to the canopy (Kus 1998). OCWD collected stacked cube data in the summer of 2020 at 40 vireo nest/territory sites and 40 mule fat (*Baccharis salicifolia*) and Goodding's black willow (*Salix gooddingii*) stand sites. At

each nest/territory site data were recorded at the nest location and three additional satellite locations located 10- meters from the nest, oriented at 0, 120-, and 240-degrees from the nest, such that the vegetation at each nest/territory site is sampled in 4 discrete stacked cubes (n=160). At mule fat and black willow stand sites the stacked cube data is only measured at a central sample point (n=40). OCWD provided the summer 2020 stacked cube field data in tabular format for the Pilot Study.

The primary objective of the pilot study was to assess if LiDAR data could be utilized to provide information on vegetation and habitat structure comparable to data produced using the field- based stacked cube method, such that LiDAR analysis might replace the stacked cube surveys in the future, either in whole or in part. An additional objective was to explore how LiDAR data might be used to provide a more general assessment of riparian habitat conditions and help define appropriate spatial scales for LiDAR vegetation structure analysis across the lower Prado Basin. A map of the study site can be seen in Figure 23

Methods

LiDAR vegetation cover densities were directly compared with summer 2020 field-based stacked cube vegetation cover field measurements at 40 mule fat and black willow stand and 152 of 160 Nest/Territory sample plots. Sample plots were created in Geographic Information Software (GIS) by generating 2-meter x 2-meter square quadrats centered on the sample plot coordinates and the three satellite sampling points at a 10-meter distance, oriented at 0, 120-, and 240-degrees. The LAS data with height above ground attributes were extracted at each sample plot, converted to ASCII format text files, and compiled for analysis with R-Statistics software. For nest/territory sites, the central location and three satellite sample plots were tested and treated as individual measurements. For mule fat and black willow sites, only the central sample plot was tested. This sample design mimics the field-based stacked cube measurements. In the next steps, the R-data processing scripts stratified the extracted LAS data into 1-meter vertical strata to create 2x2x1 meter (4-m^3) volumetric bins to mimic stacked cube field measurements and computed the NRD correction.

Additionally, 5x5x1 meter (25-m^3) bins were generated to increase the number of LiDAR returns and reduce random noise after a preliminary review indicated the 4-m^3 sample

volume may be too small to make meaningful comparisons.

Results

Results from stacked cube and circular buffer linear regressions generally confirm the NRD LiDAR metric is providing the same kind of vegetation structure data as field-based stacked cube cover estimates (good p-values, formally significant at p=0.05), but there is too much noise in one or both metrics to simply substitute one for the other (poor r-square values) at the stacked cube field sampling scale. Poor regression from the 2-meter stacked cube and 1-meter circular buffers indicates these smaller volumes contain too few LiDAR returns to make meaningful comparisons. Regression results generally improve with increasing sample volume and the nest/territory site averaging (using the mean of the center and three satellite

plots) for the 10, 15, and 20-meter circular buffers yields the highest overall r-square values. Regressions in the 0-3-meter vertical strata range are generally similar to those from higher strata, indicating the NR LiDAR metric is successfully characterizing vegetation structure within the most ecologically significant vertical zone for the Least Bell's vireo nesting habitat.

Cluster Analysis

Cluster analysis is an unsupervised classification technique that seeks to organize observations into groups that are intrinsically similar within a group but dissimilar or isolated from observations outside the group. The LAS data within the priority analysis area were divided into square grid cells, each of which was assigned a vector of attributes. The goal of the cluster analysis was to find a "natural" assignment of these cells to a manageable number of distinct categories based on their attribute vectors, in the hope that this classification would usefully represent community structure and ecological function.

In our pilot analysis, the attribute vector for each cell was calculated from the LiDAR returns from that cell. Specifically, we used the LAS data to calculate a measure of "overhead cover" from vegetation in each of two height ranges: 0.3–5 feet (0.10–1.52 meters), and >5 feet (>1.52 meters). Cells sizes ranging from 5 feet (1.52 meters) to 100 feet (30.48 meters) were tested.

We found that 20 feet (6.10 meters) and 50 feet (15.24 meters) cells, with 3 or 4 final cluster assignments, performed well for our purposes. It appears that 5 feet (1.52 meters) cells contain too few LiDAR returns to classify reliably (mirroring the results of the stacked cube and variable circular buffer testing) and cells larger than 50 feet trend toward overgeneralization and loss of detail. The spatial distribution of 3 cluster assignments for 20x20 foot cells is shown in Figure 24 below.

Figure 25 provides a graphical summary of the vertical distribution of LiDAR returns within each grid cell assigned to a given cluster class. For 3-cluster assignments, cluster class A is generally represented by sparse, short vegetation and large swaths of open ground or water with minor occurrences of denser short vegetation stands. Class A is the most abundant cluster type found in the priority analysis area with 61% of the area analyzed falling into this class. Class B contains a moderately dense canopy that stands from the ground to approximately 20-meter height. Fifty-five percent of nest/territory sample plots and 75% of mule fat and black willow samples are within cluster Class B, which represents only 26% of the analysis area. Class C represents habitat stands characterized by tall, moderately dense canopies with thick, dense closed structures in the 0–10 meter height range, with few LiDAR ground returns, and represents 13% of the analysis area.

Conclusion

The Pilot Study demonstrates that LiDAR technology can be used to characterize vegetation structure within the lower Prado Basin at scales relevant to least Bell's vireo nesting habitat but not at the scale that might define the micro-niche selected by the vireo for nest placement. The LiDAR data do not appear, at this time, to provide return densities sufficient for simple, direct replacement of field-based stacked cube data, however, there is a possibility that revised field protocols that increase field sampling volume or higher density, research-grade LiDAR data might be suitable for this purpose. Analyzing LiDAR data over volumes greater than the 2x2x1 meter stacked cubes does allow useful classification of vertical structure at spatial scales that appear to be ecologically meaningful. Averaging nest/territory central location and satellite sub-plots yielded the best linear regression comparisons and supports the conclusion that increased sample volume will likely improve field-based and LiDAR-derived vegetation structure comparisons. Cluster analysis is a promising approach for generating habitat structure classifications from LiDAR data that should show meaningful correlations to both general riparian health and habitat suitability for focal wildlife species, such as the least Bell's vireo.

Figure 23: LiDAR Pilot Study Area, nest site and other stacked cube sample locations, and remote sensing data acquisition extents

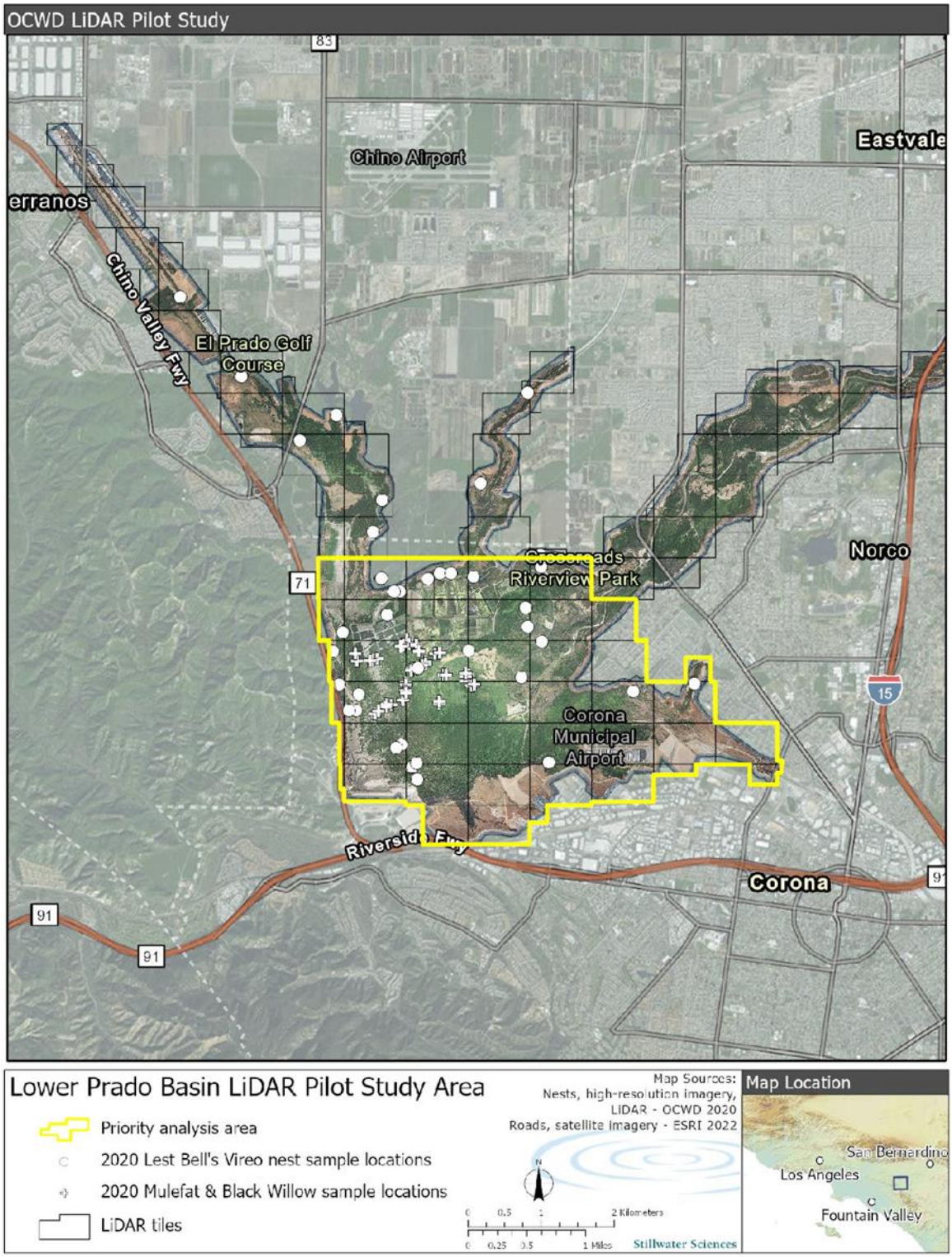


Figure 24: Cluster Assignments for 20’ X 20’ Cells

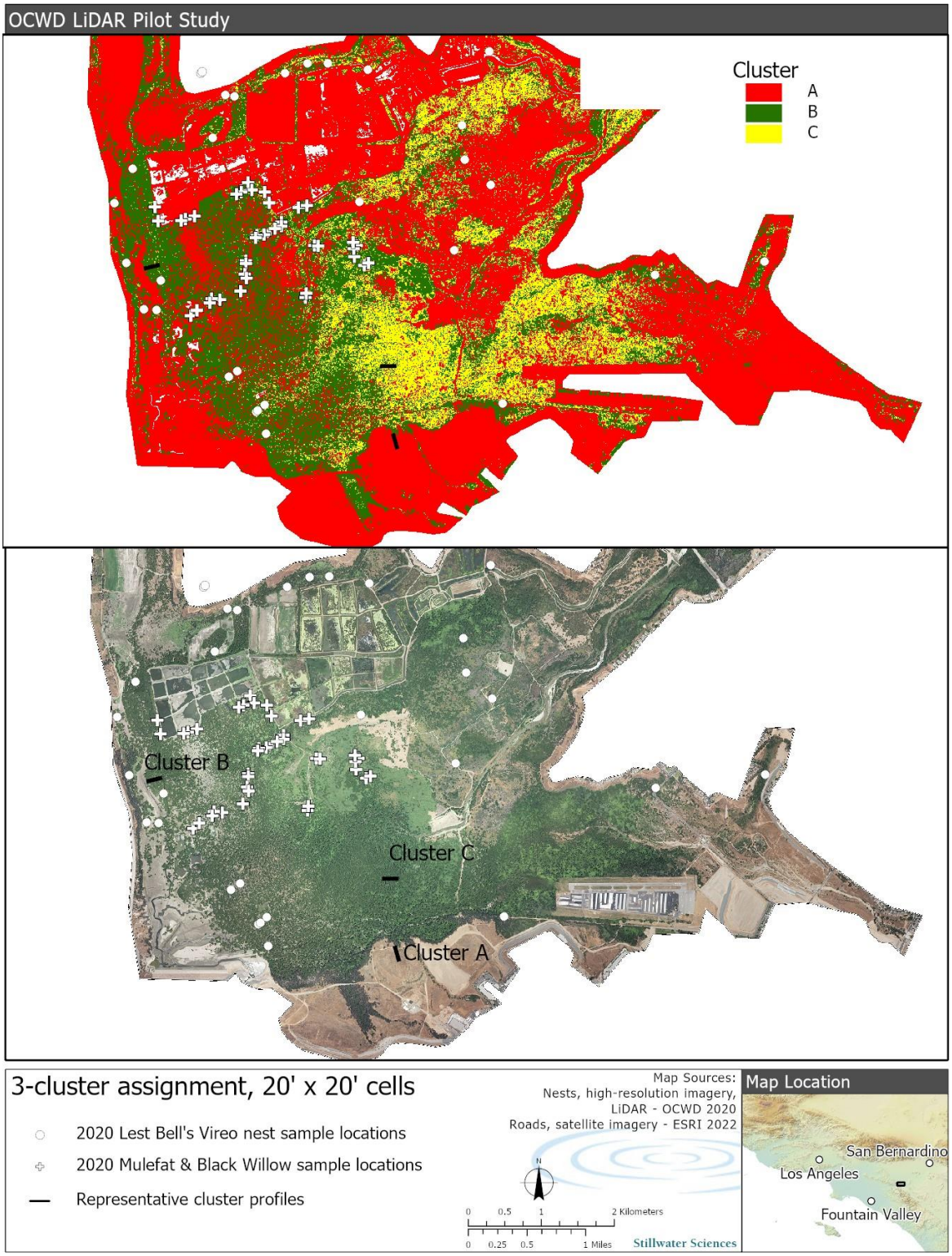
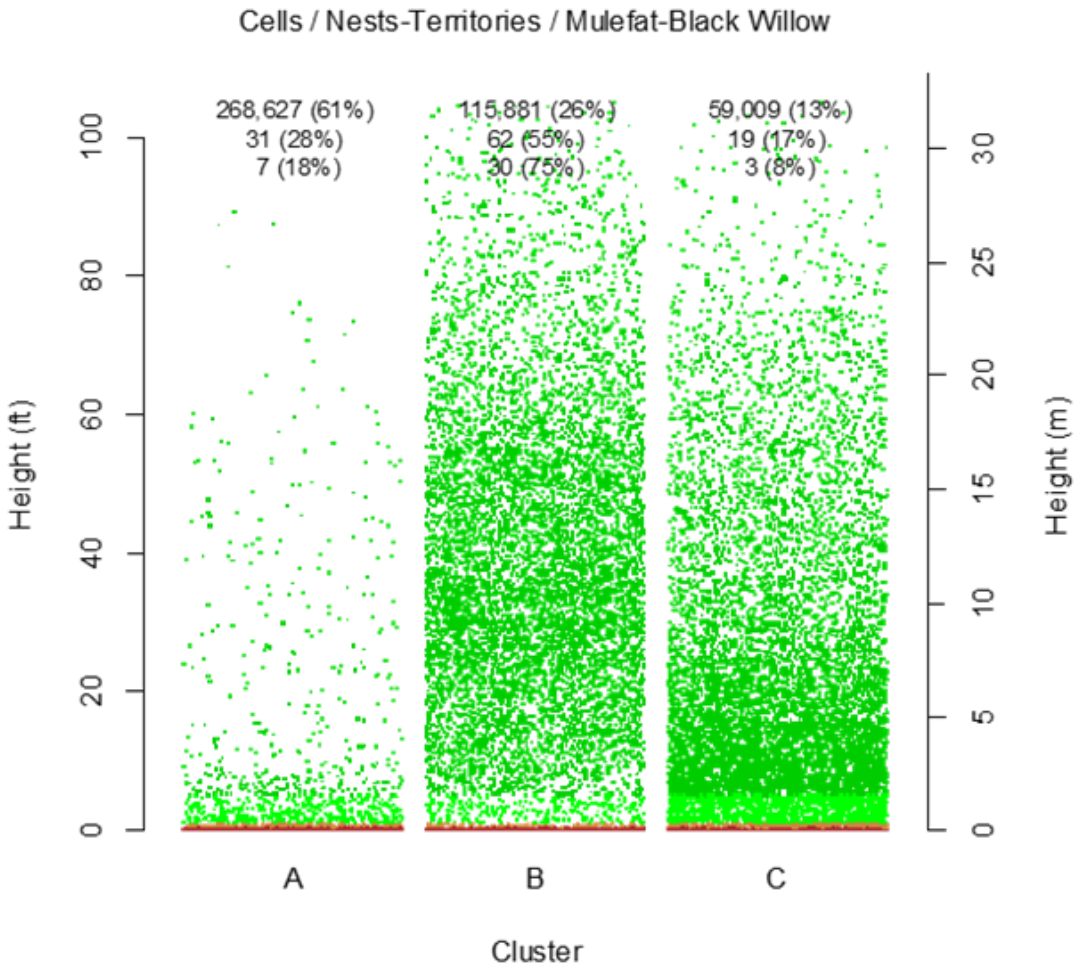


Figure 25: Vertical Summary of LiDAR Returns



Stacked Cube Method

The vegetation of the Prado Basin was studied in the springs and summers of 2018 - 2022. Plant cover sampling was done with a “stacked cube” method (Kus 1998, 2002) of estimating vegetation volume by species within a series of visualized, stacked 2x2x1 meter cubes from the ground to the top of the canopy within the “column” of stacked cubes. This method was developed on the San Luis Rey River and other rivers of San Diego County to assess the habitat requirements of the vireo. It was also used to develop a model of vireo nesting habitat known as the “Least Bell’s Vireo Habitat Suitability Model Index”, for use in assessing other sites for the presence of suitable vireo habitat.

Forty survey points in Mule fat and Black Willow stands were randomly selected in the Prado Basin with 10 plots in each of the following elevation ranges: below 490, 490 – 497, 498 – 505, and above 505 feet mean sea level. The “stacked cube” method was conducted at each of these same points once during the spring (April 9 – May 3, 2018, May 3 – June 12, 2019, April 16 – May 7, 2021, and April 15- 26, 2022) and a second time during the summer (August 2 – 6, 2018, August 2 -7, 2019, August 2 – 10, 2021, and August 5-22, 2022). In 2020, vegetational measurements were taken at these 40 points only once during the summer (August 3 – 7, 2020) due to flood conditions earlier in the season. An additional 40 points were randomly selected each year for Nest/Territory sampling at Least Bell’s Vireo nests and adjacent habitat in 2018 - 2022, equally distributed amongst the same four elevational ranges. For each of the nests, the “stacked cube” method was conducted at the center of the Nest/Territory GPS point. In the past three satellite points surrounding the center point were also surveyed for a total of four sampling locations per nest site. The three satellite points were removed from the protocol in 2022 since they did not add any statistical value during the analysis. In 2022 there were 40 nest points for elevations 490’ to >505’. In past years there were often insufficient nest points within each elevational zone and had to be supplemented with territory points. To minimize disturbance to nesting Least Bell’s Vireo, these nest points were measured after the breeding season. This also eliminated any risk to other nesting species as well.

Statistical Analysis

Years 2018-2022 survey data were analyzed within the season to compare whether there were any significant differences in cover among the elevation ranges and height classes compared to Least Bell’s Vireo Habitat Suitability Model. The summer points of 2018 and 2019, along with the Nest/Territory survey points of these years were compared between seasons and to the Habitat Suitability Model to determine how effective these methods were for finding patterns in the vegetation community. Similarly, 2020, 2021, and 2022 survey data for the 40 Mule fat and Willow points and Nest/Territory points were analyzed to compare the vegetation within height classes between the different elevation ranges and across years.

Data were checked for assumptions of normality and equal variance. If any data did not meet assumptions, they were transformed to meet assumptions before analysis. To test for the effect of elevation within the height class, one-way ANOVA's were conducted within each canopy height class. To explore differences in plant community composition, PERMANOVA's were run in Primer 7 on the fourth root transformed percent cover data and Bray Curtis similarity matrices. Fourth-root transformations were not needed for the 2022 analyses. Visualizations were created using canonical analysis of principal coordinates (CAP) plots. Graphs comparing the LBVI Habitat Suitability Model (HSI) to the average total vegetation cover at each height in the site under consideration depict the total vegetation cover with one standard deviation and LBVI HSI with two standard deviations. Having vegetation fall within two standard deviations of the corresponding averages for known vireo nesting habitat (a range representing the 95% confidence interval of each mean) had been determined to indicate acceptable vireo nesting habitat on a river (Snedecor & Cochran 1976 as cited in Kus 1998).

Results (2018 - 2022 Analyses)

Overall, the Prado vegetation profiles align with the Habitat Suitability Model with minor variability among elevations, across years and seasons; the Prado riparian habitat is suitable for vireos according to the model and highly suitable, based on the sustained and increasing level of vireo occupation. In both Spring 2018 and Spring 2019, the plant community at the higher elevations (498-505', >505') had a lower percent cover at the higher canopy classes (i.e., less tree cover) than at the lower elevations. This was reflected in other years as well.

Total vegetation cover, combined across elevations did not vary much among years except in the H0 -1 m height class where the total cover was higher in Spring 2018 than in Spring 2019 (Figure 26). This difference in H0-1 was due to increased inundation and duration of the pool in 2019. Figures 27 to 30 show the total vegetation cover in all years, seasons, and elevation zones.

For the 2018 and 2019 data, in summary, we found that:

1) The habitat available in Prado Basin, as indicated by the estimated total vegetation cover is suitable vireo habitat by comparison with the HSI model except locally in the lower elevations during Summer 2018 and Spring 2019 (both mule fat/willow points) (Figure 26).

2) Total vegetation cover for vireo varies among elevations (<490', 490-497', 498-505', >505'), but almost all elevations in both spring and summer of 2018 and 2019 are within the range for suitable vireo habitat when compared to the LBVI HSI model. Visible deviations from the HSI model mainly occur in the lowest elevation (<490') where total vegetation cover in Prado Basin is lower than the HSI model.

3) The large error bars and 2 standard deviations were included to bracket the variability among nests in each season. The interpretation of the data in this study was done in two ways, first, a general comparison of the HSI with error bars to the Prado Basin data with error bars; if there was overlap, it was stated the Prado Basin habitat was suitable vireo habitat. Second, a finer scale comparison of the HSI to the Prado Basin data noted any visible differences in average total cover.

4) Using the finer scale comparison method, vireo habitat in the Prado Basin appeared to differ from the LBVI HSI model mainly in the lower height classes (0-1, 1-2, 2-3 m classes) within the lowest elevation (<490'). In these locations, vegetation cover was less than that found in a riverine situation due to lower herbaceous and shrub-height vegetation cover. Specifically,

    a) **Spring and Summer 2018 mule fat/willow points**, lower elevations (<490', 490-497') had lower cover than the LBVI HSI model in H0-1 and H1-2m. Only <490' elevation was lower in H2-3m height class.

    b) **Summer 2018 nest and territory points** matched the LBVI HSI model in all elevations.

    c) **Spring and Summer 2019 mule fat/willow points and nest/territory points** (all sampled points), lower elevations (<490', 490-497') had lower cover than LBVI HSI model in certain lower canopy/height classes (H1-2 and H2-3 for <490' and H0-1m for 490-497' for Spring 2019 mule fat/willow points). Only <490' elevation was lower in H2-3m height class for Spring and Summer 2019 mule fat/willow and nest/territory points. For Summer 2019 mule fat/willow points, elevation 490-497' was higher than the HSI model in the lower height classes.

5) Overall, using comparison with error bars, habitat suitability for vireo does not vary among two years (2018 – drier year, 2019 – wetter year) as both years resembled the HSI model. In 2018 (a drier year), there was less total vegetation cover than in 2019 (a wetter year).

For the 2020 data analysis, the 40 Mule fat and Willow points taken in Summer were analyzed, and vegetation samples were compared between elevations and height classes (Figures 26 and 32). Overall, for the Summer 2020 40-points analysis, the lowest elevation, <490', had significantly lower total percent plant cover than the 498-505' elevation in the height classes four meters and below. When comparing among elevations, the lower height classes (< 3 meters) of the 490' elevation range had lower total percent cover than the Habitat Suitability Model (HSI) (Figure 32). However, when considering the total vegetation cover with all elevations combined, all height classes fall within the HSI model, indicating that the vegetation cover at the Prado Basin

resembles that of the HSI (Figure 26, Summer 2020). The Summer 2020 Nest/Territory points also had significant differences among elevations at all height classes except H3-4. At the higher elevations (498-505' and >505'), the plant community has a higher percent ground cover in the lower canopy height classes (i.e. closer to the ground, shrubs or lower-lying vegetation) and a lower percent cover at the higher canopy classes (i.e. less tree cover). Conversely, the lowest elevation (<490') has a lower percent ground cover in the lower canopy classes and higher percent cover at the higher canopy height classes, compared to the other elevation ranges.

For the 2021 data analysis, the 40 Mule fat and Willow points taken in Spring and Summer and the 40 Nest/Territory points taken during the Summer were compared between elevations and height classes (Figures 26 to 32). Overall, all three datasets fell within the HSI model of suitable vireo habitat, except within the H1-2 height class for total vegetation cover and by elevation in the lower elevation ranges for specific height classes (Fig.30). Those elevation ranges that fell below HIS values were the <490' and 490-497' ranges within the H0-3 height classes and the 490-497' elevation range in the H3-4 height class (Figures 27-30). A large fire event burned all but two of the 40 Mule fat and Willow points in December 2020 and is the primary reason for the low vegetation cover in the Spring results. Regrowth occurred by Summer 2021, resulting particularly in higher ground cover. Vegetation cover even in the lower height classes was higher than in previous years during this summer season (Figures 26 and 31). The ground cover within the 490-497' elevation range in Summer 2021 Mule fat and Willow points was the highest recorded for all years and seasons (Figure 28). For the Summer 2021 Mule fat and Willow points, the 498-505' elevation range had significantly higher vegetation cover than the other three elevation ranges (Figures 31 and 32). The Summer 2021 Nest and Territory points showed a pattern like the Summer 2021 Mule fat and Willow points, with high vegetation cover falling well within the HSI model. Additionally, most of the elevation ranges not only fell within the HSI values, but also met the average percent cover of the HSI model within the groundcover height class, H0-1. Some elevation ranges were lower than the average percent cover of the HSI in the middle canopy height classes but were still within the HSI criteria. All four elevation ranges decreased in vegetation cover as height class increased, but this still resembles the patterns of the HSI, indicating that the vegetation cover at the Prado Basin resembles that of the Habitat Suitability Model.

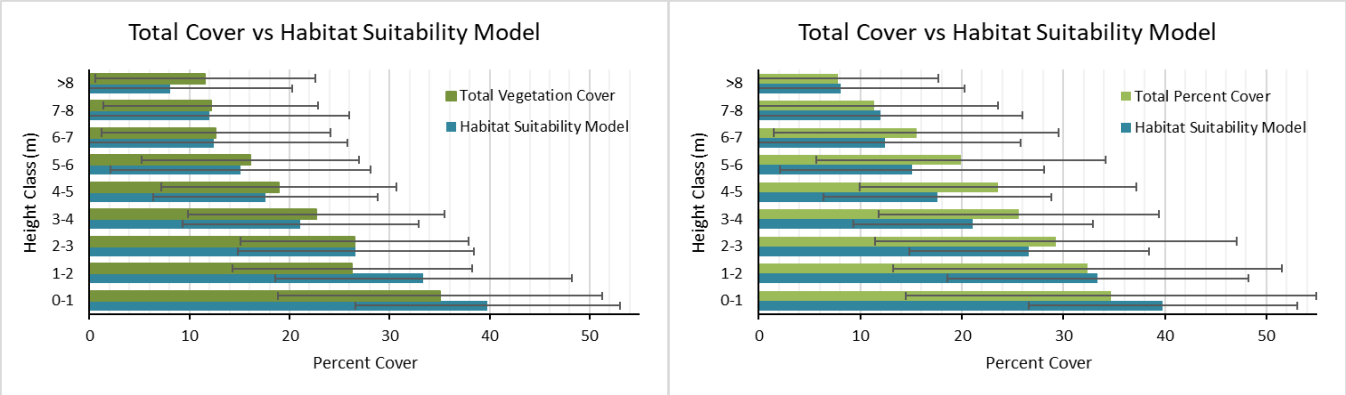
For the 2022 data analysis, the 40 Mule fat and Willow points taken in Spring and Summer and the 40 Nest/Territory points taken during the Summer were compared between elevations and height classes (Figures 26 to 34). Overall, all three datasets fall within the HSI model of suitable vireo habitat. The height class H0-3 performed better than in previous years in all the elevation ranges (Figures 27-30 and 33). For the 2022 Mule fat and Willow points, the 490-497' elevation range had significantly higher vegetation cover in the H0-1 class over previous years. This increase was nearly

double what was seen in past years. Early rains and lack of a substantial inundation pool were responsible for the growth. The Summer 2022 Nest and Territory points compared well with the Summer 2022 Mule fat and Willow points, with high vegetation cover falling well within the HSI model. Additionally, most of the elevation ranges not only fell within the HSI values, but also met the average percent cover of the HSI model within the groundcover height class, H0-1 (Figure 34). Most of the elevation ranges were lower than the average percent cover of the HSI in the middle to upper canopy height classes but were still within the HSI criteria. All four elevation ranges decreased in vegetation cover as height class increased, but this still mostly follows the patterns of the HSI, indicating that the vegetation cover at the Prado Basin resembles that of the Habitat Suitability Model (Figure 34). The decrease in vegetational cover and height in the higher elevations is largely due to the 2020 fire, prolonged drought, and damage due to polyphagous shot hole borer. This trend was also observed in 2021 except in the zone below 490 ft which was outside the fire footprint.

Figure 26: Total Vegetation Cover 2018-2022, Mule fat and Willow Points

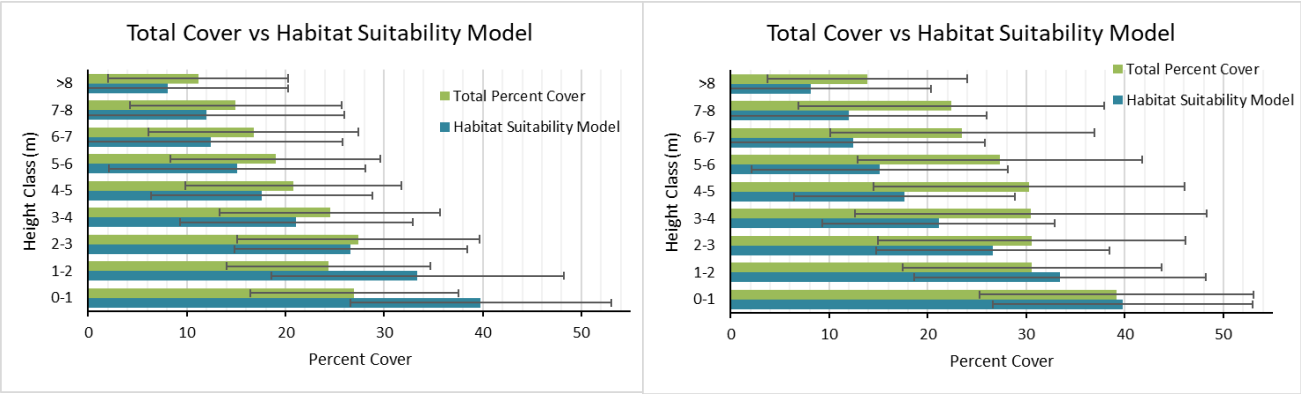
Spring (left) versus Summer (right) 2018

In addition, when all height classes are combined, spring points have more total vegetation cover than the summer points at the 0.086 level ($p = 0.086$, $F = 3.04$).

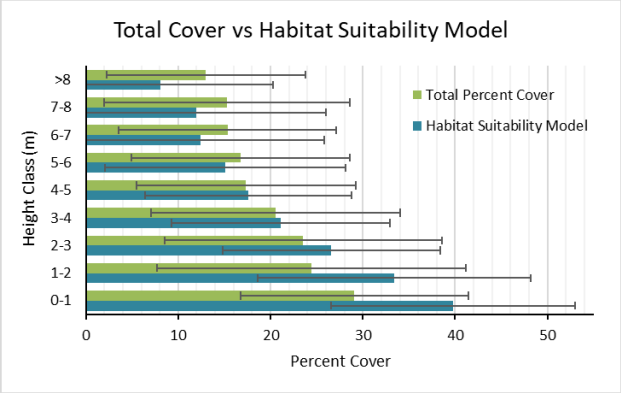


Spring (left) versus Summer (right) 2019

The total percent vegetation cover resembles that of the HSI model with summer points showing a total higher percent cover compared to the Spring points. The total percent vegetation cover is slightly low in the H0-1 height class in the Spring, but still falls within the standard deviation of the HSI model.

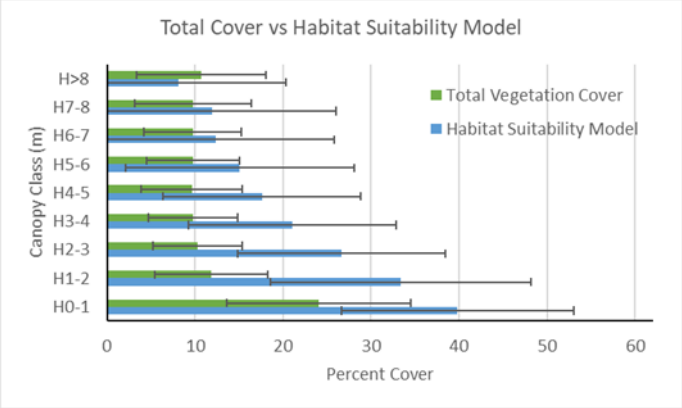


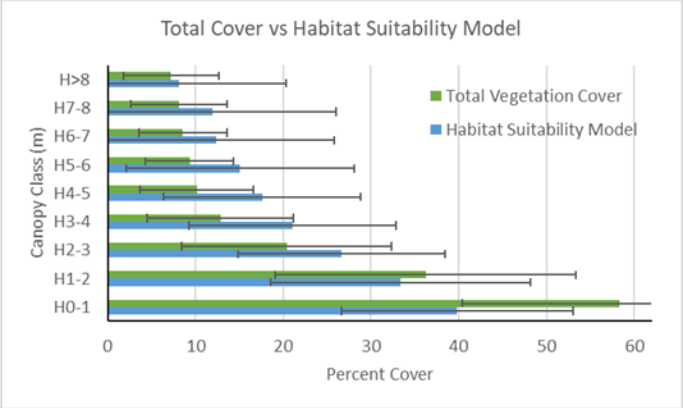
Summer 2020



Spring (left) versus Summer (right) 2021

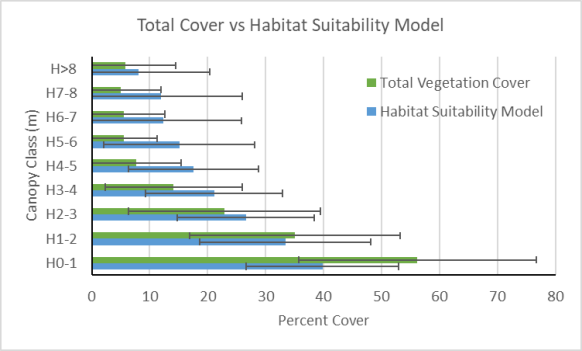
The total percent vegetation cover resembles that of the HSI model with summer points showing a total higher percent cover compared to the Spring points. However, the total percent vegetation cover is just below the HSI range for the H1-2 height class in the Spring. Lower vegetation cover in Spring is strongly due to the recent fire event.





Spring (left) versus Summer (right) 2022

Total percent vegetation cover resembles that of the HSI model but with both spring and summer points showing total higher percent cover at the H1-2, and H0-1 height class. Higher vegetation cover at the lower height classes is due to low rainfall and lack of an inundation pool.



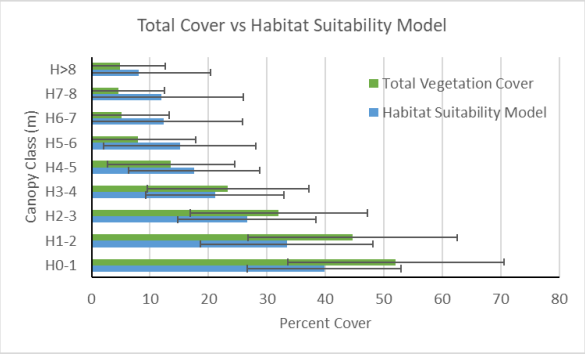


Figure 27: Total Vegetation Cover Within Elevation (< 490') for all Height Classes from Spring 2018 to Summer 2022

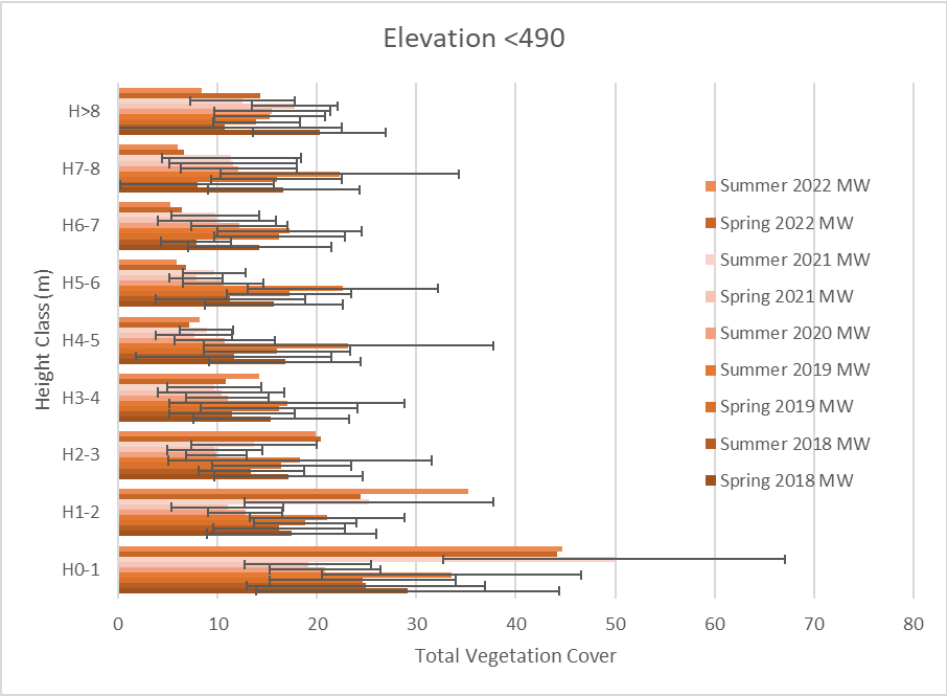


Figure 28: Total Vegetation Cover Within Elevation (490-497') for all Height Classes from Spring 2018 to Summer 2022

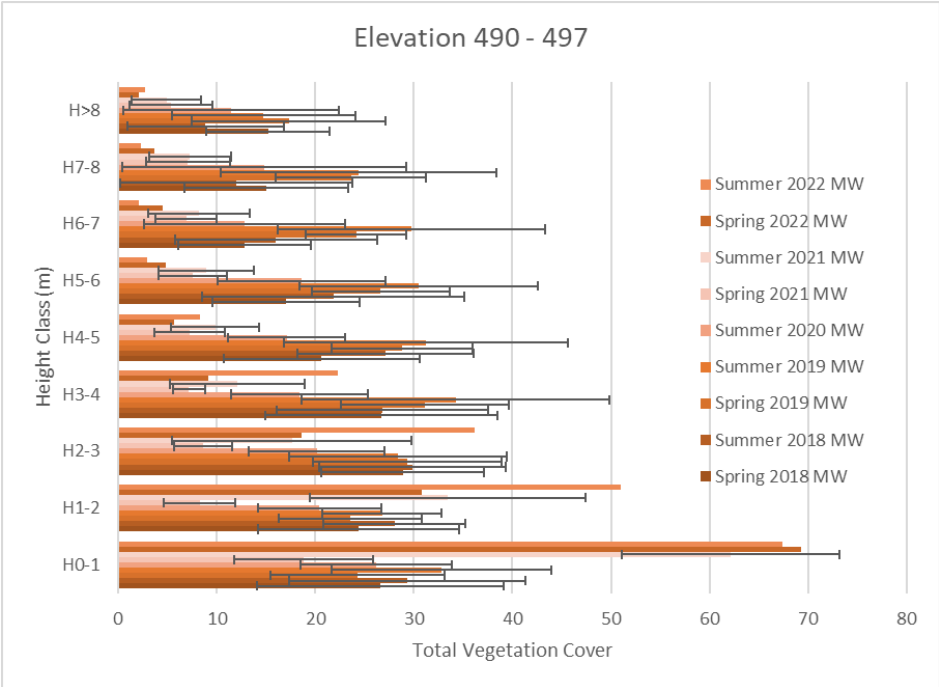


Figure 29: Total Vegetation Cover Within Elevation (498-505') for all Height Classes from Spring 2018 to Summer 2022

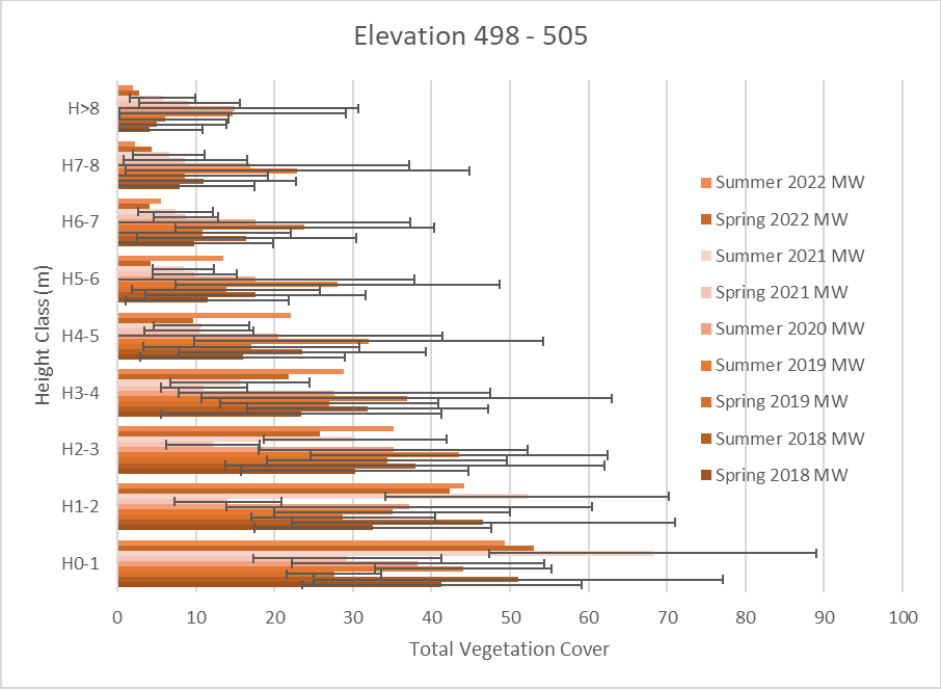


Figure 30: Total Vegetation Cover Within Elevation (Above 505) for all Height Classes from Spring 2018 to Summer 2022

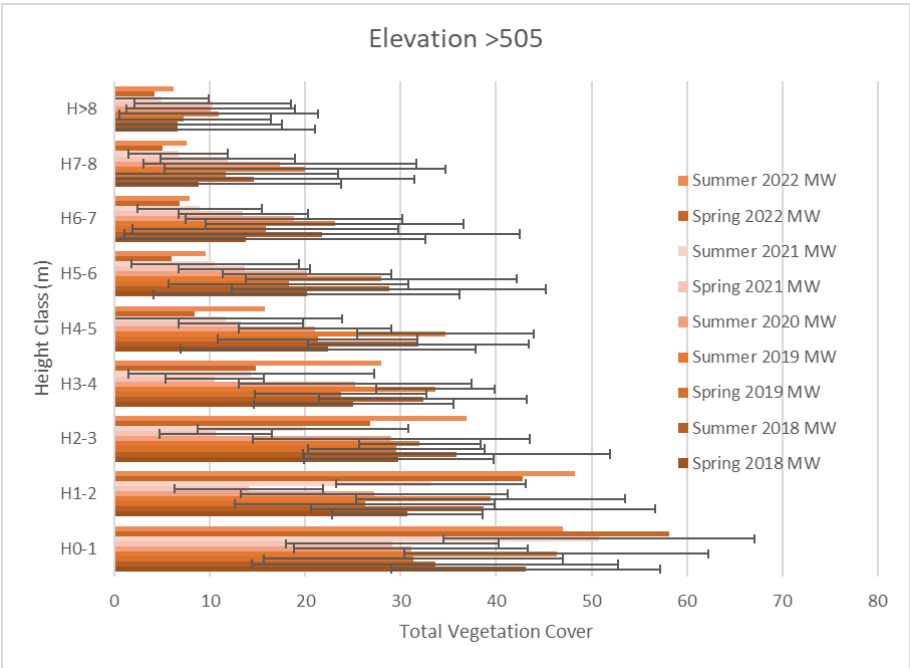


Figure 31: Total Vegetation Cover of All Elevation Ranges combined for all Height Classes from Spring 2018 to Summer 2022

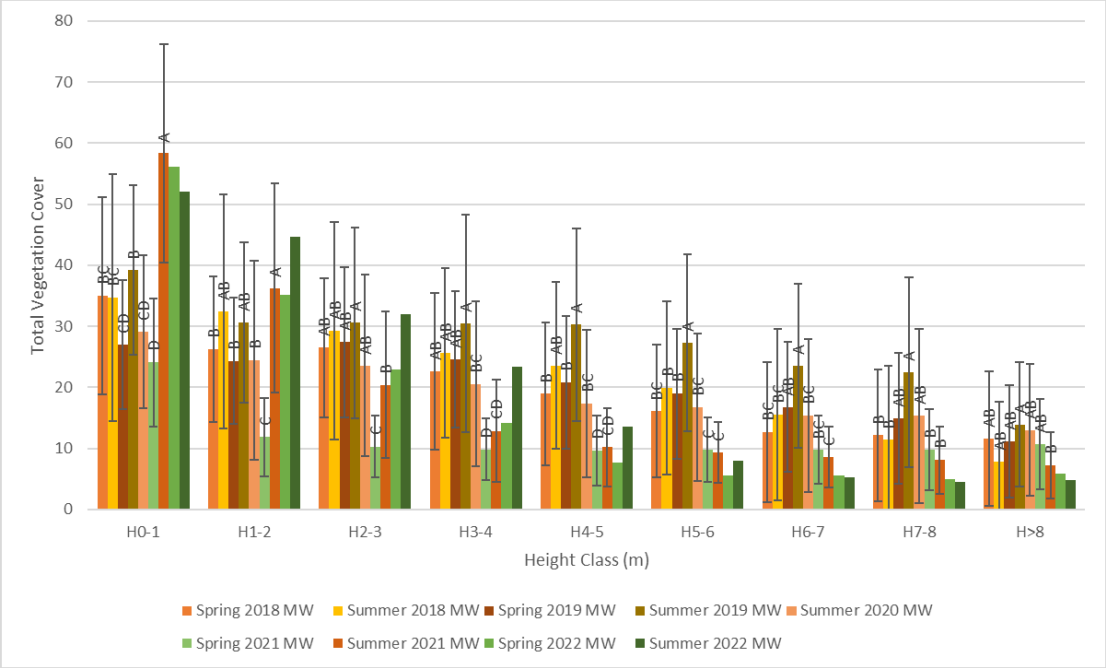
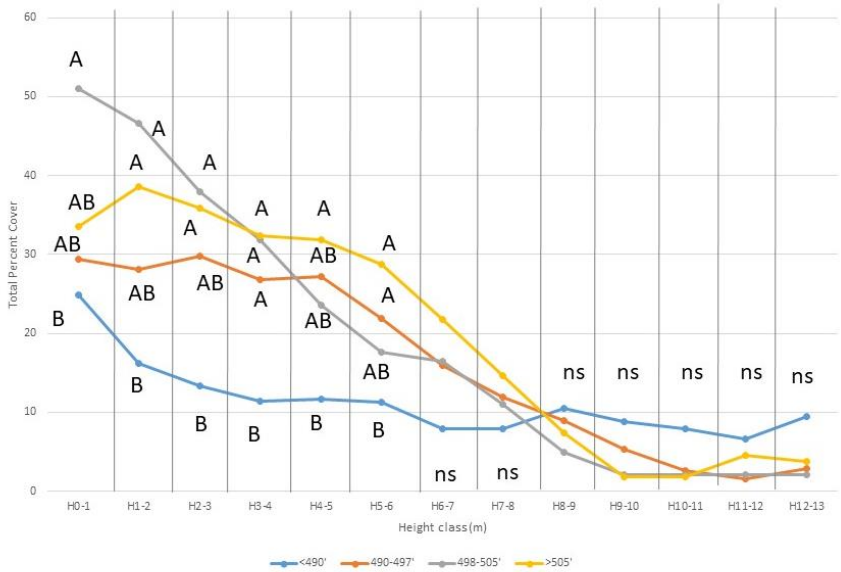


Figure 32: Total Vegetation Cover By Elevation (<490', 490-497', 498-505', >505') and Height Classes (H) for Summer 2018 – 2022 Mule fat and Willow Points

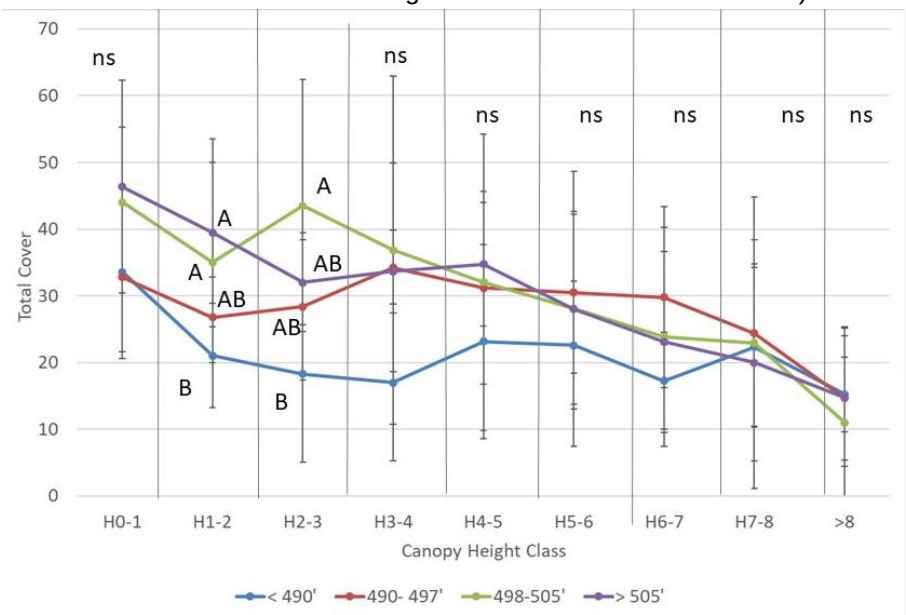
Summer 2018

("ns" indicates non-significant differences in total cover among elevations within height class. Lower elevations (<490', 490-497') are similar to each other but significantly different from higher elevations (498-505', >505') in most height classes. Letters indicate significance at $p < 0.05$.)



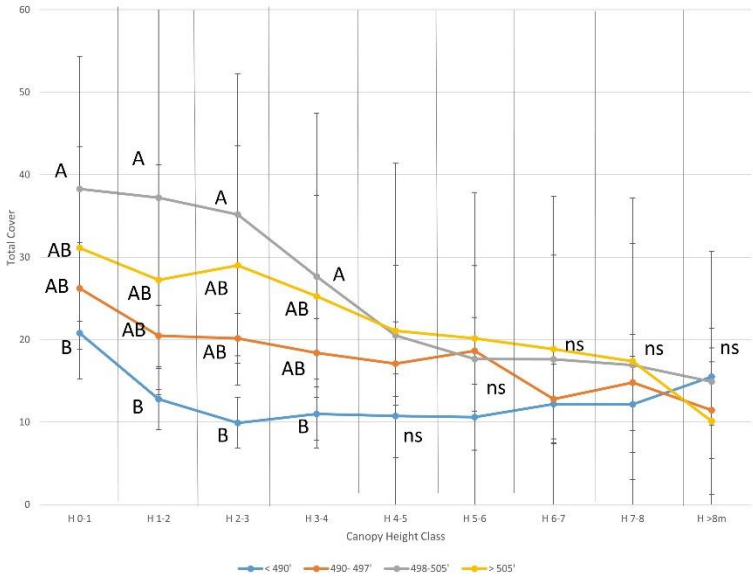
Summer 2019

("ns" indicates non-significant differences in total cover among elevations within height class. Letters indicate significance at $p < 0.05$. For the lowest elevation (<490'), percent vegetation cover at height classes H1-2 and H2-3 are lower than at other elevations, but all other height classes for this elevation and all other elevation ranges are similar across elevations.)



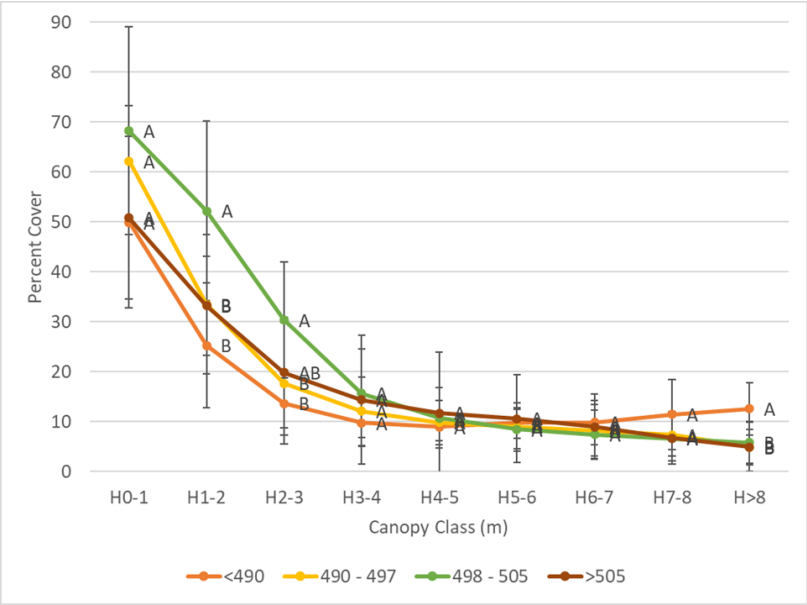
Summer 2020

"ns" indicates non-significant differences in total cover among elevations within the height class. Letters indicate significance at $p < 0.05$. For the lowest elevation (<490'), the percent vegetation cover at height classes H0-4 is significantly lower than 498-505' elevation range. There is high variability seen in the 498-505' range.



Summer 2021

Letters indicate significance at p < 0.05. The second to highest elevation (498-505'), percent vegetation cover at height classes H0-3 are significantly higher than the other three elevation ranges.



Summer 2022

Letters indicate significance at p < 0.05. The elevation range (490-497'), percent vegetation cover at height classes H0-1 are significantly higher than the other three elevation ranges.

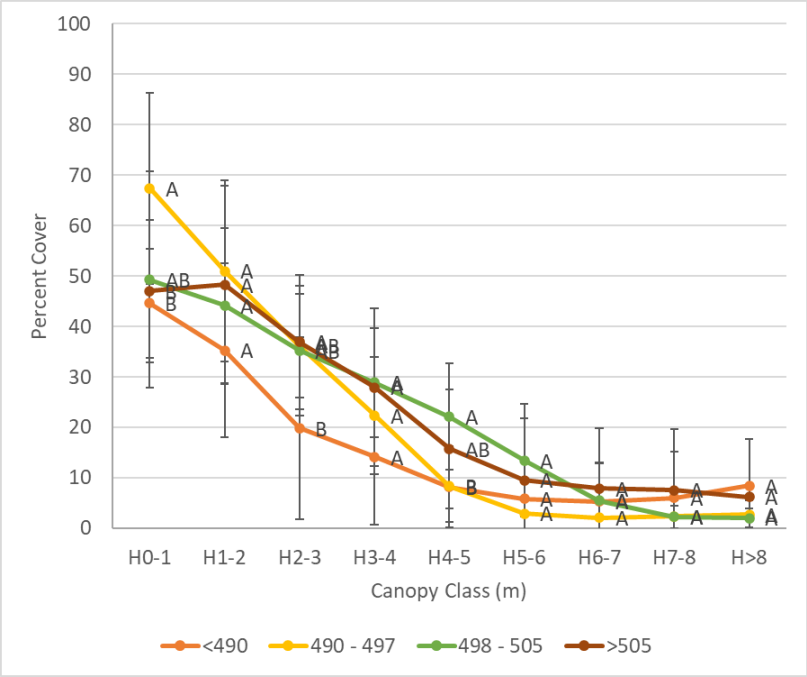
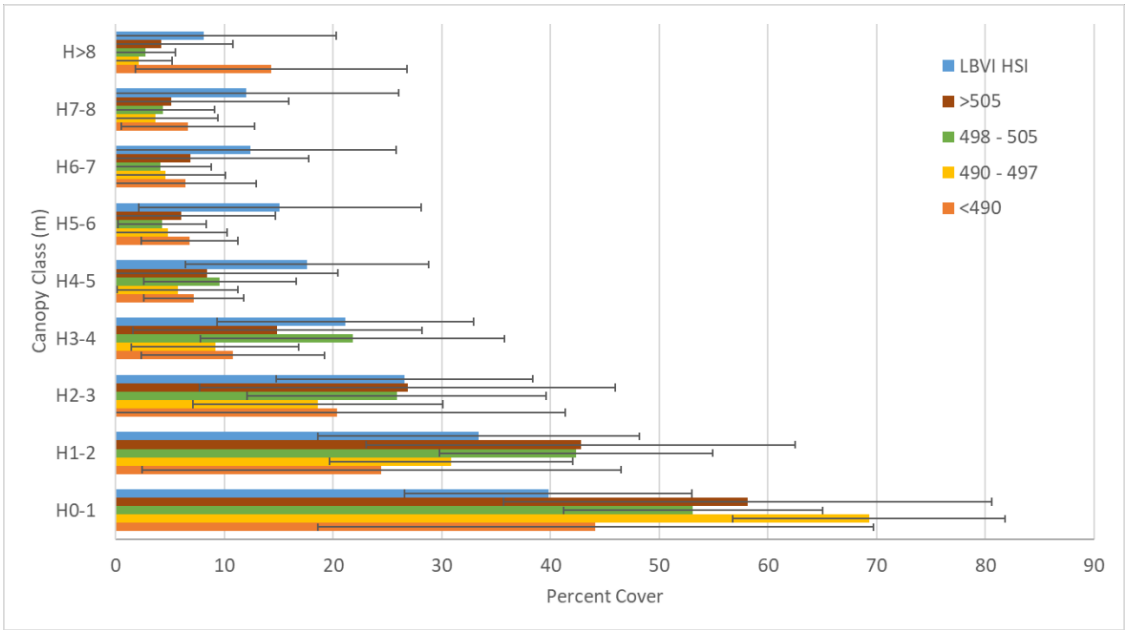


Figure 33: Total Vegetation Cover by Elevation (<490', 490-497', 498-505', >505') and Height Classes (H) for Spring and Summer 2022 Mule fat and Willow Points

Compared to the Habitat Suitability Model

Spring 2022



Summer 2022

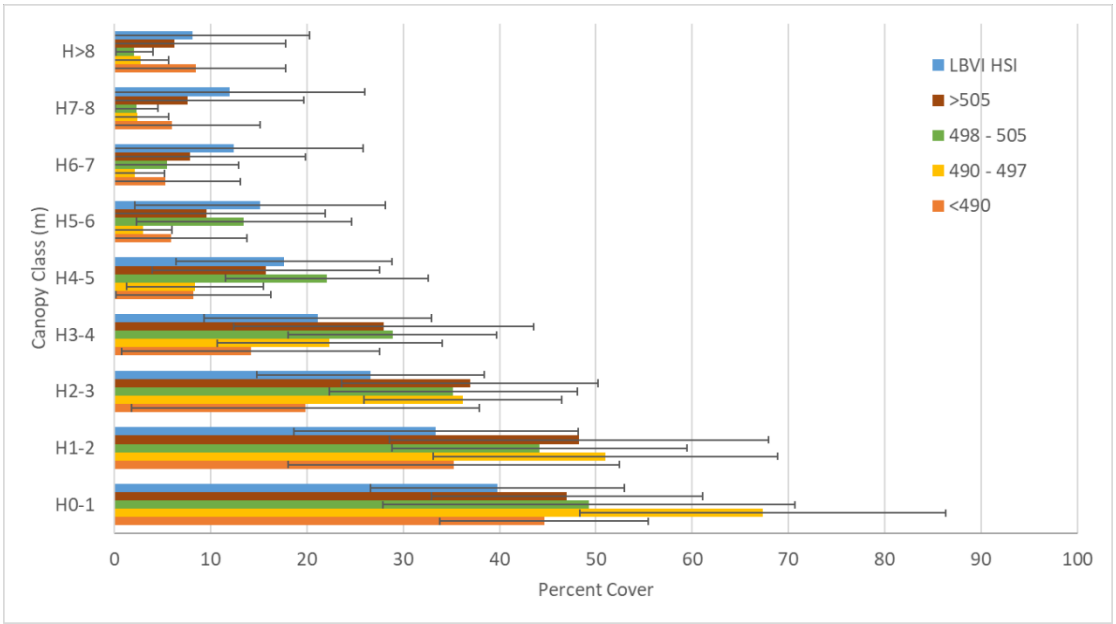
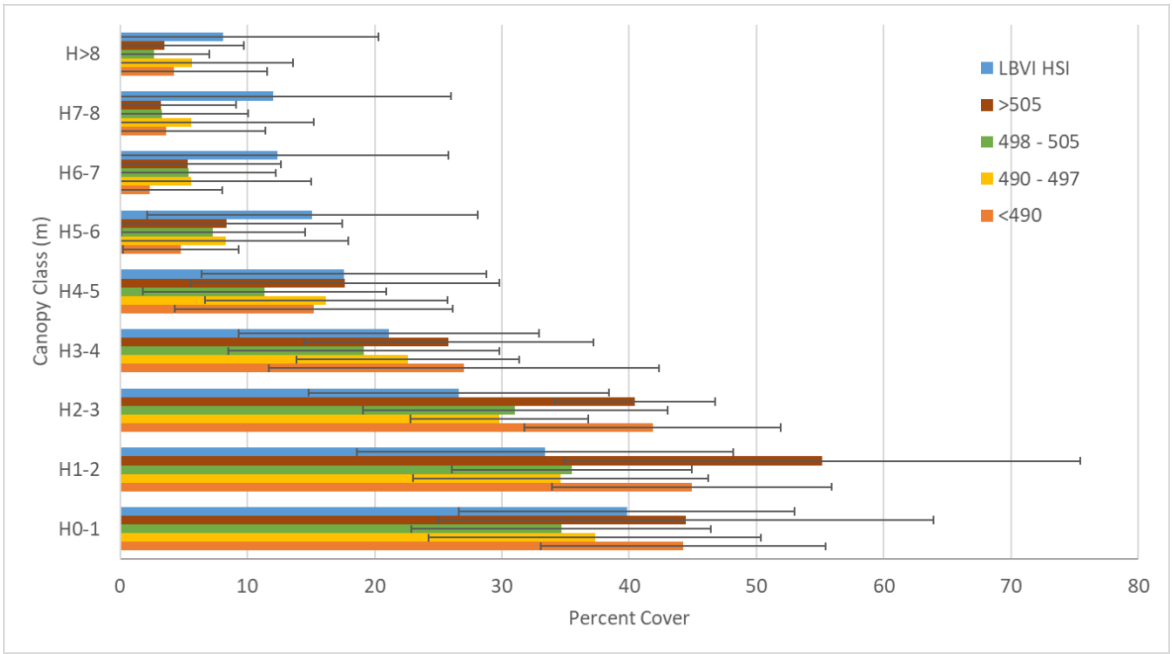


Figure 34: Total Vegetation Cover by Elevation (<490', 490-497', 498-505', >505') and Height Classes (H) for Summer 2022 – 2022 Nest and Territory Points

Compared to the Habitat Suitability Model



CONCLUSION

In conclusion, ascribing impacts to nesting vireos resulting from prolonged inundation due to water conservation in the Prado Basin is greatly confounded by: flood control operations with higher inundation levels that precede water conservation and are of longer duration at most elevations; sedimentation that has diminished the acreage of habitat at and below the 505 ft contour by at least 348.8 acres; vireos that continue to nest in the lower elevations despite of inundation effects; and an overall Basin vireo population that has increased by more than 5 times its original size since the current water conservation program was instituted in 1993.

Although near-ground foliage volume is reduced in the lower-most elevations immediately after draining the conservation pool, willow foliage, grape, and herbaceous plants fill that void quickly. Areas impacted by fire, inundation, and insect damage continued to grow trees through 2022 with the help of moderate inundation pools interspersed with many successive drought years. Tree recruitment in the Prado Basin could be increasing with flood irrigation provided by the water conservation pools that do not persist for as long as formerly due to drying conditions, particularly reduced baseflows in the river.

Many factors affect the health of the riparian forest in the Prado Basin. Lowering groundwater levels, reduced surface flows in the river and tributaries, fires, and damage due to insects, particularly the Polyphagus Shothole Borer have contributed to the decline of the Prado forest and annual losses in productivity. These factors along with the size, periodicity, and duration of a pool of water in the basin determine wildlife distribution temporally. However, the presence of surface water mitigates the effects of drought, restores groundwater, and enhances plant and insect production. Despite factors with effects much more severe than Water Conservation, the Least Bell’s Vireo population in the Basin was the highest it has ever been in 2020 and continued to thrive in 2022. This is due in part to the active management of that population, wherewithal provided by Water Conservation.

Appendix A

Prado Reservoir Inundation Levels and Discharge Rates, Dec 2021– Aug 2022

Date	Midnight WSE NGVD [ft]	Daily Mean Discharge [cfs]
01Dec2021	471.67	109
02Dec2021	471.66	107
03Dec2021	471.71	114
04Dec2021	471.82	111
05Dec2021	472.00	117
06Dec2021	471.85	115
07Dec2021	472.28	126
08Dec2021	472.12	133
09Dec2021	473.86	140
10Dec2021	473.04	183
11Dec2021	472.73	155
12Dec2021	472.75	150
13Dec2021	475.01	133
14Dec2021	492.46	142
15Dec2021	495.18	413
16Dec2021	495.02	578
17Dec2021	494.51	526
18Dec2021	493.96	467
19Dec2021	493.34	461
20Dec2021	492.66	454
21Dec2021	491.93	446
22Dec2021	491.17	437
23Dec2021	492.61	821
24Dec2021	503.39	2,234
25Dec2021	502.45	2,139
26Dec2021	502.33	1,665
27Dec2021	502.59	1,027
28Dec2021	503.44	1,047
29Dec2021	500.64	2,822
30Dec2021	501.98	863
31Dec2021	502.17	449
01Jan2022	501.99	449
02Jan2022	501.73	450
03Jan2022	501.42	450
04Jan2022	501.07	451
05Jan2022	500.70	448
06Jan2022	500.30	458
07Jan2022	499.87	477
08Jan2022	499.41	474
09Jan2022	498.93	470
10Jan2022	498.43	464
11Jan2022	497.92	460
12Jan2022	497.36	458
13Jan2022	496.78	465
14Jan2022	496.13	481

15Jan2022	495.45	477
16Jan2022	494.76	475
17Jan2022	494.09	474
18Jan2022	493.36	487
19Jan2022	492.59	490
20Jan2022	491.75	496
21Jan2022	490.76	507
22Jan2022	489.68	490
23Jan2022	488.52	472
24Jan2022	486.75	540
25Jan2022	483.94	569
26Jan2022	473.02	507
27Jan2022	472.56	165
28Jan2022	472.42	153
29Jan2022	472.51	147
30Jan2022	472.50	147
31Jan2022	472.34	147
01Feb2022	472.64	144
02Feb2022	472.14	145
03Feb2022	472.48	143
04Feb2022	472.23	140
05Feb2022	472.19	139
06Feb2022	472.38	137
07Feb2022	472.28	138
08Feb2022	472.02	133
09Feb2022	472.07	125
10Feb2022	472.01	127
11Feb2022	471.88	126
12Feb2022	472.01	122
13Feb2022	472.28	131
14Feb2022	472.06	133
15Feb2022	473.02	128
16Feb2022	472.54	174
17Feb2022	472.32	130
18Feb2022	472.35	132
19Feb2022	472.17	131
20Feb2022	472.31	131
21Feb2022	472.18	130
22Feb2022	472.73	145
23Feb2022	473.12	186
24Feb2022	472.38	155
25Feb2022	472.45	142
26Feb2022	472.51	139
27Feb2022	472.69	148
28Feb2022	472.26	151
01Mar2022	471.63	114
02Mar2022	472.12	121
03Mar2022	475.15	124

04Mar2022	476.71	152
05Mar2022	476.96	166
06Mar2022	476.99	168
07Mar2022	472.35	187
08Mar2022	471.98	140
09Mar2022	471.55	115
10Mar2022	471.56	96
11Mar2022	471.79	115
12Mar2022	471.82	135
13Mar2022	472.16	157
14Mar2022	471.83	172
15Mar2022	471.92	158
16Mar2022	471.93	163
17Mar2022	471.88	158
18Mar2022	471.67	139
19Mar2022	471.86	128
20Mar2022	472.06	140
21Mar2022	471.90	114
22Mar2022	471.68	95
23Mar2022	471.64	89
24Mar2022	473.36	75
25Mar2022	473.59	76
26Mar2022	473.58	68
27Mar2022	474.61	70
28Mar2022	479.32	82
29Mar2022	485.80	189
30Mar2022	485.32	258
31Mar2022	484.85	194
01Apr2022	484.41	165
02Apr2022	483.82	166
03Apr2022	483.21	167
04Apr2022	482.50	178
05Apr2022	481.60	181
06Apr2022	480.53	178
07Apr2022	478.70	166
08Apr2022	477.03	149
09Apr2022	476.26	133
10Apr2022	475.90	129
11Apr2022	471.79	144
12Apr2022	471.77	121
13Apr2022	471.87	109
14Apr2022	471.73	108
15Apr2022	471.83	105
16Apr2022	471.76	107
17Apr2022	471.86	110
18Apr2022	471.67	106
19Apr2022	471.59	98
20Apr2022	471.52	93

21Apr2022	472.08	105
22Apr2022	475.57	221
23Apr2022	472.32	182
24Apr2022	472.21	136
25Apr2022	471.27	117
26Apr2022	471.43	79
27Apr2022	471.64	93
28Apr2022	471.78	101
29Apr2022	471.82	106
30Apr2022	471.73	108
01May2022	471.90	105
02May2022	471.69	110
03May2022	471.45	104
04May2022	471.61	103
05May2022	471.63	96
06May2022	471.31	92
07May2022	471.40	83
08May2022	471.44	89
09May2022	471.40	89
10May2022	471.45	83
11May2022	471.39	85
12May2022	471.44	82
13May2022	471.26	82
14May2022	471.25	74
15May2022	471.28	76
16May2022	471.33	81
17May2022	471.40	79
18May2022	471.40	87
19May2022	471.31	82
20May2022	471.47	82
21May2022	471.40	85
22May2022	471.32	84
23May2022	471.40	83
24May2022	471.47	81
25May2022	471.49	87
26May2022	471.52	87
27May2022	471.28	82
28May2022	471.46	82
29May2022	471.49	88
30May2022	471.55	89
31May2022	471.66	91
01Jun2022	471.53	90
02Jun2022	471.55	96
03Jun2022	471.28	86
04Jun2022	471.61	85
05Jun2022	471.59	96
06Jun2022	471.73	101
07Jun2022	471.6	102

08Jun2022	471.6	93
09Jun2022	471.5	87
10Jun2022	471.4	83
11Jun2022	471.34	79
12Jun2022	471.47	82
13Jun2022	471.24	81
14Jun2022	471.42	80
15Jun2022	471.32	82
16Jun2022	471.38	81
17Jun2022	471.56	81
18Jun2022	471.47	85
19Jun2022	471.47	82
20Jun2022	471.33	78
21Jun2022	471.26	70
22Jun2022	471.92	76
23Jun2022	471.25	90
24Jun2022	471.23	76
25Jun2022	471.23	74
26Jun2022	471.27	76
27Jun2022	471.13	72
28Jun2022	471.07	66
29Jun2022	471.02	67
30Jun2022	471.18	62
01Jul2022	471.14	69
02Jul2022	471.07	63
03Jul2022	471.13	61
04Jul2022	471.18	62
05Jul2022	471.11	61
06Jul2022	471.11	53
07Jul2022	471.1	53
08Jul2022	471.15	56
09Jul2022	471.31	59
10Jul2022	471.35	69
11Jul2022	471.16	60
12Jul2022	471.2	62
13Jul2022	471.04	52
14Jul2022	471.08	45
15Jul2022	471.23	50
16Jul2022	471.1	50
17Jul2022	471.15	54
18Jul2022	471.12	51
19Jul2022	471.09	48
20Jul2022	471.06	48
21Jul2022	471.06	51
22Jul2022	471.07	50
23Jul2022	471.11	53
24Jul2022	471.09	62
25Jul2022	471.13	62

26Jul2022	471.13	60
27Jul2022	471.01	63
28Jul2022	470.94	54
29Jul2022	470.93	52
30Jul2022	470.92	50
31Jul2022	470.95	52
01Aug2022	470.81	51
02Aug2022	470.86	47
03Aug2022	470.87	49
04Aug2022	470.86	46
05Aug2022	470.85	47
06Aug2022	470.81	47
07Aug2022	470.89	46
08Aug2022	470.8	48
09Aug2022	470.79	44
10Aug2022	470.79	44
11Aug2022	470.81	43
12Aug2022	470.74	42
13Aug2022	470.76	40
14Aug2022	470.76	41
15Aug2022	470.78	42
16Aug2022	470.76	43
17Aug2022	470.74	45
18Aug2022	470.65	35
19Aug2022	470.62	32
20Aug2022	470.66	30
21Aug2022	470.68	34
22Aug2022	471.07	43
23Aug2022	470.94	54
24Aug2022	470.88	47
25Aug2022	470.9	43
26Aug2022	470.87	47
27Aug2022	470.89	45
28Aug2022	470.89	46
29Aug2022	470.9	46
30Aug2022	470.9	44
31Aug2022	471.12	50

LEAST BELL'S VIREOS AND SOUTHWESTERN WILLOW FLYCATCHERS IN PRADO BASIN OF THE SANTA ANA RIVER WATERSHED, CA

By

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ABSTRACT. Multiple partnerships have led to a program of resource management in southern California's largest coastal watershed. Grants and mitigation funds have supported thousands of acres of habitat restoration, largely through control of invasive giant reed (*Arundo donax*) and successful management of beleaguered species. A population of endangered least Bell's vireos (*Vireo bellii pusillus*) was studied and managed for the thirty-seventh consecutive year in the Prado Basin and environs during the 2022 breeding season. Data were taken on status, distribution, breeding chronology, reproductive success, and nest site characteristics. Additionally, brown-headed cowbirds (*Molothrus ater*) were surveyed and removed from vireo territories. Three hundred twenty-seven of the 677 territorial male vireos detected in 2022 were found to be paired, producing a minimum of 570 fledglings. This compares with 281 pairs recorded in 2021, 372 pairs recorded in 2020, and just 19 pairs in 1986. Three hundred eighty cowbirds were removed from vireo habitat during the nesting season, following the fall and winter removal of 2,980 cowbirds from adjacent dairy operations. To date, over one hundred ten thousand cowbirds have been removed from the Basin. The cowbird parasitism rate of vireo nests was 5%; no parasitism was documented in 2016. Eighty percent of 201 vireo nests were placed in willows (*Salix* spp. – three species) and mulefat (*Baccharis salicifolia*). For the sixth consecutive year, no territorial southwestern willow flycatcher was detected in the Basin. Following the discovery in 2011 of one federally threatened western yellow-billed cuckoo (*Coccyzus americanus occidentalis*) for the first time in the Basin in a decade, none was found in 2012-2022. Numerous other sensitive avian species have benefited from the habitat restoration and management efforts. For example, a minimum of 2,000 pairs of yellow warblers (*Setophaga petechia*) were estimated in the 4,500 ha (11,120 ac) study area in 2013.

Dedication: To the work and memories of Loren Hays and Dharm Pellegrini

ACKNOWLEDGMENTS

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INTRODUCTION

Least Bell's Vireo. The Least Bell's Vireo (*Vireo bellii pusillus* [Coues]; "vireo") is a small, insectivorous bird of the family Vireonidae. This vireo was described by Dr. Elliot Coues (1903) and aspects of its life history are summarized in a recovery plan and final rule (U.S. Fish and Wildlife Service 1986a, 1986b).

Vireos typically occupy "[l]ow riparian growth either in the vicinity of water or in dry parts or river bottoms. The center of activity is within a few feet of the ground, in the fairly open twigs canopied above by the foliage of willows and cottonwoods. Foraging cruises may take the birds higher into the trees but territorial interest, with song perches and nest sites, is in the lowest stratum of vegetation. Nests frequently are placed along the margins of bushes or on twigs projecting into pathways. Most typical plants frequented are willows, guatemote [mulefat], and wild blackberry. Less commonly live and valley oaks, wild grape, poison oak and sumac in the margins of watercourses are visited and may be nested in. On the desert slopes mesquite and arrowweed in canyon locations may be occupied" (Grinnell and Miller 1944).

The vireo was formerly described as common to abundant in riparian habitats from Tehama County, California to northern Baja California, Mexico (Grinnell and Storer 1924; Willett 1933; Grinnell and Miller 1944; Wilbur 1980). The vireo currently occupies a small fraction of its former range (Goldwasser *et al.* 1980; United States Fish and Wildlife Service 1986) and is a rare and local species. Grinnell and Miller (1944) noted that declines in southern California and the Sacramento-San Joaquin Valley coincided with increased cowbird parasitism. Numbers continued to decline until about 1986 when only 300 pairs were documented throughout the U. S. range (U. S. Fish and Wildlife Service 1986; RECON 1988).

The vireo's dramatic decline (Salata 1986; U. S. Fish and Wildlife Service 1986) has been attributed to the combined effects of the widespread loss of riparian habitat and brood parasitism

by the Brown-headed Cowbird (*Molothrus ater*) (Garrett and Dunn 1981). The Least Bell's Vireo was listed as an endangered species by California in 1980 and by the U.S. Fish and Wildlife Service in 1986. Critical habitat was designated for the vireo in February 1994, including most of our study area. The enactment of protective measures and subsequent management led to steadily increasing vireo numbers and, by 2005, there were nearly 3,000 territorial male vireos (U.S. Fish and Wildlife Service 2006).

Although known to be present along the middle reaches of the Santa Ana River much earlier (Goldwasser 1978), field studies of the vireo commenced in 1983 (Zembal *et al.* 1985; Zembal 1986) and continued annually (Hays 1986, 1987, 1988, 1989; Hays and Corey 1991; Pike and Hays 1992; The Nature Conservancy 1993a, 1993b, 1994, 1995, 1996, 1997; Pike and Hays 1998, 1999, 2000; Pike *et al.* 2001, 2002, 2003, 2004, 2005, 2006,2007,2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021). This paper summarizes the results of intensive monitoring and management, mostly since 1986.

Southwestern Willow Flycatcher. The Southwestern Willow Flycatcher (*Empidonax traillii extimus* [Phillips]) is a relatively small, insectivorous songbird. It is a recognized subspecies of the Willow Flycatcher (*Empidonax traillii*). Although previously considered conspecific with the Alder Flycatcher (*Empidonax alnorum*), the Willow Flycatcher is distinguishable from that species by morphology (Aldrich 1951), song type, habitat use, structure and placement of nests (Aldrich 1953), eggs (Walkinshaw 1966), ecological separation (Barlow and MacGillivray 1983), and genetic distinctness (Seutin and Simon 1988). The Southwestern Willow Flycatcher is one of five subspecies of the Willow Flycatcher currently recognized, primarily by differences in color and morphology (Hubbard 1987; Unitt 1987; Browning 1993; Pyle 1997).

The breeding range of the Southwestern Willow Flycatcher includes the southern third of California, southern Nevada, Arizona, New Mexico, and western Texas (Hubbard 1987; Unitt 1987; Browning 1993). The species may also breed in southwestern Colorado, but nesting records are lacking. Records of breeding in Mexico are few and confined to extreme northern Baja California and Sonora (Unitt 1987; Howell and Webb 1995). Willow Flycatchers winter in Mexico, Central America, and northern South America (Phillips 1948; Ridgely 1981; AOU 1983; Stiles and Skutch 1989; Ridgely and Tudor 1994; Howell and Webb 1995). They are generally gone from breeding grounds in southern California by late August (The Nature Conservancy 1994) and are exceedingly scarce in the United States after mid-October (Garrett and Dunn 1981).

Southwestern Willow Flycatchers occur in riparian habitats along watercourses where dense growth of willows *(Salix* spp.), *Baccharis*, arrowweed (*Pluchea* sp.), buttonbush (*Cephalanthus* sp.) and other wetland plants provide dense thickets. Nests are built in thickets, 4-7 meters (13-23 feet) or more in height. Occupied habitat is usually canopied in willows or cottonwoods (Phillips 1948; Grinnell and Miller 1944; Whitmore 1977; Hubbard 1987; Unitt 1987; Whitfield 1990; Brown 1991; and U.S. Fish and Wildlife Service, 1993, 1995). The subspecies of Willow Flycatcher generally prefer nesting sites with surface water nearby (Bent 1960; Stafford and Valentine 1985; and Harris *et al.* 1986) and in the Prado Basin they virtually always nested near surface water or saturated soil (e.g., The Nature Conservancy 1994).

Like the vireo, the Southwestern Willow Flycatcher has suffered extensive loss, degradation, and modification of essential riparian habitat due to grazing, flood control projects, urban developments, and other land use changes (Klebenow and Oakleaf 1984; Taylor and Littlefield 1986; and Dahl 1990). Estimated losses of wetlands between 1780 and the 1980's in the Southwest are: California 91%; Nevada 52%; Utah 30%; Arizona 36%; New Mexico 33%; and Texas 52% (Dahl 1990).

This species is also impacted by brood parasitism by cowbirds (Unitt 1987; Ehrlich *et al.* 1992; U.S. Fish and Wildlife Service 1993, 1995). Parasitism rates of Southwestern Willow Flycatcher nests have recently ranged from 50 to 80 percent in California (Whitfield 1990; M. Whitfield and S. Laymon, unpublished data), to 100% in the Grand Canyon in 1993 (U.S. Fish and Wildlife Service 1993). Mayfield (1977) thought that a species or population might be able to survive a 24% percent parasitism rate.

Willett (1933) considered the Willow Flycatcher to be a common breeder in coastal southern California. Unitt (1987) concluded that these birds were once fairly common in the Los Angeles basin, the San Bernardino/Riverside area, and San Diego County. More recently, *E. t. extimus* was documented only in small, disjunct nesting groups (e.g., Unitt 1987, U.S. Fish and Wildlife Service 1995). Status reviews done prior to State or Federal listing of the flycatcher considered extirpation from California to be possible, even likely, in the foreseeable future (Garrett and Dunn 1981; Harris *et al.* 1986). Unitt (1987) then reported the known population in California to be 87 pairs and estimated the total population of the subspecies to be under 1000 pairs, more likely 500. A total of only 104 pairs was recorded in California in 1996 (U.S. Fish and Wildlife Service, unpublished data).

With the decline in flycatcher numbers on the South Fork of the Kern River, only two California populations consisting of 15 or more pairs have been relatively stable in recent years, that being along the San Luis Rey River and the Santa Margarita River. Of eight other nesting groups known in southern California, all but one consisted recently of six or fewer nesting pairs (Unitt 1987, Fish and Wildlife Service, unpublished data).

The Southwestern Willow Flycatcher was listed as endangered on February 27, 1995 (59 *Federal Register* 10693) and critical habitat, which includes much of the Prado Basin, was designated for the species in 1997 (62 *Federal Register* 39129 and 44228). Breeding Willow Flycatchers were also State listed as endangered in California and Arizona.

The Santa Ana River Watershed Program. The waterways in the watershed of the Santa Ana River have been greatly altered and the floodplain reduced for flood control and other human purposes. As a result, riparian habitat and the diversity of wildlife it supports have been reduced to unsustainable levels for some species. This led to the listing under State and Federal Endangered Species Acts of those species most intimately dependent upon southern California's riparian systems.

The habitat degradation continues today with the edge effects associated with the adjacency and encroachment of the growing human population. One of the most immediate threats to the remaining riparian habitat is its invasion and destruction by invasive plants, including giant reed (*Arundo donax*). This bamboo-like grass recently occupied more than half of the floodplain

formerly vegetated by willows and other native wetland species, now returning due to sound management. Giant reed has little redeeming value as wildlife food or for secure nest sites. It forms impenetrable thickets, carries fire, consumes several times more water than native habitat, interferes with flood control, produces massive quantities of debris that costs millions of dollars to clean off the coast, and driven by floods has caused bridge failure.

The Santa Ana River Watershed Program was initiated to restore the natural functions of the river by removing giant reed and other invasive species, restoring, and managing habitat and sensitive species. The principal partners include the four Resource Conservation Districts in the watershed and the Orange County Water District, but many landowners and other agencies are cooperators and supporters.

Reported herein are the results of study and management of the Least Bell's Vireo and other rare species in the Prado Basin and environs, 2022.

STUDY AREA

The Prado Basin is located behind Prado Dam about 40 miles from the Pacific Ocean. The dam was constructed for flood control on the Santa Ana River in 1941. The approximate center of the study area, 33 degrees and 55 minutes north latitude and 117 degrees and 38 minutes west longitude, is located about 70 kilometers east of Los Angeles and eight kilometers north of the City of Corona in the northwestern-most corner of Riverside County, California.

Winter-spring precipitation preceding the most recent vireo study period consisted of a wet December, followed by the driest January – March on record in the state. Typically, the climate is Mediterranean and consists of warm, dry summers and cool, wet winters. The weather during March-September 2022 was in many respects typical: early mornings were generally cool (approximately 13 degrees Celsius) in spring, increasing by about 3 degrees in later months, and ranging 29 to 35 degrees in midday. Winds typically began blowing around 10 a.m. and often reached a magnitude of Beaufort category four, or about 20 miles per hour by noon. Winds thereafter frequently continued unabated until sundown. Early mornings were occasionally cloudy or foggy and were frequently partly cloudy.

Prado Basin comprises some 4,500 ha (Zembal *et al.* 1985) including approximately 2,400 ha of wetland habitats (U. S. Fish and Wildlife Service 1986). Willow woodlands, freshwater marshes, and ponds dominate the Basin. However, understory is scarce in the lower elevations due to prolonged inundation. In addition, large tracts of willow woodland habitat have been invaded, degraded, or destroyed by non-native plants, particularly giant reed. A new invasive threat is the Polyphagous Shot Hole Borer (*Euwallacea sp*.), a tiny beetle that is a vector for a pathogenic fungus that weakens and kills native willows, sycamores, and cottonwoods. Along with extensive wildlife habitat, Prado Basin and environs holds urban development, parks, an airport, dairy farming, agriculture, industry, homeless encampments, hunting, and dog-training.

METHODS

Searches and monitoring visits were conducted almost daily for Least Bell's Vireos and Southwestern Willow Flycatchers in the Basin and environs, 11 March - 20 September 2022. Initially, efforts were concentrated in areas where vireos and flycatchers occurred in prior years, but suitable habitat over the entire accessible study area was eventually surveyed. Most of the field time was spent at sites occupied in 2020 and 2021.

All individual birds or pairs were noted during each visit to each section of the Basin. Data were taken on bird location, movement, behavior, food preferences, nest placement, sex, and age. Singing vireos were identified as males. Non-singing, adult vireos were deemed to be females if they were either: 1) in the company of non-threatening males; or 2) conspicuously engaging with impunity in breeding behaviors within the boundaries of well-defended and well-defined home ranges. Fledgling young were identified on the bases of their plumages, behaviors, and vocalizations.

Nests of the endangered birds were intrusively monitored, although great care was taken to minimize visits, scent cues for predators, habitat damage, trailing, and disturbance. Nests were located from a distance when possible and the contents were checked with a mirror. Data were taken on reproductive timing and success, cowbird parasitism, and depredation. Cowbird eggs were removed or replaced with infertile ones and young cowbirds were removed. The eggs were taken with adhesive tape to avoid human contact with, and scent on the nest or contents. Nest monitoring was conducted as prescribed in memoranda and permits from the State and Federal wildlife agencies. However, no nest visits were conducted if: 1) there was a chance of inducing a nest "explosion" or premature departure by nestlings; 2) approaching the nest would result in habitat destruction or trailing; or 3) no additional significant information or benefit to the occupants would result from the visit.

Once fledglings had left a nest site or a nest was otherwise emptied or abandoned, data were taken on nest dimensions, placement, height above the ground, and supporting plant species. Unsuccessful nests were carefully examined for signs of parasitism or other disturbance. Nests were assumed depredated if all eggs or unfledged young were destroyed or removed. Cowbird parasitism events were classified as such only if a cowbird egg(s) or pieces were found in, or below, the affected nest.

Habitat management included trapping and removing cowbirds, 14 March - 28 July. Nine modified Australian crow traps were deployed adjacent to habitats occupied by breeding vireos for a total of 962 trap-days. Each trap measured approximately 6' by 6' by 8' and superficially resembled a chicken coop (see Hays 1988). Cowbirds, attracted by live decoy cowbirds, ad libitum food and water, entered the traps through slots in the center of the traps' upper surfaces. Traps were checked daily, all non-target birds were released immediately, and excess cowbirds were removed.

Several other beleaguered avian species occupied the Basin with the vireo and were studied opportunistically. Specific effort was made to detect the Western Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*), a subspecies designated as endangered by the State of

California and whose distinct population segment within the state was determined to be threatened by the U.S. Fish and Wildlife Service in November 2014 (79 *Federal Register* 59991 and 60038).

The standard definitions used herein of terms pertaining to avian breeding biology are those recommended by the Least Bell's Vireo Working Group: Adult, "an after hatch year bird"; Complete nest, "a nest built by a pair; capable of receiving young"; Expected fledglings, "number of nestlings seen on the last visit"; Failed nest, "a nest which had eggs but produced no known fledged young"; False or bachelor nest, "an incomplete nest built by a lone male"; Incomplete nest, "a nest built by a pair; abandoned prior to completion"; Juvenile, "a fledgling which has been out of the nest more than 14 days"; Known fledged young, "a fledgling seen out of the nest"; Manipulated nests, "... e.g., cowbird egg removed"; Presumed failure, "... apparently complete nest that did not receive an egg; no powdery pin feathers seen in the nest; adults seen without fledglings..."; Presumed successful (nest), "... powdery pin feathers seen in the nest; nest intact"; Productivity or breeding success (population), "the number of known fledglings divided by the number of known breeding (nesting) pairs..."; Successful nest, "a nest which fledged at least one known young"; Successful pair, "produced one [or more] successful nests".

Lastly, because "territory" has connotations not addressed in this study, we primarily use the broader term "home range" herein. "Territorial males", however, is commonly used in written reports of the vireo and retained herein, as well.

RESULTS AND DISCUSSION

Least Bell's Vireo. The first returning male vireo was detected on 17 March during the fifth focused survey of the season. By 31 March, 156 male vireos had been detected, which compares with the mere 11 males that had been detected by that date in 2021 (Pike 2021), and the record 307 males similarly detected in 2015 (Pike *et al.* 2015). An additional 242 male vireos were found by 15 April this season.

The first female vireo was detected on 25 March, while no females had been found by that date in 2021 (Pike 2021). In addition, 87 females had been detected by 15 April, while just 33 had been found by that date in 2021 (Pike 2021), and a record 137 female vireos in 2005 (Pike *et al.* 2005).

The first nest of the 2022 season was likely completed before 31 March. Nestling young were first observed on 14 April and the first fledgling on 3 May. The last nest of the season was completed on or about 30 June, exceeding the typical range of 22 - 25 June for last completed nests in recent seasons (Pike *et al*. 2011). The extreme date for last completed nest within the Basin is 18 July in 1990 (Hays and Corey 1991). Vireos had departed the Basin by about 20 September 2022, when only one male could be found. However, there has been one definite record of a vireo having overwintered in the Basin, and several instances of either late migration by vireos or additional attempts at overwintering (The Nature Conservancy 1994, 1995; Pike and Hays 1998). Exceptions as noted above notwithstanding, average arrival dates for our vireos were more than a month earlier than documented for the eastern subspecies and fall departures

were quite similar (Barlow 1962; Garrett and Dunn 1981; Salata 1986, 1987; Hays 1987, 1988; Robbins 1991; Pike and Hays 1992).

Six hundred seventy-seven males, three hundred twenty-seven females, and five hundred seventy fledged young were detected in the Prado Basin in 2022 (Table 1). The total for male vireos represents a 13% increase from the 597 vireo males recorded in 2021 (Pike 2021) and has only been exceeded by the 719 vireo males tallied in 2020 (Pike 2020). Given the early arrival of vireos to the Basin in 2022, the increase in overall numbers wasn't a surprise. The surge in vireo numbers that occurred in 2004 (Pike *et al*. 2004), 2009 (Pike *et al*. 2009), and 2013 (Pike *et al*. 2013), had all been presaged by the historically early arrival of birds in each season. Conversely, the precipitous 30% year-over-year decline in vireo numbers that occurred in 2006 (Pike *et al*. 2006), and similar significant decreases documented in 2011 and 2012 (Pike *et al*. 2011, 2012) had all followed the especially late spring arrival of vireos to the Basin.

Despite the declines that were experienced in 2006 and 2012, there has been an overarching expansion of the local Prado population. While only 20 territorial males were found in 1987 (Hays 1987), 665 were detected in 2018 (Pike *et al*. 2018), 719 in 2020 (Pike 2020), and 677 this season (Table 1). Site fidelity is extremely strong in the vireo and of the hundreds of vireos banded at other locations, relatively few have been observed at Prado. Those that were include three color-banded males detected in the Basin during the 1992 breeding season; a male and a female in 1993; a male in 1994; and a female in 1995. All seven were marked as nestlings in San Diego County: two were born on Marine Corps Base, Camp Pendleton; two came from the San Luis Rey River; and three fledged along the San Diego River. From 1996-2004, only six additional banded male vireos were detected. One of these males was present in a West Basin home range every breeding season from 1997 to 2002. Two other males found in 2002 had apparently been banded in Ventura County locales. Another banded male returned to the same territory along Mill Creek from 2015-2018; this bird had fledged along the Santa Margarita River on Camp Pendleton in 2014.

Table 1. Least Bell's Vireo Status and Management, Prado Basin, CA, 2004 - 2022.

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
A. Number of territorial males	590	600	423	420	463	538	569	517	451	561	520	532	511	549	665	606	719	597	677
B. Number of pairs [a]	413	386	219	237	236	273	286	200	158	195	172	186	208	218	301	283	372	281	327
C. Number of fledged young observed [a]	767	525	361	365	417	457	479	286	229	286	194	225	328	409	389	523	584	438	570
D. Projected total recruitment of vireo young	1115	1042	635	627	684	683	861	451	363	527	275	372	686	676	692	934	1023	666	952
E. Average number of fledglings per pair (C/B)	1.9	1.4	1.6	1.5	1.8	1.7	1.7	1.4	1.4	1.5	1.1	1.2	1.6	1.9	1.3	1.9	1.6	1.6	1.7
F. Projected number of fledglings per pair (D/B)	2.7	2.7	2.9	2.6	2.9	2.5	3.0	2.3	2.3	2.7	1.6	2.0	3.3	3.1	2.3	3.3	2.75	2.37	2.93
G. Rate of nest depredation	35%	39%	22%	32%	21%	41%	34%	33%	41%	35%	32%	43%	38%	30%	39%	28%	31%	36%	28%
H. Rate of cowbird nest parasitism	5%	5%	5%	9%	5%	7%	8%	2%	18%	6%	13%	9%	0%	3%	5%	3%	2%	7%	5%
I. Number of cowbirds trapped in study area [b]	1353	2126	1035	497	812	1768	830	436	713	314	284	360	370	585	324	656	1597	1681	380
J. Number of trap days (1 operative trap in the field for 1 day=1 trap day)	1883	1492	1139	926	761	774	685	768	661	639	496	900	900	651	508	875	1010	985	962
K. Average number of cowbirds trapped per trap day (I/J)	0.7	1.1	0.9	0.5	1.1	2.3	1.2	0.5	1.1	0.5	0.6	0.4	0.4	0.8	0.6	0.75	1.6	1.7	0.4

[a] Actual totals for pairs and fledglings are likely **significantly higher** than those stated. As the parasitism rate has diminished, so has intensive monitoring of vireo territories and nesting efforts.

[b] Totals reflect the number of cowbirds trapped and removed from mid- to late March through late July to early August of each respective season. Trapping has been conducted after those dates within dairy operations adjacent to the Prado Basin during fall/winter 1996-2006, and, again, 2011-2022 (see text).

Vireo Nests and Placement. Least Bell's Vireos typically nest in dense riparian understory dominated by mulefat (*Baccharis salicifolia*), willows, mugwort (*Artemisia douglasiana*), *Bidens* spp., Mexican tea (*Chenopodium ambrosioides*), great marsh evening primrose (*Oenothera elata* ssp. *hirsutissima*), and stinging nettle (*Urtica dioica*), among others (Wilbur 1980; Gray and Greaves 1981; Goldwasser 1981; Salata 1984, 1987; United States Fish and Wildlife Service 1986; Pike and Hays 2000). Of the 201 nests that were examined in 2022, 43 (21%) were suspended in mulefat, 86 (43%) in black willow, and 27 (13%) in arroyo willow (*Salix lasiolepis*). Overall, 59% (N=106) of vireo nests were placed in willows. On average, 51% (N=3,030) of all nests examined in the Basin, 1987-2022, were placed in willows and 33% (N=1,939) were in mulefat. Since 1987, 5,920 nests have been found in a minimum of 56 species of plants. Although a surprising 232 of these nests have been placed in non-native blue gum trees (*Eucalyptus globulus*) over the years, only 18 (2%) of these nests were found in eucalyptus during the 2014-2022 seasons. Conversely, over that same span, 62 (5%) nests were partially or entirely placed in wild grape (*Vitis girdiana*), a species that is prospering in areas where willow trees have suffered dieback due to the invasive Polyphagous Shot Hole Borer (*Euwallacea sp*.). In addition, 53 (5%) nests were found in black elderberry (*Sambucus nigra*), a native species which is spreading in the higher margins of the Basin despite a persistent trend toward drier conditions.

Nest cover was similar on the Santa Margarita River, Camp Pendleton, where approximately 59% of 394 nests, 1981-1987 were located in willows (largely arroyo willow and narrowleaf willow, *Salix exigua*) (Salata 1987) and in the Gibraltar Reservoir Watershed of Santa Barbara County where 101 (47%) of 216 nests were also in willows (Gray and Greaves 1981). However, the vireo's preponderant use of black willow and mulefat was unique for the Prado Basin. The most inundation-tolerant of the willows is the black willow, which dominates the riparian habitat in Prado Basin because of the regularity of pooled water therein (Zembal *et al.* 1985). In some areas in the lower Basin there is little else growing that could provide suitable structure for nest support and cover. Mulefat, being a more xeric species and far less tolerant of inundation, is primarily distributed around the higher margins of the Basin in local, naturally occurring stands (Zembal *et al*. 1985). In the earlier years of this study, the consistent use of mulefat by vireos was disproportionate to its availability. By example, in years 1990-1999, 41% (849 of 2094) of all vireo nests were placed in mulefat, while only 25% (N=514) of nests were placed in the more abundant black willow. However, despite the proliferation of mulefat around the perimeter of the Basin in conjunction with native plant restoration efforts, the species has experienced a high rate of attrition due to periods of high-water levels at the lowest elevations, drought and fire at the higher elevations. Thus, in years 2000-2009, only 28% (576 of 2050) of nests were placed in mulefat, while 39% (N=796) were placed in black willow. Furthermore, in December 2010 - January 2011, water was retained at an unprecedentedly high level behind the dam, resulting in the prolonged submersion and some mortality of mulefat shrubs in the lower Basin. As a corollary, the 22% (20 of 89) of vireo nests placed in mulefat the following season equaled the lowest percentage recorded (Pike *et al.* 2011). That record was exceeded by the 19% (34 of 176) (Pike 2021) and 21% (Table 2) of nests that were found supported by this species in 2021 and 2022, respectively. The proximate cause for these changes was the return of drought conditions, with extreme below-average spring precipitation resulting in the desiccation of habitat including mulefat shrubs at higher elevations, carrying fires exceeding 1,000 acre each in 2015 and 2020. Consequently, vireos shifted into less-impacted willow habitat, reflected by the 48% (85 of 176) nest-usage of black willows that occurred in 2021 (Pike 2021).

In years with abundant rainfall in late winter or early spring, water is conserved to an elevation of 505 feet in Prado Basin and vireo habitat is inundated. Understory is submerged, and particularly if the water level varies, some or many of the vireos are forced into the higher edges of their home ranges. In addition, given the strong breeding-site fidelity of vireos (Pike and Hays 2000), some or many vireo males or pairs may elect to remain in territories that are substantially flooded for most, or even all, of the breeding season (Pike *et al.* 2003). This occurred in 2005 and 2011, resulting in a minimum of 109 and 114 vireo males, respectively, establishing territories in lower elevation flooded habitat (Pike *et al.* 2005; Pike *et al.* 2011). This weather pattern was repeated during the 2020 season (Pike 2020), again leading to the inundation of the western, lower portion of the Basin and resulting in at least 195 vireo males establishing territories in flooded habitat.

The vireos typically arrive in early spring and often begin nesting in sites with minimal groundcover, particularly at the lower elevations. However, the understory can grow quickly and is usually a significant presence when birds are actively feeding nestlings. The elevational zones above 498 feet consistently have the most diverse and abundant growth of understory vegetation. Because the vegetation near and around vireo nests influences nesting site selection, nest placement, and reproductive outcome, data were collected in 2022 on groundcover at nests in addition to nesting substrate. Plant composition of the groundcover in Prado Basin is dependent on the time of year, elevation, and rainfall, along with the timing and duration of water impoundment behind the dam.

In 2022, perennial pepperweed (*Lepidium latifolium*) was the most dominant groundcover species encountered at nesting sites, found beneath 38 (19%) of nests followed by Spearscale (*Atriplex prostrata*), found beneath 16 nests (9%) (Table 4). Poison hemlock (*Conium maculatum*) grew abundantly at higher elevations and was reported at 8 (4%) nests. Spearscale (*Atriplex prostrata*) and cocklebur (*Xanthium strumarium*) tend to dominate the lowest elevational zones but in 2022 cocklebur was not a co-dominant species under any nests; spearscale was the primary understory species. This is typical of the understory composition in drought years when low water availability is not conducive to cocklebur dominance. Bare ground, leaf litter, and deadfall were also encountered more often in the lowest zones due to the lack of monotypic cocklebur fields. These inanimate cover types were also encountered at elevations above 505 feet (Table 4) where dry conditions and the density within mulefat thickets excluded much lower-growing understory vegetation.

Vireo nests in the Prado Basin are often placed at the lower edge of a horizontal belt of dense foliage volume at about 1 m from the ground (Zembal 1986). Mean nest heights of 1.13 m and 1.18 m measured in 1989 and 1990, respectively, were much higher than the corresponding values of 0.87, 0.64, and 0.99 m reported from other areas (Wilbur 1980; Gray and Greaves 1981; and, Salata 1987, respectively). In 2019, conserved water in West Basin resulted in seven nests being found higher than 2 m above the ground; the mean nest heights measured (or estimated) that season were 1.06 m from the ground (Pike *et al*. 2019). In 2020, water was again conserved in West Basin, resulting in 26 nests being found within flooded habitat. Ten of these nests were between 2.0 – 3.0 m above the water level when found, and three between 3.0 – 4.0 m. The highest were two nests estimated at 5.49 m and 6.10 m above the level of the water. Mean nest heights among vireos nesting in flooded habitat were 2.33 m in 2020, compared with

a Basin-wide mean nest height of 1.22 m. Overall, 14 nests have been recorded at 3.0 - 4.0 m above the ground, including three in 2021, and six have been measured or estimated at 4.1 - 4.9 m above the ground.

The vireos have frequently used synthetic materials in their nests. In 1995, 179 nests were examined for content after they were abandoned. About 60% (107 of 179) of the nests contained thin, pliable plastics or papers, primarily on nest bottoms, and only 40% (72 of 179) included natural materials exclusively. Of the 107 nests containing synthetics, 89% (95) primarily used white plastic, and 11% (12) mostly contained other materials, usually clear plastic or white paper. Along Temescal Creek, where trash was formerly abundant, white plastics were incorporated into 88% (49 of 56) of all nests.

Vireo Clutches, Fledglings, and Nests per Pair. In 2022, the mean clutch size of 3.54 eggs (N=152) is below the 3.66 eggs (N=128) recorded in 2021 (Pike 2021), albeit above the 3.39 eggs recorded during the exceedingly dry 2018 season (Pike *et al*. 2018). This further compares with the historic mean clutch size of 3.60 eggs recorded for 3,818 nests, 1986-2022. Record-high averages of 3.83 and 3.85 eggs were documented in the pre-drought years of 2009 and 2010, respectively (Pike *et al*. 2010), whereas the record low of 3.22 eggs occurred during the drought of 2014 (Pike *et al*. 2014). The severity of the recent drought and the concomitant decreased food available to breeding vireos was the presumed cause for the significant reduction in clutch sizes noted in 2014-2015. In addition to the deleterious effects of limited resources on the fitness of the vireos, less abundant food likely resulted in more time spent foraging away from the nest and less time in incubation. Apparently limited insect prey in 2016, for example, likely caused the decreased survival rate observed when 40% (25 of 62) of non-parasitized vireo nests produced far fewer nestlings than eggs laid (Pike *et al*. 2016). An additional reflection of drought-related decrease in vireo fecundity was observed in 2014 when nearly two weeks passed between the completion of five vireo nests and the initial laying of eggs therein; six clutches were also abandoned in 2014 (Pike *et al*. 2014). In 1999, the mean clutch size in 97 nests found within the Basin in April and May was a high of 3.88. Only 12 nests contained three eggs and no nest contained only two eggs. However, the vireos laid fewer eggs per nest during the second half of that breeding season. The average clutch in 62 nests in June and July 1999 was 3.4, with 21 three-egg nests and 4 two-egg nests.

Although it is difficult to document that two-egg clutches represent completed clutches, 91 two-egg nests have been found in Prado Basin, including five during the dry 2018 season (Pike *et al*. 2018). Remarkably, a pair incubated a single egg for at least one week during the 2021 season. After this nest subsequently failed, the pair followed with a two-egg nest that suffered the same fate. Thirteen nests within the Basin have been found to contain five vireo eggs, including two nests during the 2019 season. In one instance in the Basin, a five-egg clutch with an additional cowbird egg was found in the home range of a male that was associated with two females over a four-day period (Pike and Hays 1992).

A minimum of 570 vireo fledglings were produced in the Basin in 2022 (Table 1). Reproductive success was 67% (130 of 195) (Table 5), well above the 57% (93 of 164) recorded in 2021 (Pike 2021) and exceeding the 40% (40 of 100) recorded in 2015 (Pike *et al*. 2015). In 2022, the average number of fledglings per breeding pair was 2.15 (Table 5). This compares with the average number of fledglings per breeding pair of 1.7 recorded during the dry 2018 season (Pike *et al*. 2018), and the Prado record low (1.4) average documented during the drought-afflicted

season of 2014 (Pike *et al*. 2014). The highest productivity detected in the Basin was during 1988-1991 when the fledglings-per-pair average was 3.1. This apparent decline in productivity may be partly attributable to the substantial increase in the vireo population since 1989 and our diminished ability to track all nests closely enough to document all fledglings. However, any actual long-term decline in productivity per pair is likely also associated with increased population density and reduced nesting attempts, compounded by the near-continuous drought of recent years.

For example, seventy-seven of 137 pairs (56%) fledged young from two or three nests from 1989-1991 (Pike and Hays 1992). By comparison, from 1999-2001, when far more vireos were present in the Basin (Table 1), only 4% of pairs in each season were documented as having fledged from two nests (Pike *et al*. 2001). Although only two vireo pairs fledged from two nests in 2021 (Pike 2021), nine did so in 2022, as did a surprising seventeen of 283 pairs (6%) in 2019 (Pike *et al*. 2019). While two vireo pairs built five nests each during both the 1993 and 1994 seasons, no known pairs have built five nests since. Fifth (or sixth) nesting attempts within a given home range are exceedingly rare elsewhere as well (Greaves *et al.* 1988; Kus and Collier 1988; Salata 1983a, b). In addition, two home ranges accommodated four nests in both 1997 and 1998, as did another home range in 2003 (Pike *et al*. 2003). Unusually, a West Basin home range not only accommodated four nests in 2020 (Pike 2020), but also held a fifth completed nest that likely did not receive eggs. Four of these nests held eggs; three clutches were depredated, but young were successfully fledged from the fourth clutch.

Finally, there was a minimum of 2.4 nests per well-monitored pair in 1988 (Hays 1988) and 2.7 nests in 1990 (Hays and Corey 1991). However, in 1996 only 1.8 nests were built per well-monitored pairs (The Nature Conservancy 1996), then 1.7 nests in 1997 (The Nature Conservancy 1997), and by year 2000, the average number of nests built per pair was down to 1.2 (Pike and Hays 2000). In both 2020 and 2021 (Pike 2021), the average was again 1.2 nests per pair, while 1.3 nests per pair were recorded in 2022. As noted above, it is apparent that as the vireo population has expanded, there has been a marked reduction in re-nesting over the past two decades. However, given that this expansion has resulted in a diminished need for intrusive nest-monitoring, there has been a concomitant reduction in the quantity of the data that have been generated. Consequently, it is possible that vireo nesting fecundity is greater than is currently reported.

Table 2. Least Bell's Vireo Nest Placement Plants, Prado Basin, 2006 - 2022.

Number of Plants Containing Nests

Plant Species	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Totals*
Black Willow (*Salix gooddingii*)	38 (34%)	23 (24%)	40 (39%)	35 (35%)	43 (34%)	38 (43%)	33 (45%)	44 (42%)	24 (30%)	40 (38%)	58 (53%)	48 (40%)	81 (52%)	59 (34%)	66 (33%)	85 (48%)	85 (42%)	2,070 (35%)
Arroyo Willow (*Salix lasiolepis*)	13 (12%)	19 (20%)	15 (15%)	18 (18%)	14 (11%)	12 (13%)	11 (15%)	16 (15%)	17 (21%)	14 (13%)	11 (10%)	16 (13%)	17 (11%)	17 (10%)	31 (16%)	19 (11%)	26 (13%)	807 (14%)
Red Willow (*Salix laevigata*)	6 (5%)	0	0	0	0	1 (1%)	0	1 (1%)	1 (1%)	1 (1%)	0	1 (1%)	0	1 (1%)	0	0	2 (1%)	90 (2%)
Narrowleaf Willow (*Salix exigua*)	0	0	0	0	1 (1%)	0	0	1 (1%)	0	0	0	0	0	0	1 (1%)	2 (1%)	1 (<1%)	43 (1%)
Yellow Willow (*Salix lucida* ssp. *lasiandra*)	0	0	0	0	0	0	0	0	0	0	0	1 (1%)	1 (1%)	0	0	0	2 (1%)	11 (<1%)
Unidentified willow species	0	0	0	0	0	0	0	0	0	1 (1%)	1 (1%)	0	0	0	0	0	0	9 (<1%)
Fremont Cottonwood (*Populus fremontii*)	0	1 (1%)	1 (1%)	0	0	1 (1%)	1 (1%)	1 (1%)	1 (1%)	0	0	1 (1%)	0	1 (1%)	3 (2%)	3 (2%)	3 (1%)	15 (<1%)
Mulefat (*Baccharis salicifolia*)	28 (25%)	29 (31%)	32 (31%)	32 (32%)	56 (45%)	20 (22%)	19 (26%)	25 (24%)	27 (34%)	38 (36%)	32 (29%)	33 (27%)	37 (24%)	53 (31%)	52 (26%)	34 (19%)	44 (21%)	1,939 (33%)
Coyote Bush (*Baccharis pilularis*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9 (<1%)
Blue Gum (*Eucalyptus globulus*)	8 (7%)	9 (10%)	7 (7%)	1 (1%)	2 (2%)	3 (3%)	3 (4%)	4 (4%)	2 (3%)	0	0	1 (1%)	1 (1%)	3 (2%)	7 (4%)	2 (1%)	2 (1%)	232 (4%)
Giant Reed (*Arundo donax*)	2 (2%)	1 (1%)	1 (1%)	2 (2%)	0	0	0	2 (1%)	1 (1%)	0	0	0	2 (1%)	2 (1%)	2 (1%)	2 (1%)	2 (1%)	45 (1%)

[*] Totals include data from 3,802 nests found during the 1987-2005 seasons (Pike *et al*. 2005)

Table 2. Least Bell's Vireo Nest Placement Plants, Prado Basin, 2006 - 2022 (Continued).

Number of Plants Containing Nests

Plant Species	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Totals*
Cocklebur (*Xanthium strumarium*)	0	0	0	0	0	0	0	0	0	0	0	0	1 (1%)	0	0	0	0	8 (<1%)
Black Elderberry (*Sambucus nigra*)	4 (4%)	2 (2%)	1 (1%)	3 (3%)	1 (1%)	2 (2%)	0	0	1 (1%)	4 (4%)	1 (1%)	6 (5%)	4 (3%)	12 (7%)	7 (4%)	11 (6%)	7 (3%)	156 (3%)
Southern California Grape (*Vitis girdiana*)	2 (2%)	2 (2%)	2 (2%)	3 (3%)	0	5 (6%)	4 (5%)	0	5 (6%)	4 (4%)	5 (5%)	7 (6%)	6 (4%)	4 (2%)	4 (2%)	11 (6%)	16 (8%)	131 (2%)
Stinging Nettle (*Urtica dioica*)	0	0	0	1 (1%)	0	0	0	0	0	0	0	0	0	0	0	0	0	6 (<1%)
Himalayan Blackberry (*Rubus armeniacus*)	1 (1%)	2 (2%)	1 (1%)	1 (1%)	0	0	1 (1%)	0	0	0	0	1 (1%)	0	0	0	0	1 (<1%)	26 (<1%)
Thistle (*Cirsium* spp.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10 (<1%)
California Pepper (*Schinus molle*)	0	1 (1%)	1 (1%)	0	0	0	0	0	0	0	0	0	0	1 (1%)	1 (1%)	1 (1%)	1 (<1%)	15 (<1%)
Chinese Elm (*Ulmus parvifolia*)	0	0	0	0	1 (1%)	0	0	0	0	0	0	0	0	0	0	0	1 (<1%)	5 (<1%)
Sunflower (*Helianthus annuus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (1%)	0	0	1 (<1%)	16 (<1%)
Black Mustard (*Brassica nigra*)	2 (2%)	0	0	1 (1%)	0	1 (1%)	1 (1%)	0	0	0	0	0	0	5 (3%)	2 (1%)	1 (1%)	0	55 (1%)
Tree Tobacco (*Nicotiana glauca*)	1 (1%)	1 (1%)	1 (1%)	0	0	0	0	0	0	0	0	0	0	1 (1%)	2 (1%)	1 (1%)	0	11 (<1%)

[*] Totals include data from 3,802 nests found during the 1987-2005 seasons (Pike *et al*. 2005)

Table 2. Least Bell's Vireo Nest Placement Plants, Prado Basin, 2006 - 2022 (Continued).

Number of Plants Containing Nests

Plant Species	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Totals*
Unidentified (dead material)	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (1%)	0	0	0	2 (<1%)
California Sagebrush (*Artemisia californica*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6 (<1%)
Toyon (*Heteromeles arbutifolia*)	1 (1%)	0	0	0	0	1 (1%)	1 (1%)	1 (1%)	0	0	0	1 (1%)	0	1 (1%)	0	1 (1%)	0	13 (<1%)
Cherry (*Prunus* spp.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (<1%)
California Walnut (*Juglans californica*)	1 (1%)	0	1 (1%)	0	0	1 (1%)	0	0	0	0	0	1 (1%)	0	0	1 (1%)	1 (1%)	0	12 (<1%)
Tamarisk (*Tamarix ramosissima*)	1 (1%)	1 (1%)	0	1 (1%)	3 (2%)	1 (1%)	0	0	1 (1%)	3 (3%)	0	1 (1%)	1 (1%)	1 (1%)	4 (2%)	4 (2%)	1 (<1%)	45 (1%)
Perennial Pepperweed (*Lepidium latifolium)*	0	0	0	0	0	1 (1%)	0	1 (1%)	0	0	0	0	0	0	1 (1%)	1 (1%)	0	7 (<1%)
Mexican Tea (*Chenopodium ambrosioides*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2 (<1%)
Arizona Ash *(Fraxinus velutina*)	1 (1%)	1 (1%)	0	1 (1%)	0	0	0	0	0	0	0	1 (1%)	0	0	2 (1%)	1 (1%)	3 (2%)	16 (<1%)
Box Elder (*Acer negundo* ssp. *californicum*)	0	0	0	0	1 (<1%)	0	0	0	0	0	0	0	2 (1%)	2 (1%)	2 (1%)	1 (1%)	1 (<1%)	23 (<1%)
Brazilian Pepper (*Schinus terebinthifolius*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (<1%)

[*] Totals include data from 3,802 nests found during the 1987-2005 seasons (Pike *et al*. 2005)

Table 2. Least Bell's Vireo Nest Placement Plants, Prado Basin, 2006 - 2022 (Continued).

Number of Plants Containing Nests

Plant Species	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Totals*
Castor Bean (*Ricinus communis*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (<1%)	1 (<1%)
Wild Radish (*Raphanus sativus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3 (<1%)
Poison Hemlock (*Conium maculatum*)	1 (1%)	0	1 (1%)	0	0	0	0	0	0	0	1 (1%)	0	1 (1%)	0	0	1 (1%)	0	16 (<1%)
Western Sycamore (*Platanus racemosa*)	0	0	0	1 (1%)	0	0	0	0	0	0	0	2 (1%)	0	1 (1%)	1 (1%)	1 (1%)	0	8 (<1%)
Olive (*Olea europaea*)	0	0	0	0	2 (2%)	2 (2%)	0	0	0	0	0	0	0	2 (1%)	2 (1%)	2 (1%)	1 (<1%)	21 (<1%)
Australian Pepper (*Schinus polygamus*)	1 (1%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2 (<1%)
Curly Dock (*Rumex crispus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4 (<1%)
Wild Rose (*Rosa californica*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2 (1%)	2 (1%)	0	6 (<1%)
Clematis (*Clematis ligusticifloia*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (<1%)
Western Ragweed (*Ambrosia psilostachya*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (<1%)
Coast Live Oak (*Quercus agrifolia*)	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (1%)	1 (1%)	0	0	6 (<1%)
Bush Mallow (*Malacothamnus fasciculatus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (<1%)
Common Sow Thistle (*Sonchus oleraceus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (<1%)

[*] Totals include data from 3,802 nests found during the 1987-2005 seasons (Pike *et al*. 2005)

Table 2. Least Bell's Vireo Nest Placement Plants, Prado Basin, 2006 - 2022 (Continued).

Number of Plants Containing Nests

Plant Species	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Totals*
Tree-of-Heaven (*Ailanthus altissima*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (<1%)
Black Sage (*Salvia mellifera*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (<1%)
White Sage (*Salvia apiana*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (<1%)
Lemonadeberry (*Rhus integrifolia*)	0	1 (1%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (<1%)
Southern Catalpa (*Catalpa bignonioides*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (<1%)
White Mulberry (*Morus alba*)	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (1%)	0	0	0	1 (<1%)
Chinese Pistache (*Pistacia chinensis*)	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (1%)	0	0	0	1 (<1%)
Quince (*Cydonia oblonga*)	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (1%)	1 (1%)	0	0	2 (<1%)
Carob (*Ceratonia siliqua*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (1%)	0	0	1 (<1%)
Tipa (*Tipuana tipu*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (1%)	0	0	1 (<1%)
Kochia (*Kochia scoparia*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (1%)	0	0	1 (<1%)
African sumac (*Searsia lancea*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 (1%)	0	0	1 (<1%)
TOTALS	111	94	102	100	125	89	73	106	106	105	109	121	156	172	198	176	205	5,920

[*] Totals include data from 3,802 nests found during the 1987-2005 seasons (Pike *et al*. 2005)

Table 3. Least Bell's Vireo Nest Placement Plant by Elevation of 201 Nests, 2022.

Least Bell's Vireo Nesting Substrate - Prado Basin 2021					
Plant Species	Elevation <490'	Elevation 490-497'	Elevation 498-505'	Elevation >505'	Total
Black Willow (*Salix gooddingii*)	12 (92%)	14 (88%)	25 (64%)	34 (25%)	85 (42%)
Mulefat (*Baccharis salicifolia*)			2 (5%)	42 (32%)	44 (22%)
Arroyo Willow (*Salix lasiolepis*)			2 (5%)	24 (18%)	26 (13%)
Southern California Grape (*Vitis girdiana*)	1 (8%)	1 (6%)	7 (17%)	7 (5%)	16 (8%)
Black Elderberry (*Sambucus nigra*)				7 (5%)	7 (3%)
Tamarisk (*Tamarix ramosissima*)				1 (<1%)	1 (<1%)
Narrowleaf Willow (*Salix exigua*)				1 (<1%)	1 (<1%)
Eucalyptus sp.		1 (6%)	1 (3%)		2 (1%)
Fremont Cottonwood *(Populus fremontii)*				3 (2%)	3 (1.5%)
Olive (*Olea europaea*)				1 (<1%)	1 (<1%)
Castor Bean *(Ricinus communis)*			1 (3%)		1 (<1%)
Common Sunflower *(Helianthus annuus)*			1 (3%)		1 (<1%)
Arizona Ash (*Fraxinus velutina*)				3 (2%)	3 (2%)
Pacific Willow *(Salix lucida)*				2 (1%)	2 (1%)
Red Willow *(Salix laevigata)*				2 (1%)	2 (1%)
Box Elder (*Acer negundo*)				1 (<1%)	1 (<1%)
Chinese Elm *(Ulmus parvifolia)*				1 (<1%)	1 (<1%)
California Pepper *(Schinus molle)*				1 (<1%)	1 (<1%)
Himalayan Blackberry *(Rubus armeniacus)*				1 (<1%)	1 (<1%)
Giant Reed *(Arundo donax)*				2 (1%)	2 (1%)
Total Nests	13	16	39	133	201

Table 4. Dominant Understory Plants and Groundcover Below 201 Least Bell's Vireo Nests in Prado Basin, 2022.

Plant Species	**Elevation <490'**	**Elevation 490-497'**	**Elevation 498-505'**	**Elevation >505'**
Bareground/Leaflitter/Deadfall	8	4	19	83
Castor bean *(Ricinus communis)*			1	
Poison Hemlock *(Conium maculatum)*			1	7
Black Mustard *(Brassica nigra)*			1	1
Stinging Nettle *(Urtica dioica L. Ssp holosericea)*			2	2
Non-Native Grasses	1			
Perennial Pepperweed *(Lepidium latifolium)*		1	6	31
Spearscale *(Atriplex prostrata)*	3	8	4	1
Common Sunflower *(Helianthus annuus)*	1	1	2	1
Horseweed *(Erigeron canadensis)*		1		
Caterpillar Phacelia *(Phacelia cicutaria)*				3
Curly Dock *(Rumex crispus)*				1
White Nightshade *(Solanum Americanum)*			1	
Himalayan Blackberry *(Rubus armeniacus)*				3
Wild Radish *(Raphanus sativus)*				1
Milkweed sp. *(Asclepias)*		1		

Dominant Feature	Elevation <490’	Elevation 490-497’	Elevation 498-505’	Elevation >505’
Vegetated	5	12	18	51
	38%	76%	49%	38%
Deadfall/Leaflitter/Bareground	8	4	19	83
	62%	24%	51%	62%
Average Substrate Height	21”	27”	25”	25”

Unusual Vireo Nestings. Over the course of this 37-year study, numerous unexpected, breeding-related events have occurred in the Prado Basin. For example, in 1998 a nest along Temescal Creek containing four eggs on 3 May was found empty, depredated, but intact by 18 May. The affected pair moved to an adjacent area to renest. Then, by 29 May a second clutch of four eggs had been laid in the original nest by another, newly detected pair. This nest was subsequently depredated for a second time. In both the 2001 and 2021 seasons, single vireo pairs initiated successive nesting efforts with intact nests that had experienced depredation on their first attempts, only to experience the same results on their second. In 2003, a nest that had been used to fledge four vireo young in early May, was found to contain three eggs of the same pair on 25 June. In 2017, a vireo pair along Mill Creek fledged seven young on successive efforts from the same nest. On four occasions, vireo pairs have reused intact nests from the previous season, with three of these attempts proving successful. In 2004, a complete nest from the previous season was strangely incorporated into a new nest, with the mouth of the old, leaning nest being grafted onto the side of the new one. In 2017, a new nest was positioned in a mulefat shrub so that it rested atop a nest from the previous season; an even older nest was present in the same shrub approximately 1 m distant. In 2019, a nest holding four eggs over a 13-day period was found to contain seven vireo eggs on day 18; five days later, three of the eggs were on the ground, with one appearing to have been pecked. Shortly thereafter, this pair had a new nest in which three eggs were laid, all of which again proved to be non-viable. In 2009, a West Basin vireo pair was observed to repeatedly interrupt the incubation of eggs in their own nest to provision begging Spotted Towhee (*Pipilo maculatus*) young in a ground-level nest nearby. Lastly, a nest discovered in the South Basin in 1998 that had just fledged a vireo, still contained a large Brown-headed Cowbird nestling. Evidently this nest had been parasitized after incubation was well advanced. Elsewise, the likelihood of a vireo nestling surviving the competition with a much larger cowbird nestling would be very remote. This is the only observation of a vireo successfully fledging from a nest in the Basin that simultaneously contained a cowbird nestling. Finally, two challenging nesting situations occurred within Mill Creek home ranges. In the first instance, in 2002, the depredation of an adult female vireo resulted in a detached nest containing four 5-day old nestlings landing upright in the vegetative substrate below. Prolonged observation revealed that the surviving vireo male was neither feeding nor brooding the young while the nest remained on the ground nor after it had been replaced very near its original location. It was eventually determined that the best hope of survival for the nestlings was to individually place them in the nests of other vireo pairs. It was decided that candidate-host nests should contain fewer than four nestlings and, ideally, that host nestlings should be of a similar age. Two of the Mill Creek nestlings were placed in two nests fitting these criteria, and one of the nestlings eventually fledged

along with the 'foster' siblings. The remaining two nestlings were placed in an East Basin nest containing two older nestlings. Although the vireo hosts again apparently accepted the new arrivals, one nestling was evidently too weak to survive and the other was depredated on the nest after the fledging of the older 'foster' siblings. In the second case, in 2005, a nestling was found below a twisted, disintegrating nest that was being supported by the crossed stems of a mustard plant. To save this nestling and the two young remaining in the nest, an intact depredated nest was procured from the territory of a different pair. The three nestlings were then placed in the procured nest, which was attached near the original nest location. All three young eventually fledged from the 'substitute' nest.

Cowbird Parasitism and Management. Increasing breeding success and recruitment in the Prado Basin vireo population over the past 37 breeding seasons is probably due in large part to the active cowbird management program. Data collected in the Basin prior to the initiation of management efforts (Zembal *et al.* 1985; Zembal 1986) corroborate Jones' (1985) observations of extremely low reproductive success rates in 1984 at the unmanaged San Luis Rey, San Diego, and Sweetwater River sites. Jones (1985) reported an overall reproductive success of 14% for these three populations and average fledging rates of 0.25, 0.17, and 0.50 fledglings per nesting pair for the San Luis Rey, San Diego, and Sweetwater River locales, respectively. In the absence of effective cowbird control programs, cowbird parasitism rates ranged as high as 80% at these San Diego County sites (Jones 1985), to 77% (Zembal 1986) and even 100% (Zembal *et al.* 1985) in the Prado Basin.

By 28 July 2022, 380 (205 males, 111 females, 64 juveniles) Brown-headed Cowbirds had been trapped and removed from vireo habitat in the Prado Basin. This is far below the 1,681 cowbirds trapped in 2021 (Pike 2021) and is proximate to the 324 cowbirds removed in 2018 (Pike *et al*. 2018). The most effective traps in 2022 were three placed within extant dairy operations, which accounted for fully 94% (N=357) of all cowbirds removed during the season. By comparison, the most effective of the 'field traps' (*i.e*., those situated in or near riparian habitat adjacent to nesting vireos) this season accounted for the removal of 17 cowbirds, with the remaining five 'field' traps capturing a mere 6 cowbirds.

After a five-year absence, off-season trapping was reinitiated during the winter season of 2011/2012. Between 2 August 2021 and 11 March 2022, three dairy traps accounted for the capture and removal of 2,980 cowbirds. Since 1986, 114,977 cowbirds have been trapped or otherwise collected in the Prado Basin.

Among 45 banded cowbirds discovered in the Basin through 2001, only eight were females and most were banded in Riverside and San Diego Counties from about 76 km to 161 km away. A female and second-year male were recaptured in the Basin four days after they were banded on the coast, 40 km distant. The long-range record was a female banded in Ridgefield, Washington and recaptured in the Basin two months later, on 18 April 1999.

The parasitism rate of vireo nests has varied over the past decade, with no clear correlation between the yearly parasitism rates and the total number of cowbirds trapped in each respective season (Table 1). For example, the 370 cowbirds trapped in 2016 (Pike *et al*. 2016) coincided with the complete absence of any vireo nest being parasitized by a cowbird. By contrast, the similar trapped total of

360 in 2015 co-occurred with a relatively high parasitism rate of 9% (Pike *et al*. 2015). Furthermore, the relatively high number of cowbirds (N=713) that were trapped in 2012 paradoxically coincided with the highest parasitism rate (18%) since 1997 (Table 1). The variability in the annual parasitism rate is at least partly a consequence of the decreased number of vireo nests being monitored in recent years (Pike *et al*. 2012) since there are so many more vireo territories to be counted. Another contributing factor is that while field traps have become gradually less effective, parasitism 'hot spots' have periodically erupted in outlying portions of the Basin. For example, 86% (6 of 7) of all parasitism events recorded during the 2015 season occurred within a small subpopulation of vireos along upper Mill Creek (Pike *et al*. 2015). The Prado Basin cowbird management program has attempted to adapt to this evolving situation by periodically shifting from a static, field trap-based model to one with an increasing focus on the ready portability and rapid deployment of traps wherever needed.

Although the rate of cowbird parasitism of vireo nests has ranged from 0% to 57% within the Prado Basin since 1986, the rate declined significantly after the commencement of the cowbird trapping effort (Chi-square 2 x 2 contingency table; statistic = 20.3 [Yates correction factor applied]; $p < 0.00001$). It was also determined in 1996 that the parasitism rate for vireo nests on the fringes of the Basin, well removed from cowbird traps, was 85%. Basin-wide, the combined parasitism rate for vireo nests was 35% in 1996 (The Nature Conservancy 1996).

Based upon the current study and data collected elsewhere (Pitelka and Koestner 1942; Mumford 1952; Barlow 1962; Salata 1983a,b, 1984, 1986, 1987a, 1987b; Jones 1985; United States Fish and Wildlife Service 1986), we conclude that the Prado Basin population of vireos would have been subjected to much higher rates of cowbird parasitism and reproductive failure in the absence of an effective management program (Hays 1986, 1987, 1988, 1989, 1990; Hays and Corey 1991, Pike and Hays 1992, The Nature Conservancy 1993a, 1993b, 1994, 1995, 1996, 1997; Pike and Hays 1998, 1999, 2000; Pike *et al*. 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019; Pike 2020, 2021). Other published accounts of the efficacy of cowbird trapping programs as part of comprehensive vireo and flycatcher management efforts corroborate this fundamental assumption (Kus 1999, Whitfield and Sogge 1999, and Whitfield *et al.* 1999).

Despite the recent widespread closure of dairies, cowbirds remain plentiful in the Prado Basin, compared to many other sites managed for endangered birds. The adjacent cattle, dairy, and agricultural operations are conducive to a large cowbird population and cowbird management is a relatively recent tool. Consequently, trapping techniques have been refined and improved over the course of this study. Optimum trapping results apparently are achieved if: 1) the appropriate ratio of male and female cowbirds is used in the decoy population; 2) field traps are placed in open areas immediately adjacent to occupied vireo habitats; 3) traps are placed near favored cowbird feeding and roosting sites; and 4) the traps are free from disturbance. First, a maximum yield of female cowbirds is achieved when the decoy population is female-skewed. We recommend the use of 4 or 5 females and 1 or 2 vocal males in a modified Australian crow trap, measuring 6' X 6' X 8'. Secondly, field traps should be positioned in the open, near riparian habitat but not enveloped by it. Third, as noted previously, significant decreases in cowbird parasitism can apparently be achieved by trapping in locales where cowbirds congregate, such as

horse stables or dairy operations. Lastly, the traps must remain as undisturbed as possible (Hays 1986).

In addition to an ongoing effort to improve the methodology of removing cowbirds from the Prado Basin, an effort to age the population of male cowbirds captured in the traps was conducted in years 1996-2011. Per Pyle (1997), "second (calendar) year males" were distinguished by pale brown to grayish greater underwing coverts, which contrast greatly with the adjacent blacker feathers. By contrast, those males with blackish greater underwing coverts showing only moderate contrasts between adjacent feathers were identified as "after second (calendar) year" males (*i.e*., adults) (Pyle 1997). As the preformative molt in juvenile Brown-headed Cowbirds can rarely be complete (Pyle 1997), males with wholly blackish greater underwing coverts but also with contrastingly brownish primaries suggestive of second-year plumage (*pers. obs*., J. Pike; Ortega *et al*. 1996) were excluded from the database. The aging of male cowbirds was routinely terminated on or about 11 July after it had become apparent that feather molt had obscured previously observed (and readily apparent) plumage differences. In 2011, of the 50 males that could be reliably aged, 6% (3) were judged to be adults and 94% (47) were judged to be second-year birds. This compared with the 11% that were determined to be adults in 2010 (Pike *et al*. 2010), and the 9% that were determined to be adults in 2009 (Pike *et al*. 2009). By comparison, in years 1996 and 1997, the recorded percentages for adult males were 29% and 30%, respectively (The Nature Conservancy 1997). The data thus suggest that trapping efforts have not only greatly reduced the overall cowbird numbers within the Basin but have had a profound demographic impact on the population, as well.

Table 5. Least Bell's Vireo Reproductive Success and Associated Breeding Data in Prado Basin, 2022

A. Number of pairs 327
B. Number of breeding (nesting) pairs 265
C. Number of breeding pairs that were well-monitored throughout the breeding season 112
D. Number of `known fledged young' {a}.....570
E. Number of `known fledged young' produced by pairs monitored throughout the breeding season 328
F. Average number of fledglings produced per breeding pair (minimum; D/B; = `productivity or breeding success') 2.15
G. Average number of fledglings produced by pairs monitored throughout the breeding season (E/C)..... 2.93
H. Number of nests that were discovered.....201
I. Number of nests that were regularly monitored or "tracked" 195
J. Number of "tracked" nests that were successful [%= J/I x 100] {c} .....130 [67%]
K. Number of "tracked" nests that were depredated [%= K/I x 100] . ..... 55 [28%]
L. Number of "tracked" nests that were parasitized by cowbirds [%= L/149 x 100]{b} 10
M. Number of nests that failed as a result of reproductive failure……6
N. Average clutch size (N= 152)....…...…….……..……3.5
O. Number of cowbird eggs found in or near vireo nests.....10
P. Number of cowbird nestlings removed from "tracked" nests 0
Q. Number of known cowbird young fledged by vireos 0
R. Number of `manipulated', parasitized nests 5
S. Number of `successful, manipulated' nests [%=S/R x 100].....4
T. Number of vireos fledged from `manipulated', parasitized nests.....7

{a} This is minimum recruitment corresponding to Least Bell's Vireo Working Group definition of `known fledged young'.
{b} Thirteen of the 195 "tracked" nests were depredated or otherwise failed before it could be determined if they had been parasitized. Therefore, these 13 nests were excluded from the calculation of the rate of cowbird parasitism.
{c} One nest was both depredated and successful, as a fledgling survived the event.

Predation. The 28% (55 of 195) of well-tracked nests that were predated during the 2022 breeding season compares with the 36% (59 of 164) of nests that were predated in 2021 (Pike 2021), and the 31% rate documented in 2020 (Pike 2020). As nest contents are not checked daily, it is not always possible to determine at what stage of the nesting cycle predation occurred. Nonetheless, in year 2004, it was evident that 31% (16 of 52) of the nests were predated during the 14-day incubation phase, while 69% (36 of 52) of the nests were predated during the 11-day nestling phase. In 2022, the large majority of depredated nests were once again found to be intact and relatively undisturbed, with only 12 (22%) being discovered on the ground or otherwise significantly damaged. The cumulative evidence thus suggests that snakes, avian predators, and, especially, small rodents (Salata 1987b), are the primary nest predators in the Basin (Pike and Hays 2000). By contrast, 32% (18 of 56) of all depredated nests examined were severely damaged in 2021 (Pike 2021), suggesting that large mammalian predators were evidently a greater factor last season.

Mice and rats are probable nest predators based upon droppings left in depredated nests, small, neat holes in nest bottoms, and nests being domed over (Hays 1986; The Nature Conservancy 1993a, 1997; Pike and Hays 2000). Further, a mound of adult vireo feathers was found below a recently depredated nest that contained a rat dropping in 2001. In 2003, two additional depredated nests were found with rodent droppings on the rim. In 2017, a nest was discovered in which vireo nestlings were in the process of being consumed by Argentine ants (*Linepithema humile*); four additional incidents were documented during the 2019 and 2020 seasons. Additional cases of ant depredation had been recorded in the Basin, but often it is indeterminable if the predation occurred postmortem. However, Argentine ants have been documented in the depredation of vireo nestlings in previous vireo studies (Ferree and Kus 2008; Peterson *et al*. 2004). A lack of evidence precludes a thorough understanding of the amount of nest depredation for which reptiles are responsible. However, five species of snakes have been found in or near occupied vireo habitats. Further, in 2005, a Common Kingsnake (*Lampropeltis getulus*) was observed in the act of swallowing a vireo nestling near a West Basin nest and was evidently responsible for predating the remaining nestling and egg later the same day. Notably, in 6 of eight recent studies utilizing video cameras at the nests of New World passerine birds, snakes were found to be the most important nest predator (Weatherhead and Blouin-Demers 2004). Lastly, in 2000, a Southern Alligator Lizard (*Elgaria multicarinata*) was detected on a branch directly above a recently depredated, intact vireo nest (Pike and Hays 2000).

Among potential avian nest predators, the Greater Roadrunner (*Geococcyx californianus*) has previously been implicated in local depredation events (Pike *et al*. 2006). Although a study conducted along the San Luis Rey River in San Diego County found the California Scrub-Jay (*Aphelocoma californica*) to be the primary nest predator of vireo nests (Peterson *et al.* 2004), this species is only scarcely present around the fringes of the Basin.

Predation and Parasitism. Additional studies have revealed that Brown-headed Cowbirds may be responsible for a significant number of depredation events, and likely to a degree not entirely appreciated (e.g., Hoover and Robinson 2007). For example, Arcese *et al.* (1996) concluded that "cowbirds regularly depredate nests that are discovered too late in the host's nesting cycle to be suitable for parasitism, because this enhances future laying opportunities". Further, their 20-year study of cowbirds and Song Sparrows (*Melospiza melodia)*

uncovered a positive correlation between predation and parasitism rates and indicated that "nest failure was lower when cowbirds were rare or absent than when they were common". An analysis of predation and parasitism rates within the Basin (Table 1), 1991-2008, suggests the possibility of a similar correlation here. For example, 1991-1999, the lowest percentage parasitism rate recorded was 13% in 1998 (Pike and Hays 1998), with a mean percentage rate of 29%. By contrast, 2000-2008, the highest percentage parasitism rate recorded was a relatively low 13% in 2001 (Pike *et al.* 2001), with a mean percentage rate of just 7%. Notably, in six of the 9 years, 1991-1999, during the time-period within which the parasitism rates were at their highest, the predation rate was 40% or greater (Table 1), with an overall mean of 41%. By contrast, during the more recent time frame when the parasitism rates were at their lowest, 2000-2008, a predation rate as high as 40% was recorded only once (Pike *et al.* 2003), with a mean of 32%. In 2011, the parasitism rate in the Basin was just 2%, while the predation rate was 33% (Pike *et al.* 2011). By contrast, in 2012, the parasitism jumped to 18%, and the predation rate was 41% (Pike *et al.* 2012). In 2022, the parasitism rate was 5%, and the predation rate was 28% (Table 5).

Southwestern Willow Flycatcher. For the sixth consecutive year, no Southwestern Willow Flycatcher home range was detected within the Prado Basin in 2022. Despite a peak of nine flycatcher territories within the Basin that was reached in 2003 (Pike *et al*. 2003), flycatcher numbers have been steadily declining ever since.

All known flycatcher territories in the Basin have been associated with water-filled creeks or channels. In addition, territories have usually consisted of overgrown clearings containing varying amounts of nettles (*Urtica dioica*) and other 1 - 2 m tall mesic herbaceous growth with a few to many moderately tall, often dense, willows. Of the 37 nests discovered from 1996-2013, 13 (35%) were found in willows with 8 (22%) of these being in arroyo willow. A total of 16 (43%) nests were found in tamarisk (*Tamarix ramosissima*). This predilection for tamarisk occurred despite the relatively scarce of tamarisk in most of the areas within which the flycatchers have bred. For example, all seven of the nests constructed within a North Basin willow-dominated home range in 2011-2013 were found in tamarisk. Overall heights of the 37 nests have ranged from 0.61 m to 4.50 m, with an average of 2.09 m.

In both the 2003 (Pike *et al*. 2003) and 2004 (Pike *et al*. 2004) seasons, it was discovered that a flycatcher male had paired with two females simultaneously. Neither pairing successfully produced young. This represented just the second and third time that bigyny among Willow Flycatchers had been recorded in the Basin (The Nature Conservancy 1996). Polygyny has previously been documented as a breeding strategy occasionally utilized by this species (Prescott 1986a; Sedgwick and Knopf 1989).

Although flycatcher home ranges have been detected nearly throughout the surveyed portions of the Basin, only four locales have supported more than one territory within a season. Riparian habitat along an effluent channel at the northeastern perimeter of the Basin, Chino Creek on El Prado Golf Course, Butterfield Drain near Corona Airport, and another water-filled channel in the center of the Basin all formerly accommodated as many as three flycatcher territories for periods that extended over multiple consecutive seasons. However, once gone from these locales,

flycatchers have never been detected therein during subsequent breeding seasons. Through 2022, only 50 fledged young have ever been observed in the Basin.

Other Sensitive Avian Species. No federally threatened Western Yellow-billed Cuckoos were found within the Prado Basin in 2022. A cuckoo detected in Central Basin on 23 June 2011, but not thereafter, was the first to be detected in the Basin in ten years. Another one-day sighting of a cuckoo occurred on 21 June 2010 a few miles upriver of the Basin (J. Pike). An additional cuckoo was sighted downriver of the Basin 21-24 July 2018 in Yorba Linda (R. Packard). Whether these observations represented birds migrating through the area or attempting to summer locally is unknown.

Historically, the Western Yellow-billed Cuckoo was considered common in riverbottoms throughout the western United States and southern British Columbia (Gaines and Laymon 1984). It began a drastic decline in numbers as the riparian forests on which it depended were cleared for agriculture and grazing. Along with local declines, there was an overall range contraction; the last known breeding birds were in British Columbia in the 1920s, in Washington in the 1930s, in Oregon in the 1940s, and in California north of the Sacramento Valley in the 1950s (Roberson 1980; Gaines and Laymon 1984). Studies conducted since the 1970s indicate that there may be fewer than 50 breeding pairs in California (Gaines 1974, Laymon and Halterman 1987, Halterman 1991, Laymon et al. 1997). While a few occurrences have been documented at other sites, the only locations in California that currently sustain breeding populations include the Colorado River system in southern California, the South Fork of the Kern River east of Bakersfield, and isolated sites along the Sacramento River in northern California (Laymon and Halterman 1989, Laymon 1998). Studies have indicated that small populations under 25 pairs are vulnerable to stochastic events that can lead to local extinctions (Soule and Wilcox 1980). The Yellow-billed Cuckoo was listed as endangered by the California Department of Fish and Wildlife in 2000 (CDFG 2000) and as threatened by the U.S. Fish and Wildlife Service in 2014.

Western Yellow-billed Cuckoo breeding habitat has been determined to be willow-cottonwood forests below 1300 m elevation that average 10 ha in extent and greater than 100 m in width (Gaines 1974). While Yellow-billed Cuckoos nest primarily in willow trees, cottonwood trees are important as foraging habitat, particularly as a source of insect prey, such as sphinx moth (Sphingidae family) larvae. Continuing habitat succession has also been identified as important in sustaining breeding populations (Laymon 1998). Channelized streams or levied systems that do not allow for these natural processes become over-mature and presumably less optimal (Greco 2008).

Yellow-billed Cuckoos were never a primary focus of this study. The western subspecies is extremely secretive, and little was learned of the size, behavior, or reproductive success of this remnant population. Prior to 1995, the small local population appeared to be somewhat stable, with three (Zembal 1985) to seven (Hays 1987) cuckoos being recorded annually. However, following the inundation of a widespread portion of the Basin in 1995, cuckoo numbers began to decline, and in each of the next seven years, just one or two cuckoos were usually detected. The last confirmed summering cuckoo to be heard in the Basin was in the willow forest to the south of Prado Regional Park (i.e., West Basin) in the southwestern corner of San Bernardino County in 2001 (Pike *et al*. 2001).

The expansive riparian forest present in the Prado Basin would appear to be sustainable habitat for the Yellow-billed Cuckoo, and that was apparently the case prior to 2001. It is likely that the relative scarcity of cottonwoods within the Basin has served as a limiting factor, as has the continuing debasement of the Santa Ana River from a once dynamic, riverine system. Hopefully, the detection of single birds in or near the Basin in recent seasons indicates that this species has not been permanently extirpated from the Basin and environs.

Several other species designated by the California Department of Fish and Wildlife as "Bird Species of Special Concern" (Shuford and Gardali 2008) have bred or attempted to breed within the Prado Basin and environs. Included among these were the Redhead (*Aythya americana*), Least Bittern (*Ixobrychus exilis*), Burrowing Owl (*Speotyto cunicularia*), Long-eared Owl (*Asio otus*), Vermilion Flycatcher (*Pyrocephalus rubinus*), Loggerhead Shrike (*Lanius ludovicianus*), Clark's Marsh Wren (*Cistothorus palustris clarkae*), Yellow Warbler *(Setophaga petechia*), Yellow-breasted Chat (*Icteria virens*), Summer Tanager (*Piranga rubra*), Grasshopper Sparrow (*Ammodramus savannarum*), Tricolored Blackbird (*Agelaius tricolor*), and Yellow-headed Blackbird (*Xanthocephalus xanthocephalus*). These and several other local breeders, including the Common Ground-Dove (*Columbina passerina*), Swainson's Thrush (*Catharus ustulatus*), Blue Grosbeak (*Passerina caerulea*), and Lazuli Bunting (*Passerina amoena*) have declined in southern California due to habitat destruction and/or brood parasitism by the Brown-headed Cowbird (Garrett and Dunn 1981).

Many of these species may benefit from this management program, although focused upon the vireo and flycatcher. For example, Yellow Warblers breed in proximity to the vireos and were also quite scarce in the Basin in the early 1980s (Zembal *et al*.1985). It is believed that fewer than 15 pairs occurred in the Basin as recently as 1987. However, a 1992 survey revealed 75 - 100 pairs, and the 2013 estimate was 2,000 pairs.

The vireo population itself has increased from 19 to a high of 413 pairs over the course of this study, giving hope that this species may someday be recovered in this watershed. However, there is no reason to believe that the vireo would continue to prosper without these management efforts and there may be less hope for the many other imperiled species receiving no focused effort. Most other vireo populations in the state are declining, maintaining, or just moderately increasing. Other than Prado, only the populations on the Santa Margarita and San Luis Rey Rivers have sustained significant increases in size due to intensive management since the Least Bell's Vireo was federally listed.

The management of wildlife in southern California is lagging far behind critical needs. Many environmental advocates are busy trying to get land set aside and as important as those efforts are, they are very slow because of the great complexities and land costs. In the meantime, the effects of so many millions of people cohabiting is eroding habitat carrying capacity and long-term viability to such a degree that the potential for recovery and persistence of a full, intact southern California wildlife heritage is in question. The Santa Ana River Watershed Program and other similar programs demonstrate that wildlife management works for some species. Whether or not it will work for entire ecosystems remains to be determined. The longer it takes us to prioritize habitat and wildlife restoration to the degree necessary to get on with ecosystem reparation, the less likely are the chances for ultimate success.

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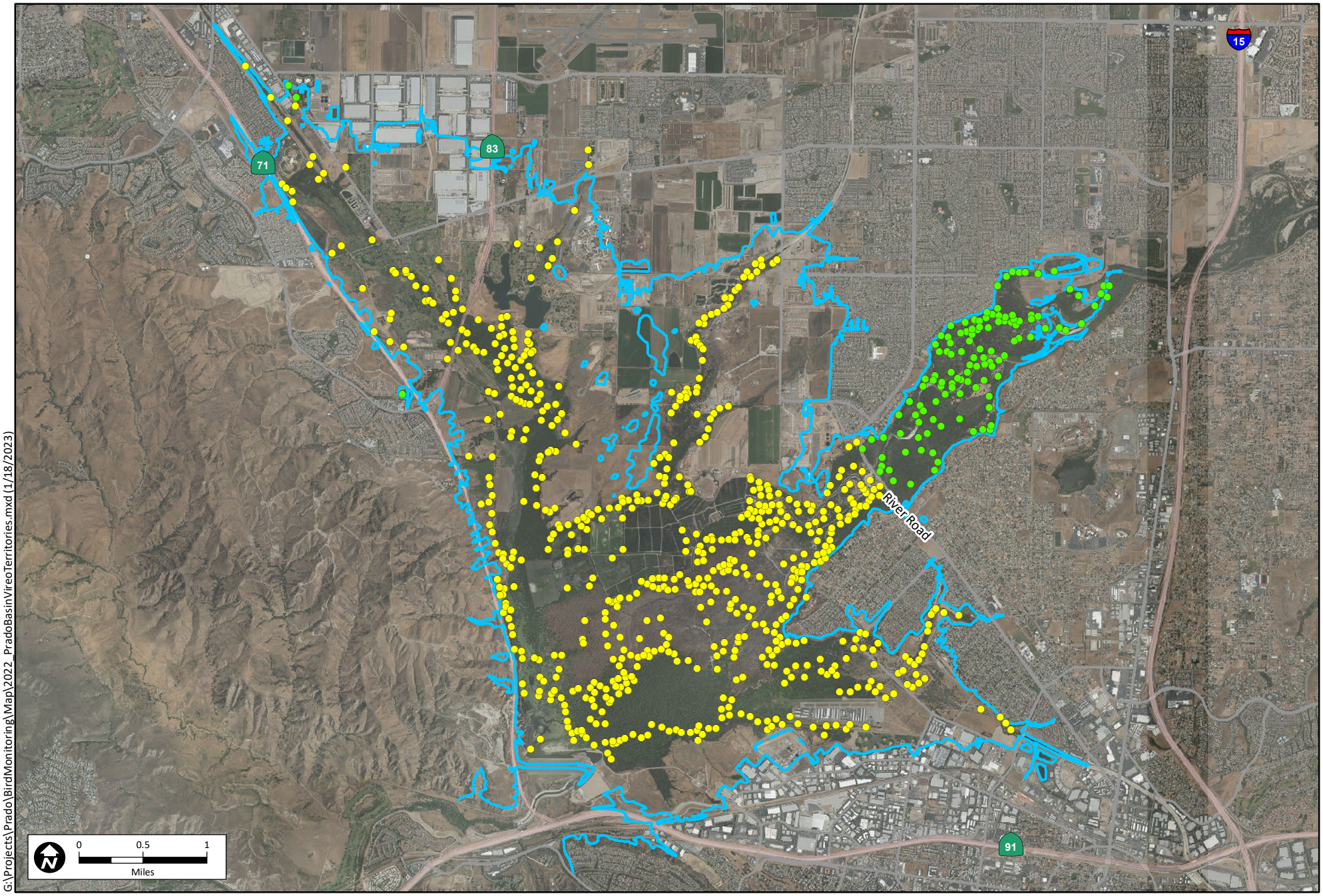


G:\Projects\Prado\BirdMonitoring\Map\2022_PradoBasinVireoTerritories.mxd (1/18/2023)

OCWD Prado Basin Least Bell's Vireo Territories 2022

- Least Bell's Vireo (Count 677, reported by OCWD)
- Least Bell's Vireo (Count 122, reported by SAWA)
- 566 Feet, Maximum Inundation Level

SOURCE: OCWD (07/2022), SAWA (12/2022)

Appendix F— Decision Support Tools (Section 8)

Prado Dam FIRO Decision Support Tools
Workshop #1
August 16, 2022
18700 Ward St, Laboratory conference room, L-1
Fountain Valley, CA

Join Zoom Meeting:
https://ucsd.zoom.us/j/93966980504

9:00-9:10 **Welcome and Introductions**

9:10-9:30 **Importance of DSTs for FIRO at Prado Dam (Chris Delaney)**

9:30-10:45 **Review of Corps tools, operations and decision-making timelines, using February 2019 AR event as case example (L.A. District Staff)**

- **Characteristics of the Feb 2019 storm (20 min)**
- **Decision making process: forecast, operational and on-the-ground considerations (40 min)**
- **Intro to USACE Existing Decision Support Tools (15 min)**

10:45-11:00 **Break**

11:00-12:00 **How Existing DSTs were Used for the Feb 2019 Event (30 min)**

Q/A and Discussion on How Existing DSTs were Used (30 min)

12:00-12:45 **Lunch**

12:45-1:45 **Key Needs/Gaps**

1:45-2:00 **Review Agenda for Next Session and Wrap Up**

Prado Dam Final Viability Assessment

Decision Support Tools

Workshop 1 Notes

8/16/2022

- Overview of current decision support tools used by L.A. District (LAD)
    - FOX Weather QPF and Zones
        - FOX provides hourly QPF w/ 3-day lead time
        - HEC Meteorological Forecast Processor (MFP) for 15-minute
        - QPF can be routed through CWMS (CAVI)
            - Previous attempts have shown that this overestimates inflows compared to observed
        - 10 to 15 years of archive forecasts are available
        - Archived data could be used for calibration
        - Might be useful for FOX to verify historical events
    - RFC inflow forecasts
        - Only look at deterministic inflows
        - Used with spreadsheet tool to evaluate release alternatives during storm events
            - Use starting elevation to evaluate release alternatives
    - CWMS (Corps Water Management Systems)
        - Control Acquisition Visualization Interface (CAVI)
            - Desktop software for CWMS
        - ResSim is the primary model used in CWMS
        - Runs existing operations rule set
        - Alternatives are defined that hold releases at different rates
            - 1K, 2K and 5K cfs
        - Storage results are evaluated for the alternatives to aid in the formulation of a release schedule
        - Compute times of other models in CWMS can be long so they are less frequently used:
            - HEC-RAS = 3 hours
            - HEC-FIA = 1 hour
        - CWMS is linked to database for USGS and GOES data
    - Reservoir Regulation Website
    - Site access coordination (any work in channel or reservoir)
        - Forms are provided to entities working within the reservoir or downstream
            - Include notification requirements
        - Forms are completed to notify Corps of work in channel
        - Many entities are doing work without completing forms
    - Orange Book and Notification Software
        - Permanent notifications
        - Releases can be delay by 3 to 4 hours based on downstream needs
        - 5,000 cfs release typically results in 20-30 notifications

        - Notifications are automated w/ some phone calls
- February 2019 Case Study Event
    - 2/11/19 - Notifications were made based on the storage forecast of 510' for golf course
        - 5 notifications made
            - Elevations triggers
            - Flow triggers
    - Event forecasting
        - FOX provided 2/day
        - RFC up to 3/day (9, 15, 21)
        - Multiple release scenarios are evaluated
        - RFC inflows applied with spreadsheet model
            - Forecast uncertainty may be accounted for by scaling deterministic flows (up to 50%)
        - Don't consider any local flows downstream of dam
            - Local flows are accounted for when coordinating releases with OCWD
        - 24-hour and/or 48-hour volume ensemble would be useful for decision support
    - 2/12/19 – Pre-release of 1,500 cfs made to begin drawing down storage in advance of event (dig hole)
        - Pre-releases made to manage peak storage at or below 512'
            - To manage for potential flooding at the airport
    - 2/13/19 ROC Activations Notes
        - 3 shifts @ 8 hours each
        - 24/7 staffing during activation
        - Forecasted 2000 cfs release triggers activation
        - Lead time for activation depends on day of week
            - Dam operators don't work on Fridays
        - 30-minute overlap between shifts
    - 2/14/19 – Releases increased to 5,000 cfs (just below this level)
        - Downstream: Green River Golf Course
            - Bridge floods at 5,000 cfs
    - Continually communicated with airport for flood concerns during event
- December 2021 Event
    - Activated on 12/13 and deactivated on 12/14 due to over forecast
        - FOX weather briefing also showed over forecast
    - 12/15 release increase to 600 cfs based on coordination w/ OCWD
    - Management of peak storage levels was more conservative for this event than Feb 2019 event
        - Maintain peak storage to ~507'
        - Possibly a tiered approach since storage could not be managed to 507' for 2019 event therefore storage management targeted 510'
    - Swiftwater rescue of homeless person (date?)
        - Rescue is notified in advance of release increases – prefer 24-hour lead time of high releases
        - Rescue occurred downstream of OCWD facilities

        - Mandated to provide lead time notice
            - Any time that there is flow past OCWD
            - Sunny day releases are of greatest concern because people are less aware of high releases
            - Once flow is past OCWD (channel is wet) then release changes do not require notifications
- Key DST Needs to Implement FIRO at Prado Dam (based on case studies)
    - Processing of Ensemble forecasts
        - Build probability statistics to get potential outcomes of release options
        - Excel spreadsheet and how deterministic forecast is put in to show range of possible outcomes: include ensemble forecast by adding tab (drop in selectively). Showing span of outcomes based on decisions made with deterministic forecast. One step toward seeing possible outcomes of ensemble based on decisions already made.
        - Can help inform next decision point.
        - Would allow operators and water managers become more accustomed to ensemble forecasts and bring ensembles in a small way before getting processed into decisions (as trial period).
    - QPF Verification
        - Conditional – based on storm type –
        - What outcomes could you expect for different storm types (10-20 years)
        - Verification could be completed by FOX
    - Look at triggers such as certain precip levels, available storage, release rates, forecast trends in the tool with alert based on thresholds.
        - Allows targeting of forecast information to inform release decisions.
    - Is more information better?
        - How much information is really needed?
        - Decision making during large storm events must be timely and we don't want to burden operators with running lots of analysis.
    - Explicit FIRO WCP.
        - Consistent method on how forecasts are used/processed to make release decisions.
        - Could be tiered approach based on forecast information.
    - EFO develops release schedules for all ensembles at all lead times to show what release schedule and forecast lead time that should be to meet management objective.
        - Changes in release schedule based on forecast storage and release constraints.
    - Get FOX weather QPF assessed. Look at the RFC vs Fox QPF (real time). RFP can request supporting verification study (Rachel can provide guidance on what metrics to include).
    - Include WestWRF (and other improvements in modeling) in DSTs.
    - Automate/streamline notification process allowing >1 person evaluating forecasts
        - Make process more consistent for all stakeholders
        - Decision support system could be used to provide additional information to stakeholders

        - AR landfall tool could be used to help situational awareness and provide more lead time for notifications
    - Automate model runs (improve model we have now, maybe increase data refresh frequency)
    - Design FIRO-based operations framework to integrate with CWMS (CAVI).
    - Decision support framework consistent across all reservoirs and develop way to incorporate things like EFO, WestWRF, QPF from different sources, AR landfall tool, etc. into the existing DSS.
    - Stakeholder access to supplement notifications that the EM community might also be able to use in the DST so everyone has common operating picture.
    - Observational gaps to support decision making? Compare observed vs. forecasts post-event to get trend. Not a way to do this during an event currently.
    - Automate real time QPE. Look at what might be possible.

Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

Prado Dam FIRO Final Viability Assess Decision Support Tools Workshop #1

August 16, 2022

Chris Delaney, Research Engineer
Center for Western Weather and Water Extremes

UC San Diego | SCRIPPS INSTITUTION OF OCEANOGRAPHY

DST Workshops

- **Workshop 1:** Review Corps existing tools and operations for Prado Dam
  - Historical storm events: February 2019 and December 2021
  - Facilitate learning of existing operational practices and constraints
- **Workshop 2:** Review needs assessment analysis and new tools
  - Demonstration of CW3E and ERDC tools
- **Workshop 3:** Scope the development of new tools

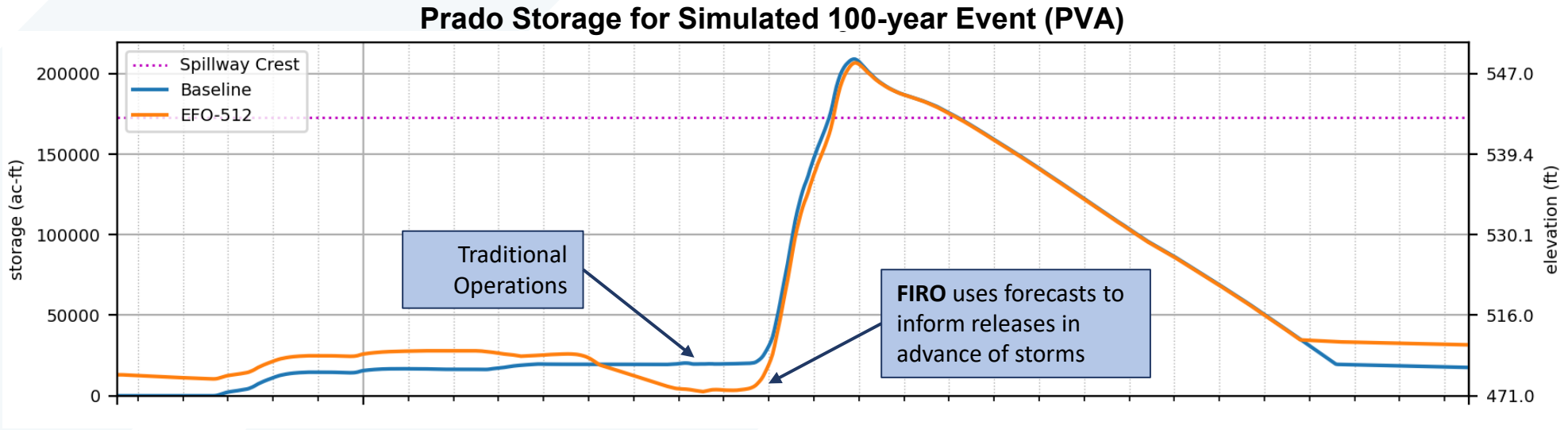
Decision Support Tools are necessary for FIRO

9:00-9:10	Welcome and Introductions
9:10-9:30	Overview of existing LAD tools to support Prado Dam flood control operations (Amanda Walsh)
9:30-10:45	February 2019 Atmospheric River Event (Amanda Walsh & Angela Hogan) ▪ Overview of decision-making timeline ▪ Chronological review of key decision points and the information and tools to support those decisions
10:45-11:00	Break
11:00-12:15	December 2021 Storm Event (Amanda Walsh & Angela Hogan) ▪ Overview of decision-making timeline ▪ Chronological review of key decision points and the information and tools to support those decisions
12:15-1:00	Lunch
1:00-1:45	Key needs to implement FIRO at Prado Dam
1:45-2:00	Review Agenda for Workshop #2 and Wrap Up

Decision Support Tools are necessary for FIRO

- Traditional reservoir operations rely on observations to inform operations.
  - ➢ Forecasts are used, but primarily for awareness of future conditions.

- FIRO water control plans (WCPs) use forecast information as the primary component of the decision-making process.
  - ➢ Reoperation to improve water management objectives:
    - Improve water supply reliability
    - Decrease downstream flood risk



PRADO DAM FVA DST WORKSHOP #1

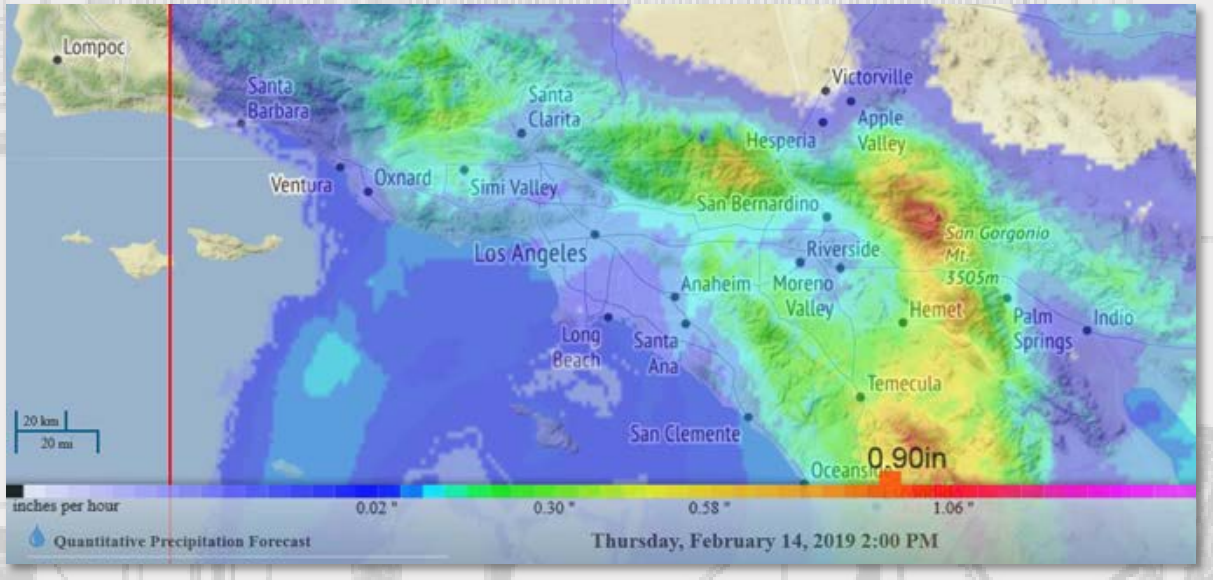
REVIEW OF FEBRUARY 2019 AND DECEMBER 2021 OPERATIONS

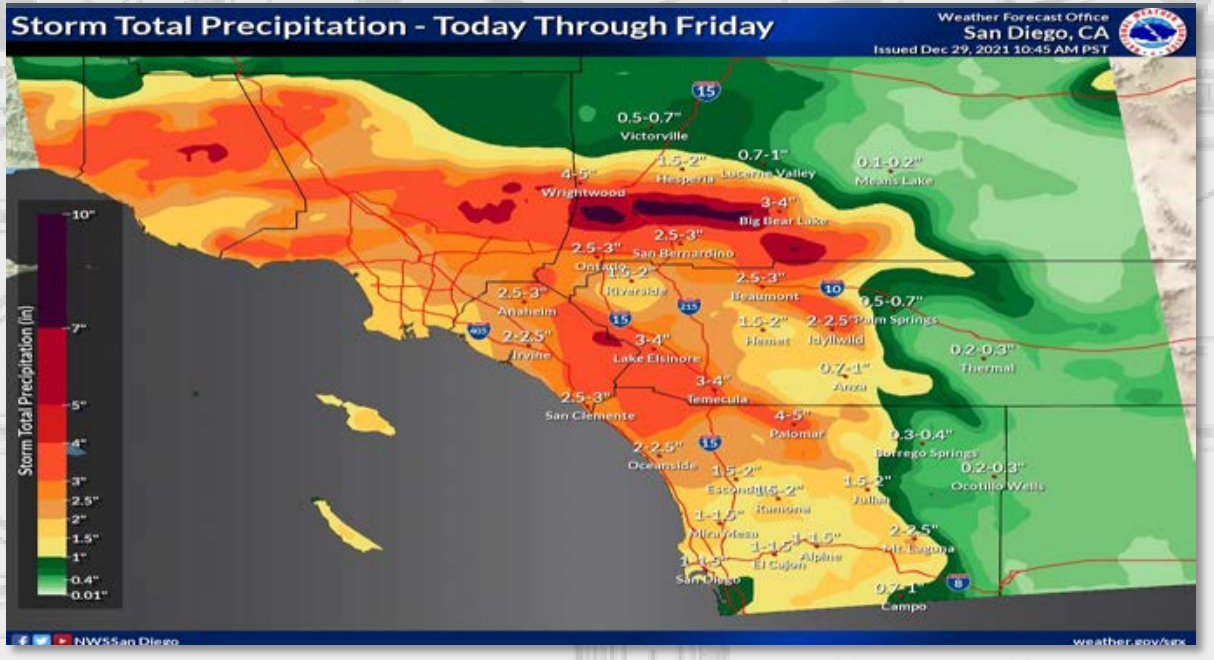
Presenters:

- Amanda Walsh, PE
- Angela Hogan
- Kim Gilbert, PE
- Jon Sweeten, PE
- Jose Paredez, PE

USACE SPL Reservoir Regulation Section

16 August 2022



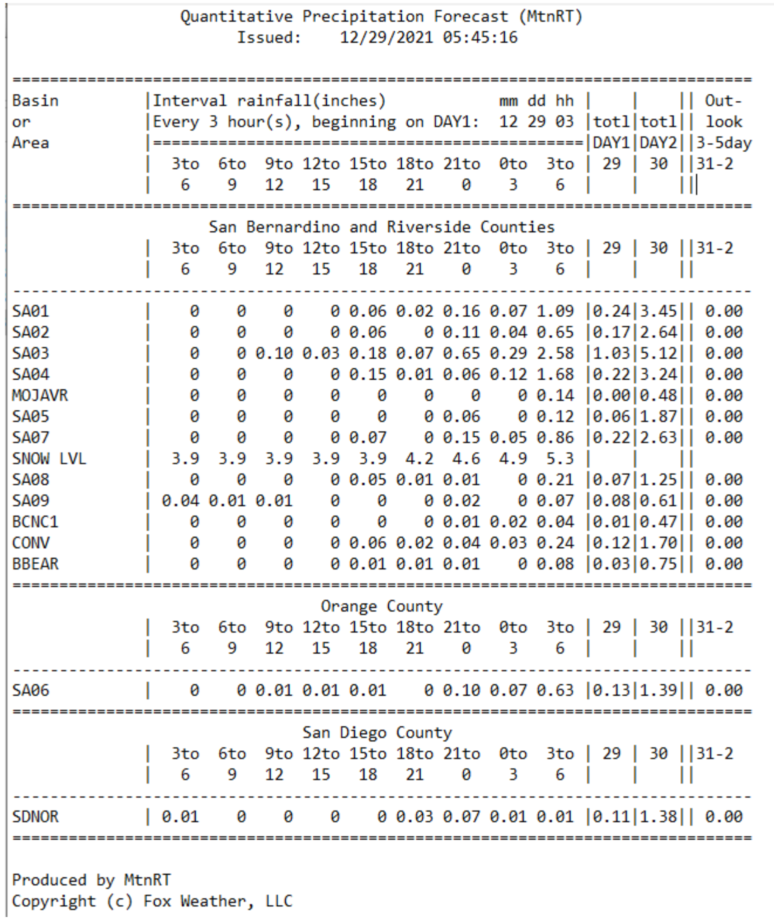


US Army Corps of Engineers®

Overview of Corps Tools

- FOX Weather QPF and Zones
- RFC inflow forecasts
- CWMS (Corps Water Management Systems)
- Reservoir Regulation Website
- Site access coordination (any work in channel or reservoir)
- Orange Book and Notification Software

Fox Weather – Contracted Meteorologist



```
                  Quantitative Precipitation Forecast (MtnRT)
                        Issued:    12/29/2021 05:45:16

===============================================================================
Basin         |Interval rainfall(inches)            mm dd hh |    |    || Out-
or            |Every 3 hour(s), beginning on DAY1:  12 29 03 |totl|totl|| look
Area          |==============================================|DAY1|DAY2||3-5day
              |  3to  6to  9to 12to 15to 18to 21to  0to  3to | 29 | 30 ||31-2
              |   6    9   12   15   18   21    0    3    6  |    |    ||
===============================================================================
                     San Bernardino and Riverside Counties
              |  3to  6to  9to 12to 15to 18to 21to  0to  3to | 29 | 30 ||31-2
              |   6    9   12   15   18   21    0    3    6  |    |    ||
-------------------------------------------------------------------------------
SA01          |    0    0    0    0 0.06 0.02 0.16 0.07 1.09 |0.24|3.45|| 0.00
SA02          |    0    0    0    0 0.06    0 0.11 0.04 0.65 |0.17|2.64|| 0.00
SA03          |    0    0 0.10 0.03 0.18 0.07 0.65 0.29 2.58 |1.03|5.12|| 0.00
SA04          |    0    0    0    0 0.15 0.01 0.06 0.12 1.68 |0.22|3.24|| 0.00
MOJAVR        |    0    0    0    0    0    0    0    0 0.14 |0.00|0.48|| 0.00
SA05          |    0    0    0    0    0    0 0.06    0 0.12 |0.06|1.87|| 0.00
SA07          |    0    0    0    0 0.07    0 0.15 0.05 0.86 |0.22|2.63|| 0.00
SNOW LVL      |  3.9  3.9  3.9  3.9  3.9  4.2  4.6  4.9  5.3 |    |    ||
SA08          |    0    0    0    0 0.05 0.01 0.01    0 0.21 |0.07|1.25|| 0.00
SA09          | 0.04 0.01 0.01    0    0    0 0.02    0 0.07 |0.08|0.61|| 0.00
BCNC1         |    0    0    0    0    0    0 0.01 0.02 0.04 |0.01|0.47|| 0.00
CONV          |    0    0    0    0 0.06 0.02 0.04 0.03 0.24 |0.12|1.70|| 0.00
BBEAR         |    0    0    0    0 0.01 0.01 0.01    0 0.08 |0.03|0.75|| 0.00
===============================================================================
                                 Orange County
              |  3to  6to  9to 12to 15to 18to 21to  0to  3to | 29 | 30 ||31-2
              |   6    9   12   15   18   21    0    3    6  |    |    ||
-------------------------------------------------------------------------------
SA06          |    0    0 0.01 0.01 0.01    0 0.10 0.07 0.63 |0.13|1.39|| 0.00
===============================================================================
                               San Diego County
              |  3to  6to  9to 12to 15to 18to 21to  0to  3to | 29 | 30 ||31-2
              |   6    9   12   15   18   21    0    3    6  |    |    ||
-------------------------------------------------------------------------------
SDNOR         | 0.01    0    0    0    0 0.03 0.07 0.01 0.01 |0.11|1.38|| 0.00
===============================================================================

Produced by MtnRT
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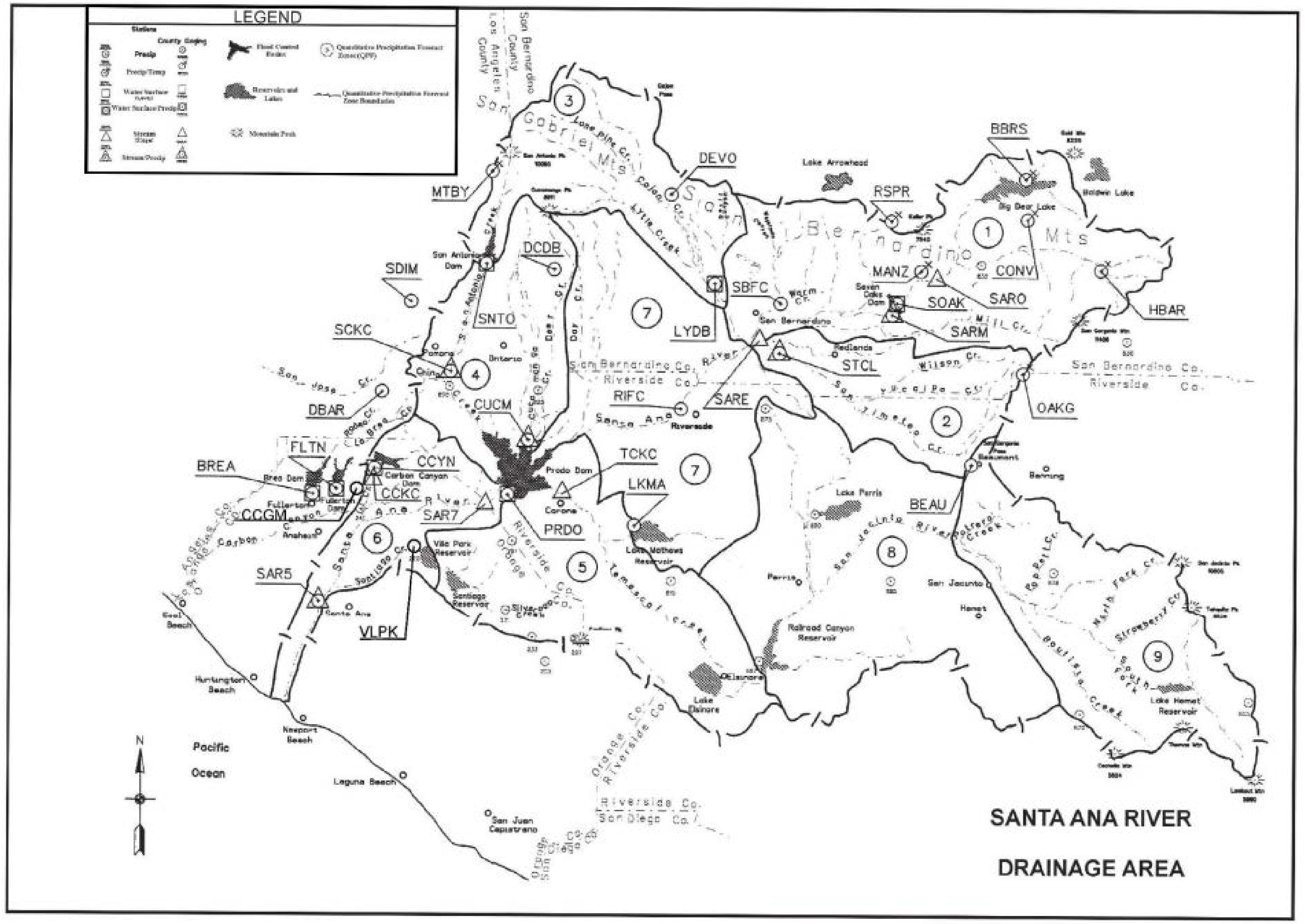
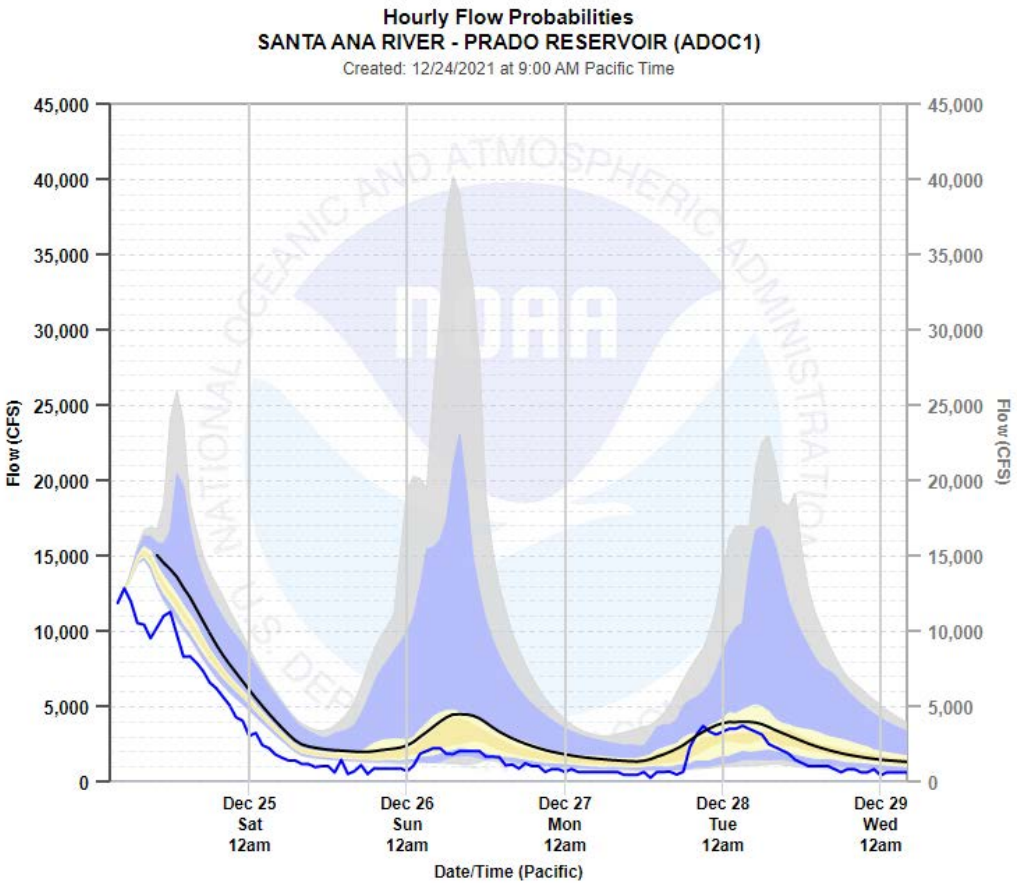


RFC Inflow Forecasts



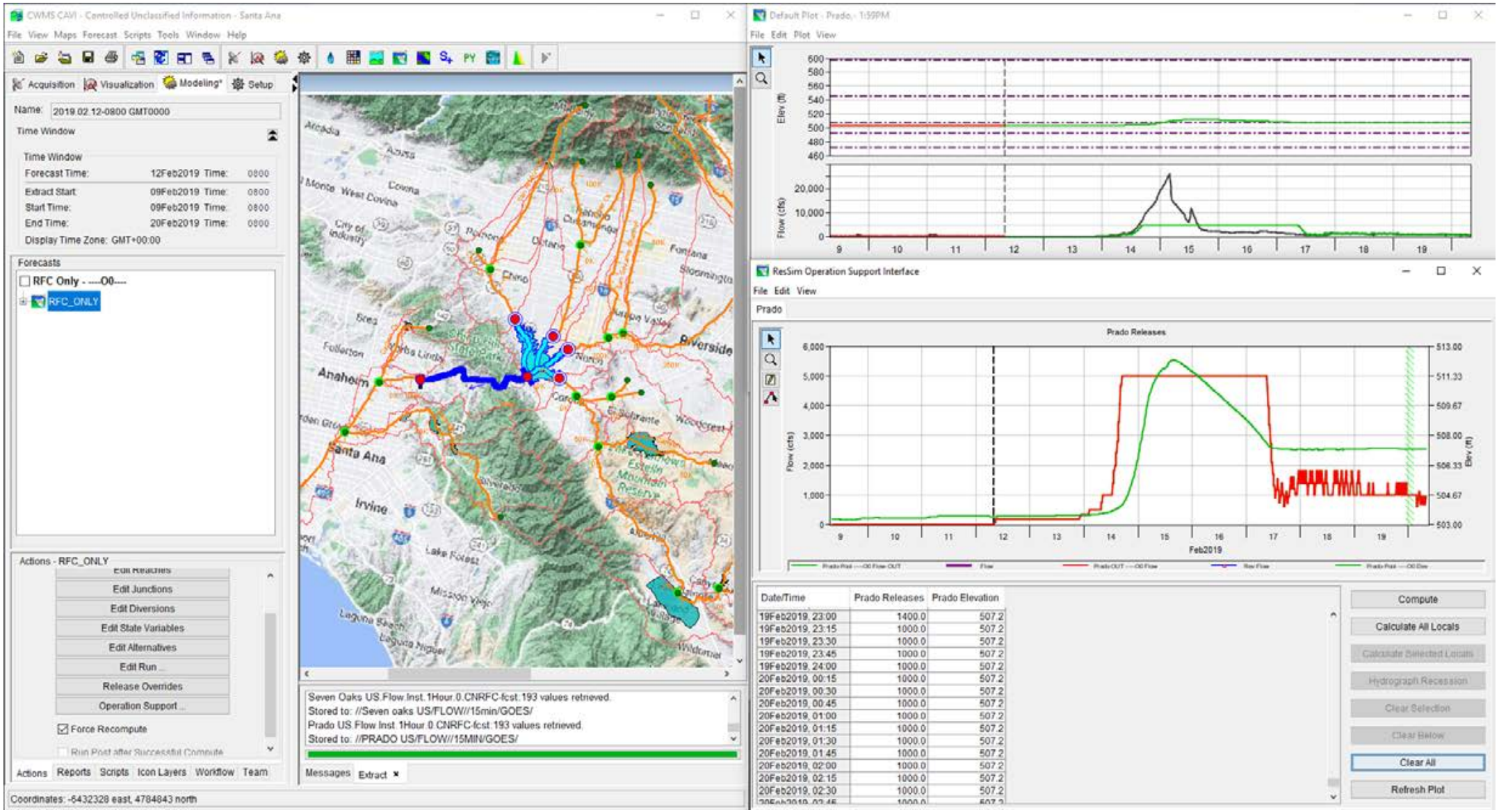
Prado Dam

5-day Inflow Forecast from NWS

Max WSEL =	**504.7**
Date =	26-Dec-21
Time =	1:00 PM

Time	Time (incrment) (hrs)	Forecast Inflow (cfs)	Avg Inflow (cfs)	Inflow volume 1-hour time (af)	Outflow (cfs)	Outflow Check	Inflow-Outflow (cfs)	Inflow-Outflow (af)	Running Total (af)	Res Storage (af)	Elevation (ft)
12/23/2021 8:00	0	271			430	430				3,191	490.95
12/23/2021 9:00	1	291	281	23	430	430	-149	-12	-12	3,179	490.80
12/23/2021 10:00	2	306	299	25	430	430	-132	-11	-23	3,168	490.80
12/23/2021 11:00	3	334	320	26	430	430	-110	-9	-32	3,159	490.80
12/23/2021 12:00	4	405	370	31	430	430	-61	-5	-37	3,154	490.80
12/23/2021 13:00	5	523	464	38	430	430	34	3	-34	3,157	490.80
12/23/2021 14:00	6	691	607	50	430	430	177	15	-20	3,171	490.80
12/23/2021 15:00	7	800	746	62	460	460	286	24	4	3,195	490.90
12/23/2021 16:00	8	888	844	70	600	500	244	20	24	3,215	490.90
12/23/2021 17:00	9	1,014	951	79	800	500	151	12	36	3,227	490.90
12/23/2021 18:00	10	1,267	1,141	94	1,500	0	-360	-30	7	3,198	490.90
12/23/2021 19:00	11	1,715	1,491	123	2,000	0	-509	-42	-35	3,156	490.80
12/23/2021 20:00	12	2,374	2,045	169	2,000	0	45	4	-32	3,159	490.80
12/23/2021 21:00	13	3,017	2,696	223	2,000	0	696	57	26	3,217	490.90
12/23/2021 22:00	14	3,658	3,338	276	2,000	0	1,338	111	136	3,327	491.10
12/23/2021 23:00	15	4,303	3,981	329	2,000	0	1,981	164	300	3,491	491.30
12/24/2021 0:00	16	5,029	4,666	386	2,000	0	2,666	220	520	3,711	491.60
12/24/2021 1:00	17	5,850	5,440	450	2,000	0	3,440	284	805	3,996	492.10
12/24/2021 2:00	18	6,720	6,285	519	2,000	0	4,285	354	1,159	4,350	492.60
12/24/2021 3:00	19	7,495	7,108	587	2,000	0	5,108	422	1,581	4,772	493.10
12/24/2021 4:00	20	8,273	7,884	652	2,000	0	5,884	486	2,067	5,258	493.70
12/24/2021 5:00	21	9,045	8,659	716	2,000	0	6,659	550	2,617	5,808	494.40
12/24/2021 6:00	22	9,714	9,380	775	2,000	0	7,380	610	3,227	6,418	495.10

CWMS (Corps Water Management Systems)



Reservoir Regulation Website

- External: resreg.spl.usace.army.mil/
- Google Maps
  - Elevation
  - Streamflow
  - Precip
- Gages are color coded to thresholds
- Also have an alert system to contact ResReg staff if thresholds are met

NWS Text Products & QPF

US Army Corps of Engineers
Los Angeles District
Reservoir Regulation Section

National Weather Service Products
(As Collected by SPL)

Compiled: 16Aug2022 1402

Note: Green cells denote products dated within previous six hours.

Product Title	Product ID	Date/Time (Local)
California and Regional Products		
6-Day QPF	RNOHD6RSA	16 Aug 2022 1406
4-County Precipitation Summary	LAXRRMLOX	23 Jun 2022 0539
Los Angeles, Ventura, Santa Barbara, San Luis Obispo Counties		
7-Day Tabular Forecast	LAXSFTLOX	16 Aug 2022 0320
Quantitative Precipitation Forecast	LAXQPSLOX	30 Apr 2022 1251
7-Day Zone Forecast	LAXZFPLOX	16 Aug 2022 0318
Forecast Discussion	LAXAFDLOX	16 Aug 2022 1047
Special Weather Statement	LAXSPSLOX	17 Jul 2022 1615
NowCast	LAXNOWLOX	19 Apr 2019 0650
Coastal Waters Forecast	LAXCWFLOX	16 Aug 2022 0851
Flash Flood Watch	LAXFFALOX	31 Jul 2022 2011
Flash Flood Warning	LAXFFWLOX	28 Mar 2022 0555
Flash Flood Statement	LAXFFSLOX	28 Mar 2022 0738
Flood Statement	LAXFLSLOX	04 Aug 2022 1843
Flood Warning	LAXFLWLOX	11 Apr 2019 1002
Severe Thunderstorm Warning	LAXSVRLOX	22 Jun 2022 0110
Urgent Winter Weather Message	LAXWSWLOX	29 Mar 2022 0306
Severe Weather Statement	LAXSVSLOX	03 Jun 2020 1543
Tornado Warning	LAXTORLOX	25 Dec 2019 2155
Hydrologic (River) Statement	LAXRVSLOX	05 Mar 2019 2212
Hydrologic Outlook	LAXESFLOX	31 Jan 2019 1734
Los Angeles County Precipitation Summary	LAXRRMLOS	16 Aug 2022 0102
Ventura County Precipitation Summary	LAXRRMVTU	16 Aug 2022 0102
Santa Barbara County Precipitation Summary	LAXRRMSBA	16 Aug 2022 0102
San Luis Obispo County Precipitation Summary	LAXRRMSLO	16 Aug 2022 0102
Orange, San Diego, W. San Bernardino and W. Riverside Counties		
7-Day Tabular Forecast	LAXSFTSGX	16 Aug 2022 1242
Quantitative Precipitation Forecast	LAXQPSSGX	05 May 2022 1424
7-Day Zonal Forecast	LAXZFPSGX	16 Aug 2022 1243
Forecast Discussion	LAXAFDSGX	16 Aug 2022 1306
Special Weather Statement	LAXSPSSGX	16 Aug 2022 1342
NowCast	LAXNOWSGX	23 Dec 2014 0448
Coastal Waters Forecast	LAXCWFSGX	16 Aug 2022 1328
Flash Flood Watch	LAXFFASGX	13 Aug 2022 1854
Flash Flood Warning	LAXFFWSGX	16 Aug 2022 1312
Flash Flood Statement	LAXFFSSGX	16 Aug 2022 1346
Flood Statement	LAXFLSSGX	16 Aug 2022 1255
Flood Warning	LAXFLWSGX	10 Apr 2020 1451

Site Access Coordination Forms

- Provided to any entities working within the basin or downstream of the reservoir in the channel
  - Also have a link on our external website

US Army Corps of Engineers ®
Los Angeles District

Reservoir Regulation Section

Site Access Coordination Info

Flood Control Basins & River Channels

This form applies only after a permit or permission has been granted.

NAME OF BASIN/CHANNEL/RIVER:	FROM (DATE):	TO (DATE):
REQUESTING AGENCY & NAME OF PROJECT MANAGER:	EMAIL ADDRESS:	PHONE NO:
RELATED TO WHAT PROJECT:		
ON-SITE POC (Company, Job Title and Name):	CELL PHONE NO:	24 HR PHONE NO:
	EMAIL ADDRESS:	
ALTERNATE ON-SITE POC (Company, Job Title and Name):	CELL PHONE NO:	24 HR PHONE NO:
	EMAIL ADDRESS:	
DESCRIPTION OF WORK & SITE LOCATION (*submit site vicinity map with work location in circle/highlight on google maps in pdf format*):		

ESTIMATED WORK SITE ELEVATION (*for work sites inside the basin/reservoir*): feet VERTICAL DATUM USED: NGVD 29 ☐ NAVD 88 ☐	JOB SITE WORK SCHEDULE: ☐ M – F ☐ WEEKENDS ☐ 7 DAYS/WEEK ☐ Other (specify)	WILL ANYTHING BE LEFT ON-SITE OVERNIGHT? YES ☐ NO ☐
SITE HAS COFFERDAM / WATER DIVERSION BEEN SETUP? YES ☐ NO ☐		HOW MANY VEHICLES? / HOW MANY PEOPLE ONSITE?
LIST TYPE OF EQUIPMENT ON-SITE:	LIST HEAVY EQUIPMENT (*REQUIRING EXTRA LEAD TIME TO REMOVE FROM WORK SITE*):	

Send Completed Form to ROC-LA@usace.army.mil or CESPL-ROC@usace.army.mil

→**Attention**: Flood control basins & channels can experience water flow or rising water levels at any time, regardless of existing weather.

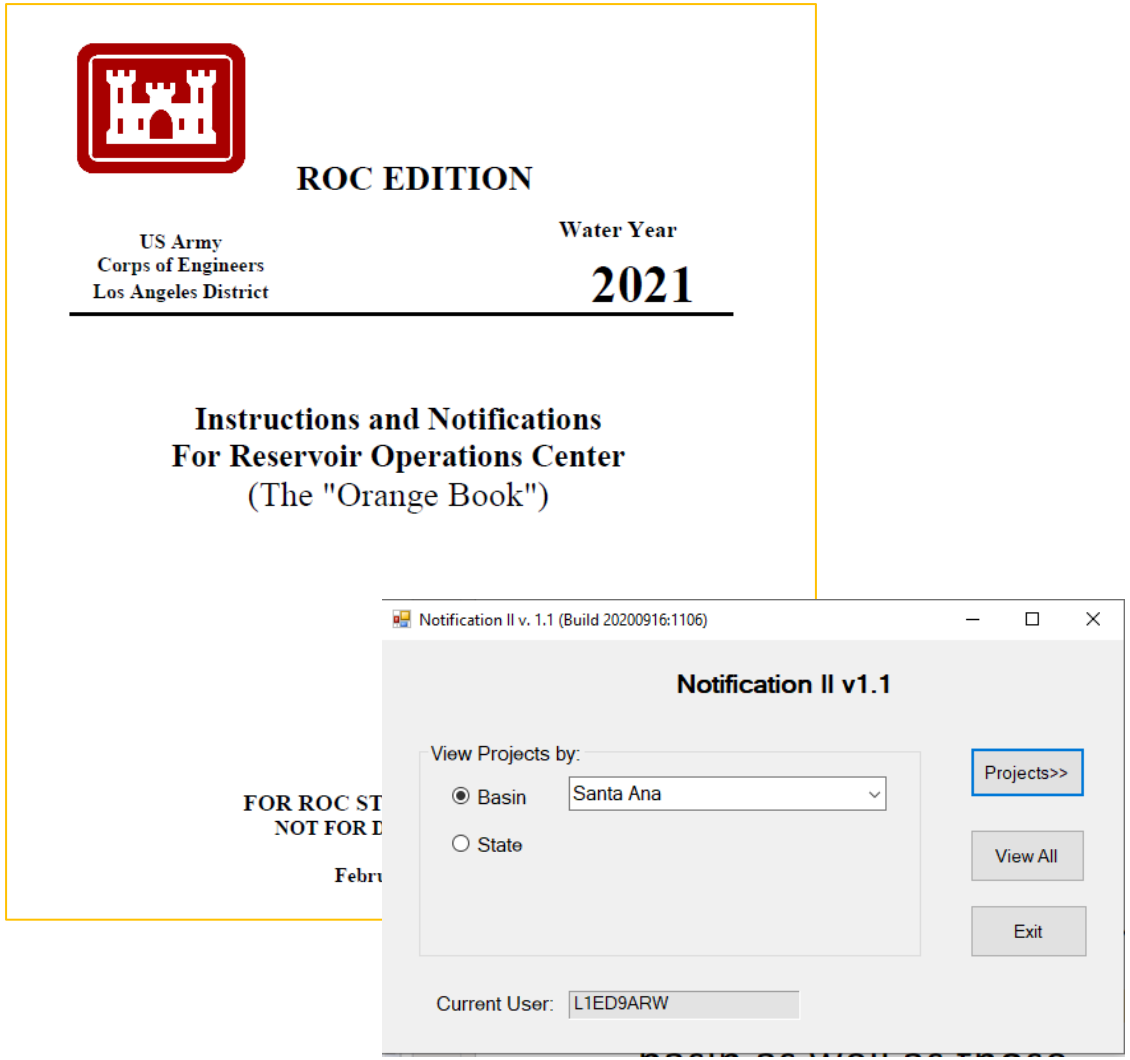
Notify the LA District Reservoir Operations Center (ROC) when entering and leaving a district basin /channel/river.

Call (213) 452-3623 leave a message with callback phone number

CESPL-ED-HR Doc: 06/2021

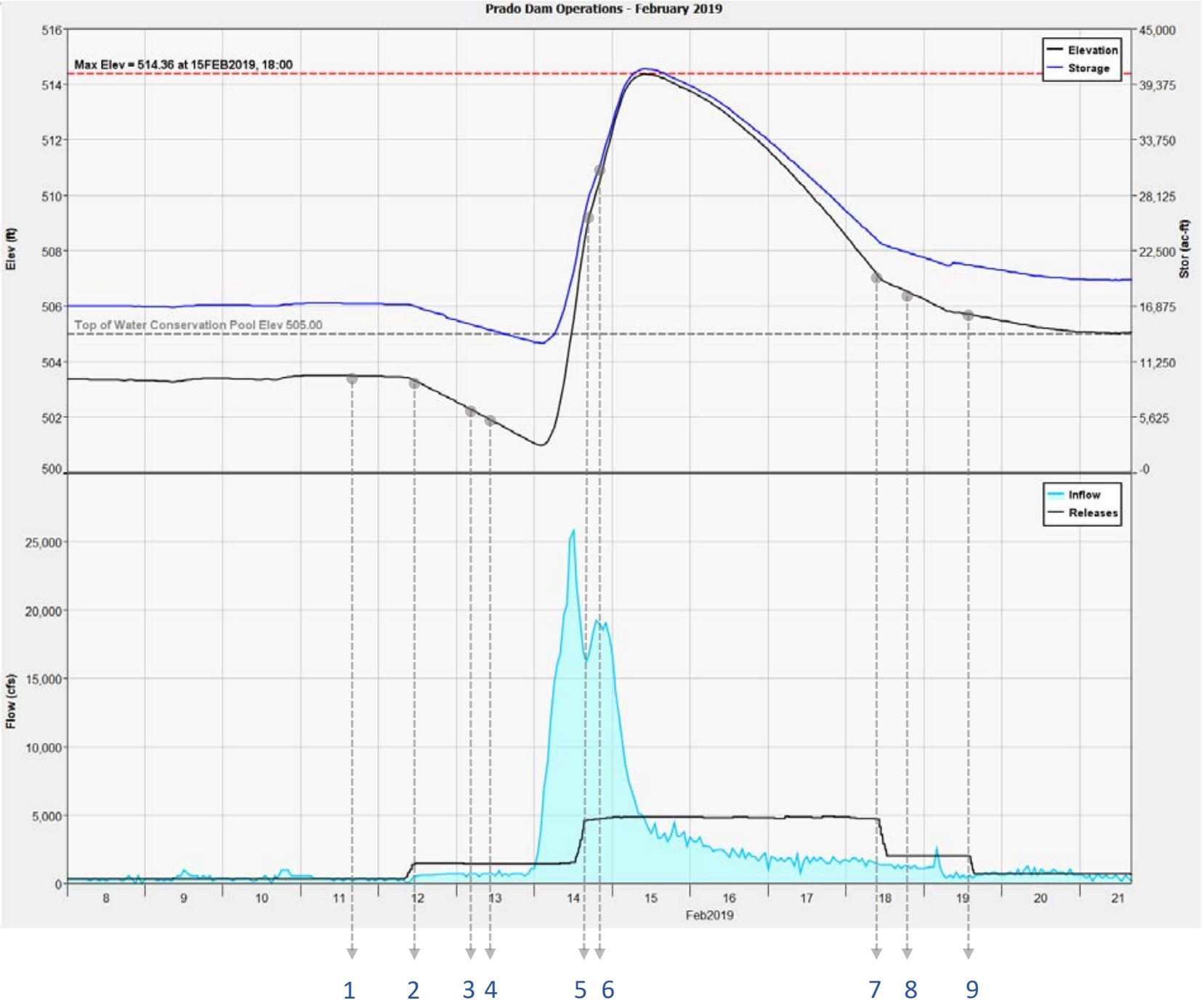
Orange Book

- Updated annually
- Main purpose is for internal use
- Lists those impacted within the basin as well as those downstream.
  - And at what elevation or flow they are impacted
- Notification Tool – internal software developed to log when we make notifications

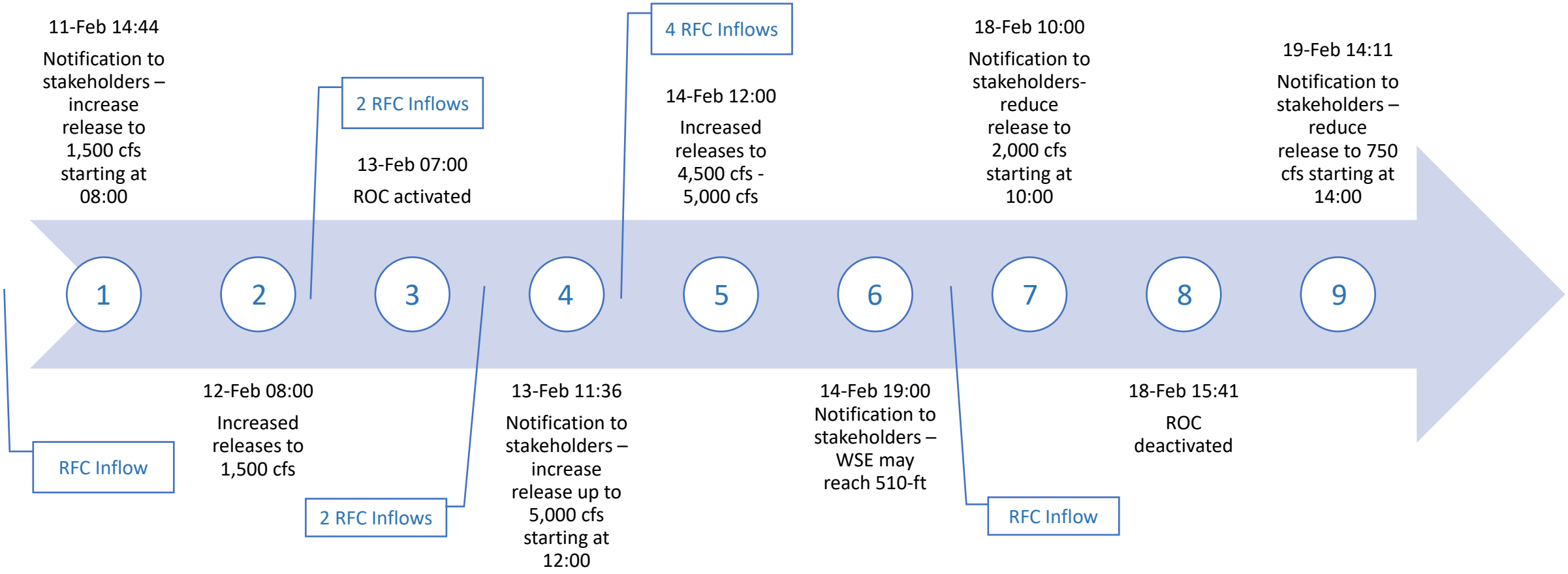


February 2019 Event

1. Notification – increase release to 1,500 cfs
2. Prerelease – 1,500 cfs
3. ROC Activated
4. Notification – increase release to 5,000 cfs
5. Increase release – 5,000 cfs
6. Notification – WSE = 510’
7. Notification – reduce release to 2,000 cfs
8. ROC Deactivated
9. Notification – reduce release to 750 cfs



Timeline of Events – February 2019



Timeline of Events – February 2019

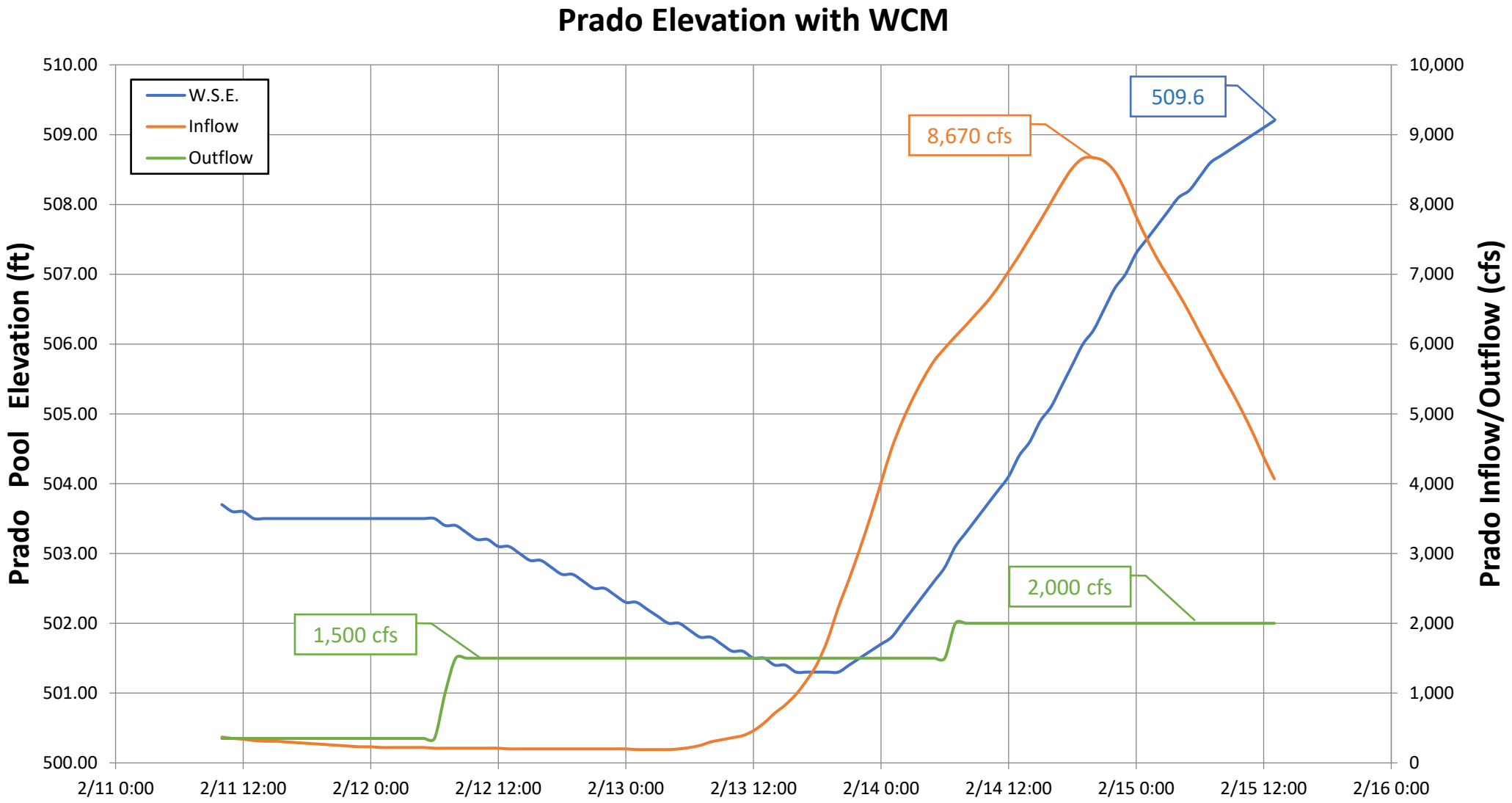
Date	Time	Plan / Action
11-Feb	9:00	11 FEB 0900 Forecast received and used for planning operations. Peak inflow = 8,670 cfs (14 FEB @ 2000). Currently releasing 350 cfs and plan to increase releases to 1,500 cfs.
11-Feb	14:44	Action 1. Notification to stakeholders - Planned release increase from 350 cfs to 1,500 cfs on 12 FEB beginning at 0800
12-Feb	8:00	Action 2. Started increasing releases to 1,500 cfs
12-Feb	9:00	12 FEB 0900 Forecast received and used for planning operations. Peak inflow = 10,510 cfs (14 FEB @ 2000). Currently releasing 1,400 cfs and plan to maintain that until further notice.
12-Feb	15:00	12 FEB 1500 Forecast received and used for planning operations. Peak inflow = 11,340 cfs (14 FEB @ 1800). Currently releasing 1,400 cfs and plan to maintain that until further notice.
13-Feb	6:34	Action 3. ROC Activated
13-Feb	9:00	13 FEB 0900 Forecast received and used for planning operations. Considered a 50% reduction in the RFC forecasted inflow. Inflow forecast shows a peak of 30,680 cfs occurring on 14-Feb at 21:00. Currently releasing 1,500 cfs and plan to maintain that until further notice while considering the signficant inflow forecast.
13-Feb	11:36	Action 4. Notifications made to stakeholders of increase in release up to 5,000 cfs
13-Feb	14:00	13 FEB 1400 Forecast received and used for planning operations. Peak inflow = 28,290 cfs (14 FEB @ 2000). Currently releasing 1,500 cfs. Plan to increase releases up to 5,000 cfs. New inflow forecast peak is less than previous forecast, but still signficant.
13-Feb	21:00	13 FEB 2100 Forecast received and used for planning operations. Peak inflow = 27,390 cfs (14 FEB @ 1900). Currently releasing 1,500 cfs. Plan to increase releases up to 4,500 cfs, possibly 5,000 cfs.

Timeline of Events – February 2019

Date	Time	Plan / Action
14-Feb	2:00	14 FEB 0200 Forecast received and used for planning operations. Peak inflow = 28,340 (14 FEB @ 2000). Currently releasing 1,500 cfs. Plan to increase releases up to 4,500 cfs, possibly 5,000 cfs.
14-Feb	9:00	14 FEB 0900 Forecast received and used for planning operations. Peak inflow = 25,795 cfs (14 FEB 2000). Currently releasing 1,500 cfs. Plan to increase releases up to 4,500 cfs and start ramping down early 18-Feb to 600 cfs.
14-Feb	12:00	Action 5. Started increasing releases from 1,500 cfs to 4,500 cfs
14-Feb	19:00	Action 6. Notifications made to stakeholders of the WSE reaching 510-ft
14-Feb	23:19	Releases have increased to 4,800 cfs (due to higher pool and inflow). Expect to maintain this release until further notice.
15-Feb	4:00	15 FEB 0400 Forecast received and used for planning operations. Peak inflow = 14,200 cfs (15 FEB @ 0400). Currently releasing 4,800 cfs. Plan maintain this release until further notice.
15-Feb	19:38	Releases remain at around 4,900 cfs (due to rising pool)
18-Feb	10:01	Action 7. Notification to stakeholders - reducing releases to 2,000 cfs starting at 1000. Started reducing releases to 2,000 cfs (achieved at 12:30)
18-Feb	15:41	Action 8. ROC Deactivated
19-Feb	14:11	Action 9. Notification to stakeholders - reducing releases to 750 cfs starting at 1400. Started reducing releases from about 2,000 cfs down to 750 cfs (achieved at 15:30)
25-Feb	7:22	Action 10. Notification to stakeholders - reducing releases to 350 cfs starting at 08:00
25-Feb	10:06	Action 11. Notification to stakeholders - reducing releases to 250 cfs starting at 11:00

Details of Decision Points – February 2019

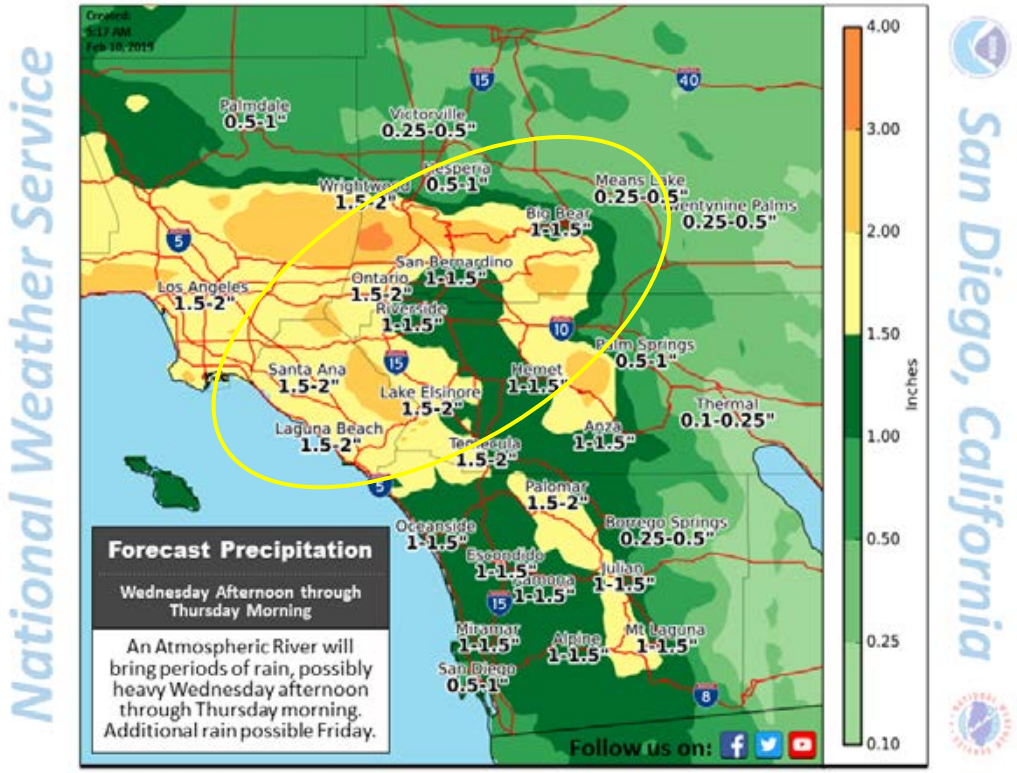
11 FEB 0900 Forecast

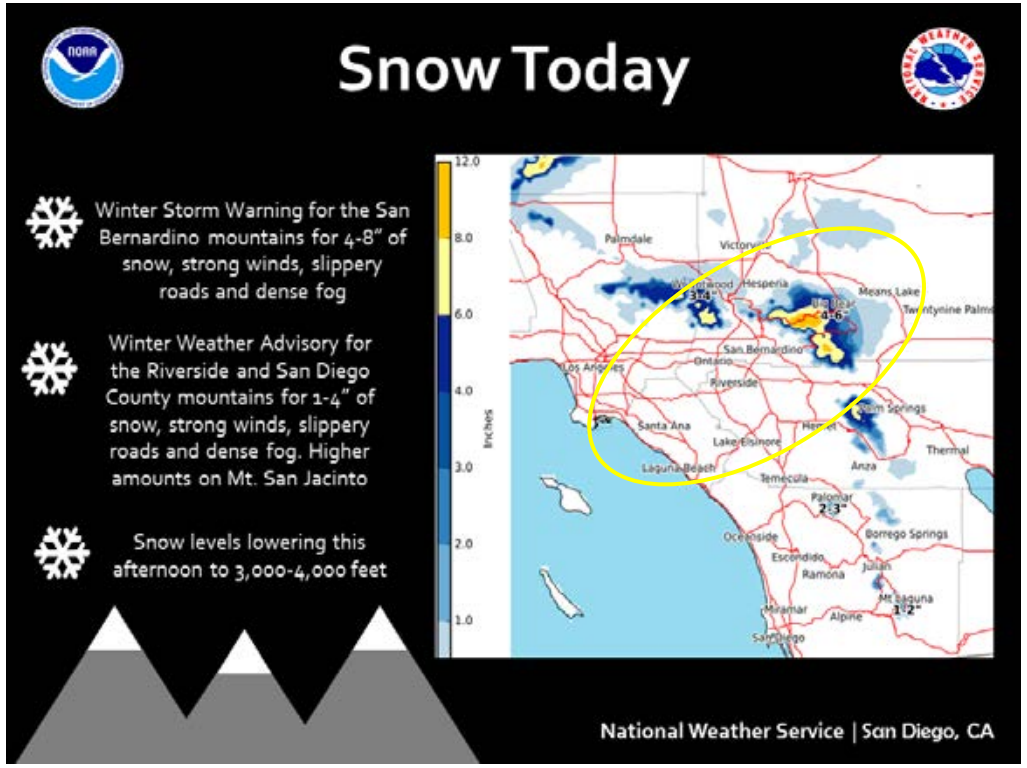


Details of Decision Points – February 2019

11-12 February 2019

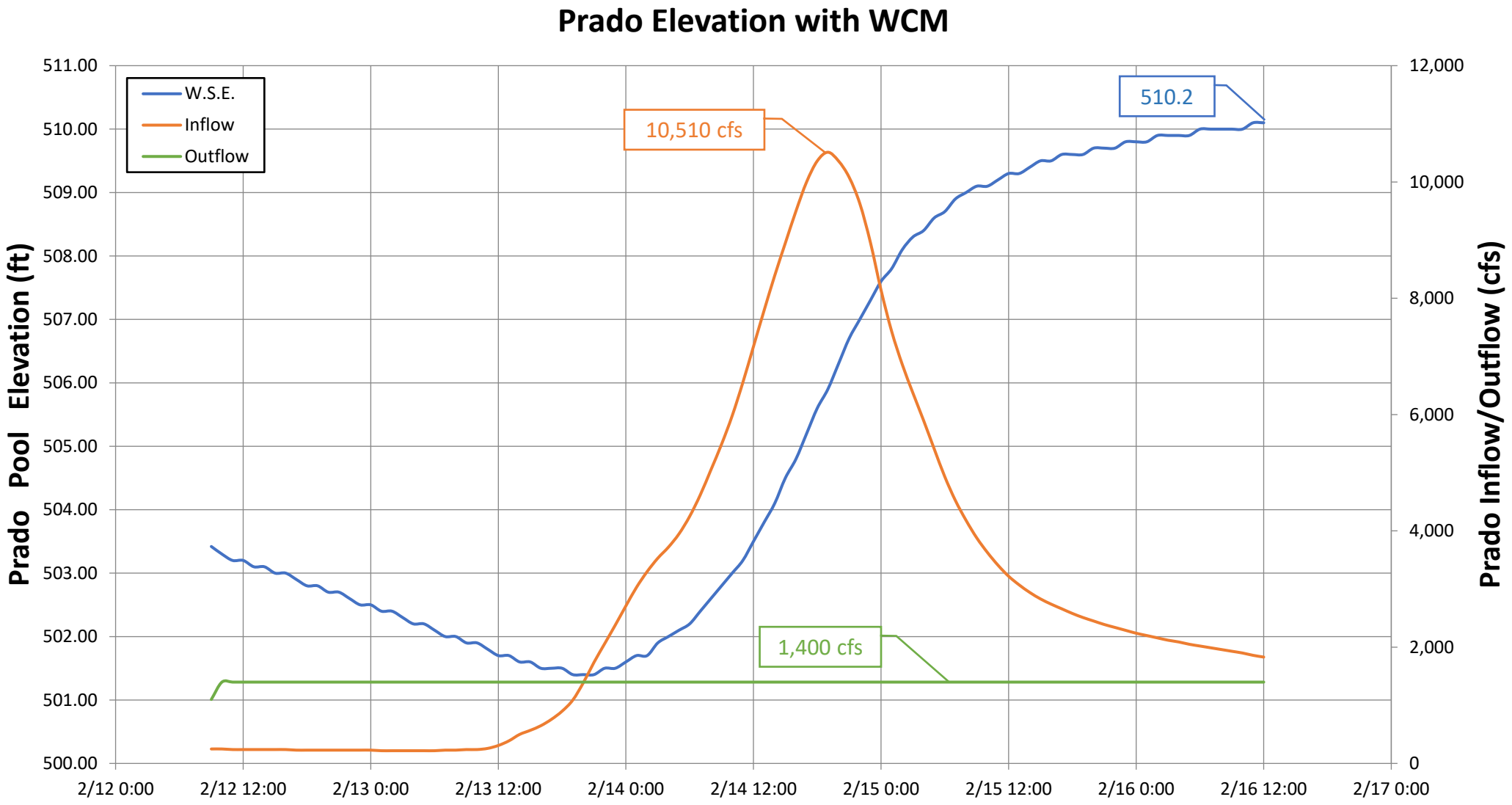
Date	Time	Plan / Action
11-Feb	9:00	11 FEB 0900 Forecast received and used for planning operations. Peak inflow = 8,670 cfs (14 FEB @ 2000). Currently releasing 350 cfs and plan to increase releases to 1,500 cfs.
11-Feb	14:44	Action 1. Notification to stakeholders - Planned release increase from 350 cfs to 1,500 cfs on 12 FEB beginning at 0800
12-Feb	8:00	Action 2. Started increasing releases to 1,500 cfs





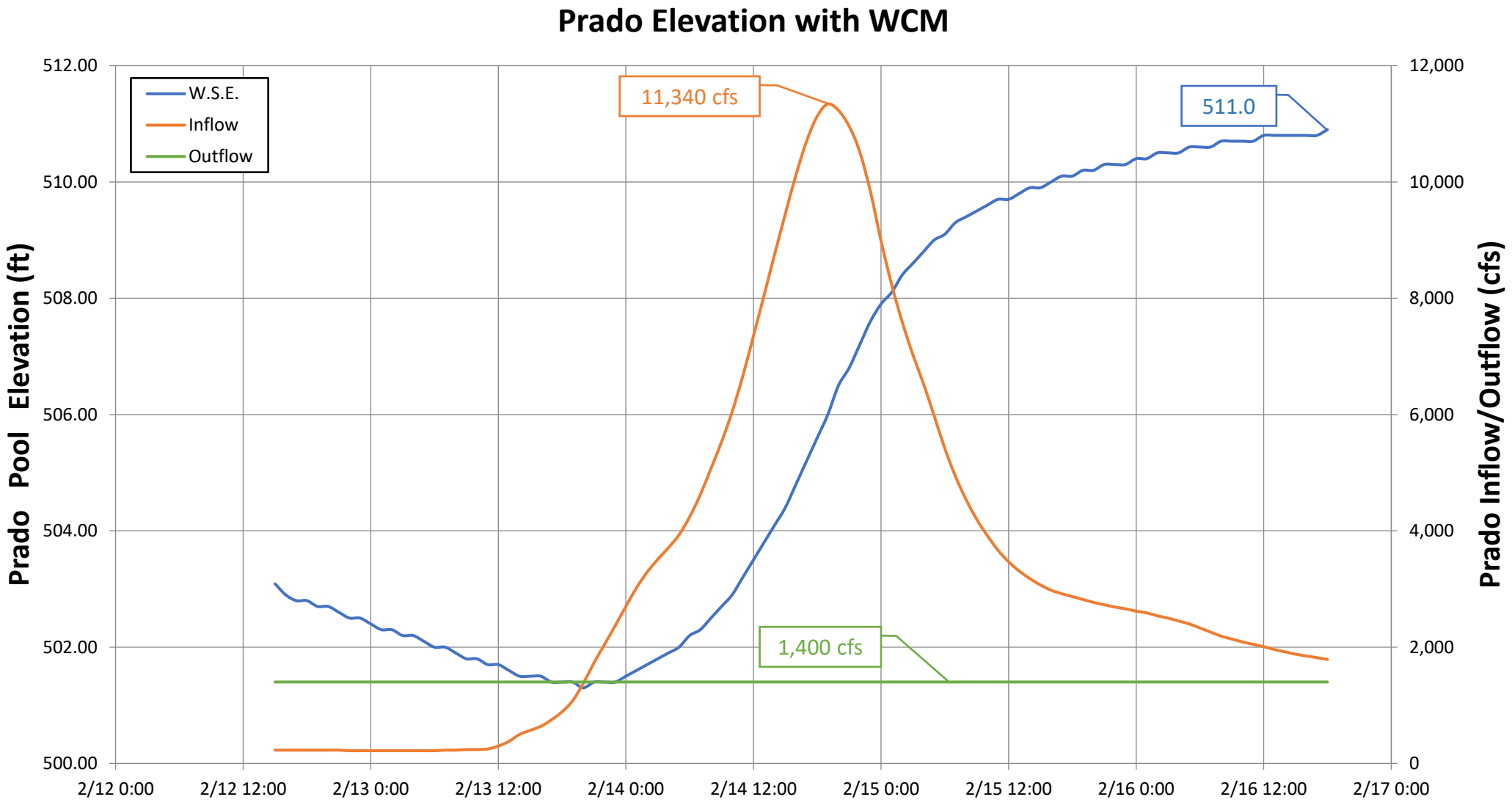
Details of Decision Points – February 2019

12 FEB 0900 Forecast



Details of Decision Points – February 2019

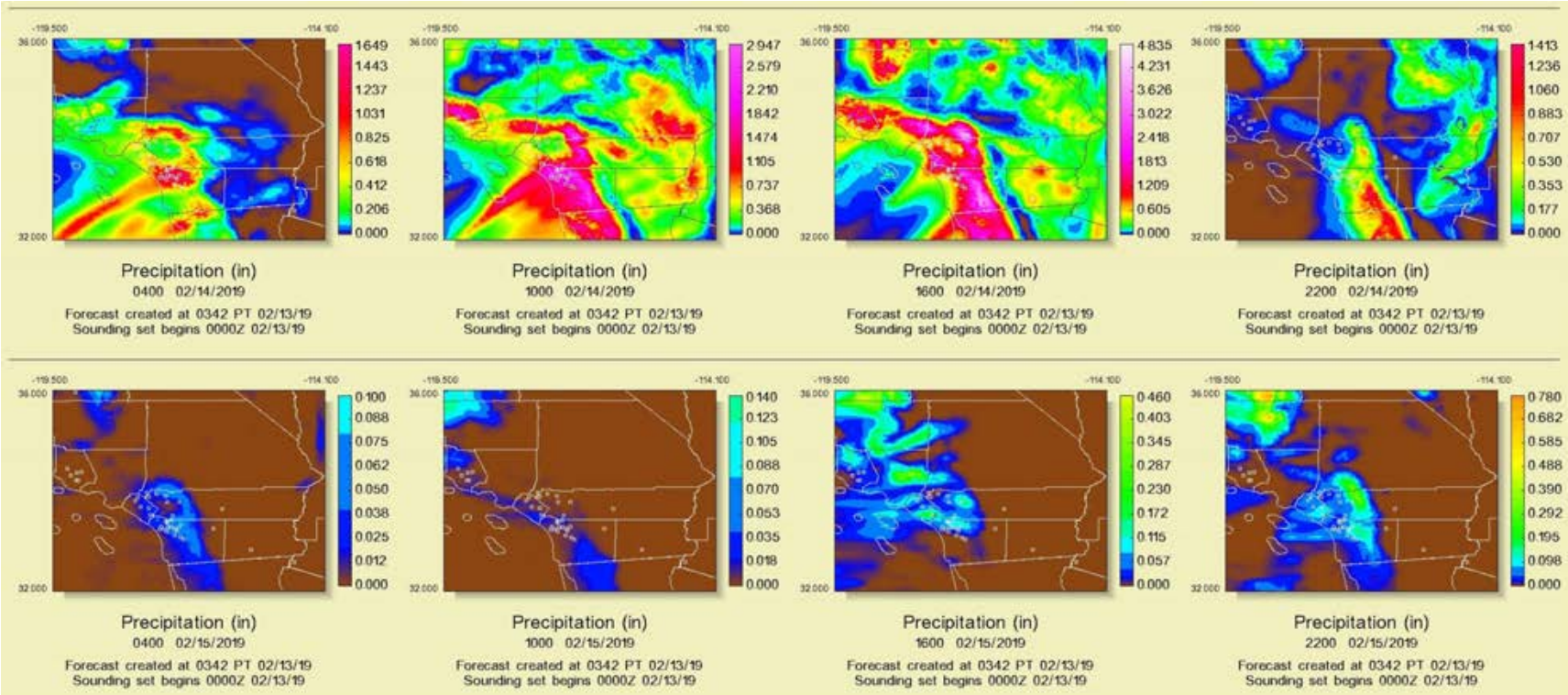
12 FEB 1500 Forecast



Details of Decision Points – February 2019

12-13 February 2019

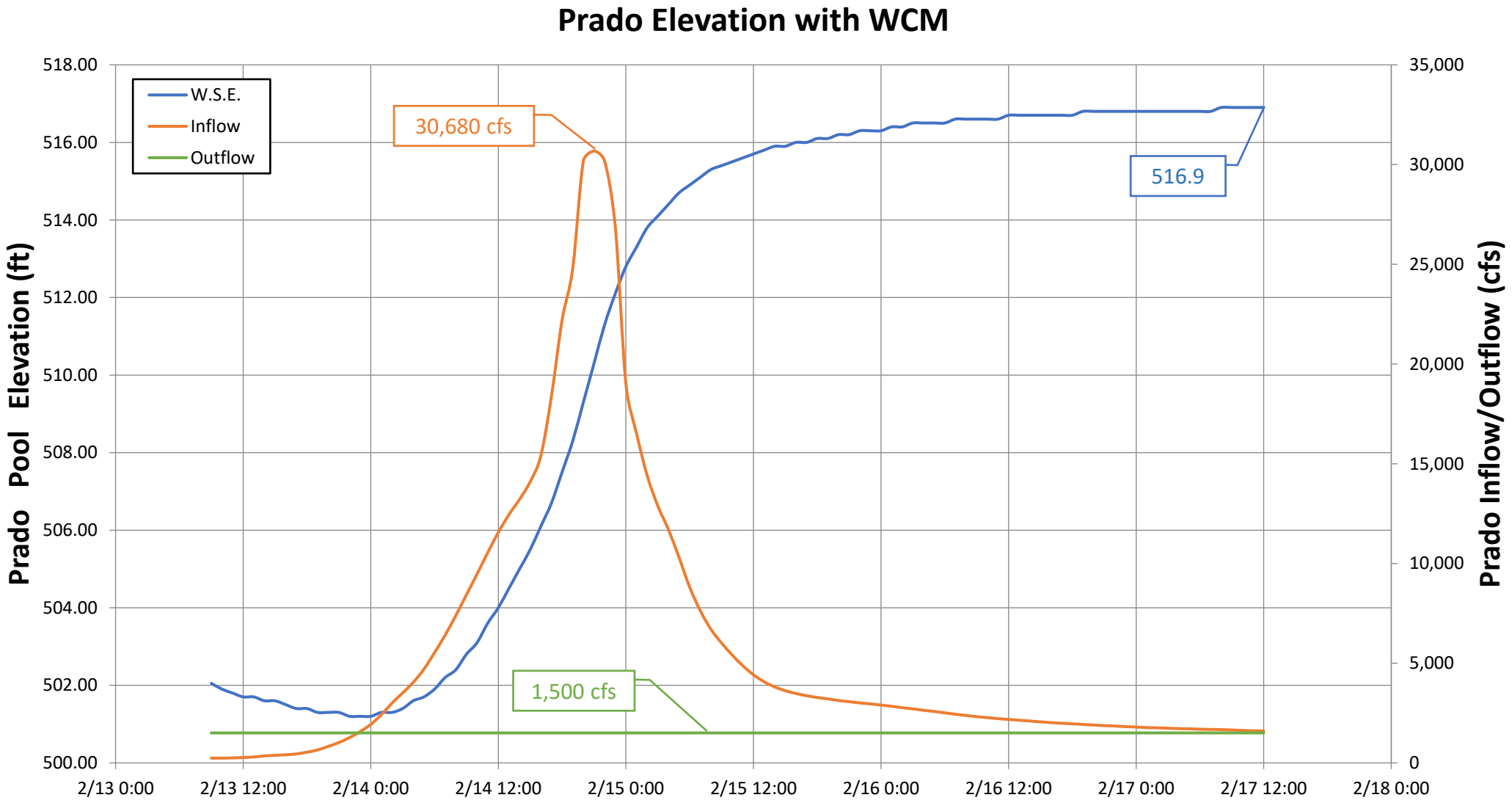
12-Feb	9:00	12 FEB 0900 Forecast received and used for planning operations. Peak inflow = 10,510 cfs (14 FEB @ 2000). Currently releasing 1,400 cfs and plan to maintain that until further notice.
12-Feb	15:00	12 FEB 1500 Forecast received and used for planning operations. Peak inflow = 11,340 cfs (14 FEB @ 1800). Currently releasing 1,400 cfs and plan to maintain that until further notice.
13-Feb	6:34	Action 3. ROC Activated



A portion of the QPF maps provided by Fox Weather

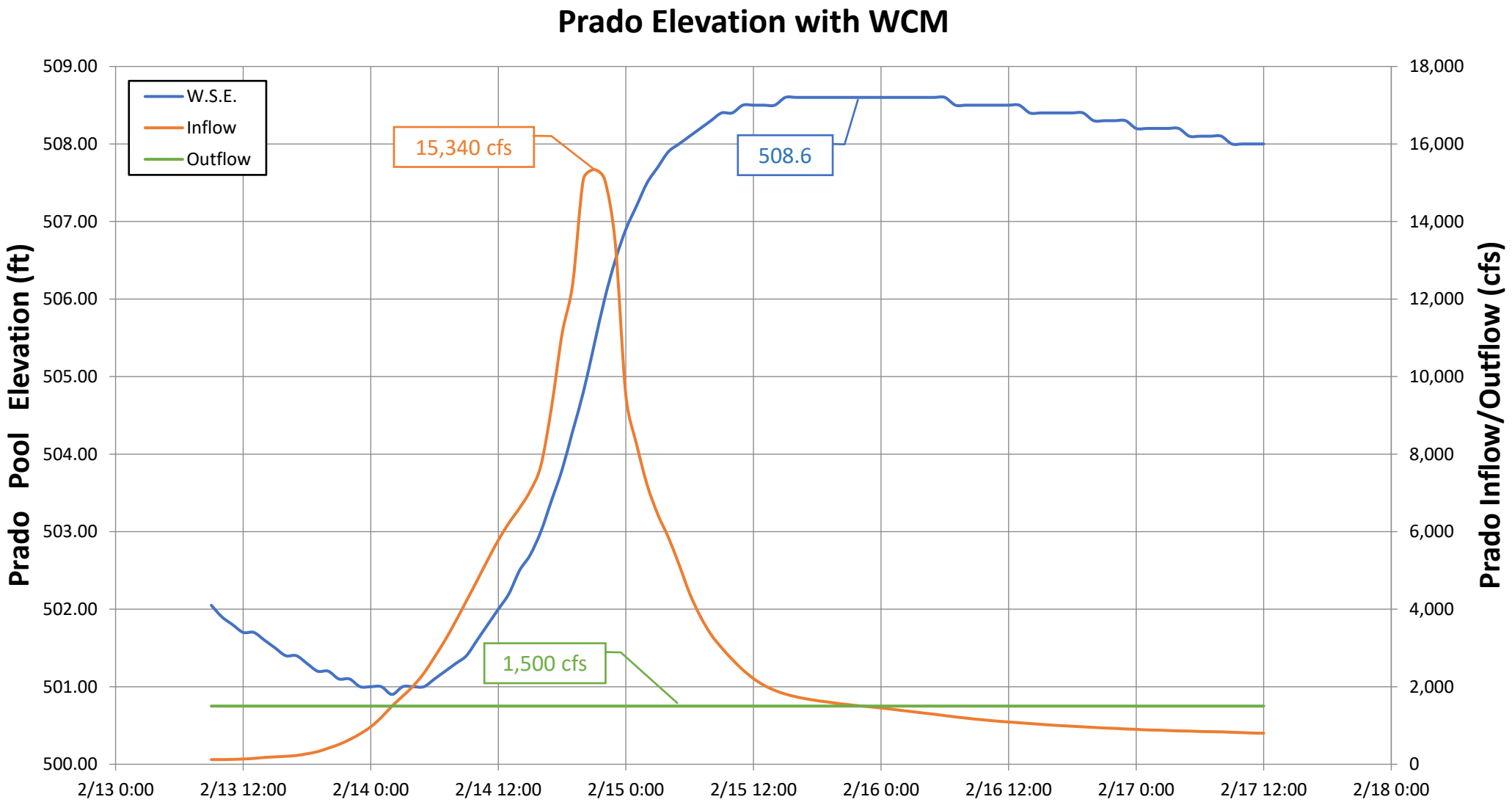
Details of Decision Points – February 2019

13 FEB 0900 Forecast



Details of Decision Points – February 2019

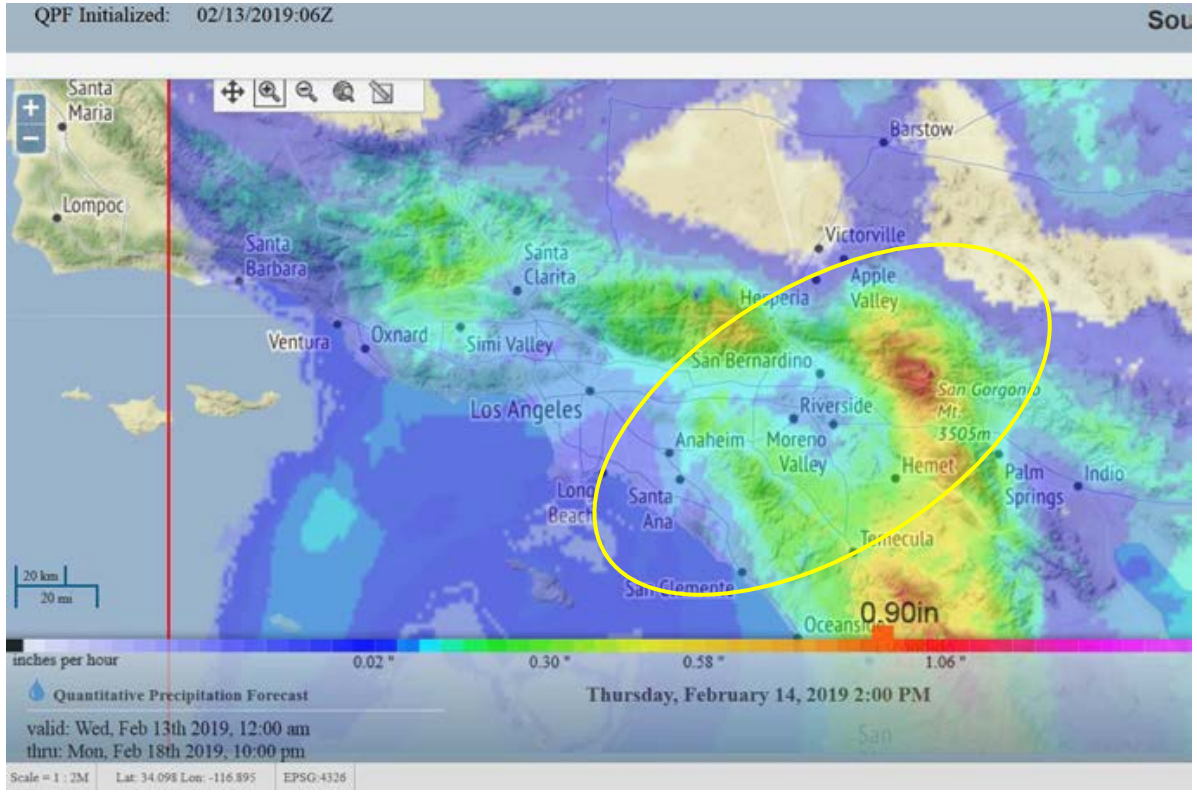
13 FEB 0900 Forecast – 50% Reduction



Details of Decision Points – February 2019

13 February 2019

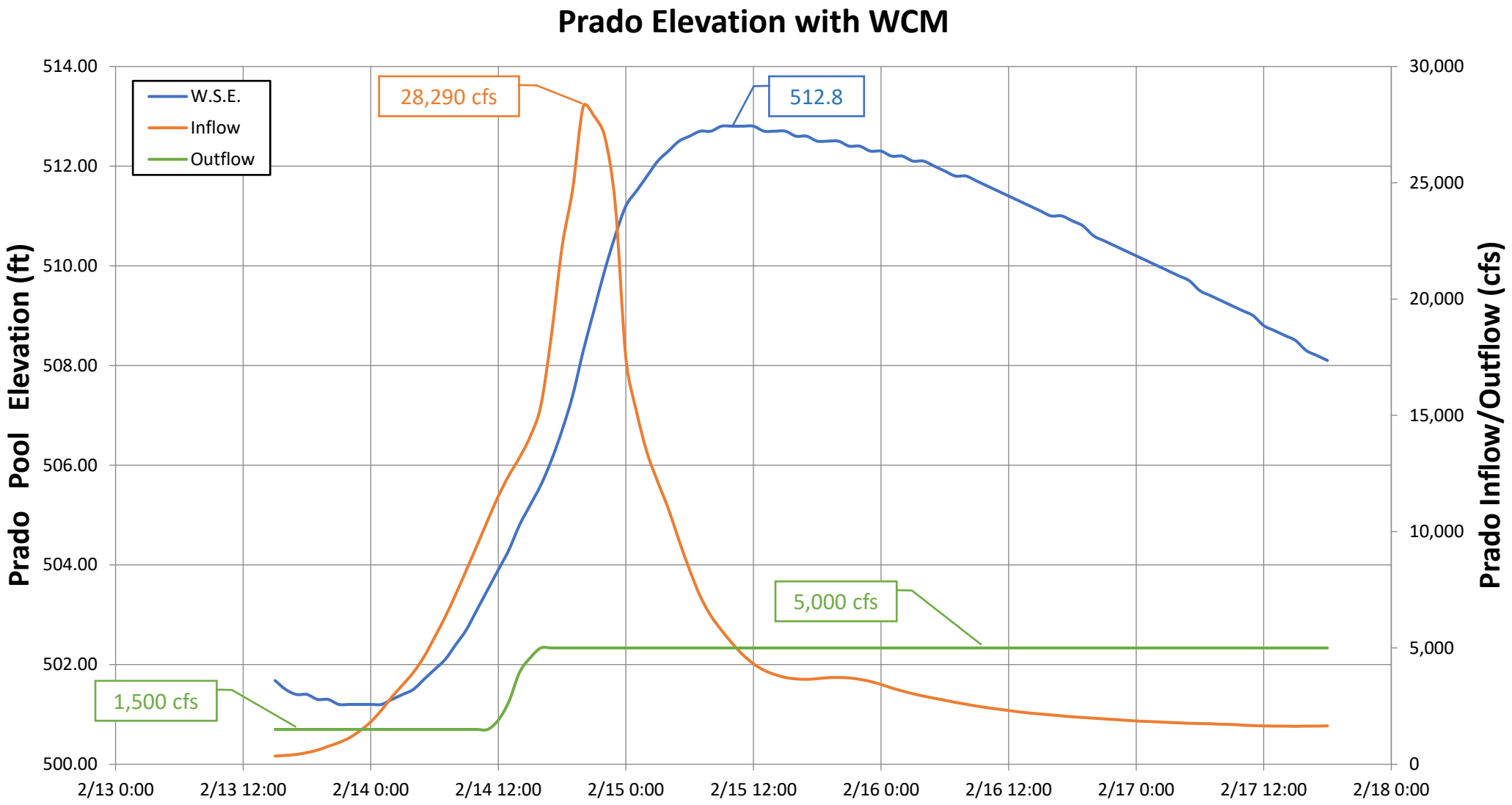
13-Feb	9:00	13 FEB 0900 Forecast received and used for planning operations. Considered a 50% reduction in the RFC forecasted inflow. Inflow forecast shows a peak of 30,680 cfs occurring on 14-Feb at 21:00. Currently releasing 1,500 cfs and plan to maintain that until further notice while considering the signficant inflow forecast.
13-Feb	11:36	Action 4. Notifications made to stakeholders of increase in release up to 5,000 cfs



Maps taken from Fox Weather briefing on 13-Feb

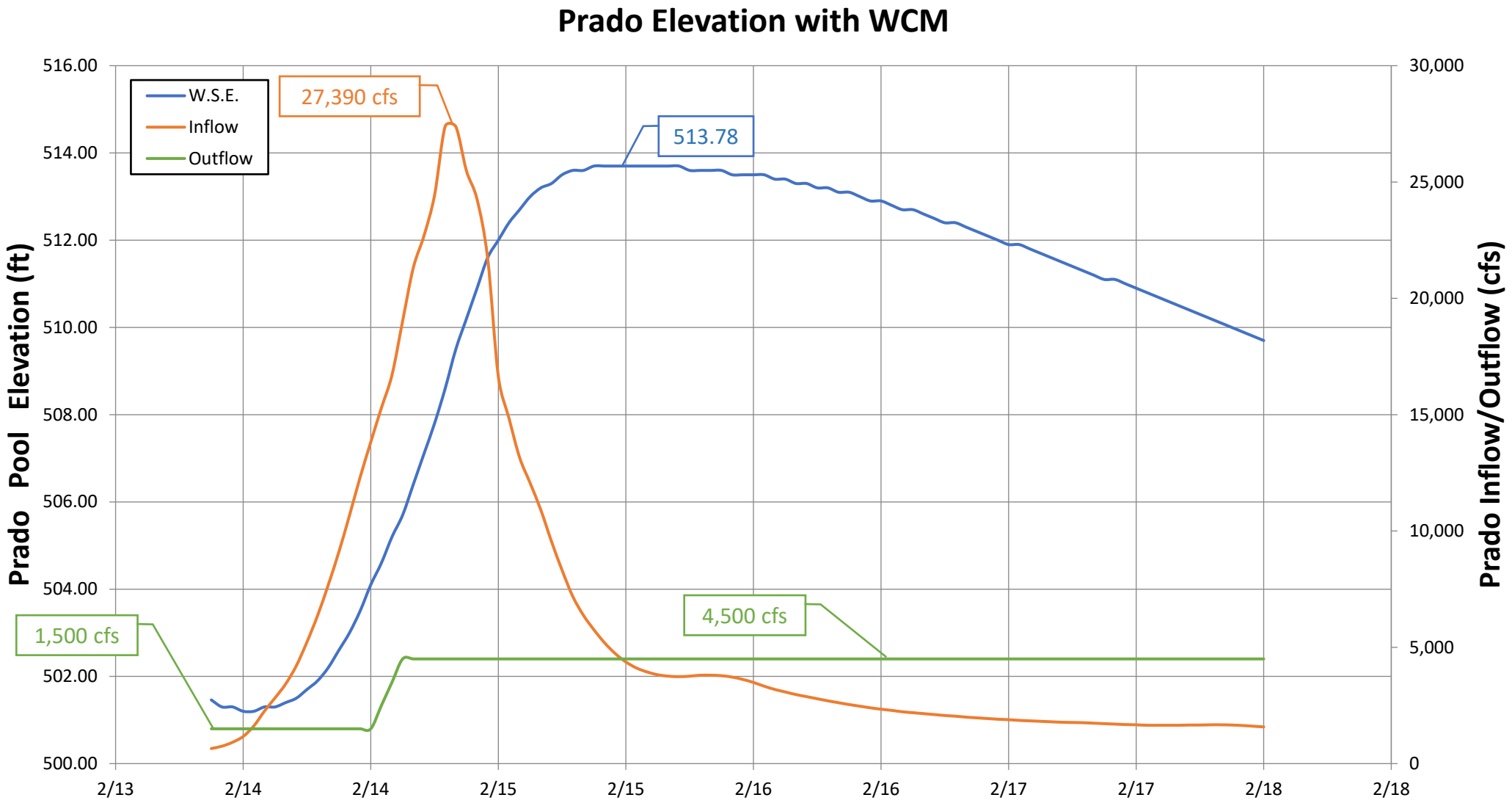
Details of Decision Points – February 2019

13 FEB 1400 Forecast



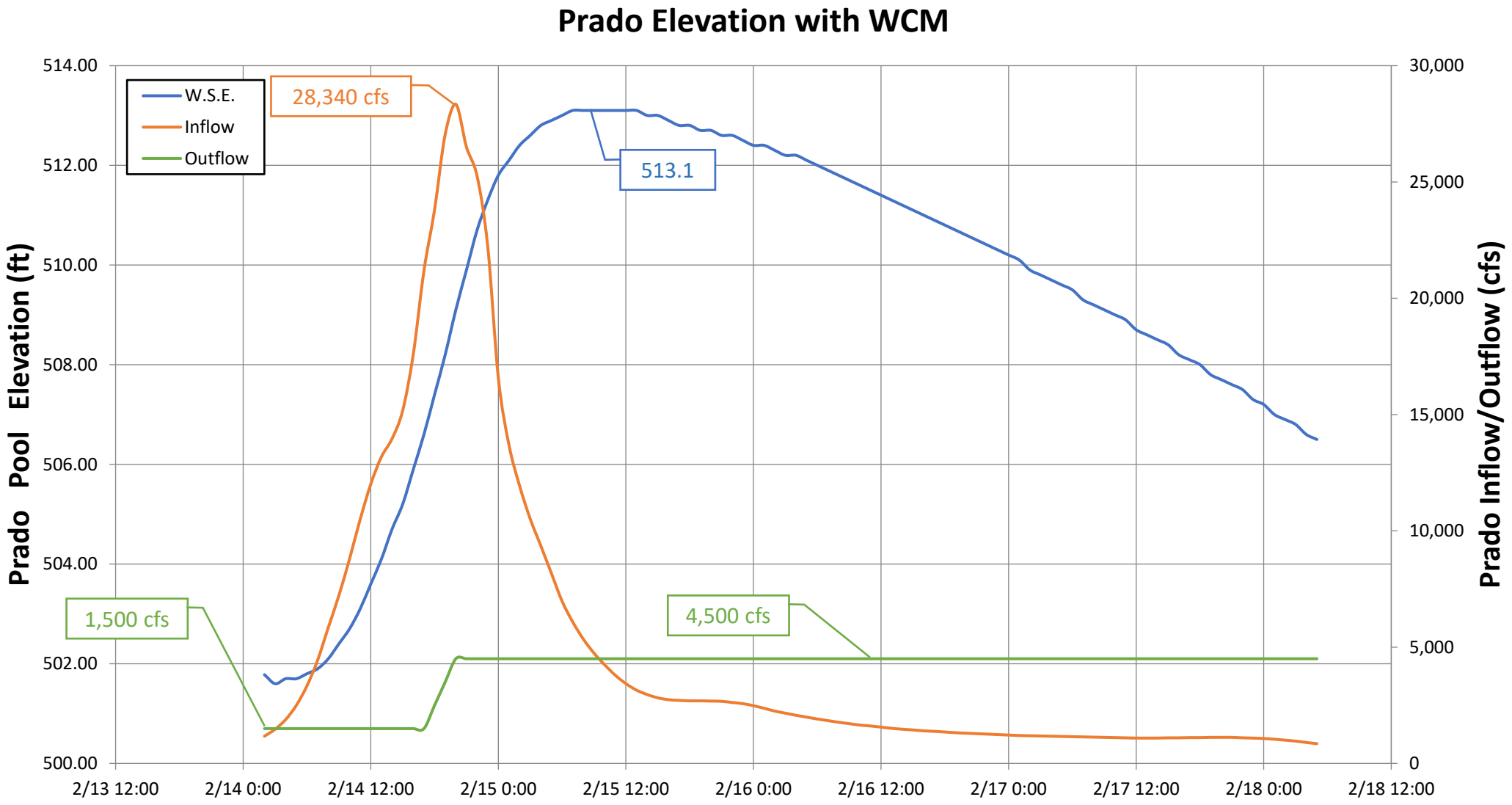
Details of Decision Points – February 2019

13 FEB 2100 Forecast



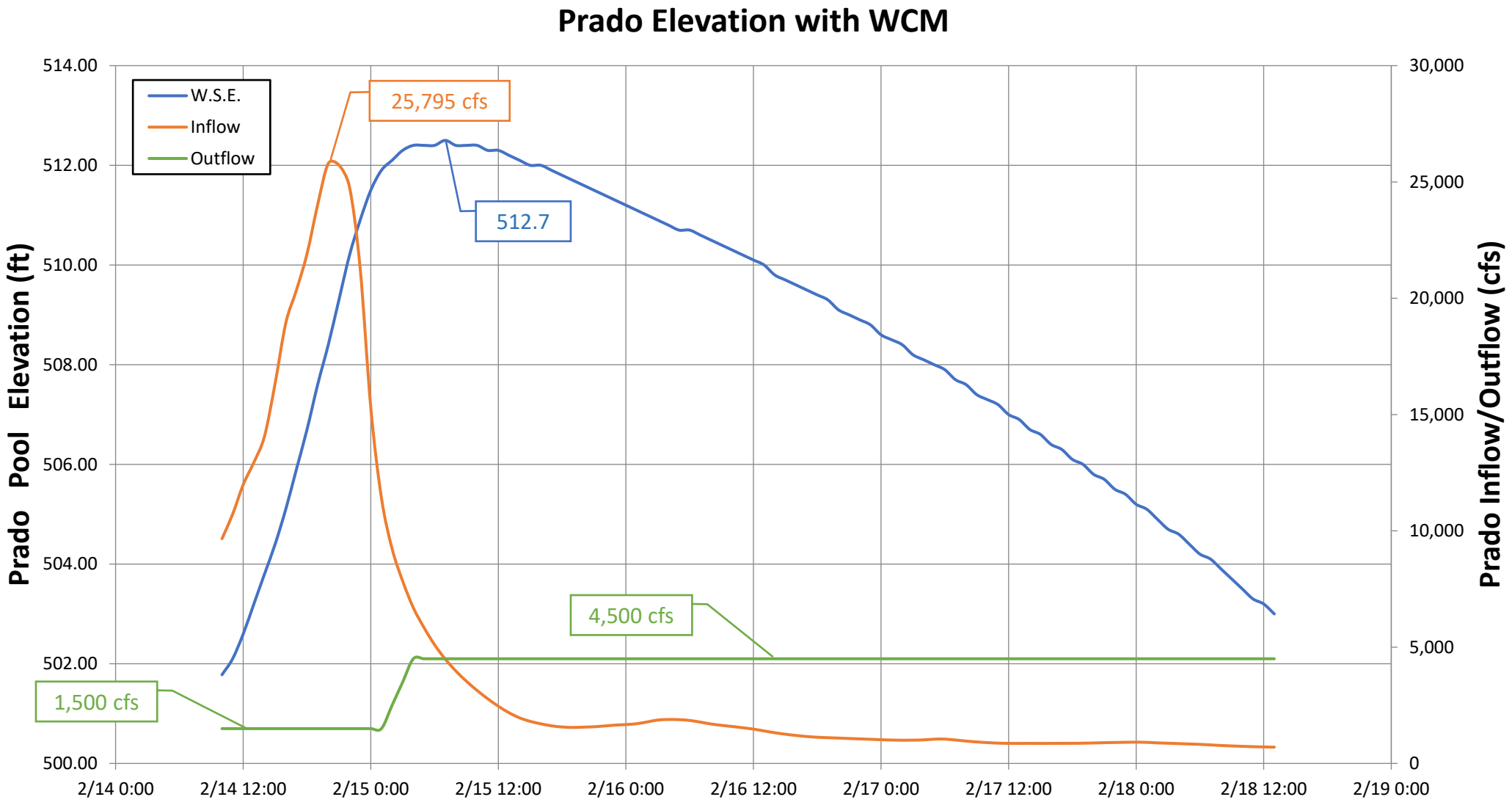
Details of Decision Points – February 2019

14 FEB 0200 Forecast



Details of Decision Points – February 2019

14 FEB 0900 Forecast

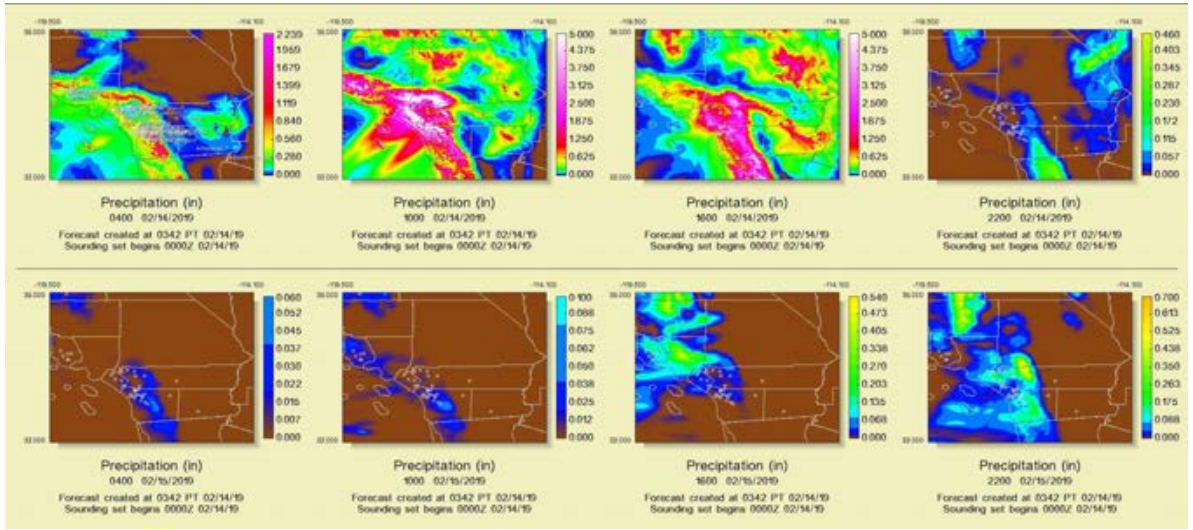


Details of Decision Points – February 2019

13 February 2019

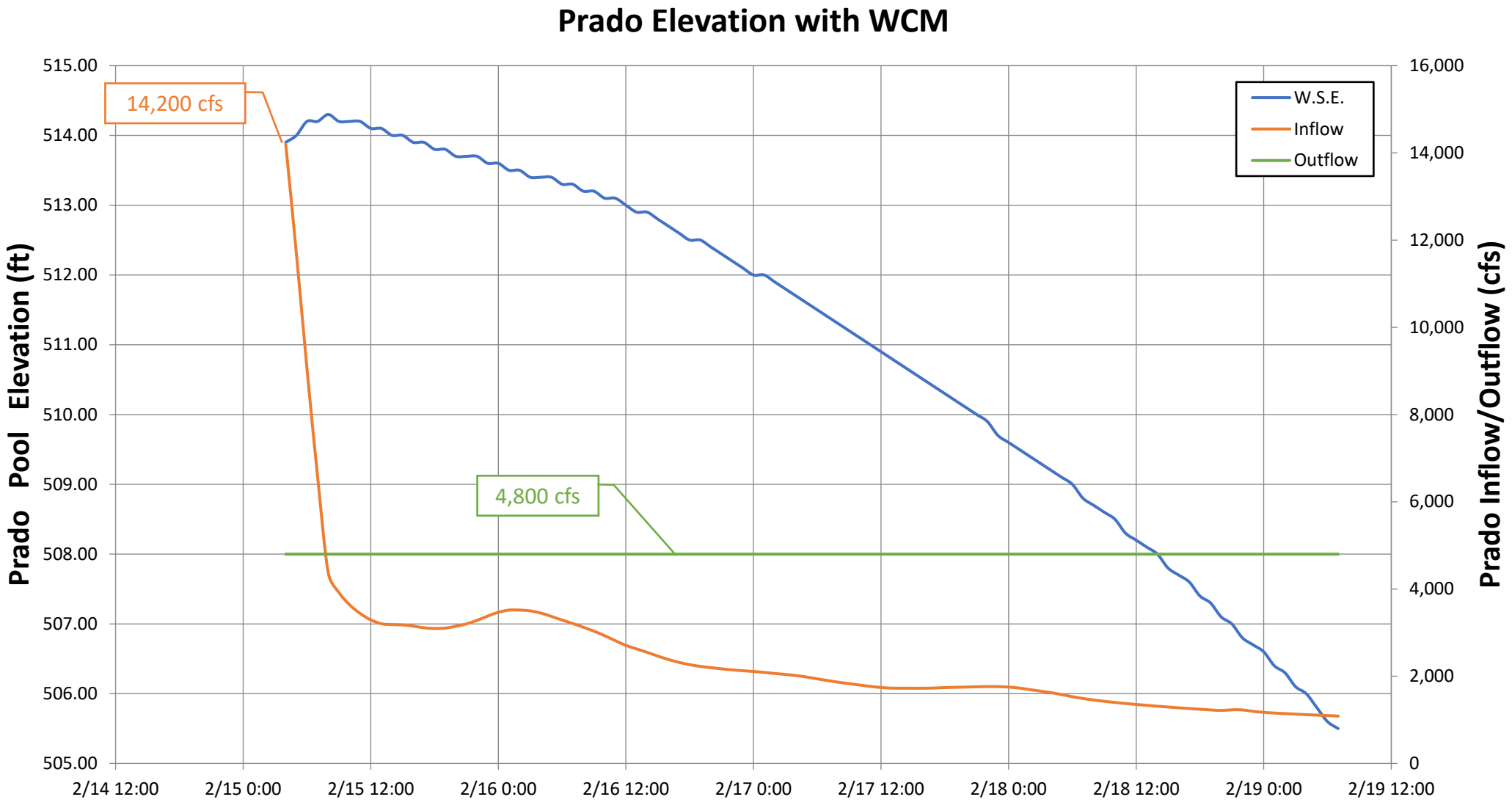
13-Feb	14:00	13 FEB 1400 Forecast received and used for planning operations. Peak inflow = 28,290 cfs (14 FEB @ 2000). Currently releasing 1,500 cfs. Plan to increase releases up to 5,000 cfs. New inflow forecast peak is less than previous forecast, but still signficant.
13-Feb	21:00	13 FEB 2100 Forecast received and used for planning operations. Peak inflow = 27,390 cfs (14 FEB @ 1900). Currently releasing 1,500 cfs. Plan to increase releases up to 4,500 cfs, possibly 5,000 cfs.
14-Feb	2:00	14 FEB 0200 Forecast received and used for planning operations. Peak inflow = 28,340 (14 FEB @ 2000). Currently releasing 1,500 cfs. Plan to increase releases up to 4,500 cfs, possibly 5,000 cfs.
14-Feb	9:00	14 FEB 0900 Forecast received and used for planning operations. Peak inflow = 25,795 cfs (14 FEB 2000). Currently releasing 1,500 cfs. Plan to increase releases up to 4,500 cfs and start ramping down early 18-Feb to 600 cfs.
14-Feb	12:00	Action 5. Started increasing releases from 1,500 cfs to 4,500 cfs
14-Feb	19:00	Action 6. Notifications made to stakeholders of the WSE reaching 510-ft

Basin or Area	Interval rainfall(inches) Every 3 hour(s), beginning on DAY1: mm dd hh 02 14 01									totl DAY1	totl DAY2	Out-look 3-5day 16-18
	1to 4	4to 7	7to 10	10to 13	13to 16	16to 19	19to 22	22to 1	1to 4	14	15	
Orange County												
Huntington	0.13	0.83	1.02	0.93	0.14	0	0	0	0	3.05	0.11	0.02
N Orange Co	0.44	2.10	2.42	2.10	0.14	0.07	0	0	0	7.27	0.15	0.01
Irvine/Tustin	0.13	0.81	1.01	1.28	0.34	0.21	0	0	0	3.78	0.14	0.03
OC Cstl Hills	0.23	1.65	2.09	1.97	0.17	0.10	0	0	0	6.21	0.10	0.03
San Juan Ck	0.20	0.97	1.10	1.63	0.64	0.40	0.01	0.01	0	4.96	0.07	0.02
MtnsCanyons	0.44	2.93	3.90	3.51	0.53	0.17	0.01	0	0.02	11.49	0.21	0.06



Details of Decision Points – February 2019

15 FEB 0400 Forecast



Details of Decision Points – February 2019

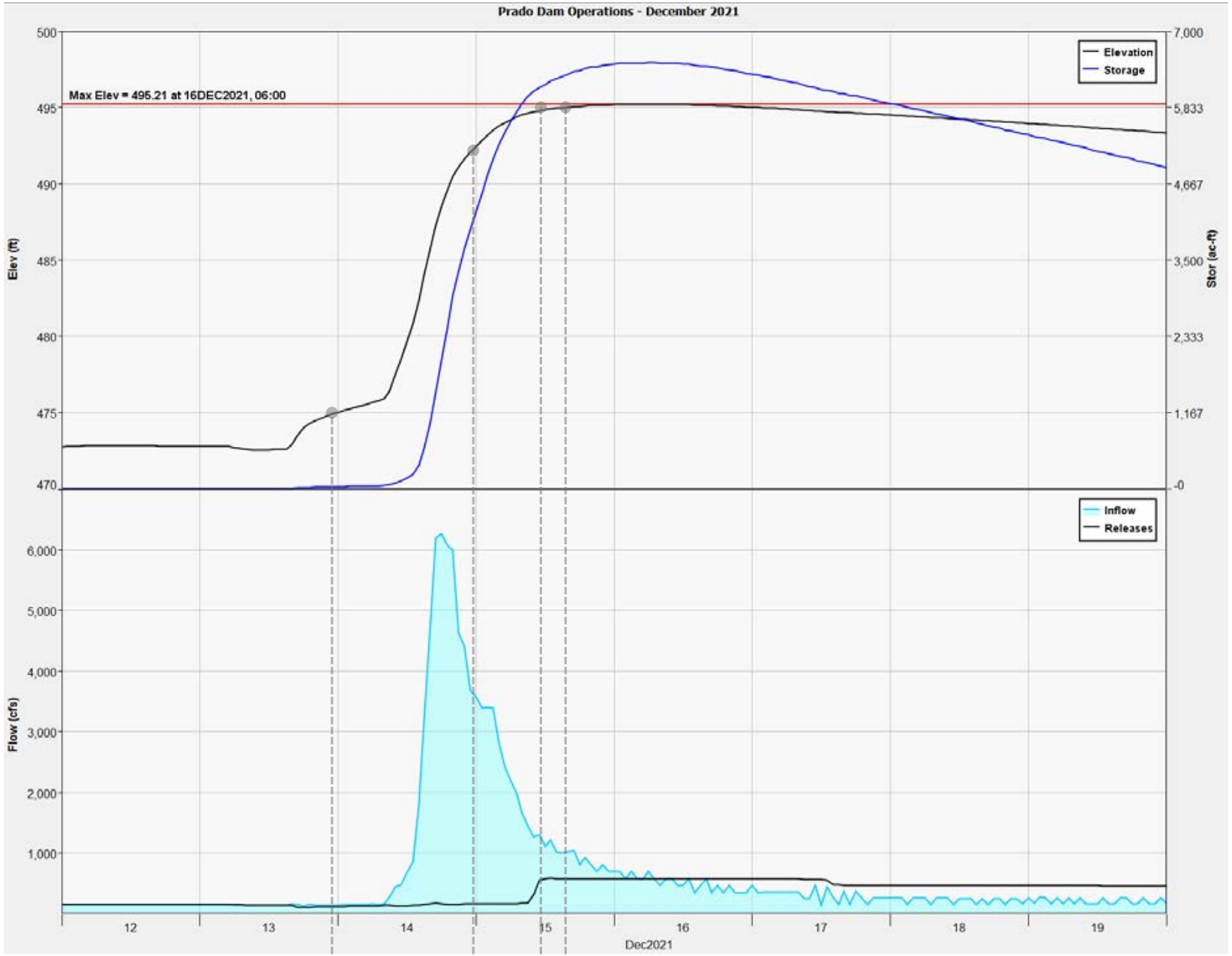
13 February 2019

14-Feb	23:19	Releases have increased to 4,800 cfs (due to higher pool and inflow). Expect to maintain this release until further notice.
15-Feb	4:00	15 FEB 0400 Forecast received and used for planning operations. Peak inflow = 14,200 cfs (15 FEB @ 0400). Currently releasing 4,800 cfs. Plan maintain this release until further notice.
15-Feb	19:38	Releases remain at around 4,900 cfs (due to rising pool)
18-Feb	10:01	Action 7. Notification to stakeholders - reducing releases to 2,000 cfs starting at 1000. Started reducing releases to 2,000 cfs (achieved at 12:30)
18-Feb	15:41	Action 8. ROC Deactivated
19-Feb	14:11	Action 9. Notification to stakeholders - reducing releases to 750 cfs starting at 1400. Started reducing releases from about 2,000 cfs down to 750 cfs (achieved at 15:30)
25-Feb	7:22	Action 10. Notification to stakeholders - reducing releases to 350 cfs starting at 08:00
25-Feb	10:06	Action 11. Notification to stakeholders - reducing releases to 250 cfs starting at 11:00

December 2021 Event

December 2021 Event

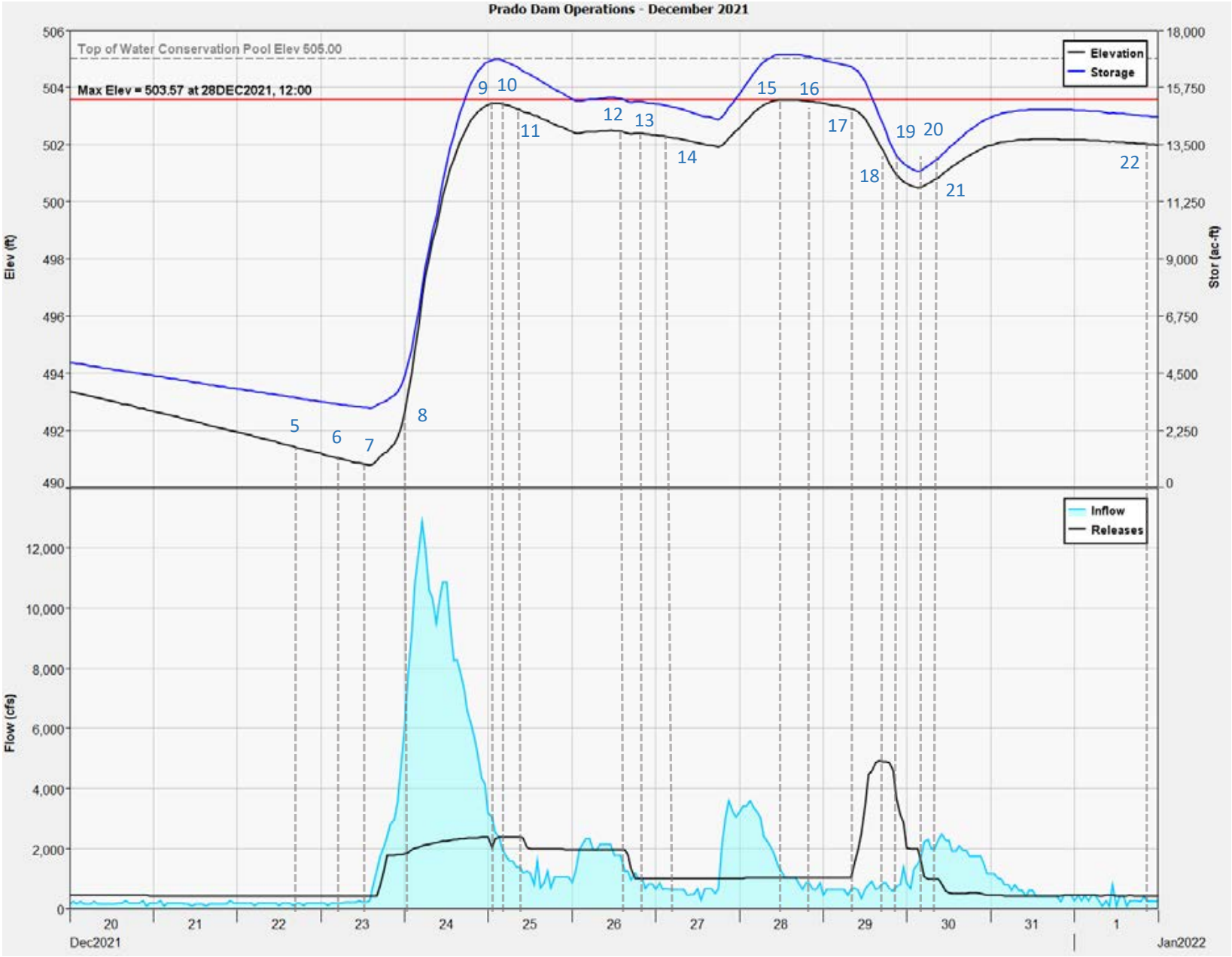
1. ROC activated
2. ROC deactivated
3. Releases increased to 600 cfs
4. Notification – increase release to 600 cfs



1 2 3 4

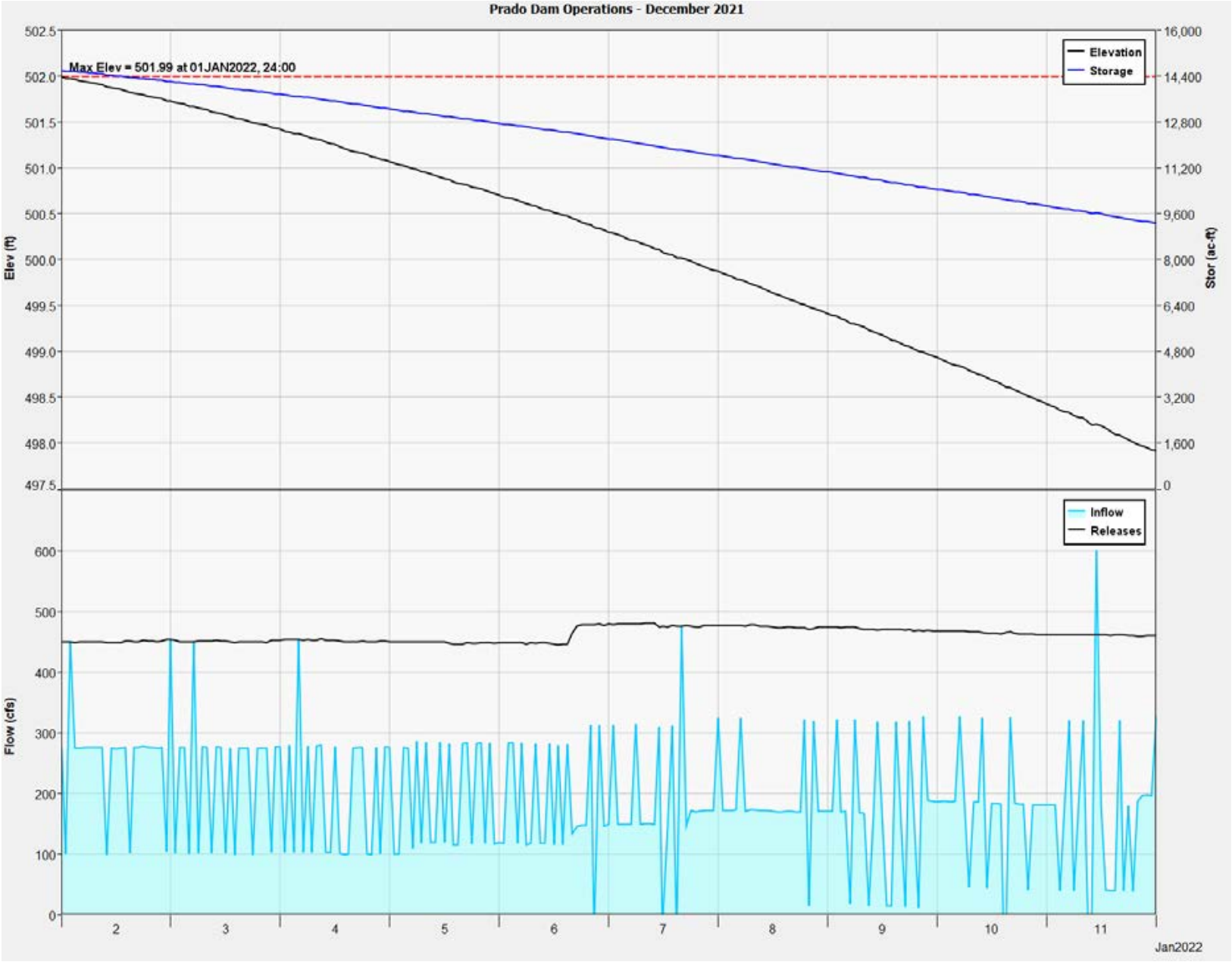
December 2021 Event

5. Notification – increase release to 1,000 cfs
6. ROC activated
7. Notification – increase release to 2,000 cfs
8. Released increased to 2,000 cfs
9. Gates pinched to limit outflow
10. Gates raised
11. Gates pinched
12. Notification – reduce release to 1,000 cfs
13. ROC deactivated
14. ROC activated, then deactivated a few hours later
15. Notification – increase release to 5,000 cfs
16. Channel watch team preparing for activation
17. ROC activated and releases increasing to 5,000 cfs
18. Notification - reduce release to 3,000 cfs
19. Notification – reduce release to 2,500 cfs, then to 2,000 cfs
20. Notification – reduce release to 1,000 cfs
21. Notification – reduce release to 550 cfs
22. ROC deactivated

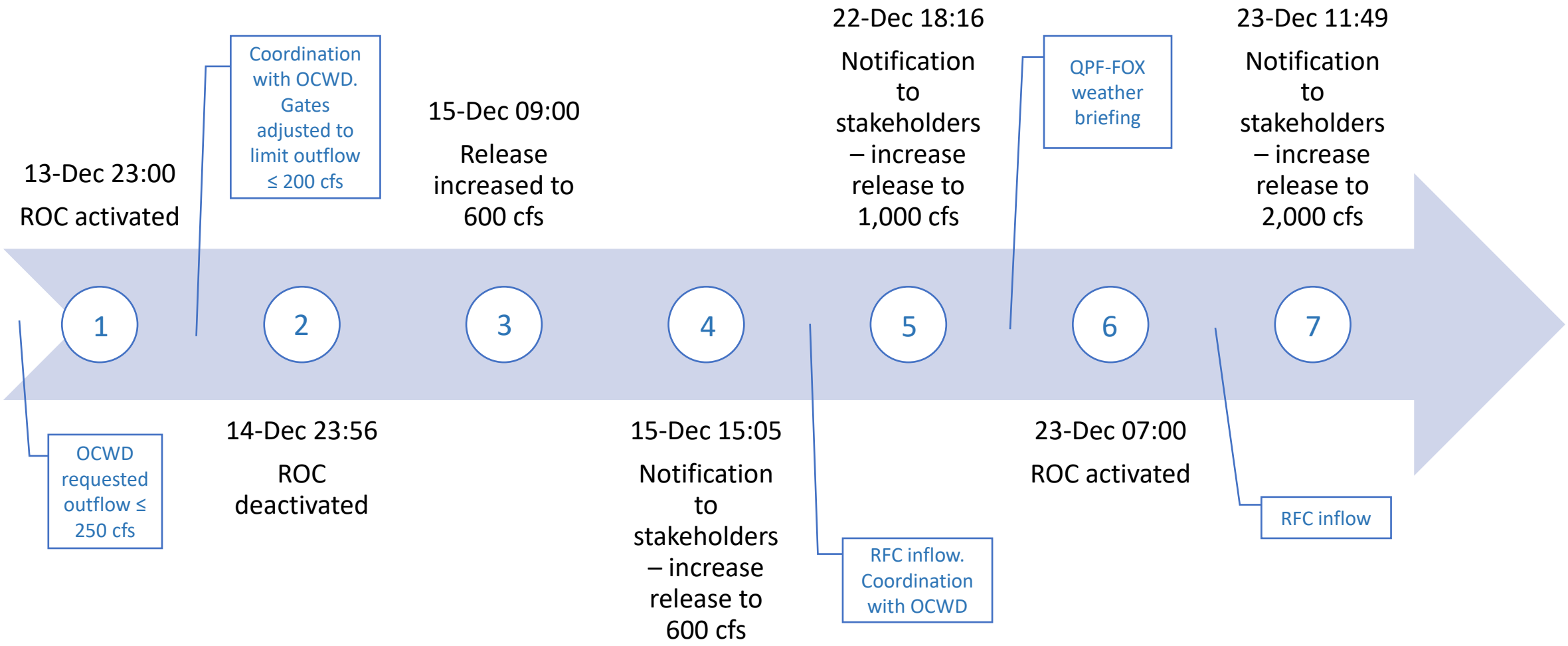


December 2021 Event

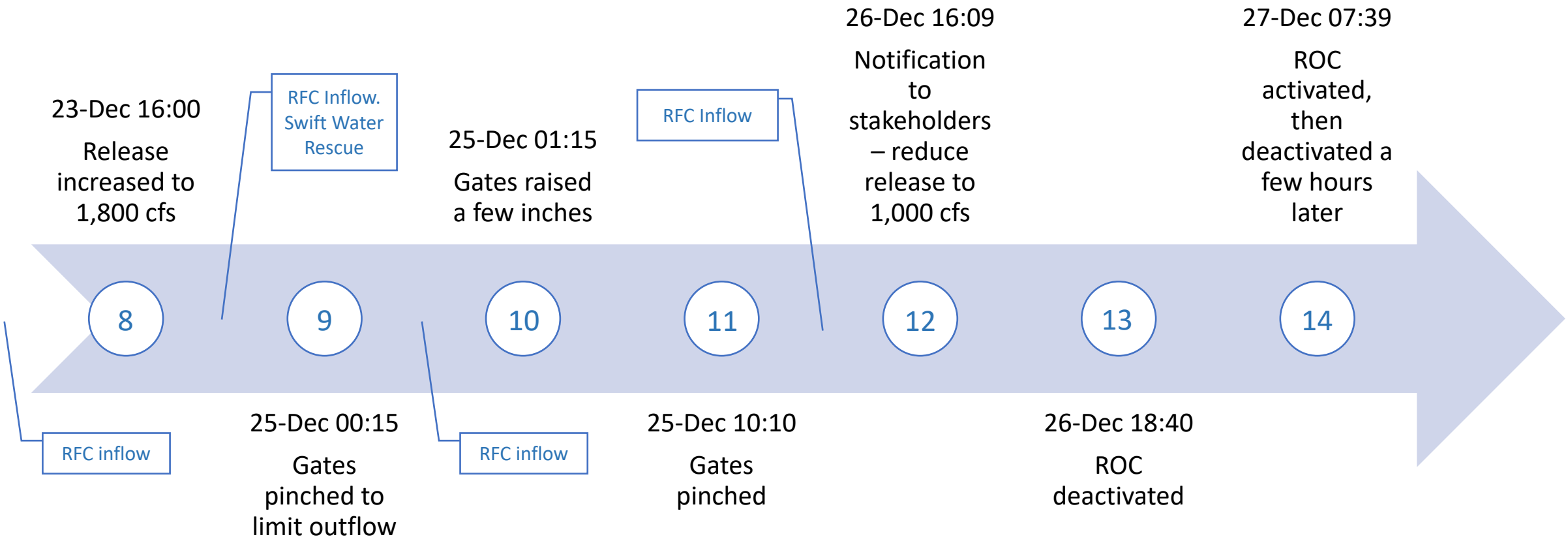
Prado continued to be monitored and slowly drained in coordination with OCWD



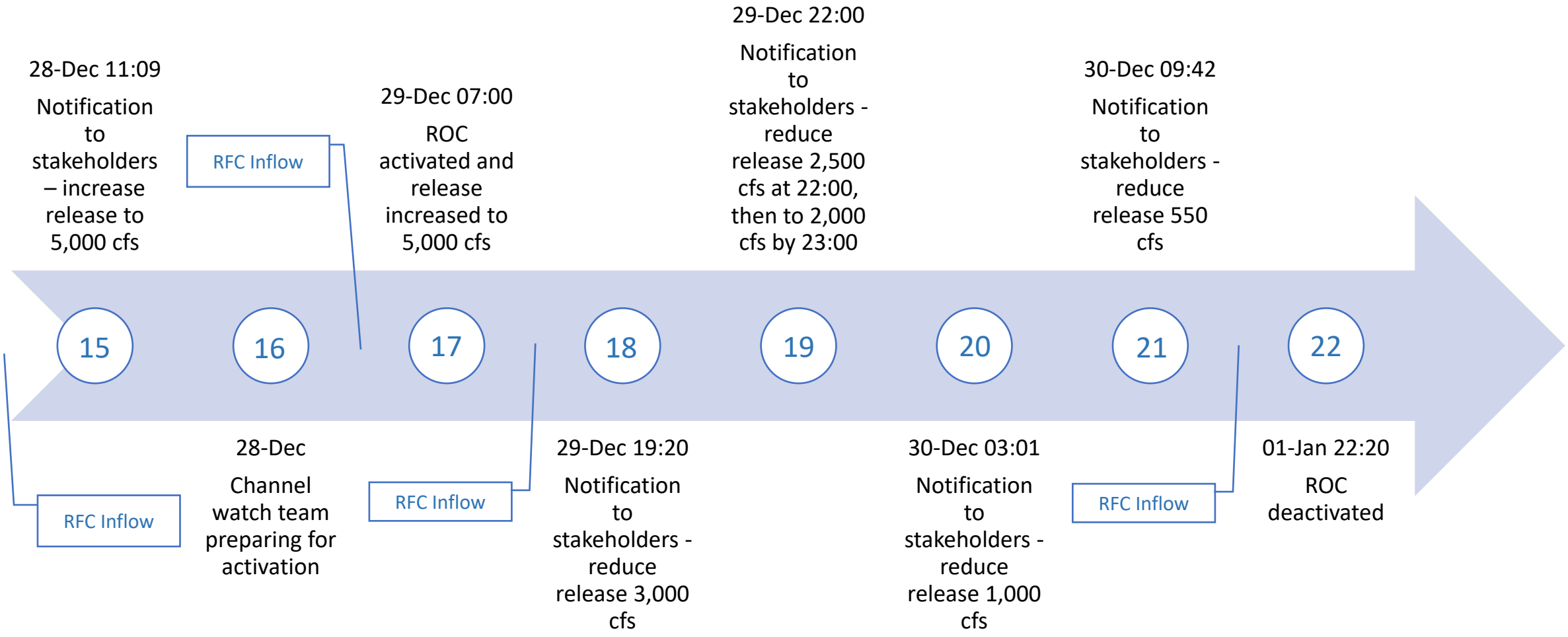
Timeline of Events – December 2021



Timeline of Events – December 2021



Timeline of Events – December 2021



Timeline of Events – December 2021

Date	Time	Plan / Action
13-Dec	9:00	Coordination with OCWD to limit release to 250 cfs.
13-Dec	23:00	Action 1. ROC activated
14-Dec	7:30	ROC status = Gates adjusted to limit release to 250 cfs
14-Dec	10:44	Coordination with OCWD to limit release to 200 cfs.
14-Dec	15:24	ROC status = Gates adjusted to limit release to 200 cfs
14-Dec	23:56	Action 2. ROC deactivated
15-Dec	9:00	Action 3. Releases increased to 600 cfs.
15-Dec	15:05	Action 4. Notification to stakeholders - increase release to 600 cfs
22-Dec	9:00	22 DEC 2021 0900 Forecast received and used for planning operations. Peak inflow = 8,425 (24 DEC @ 1300). Currently releasing 440 cfs. Plan to increase releases up to 1,000 cfs.
22-Dec	11:49	Coordination with OCWD to reduce release on 23 DEC at 08:00 to 200-250 cfs through Saturday morning. OCWD requesting coordination calls each morning.
22-Dec	18:16	Action 5. Notification to stakeholders - increase release to 1,000 cfs beginning 23-DEC morning.
22-Dec	20:26	Received QPF-FOX weather briefing.
23-Dec	7:00	Action 6. ROC activated
23-Dec	9:00	23 DEC 2021 0900 Forecast received and used for planning operations. Peak inflow = 10,585 (24 DEC @ 1000). Currently releasing 1,800 cfs. Plan to increase to 2,000 cfs.
23-Dec	11:49	Action 7. Notification to stakeholders - increase release to 2,000 cfs starting at 16:00

Timeline of Events – December 2021

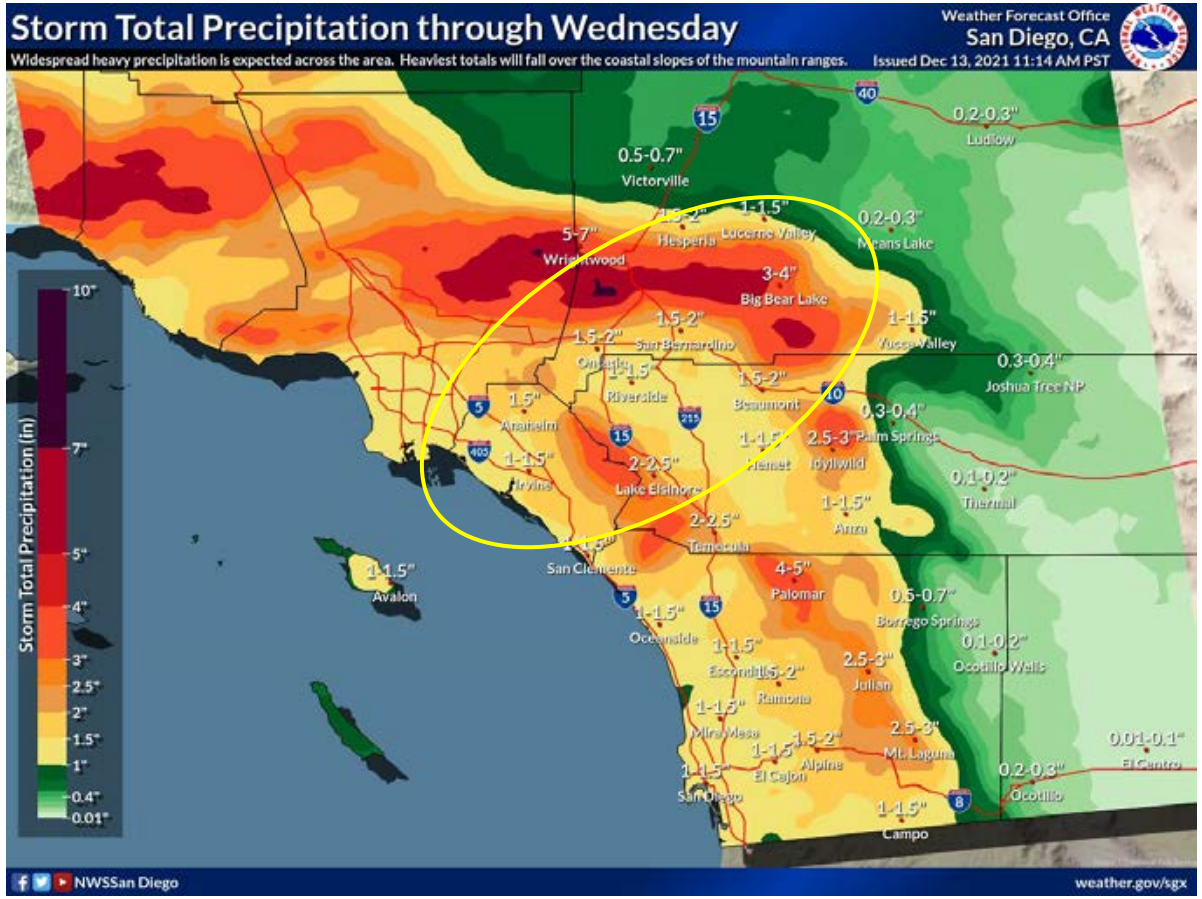
Date	Time	Plan / Action
23-Dec	15:00	23 DEC 2021 1500 Forecast received and used for planning operations. Peak inflow = 11,215 (24 DEC @ 0900). Currently releasing 1,800 cfs. Plan to increase to 2,000 cfs.
23-Dec	16:00	Action 8. Release increased to 1,800 cfs
24-Dec	7:01	Release = 2,000 cfs (due to rising pool)
24-Dec	15:00	24 DEC 2021 1500 Forecast received and used for planning operations. Peak inflow = 10,832 cfs (24 DEC @ 1500) but 2 smaller peaks following with 5,819 cfs (26 DEC @ 0900) and 4,233 cfs (28 DEC @ 0100). Currently releasing 2,350 cfs. Plan to leave release at around 2,000 cfs.
24-Dec	15:05	Swift Water Rescue working on a retrieval in the lower Santa Ana River. Received call from OC Fire Authority. At this time, we have not been requested to adjust project operations.
25-Dec	0:15	Action 9. Gates pinched to limit outflow to about 2,000 cfs
25-Dec	9:00	25 DEC 2021 0900 Forecast received and used for planning operations. Peak inflow = 4,243 (26 DEC @ 0900) and 5,097 cfs (28 DEC @ 0200). Currently releasing 2,000 cfs. Plan to reduce release to 1,800 cfs on 28-DEC at 08:00, then to 1,500 cfs on 29-DEC at 11:00.
25-Dec	1:15	Action 10. Gates raised a few inches
25-Dec	10:10	Action 11. Gates pinched to limit outflow
26-Dec	9:00	26 DEC 2021 0900 Forecast received and used for planning operations. Peak inflow = 3,454 (28 DEC @ 0300) and 5,272 cfs (30 DEC @ 1000). Currently releasing 1,000 cfs. Expecting to maintain 1,000 cfs and then increase to 4,000 cfs on 29-DEC at 15:00
26-Dec	16:09	Action 12. Notification to stakeholders - reduce release to 1,000 cfs at 18:00. Started reducing at 15:00 (1,000 cfs achieved at 18:00).
26-Dec	18:40	Action 13. ROC deactivated
27-Dec	7:39	Action 14. ROC activated, then deactivated a few hours later.

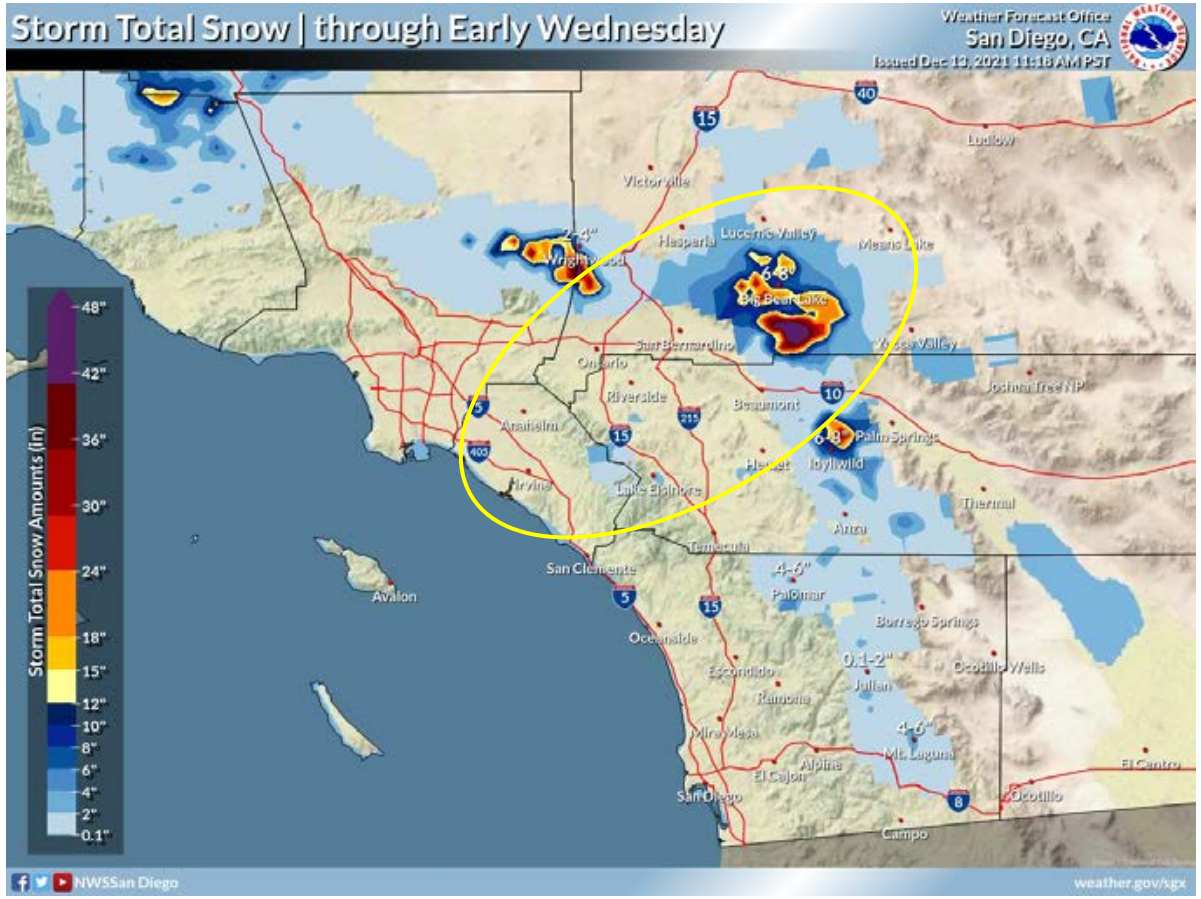
Timeline of Events – December 2021

Date	Time	Plan / Action
27-Dec	9:00	27 DEC 2021 0900 Forecast received and used for planning operations. Peak inflow = 2,345 (28 DEC @ 0100) and 9,104 cfs (30 DEC @ 0700). Currently releasing 1,000 cfs. Expecting to maintain 1,000 cfs and then increase to 4,200 cfs on 29-DEC at 08:00, then reduce to 4,000 cfs on 31-DEC at 12:00.
28-Dec	11:09	Action 15. Notification to stakeholders - increase release to 5,000 cfs starting on 29-DEC at 07:00.
28-Dec		Action 16. Channel watch team preparing for activation on 29-DEC, to observe releases of 5,000 cfs.
28-Dec	14:00	28 DEC 2021 1400 Forecast received and used for planning operations. Peak inflow = 14,285 (30 DEC @ 1300). Currently releasing 1,000 cfs. Expecting to maintain 1,000 cfs and then increase to 5,000 cfs on 29-DEC at 07:00, then reduce to 4,000 cfs on 31-DEC at 06:00, then to 2,500 cfs on 01-JAN at 06:00.
29-Dec	8:22	Action 17. ROC activated and release increased to 5,000 cfs
29-Dec	9:00	29 DEC 2021 0900 Forecast received and used for planning operations. Peak inflow = 14,955 (30 DEC @ 1400). Currently releasing 1,000 cfs. Expecting to maintain 1,000 cfs and then increase to 5,000 cfs on 29-DEC at 07:00, then reduce to 4,000 cfs on 31-DEC at 06:00, then to 2,500 cfs on 01-JAN at 06:00.
29-Dec	14:00	29 DEC 2021 1400 Forecast received and used for planning operations. Peak inflow = 7,614 (30 DEC @ 1800). Currently releasing 5,000 cfs, immediate reduction to 1,500 cfs until 31-DEC at 05:00, then increase to 2,500 cfs until 01-JAN at 06:00, then to 2,000 cfs until 17:00, then to 1,000 cfs until further notice.
29-Dec	14:00	29 DEC 2021 1400 Forecast received and used for planning operations. Peak inflow = 7,614 (30 DEC @ 1800). Currently releasing 5,000 cfs, immediate reduction to 1,000 cfs until further notice.
29-Dec	19:20	Action 18. Notification to stakeholders - reduce release 3,000 cfs
29-Dec	21:59	Action 19. Notification to stakeholders - reduce release 2,500 cfs at 22:00, then to 2,000 cfs by 23:00.
29-Dec	22:19	
30-Dec	3:01	Action 20. Notification to stakeholders - reduce release 1,000 cfs
30-Dec	9:42	Action 21. Notification to stakeholders - reduce release 550 cfs
30-Dec	14:00	30 DEC 2021 1400 Forecast received and used for planning operations. Peak inflow = 3,640 (30 DEC @ 1900). Currently releasing 550 cfs. Expecting to decrease to 500 cfs and maintain that until futher notice.
1-Jan	22:20	Action 22. ROC deactivated

Details of Decision Points – December 2021

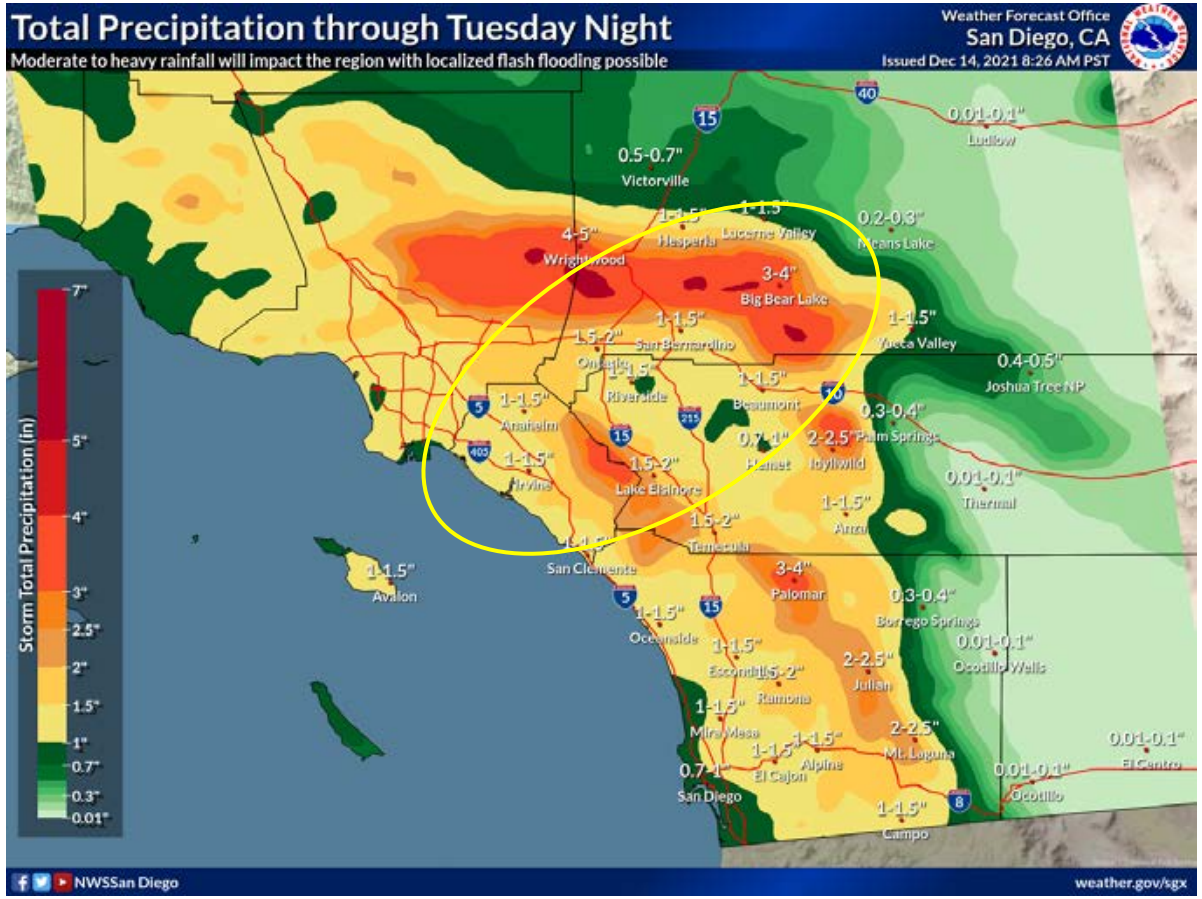
13 December 2021

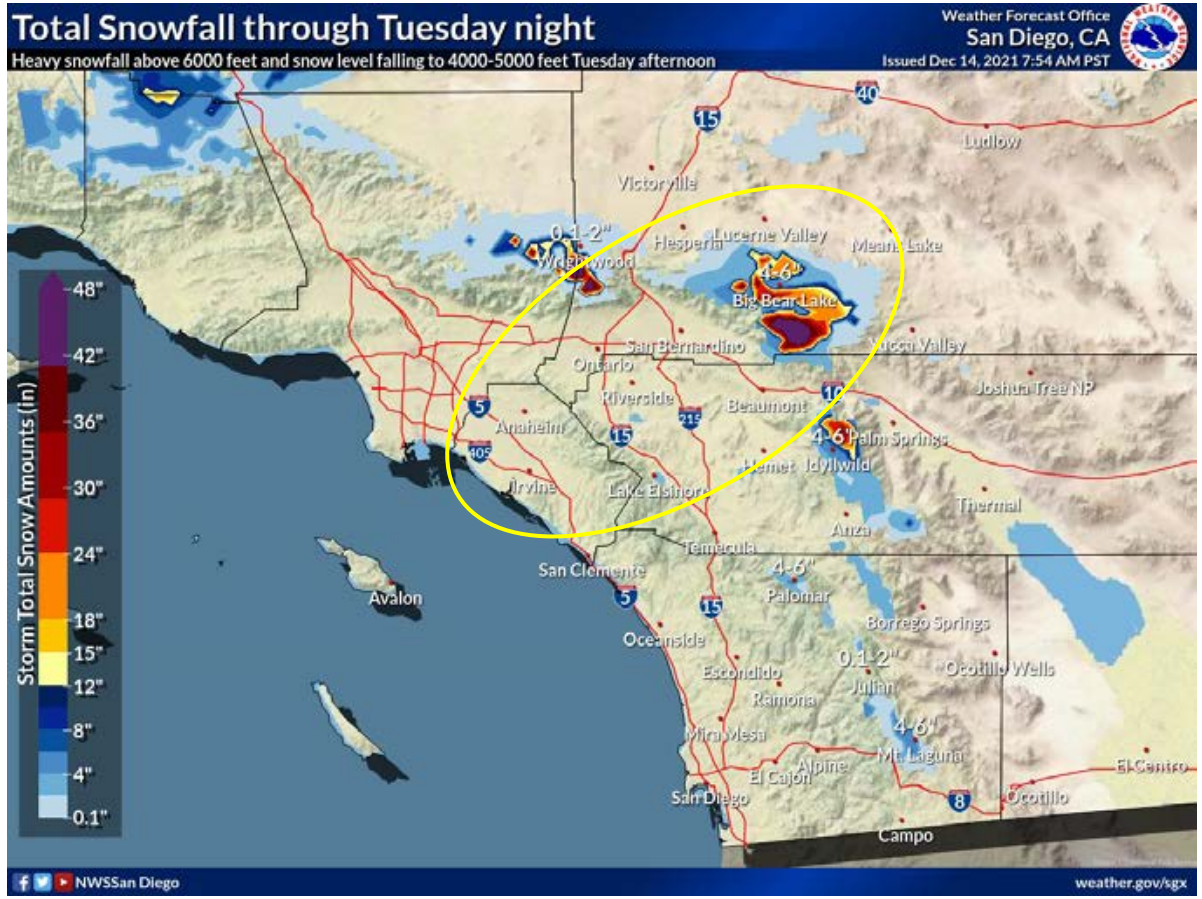




Details of Decision Points – December 2021

14 December 2021





Details of Decision Points – December 2021

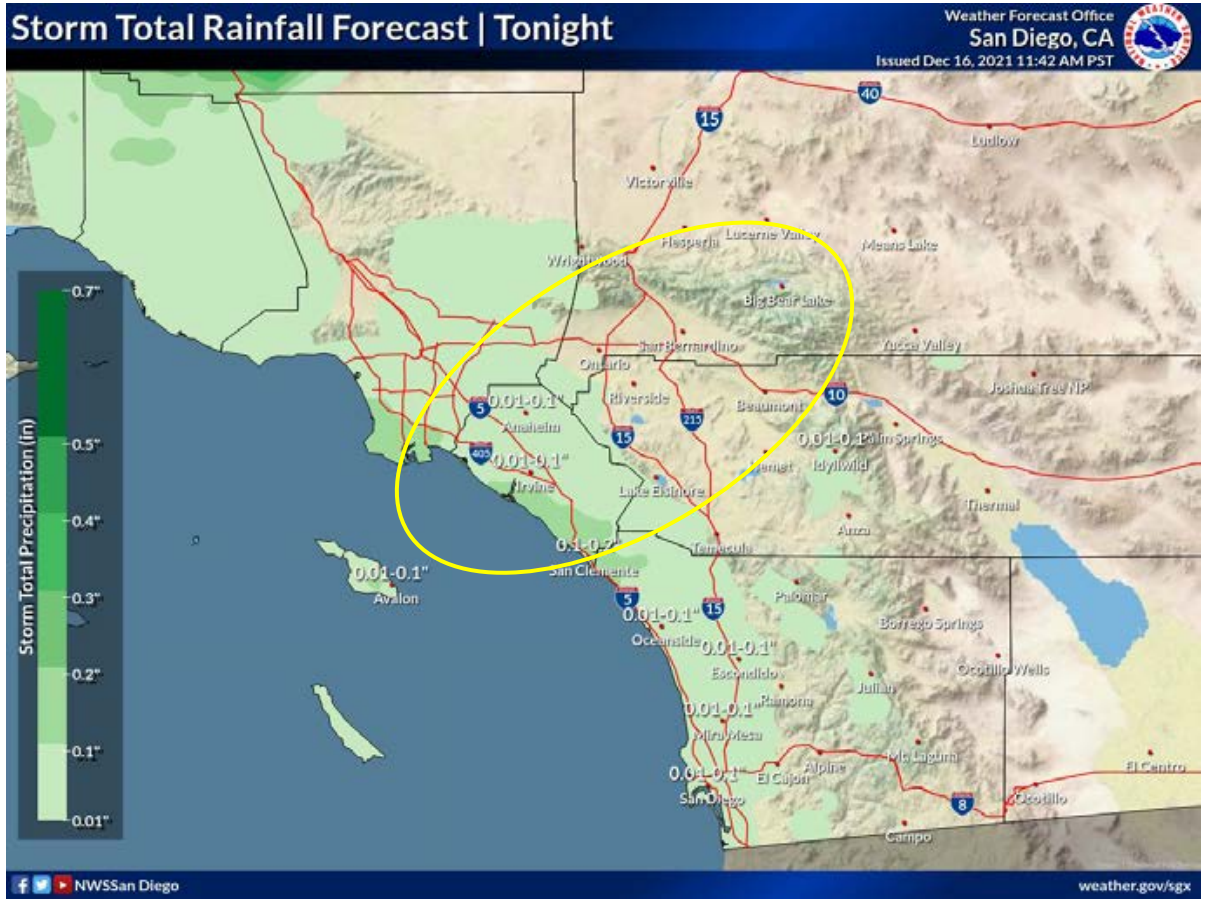
15 December 2021

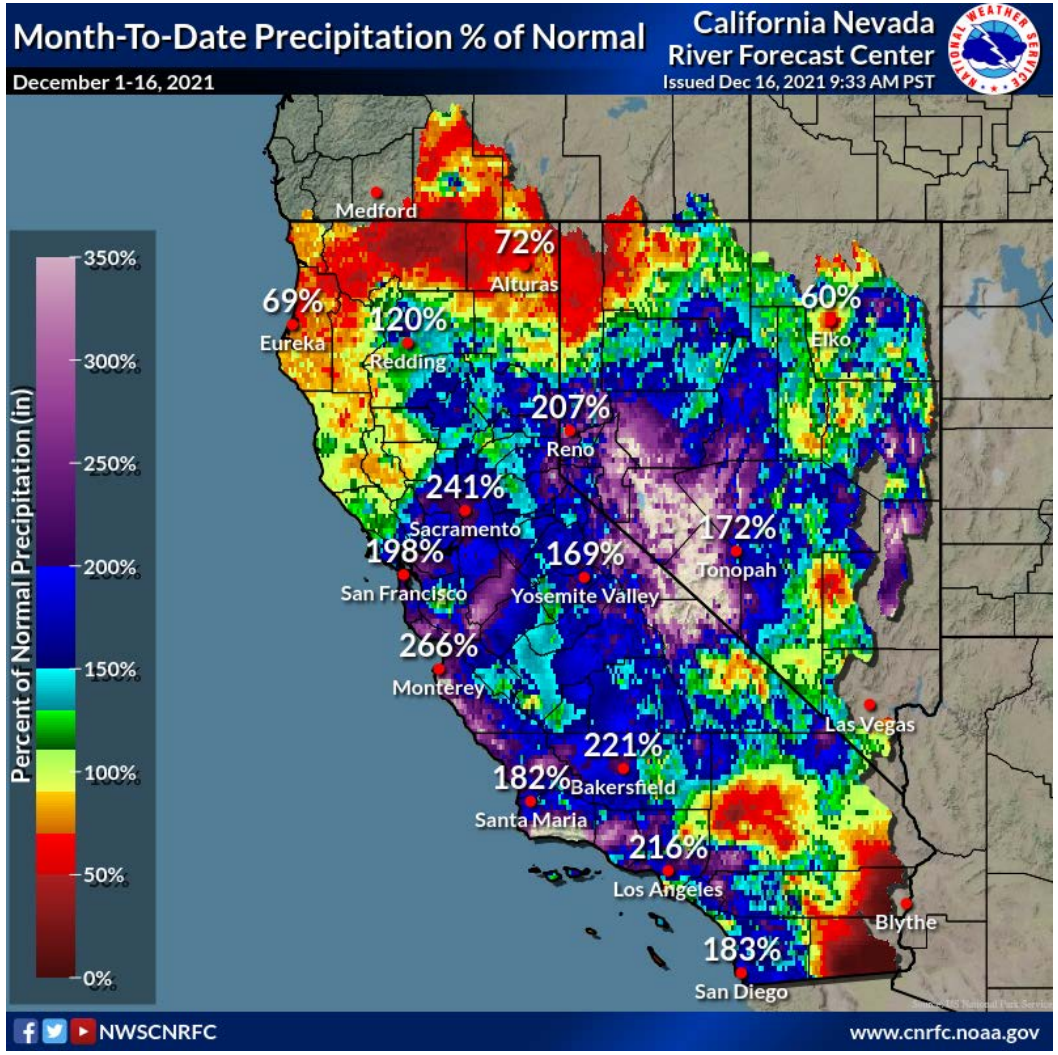
Date	Time	Plan / Action
13-Dec	9:00	Coordination with OCWD to limit release to 250 cfs.
13-Dec	23:00	Action 1. ROC activated
14-Dec	7:30	ROC status = Gates adjusted to limit release to 250 cfs
14-Dec	10:44	Coordination with OCWD to limit release to 200 cfs.
14-Dec	15:24	ROC status = Gates adjusted to limit release to 200 cfs
14-Dec	23:56	Action 2. ROC deactivated
15-Dec	9:00	Action 3. Releases increased to 600 cfs.
15-Dec	15:05	Action 4. Notification to stakeholders - increase release to 600 cfs

On 15-Dec, OCWD requested a max release of 600 cfs

Details of Decision Points – December 2021

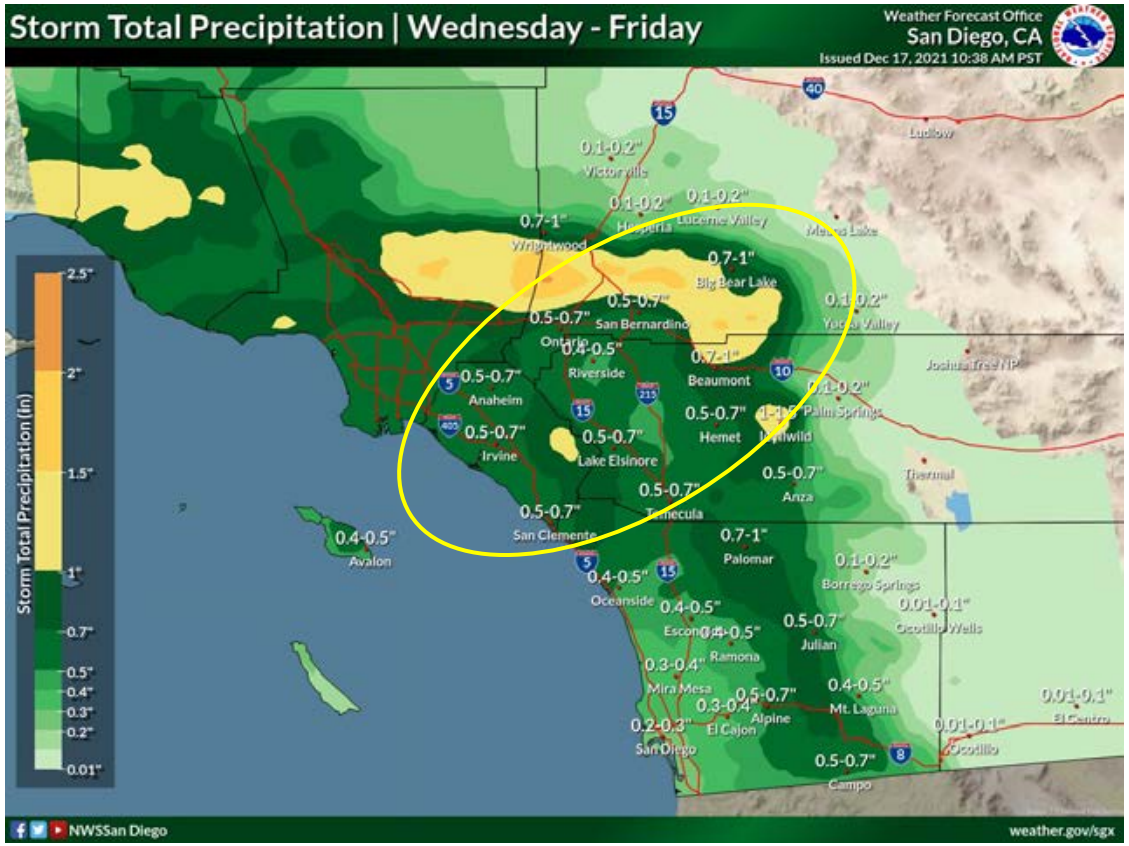
16 December 2021

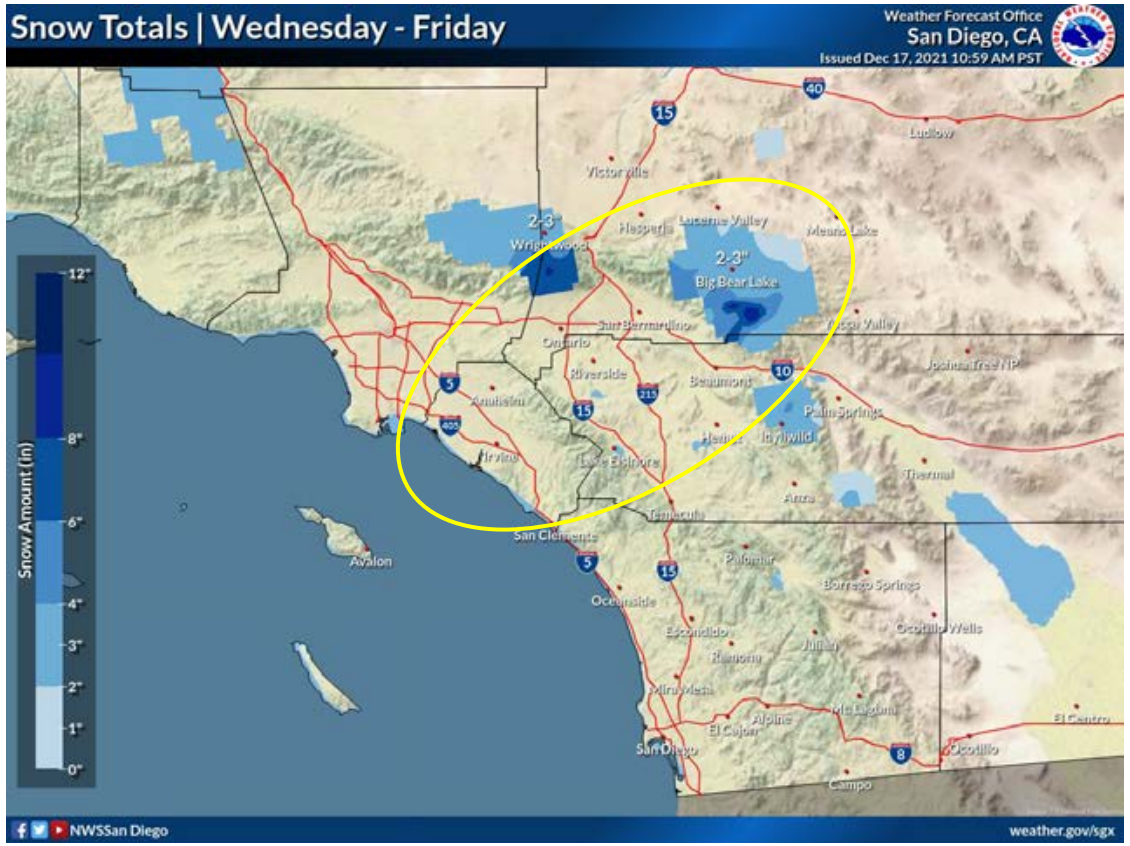




Details of Decision Points – December 2021

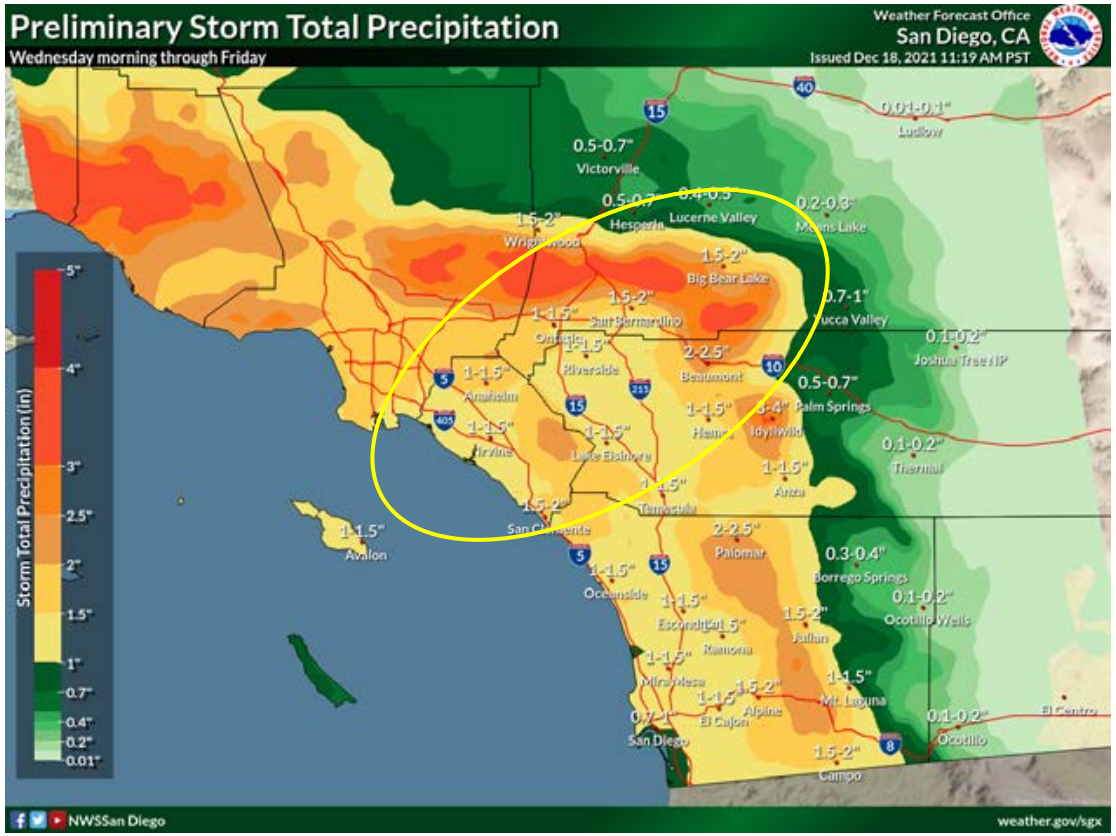
17 December 2021





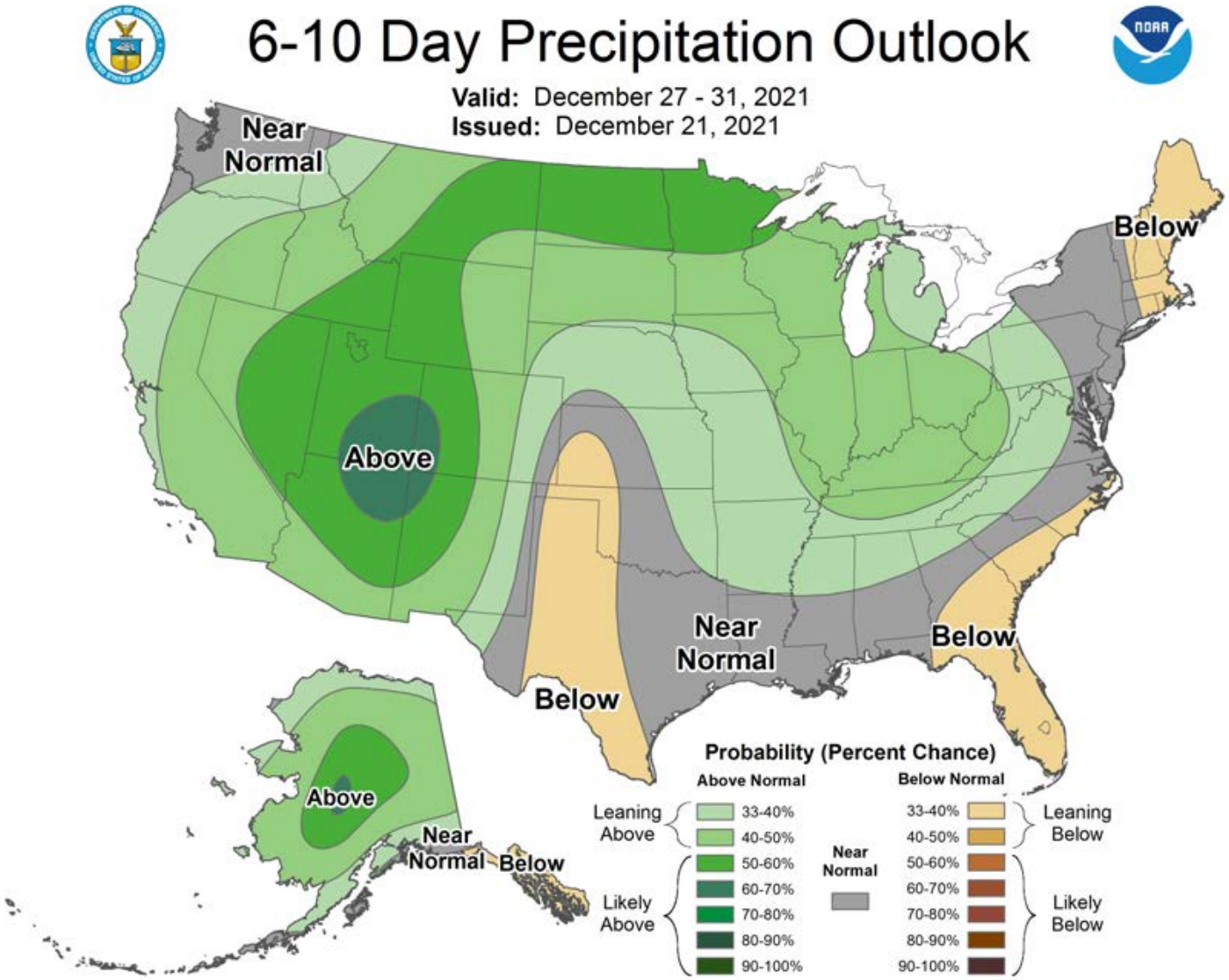
Details of Decision Points – December 2021

18 December 2021



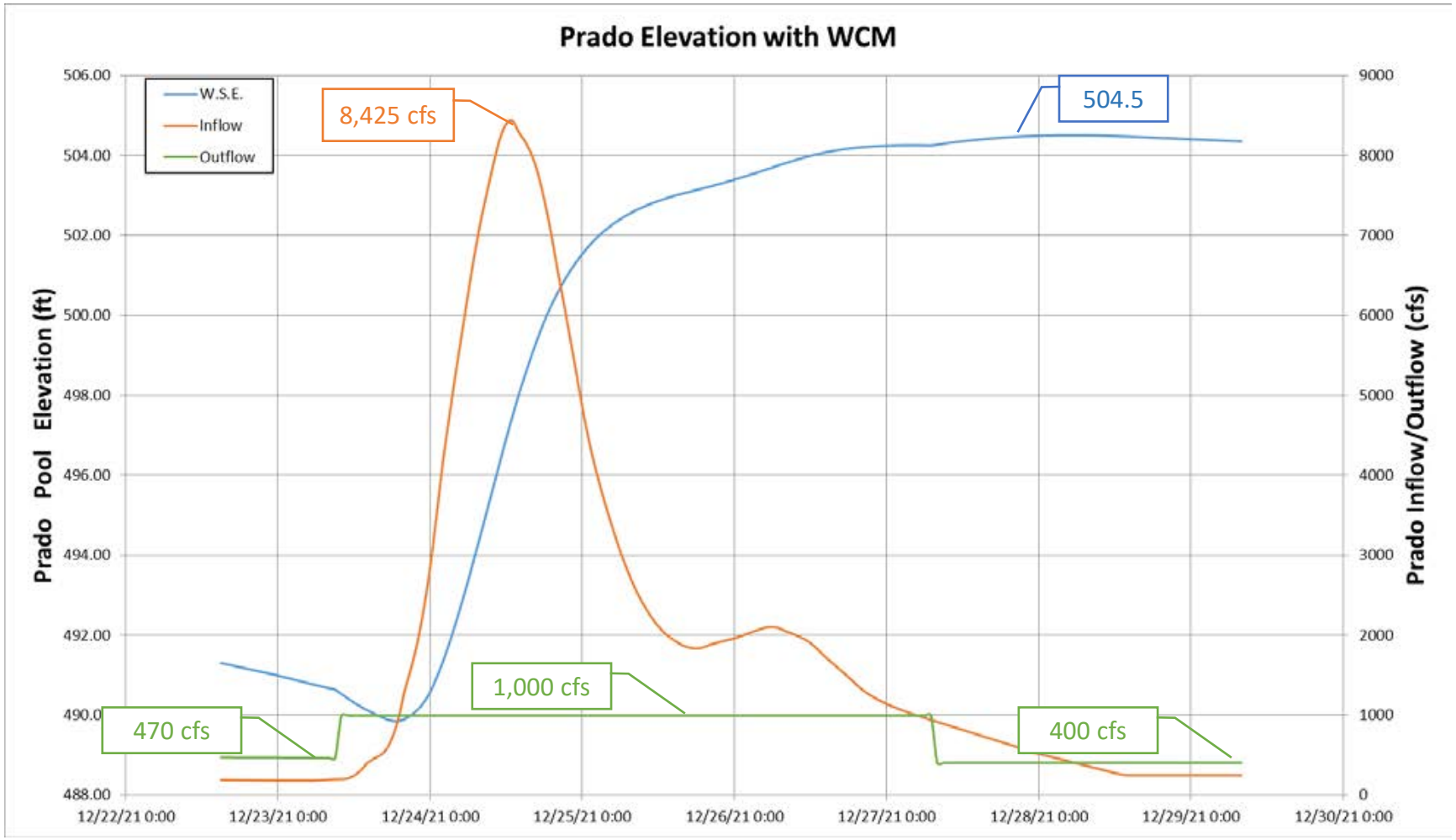
Details of Decision Points – December 2021

21 December 2021



Details of Decision Points – December 2021

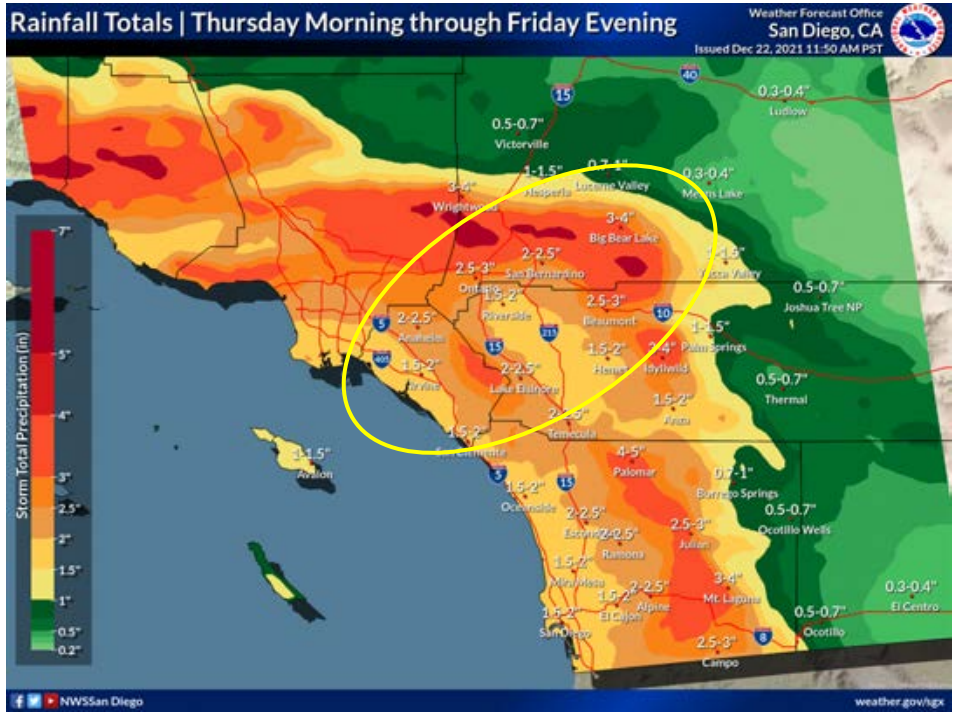
22 DEC 0900 Forecast



Details of Decision Points – December 2021

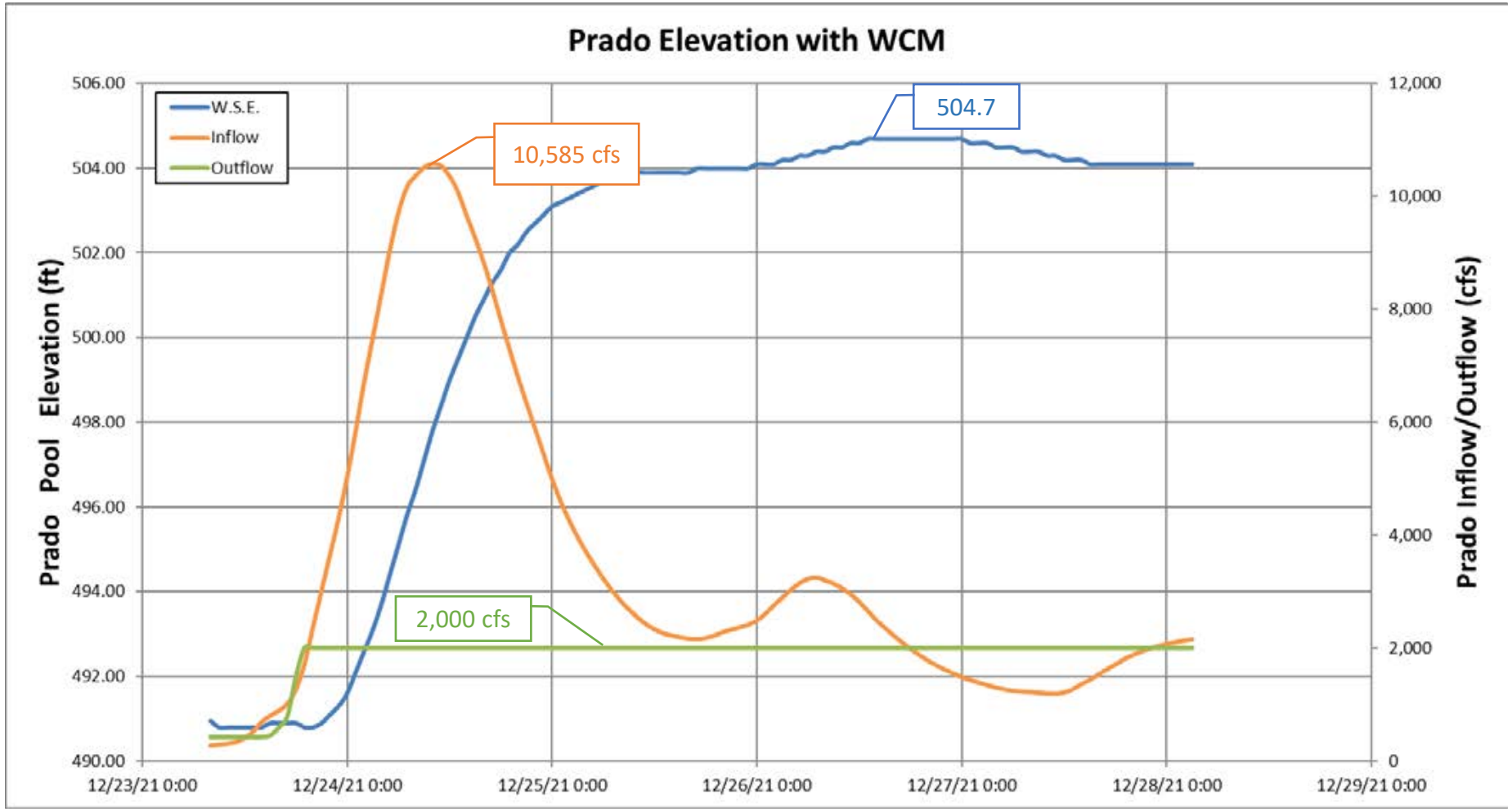
22 December 2021

22-Dec	9:00	22 DEC 2021 0900 Forecast received and used for planning operations. Peak inflow = 8,425 (24 DEC @ 1300). Currently releasing 440 cfs. Plan to increase releases up to 1,000 cfs.
22-Dec	11:49	Coordination with OCWD to reduce release on 23 DEC at 08:00 to 200-250 cfs through Saturday morning. OCWD requesting coordination calls each morning.
22-Dec	18:16	Action 5. Notification to stakeholders - increase release to 1,000 cfs beginning 23-DEC morning.
22-Dec	20:26	Received QPF-FOX weather briefing.
23-Dec	7:00	Action 6. ROC activated



Details of Decision Points – December 2021

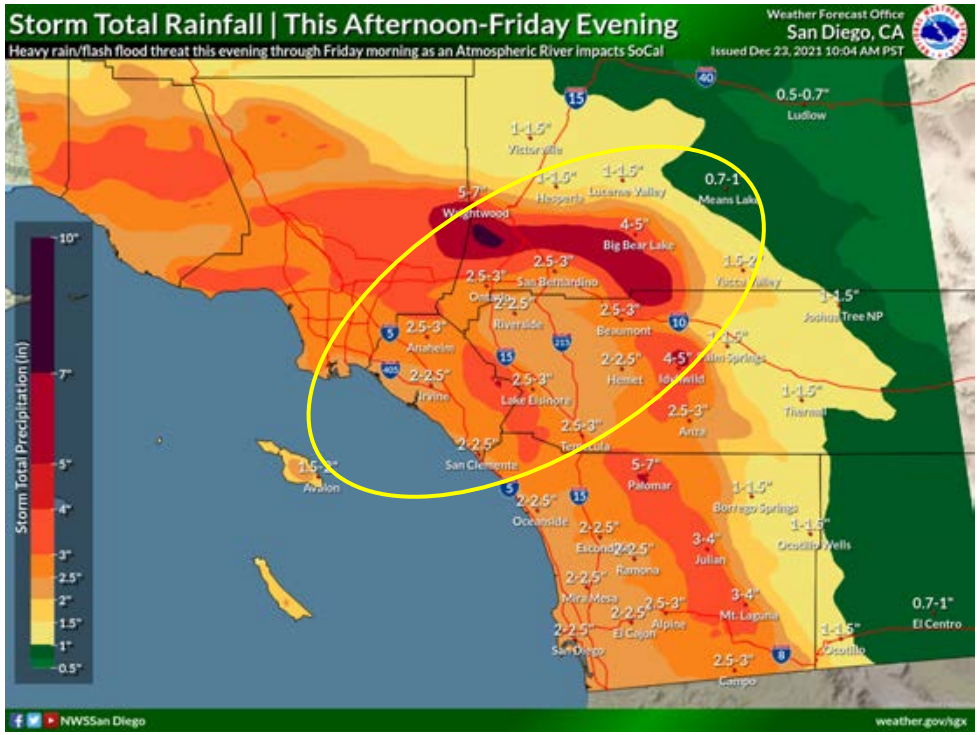
23 DEC 0900 Forecast

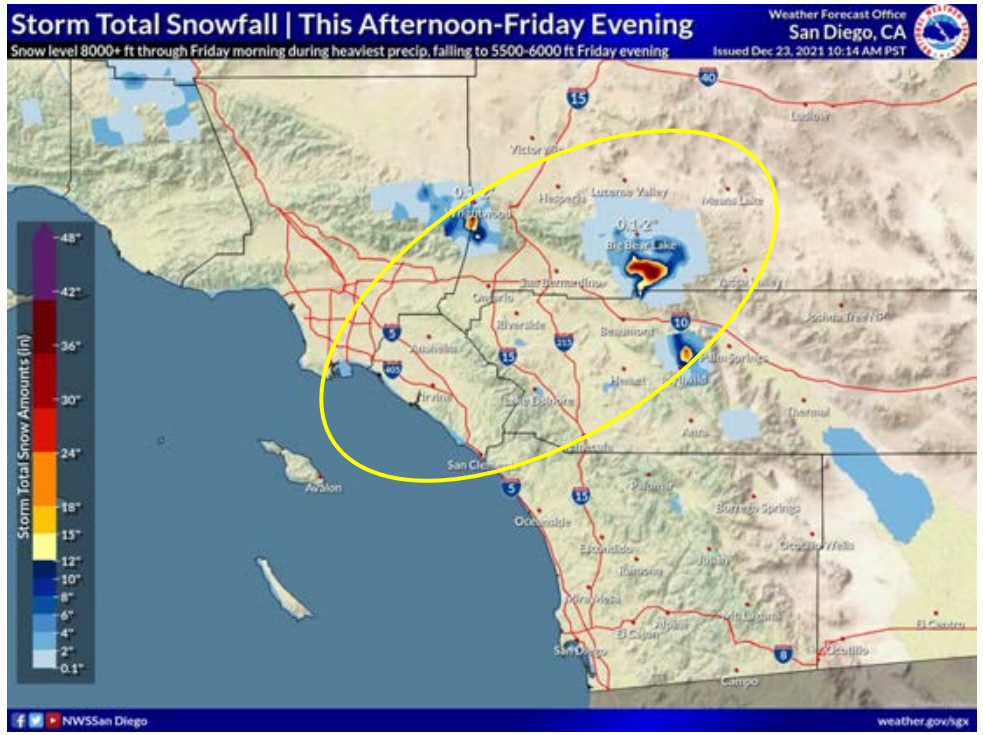


Details of Decision Points – December 2021

23 December 2021

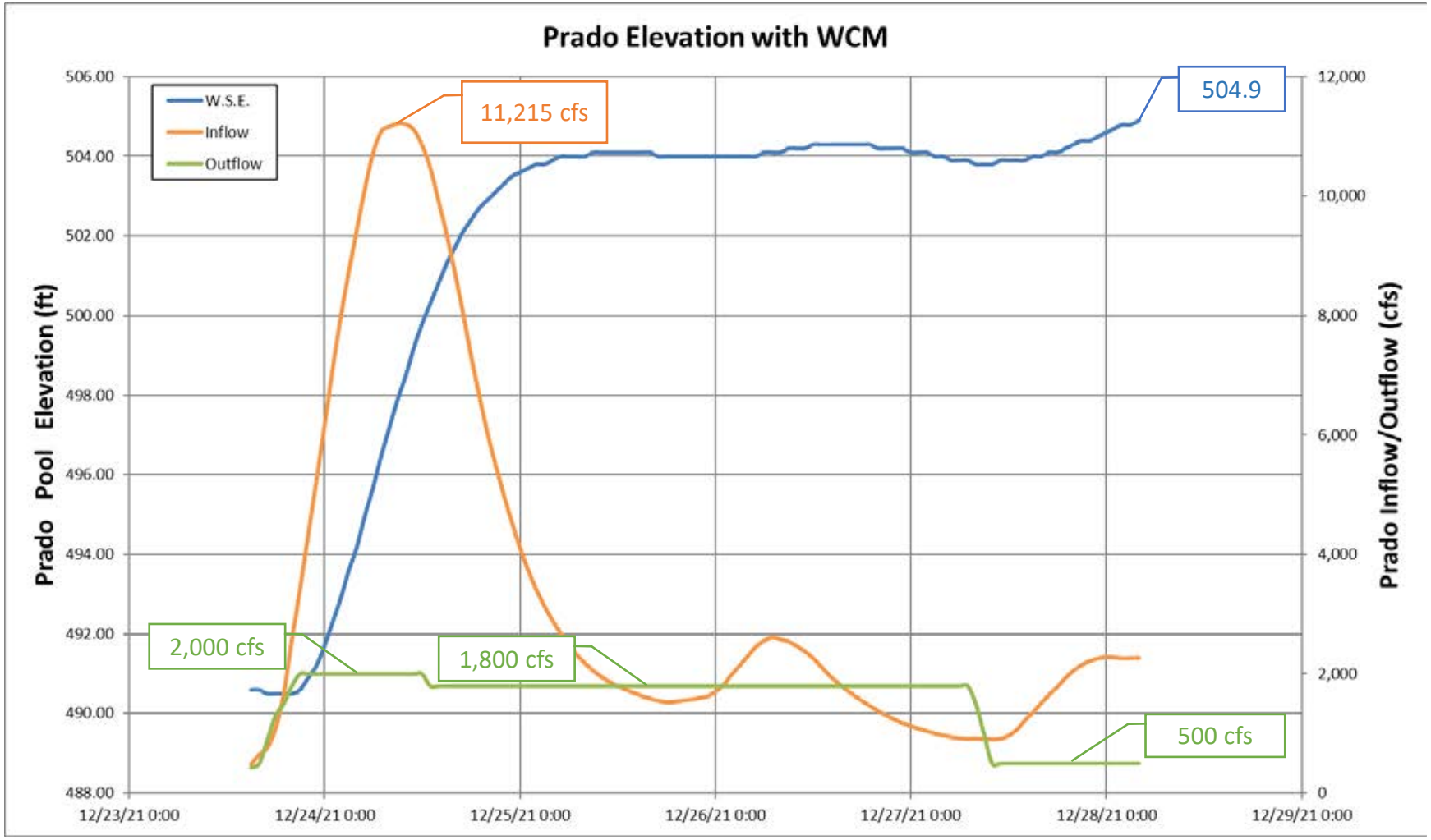
23-Dec	9:00	23 DEC 2021 0900 Forecast received and used for planning operations. Peak inflow = 10,585 (24 DEC @ 1000). Currently releasing 1,800 cfs. Plan to increase to 2,000 cfs.
23-Dec	11:49	Action 7. Notification to stakeholders - increase release to 2,000 cfs starting at 16:00





Details of Decision Points – December 2021

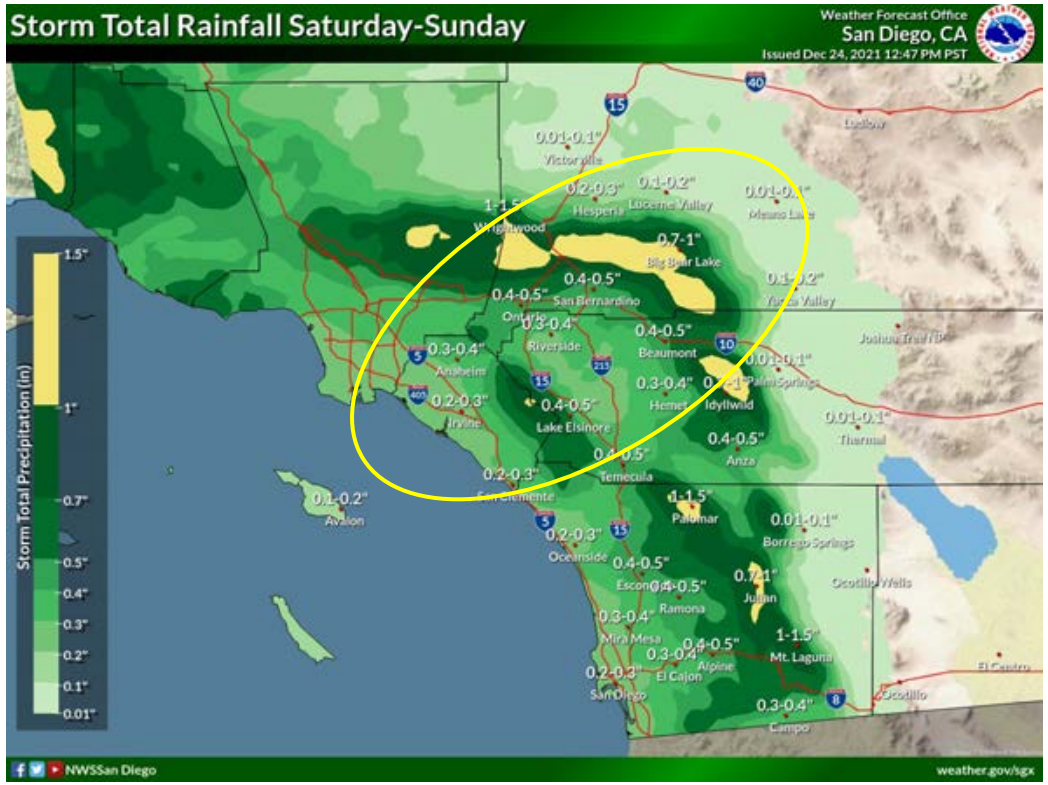
23 DEC 1500 Forecast

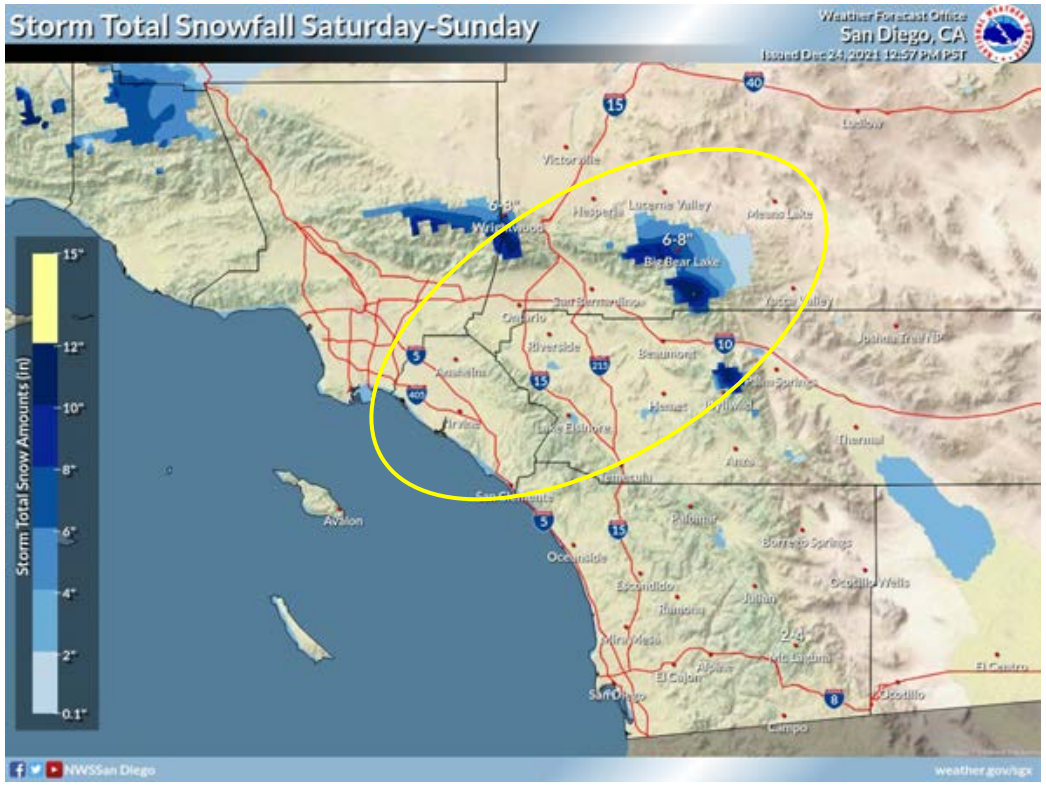


Details of Decision Points – December 2021

23-24 December 2021

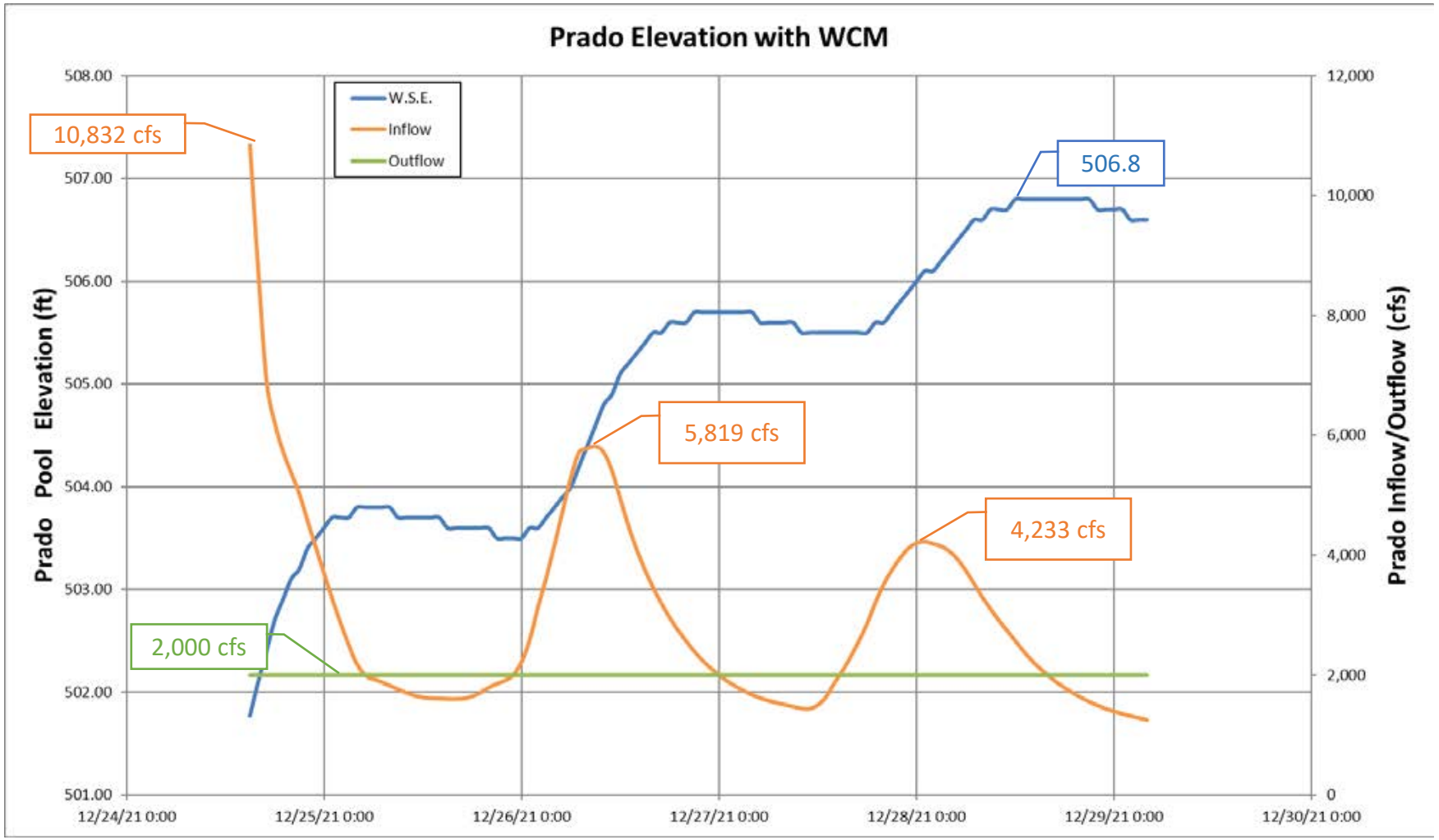
Date	Time	Plan / Action
23-Dec	15:00	23 DEC 2021 1500 Forecast received and used for planning operations. Peak inflow = 11,215 (24 DEC @ 0900). Currently releasing 1,800 cfs. Plan to increase to 2,000 cfs.
23-Dec	16:00	Action 8. Release increased to 1,800 cfs
24-Dec	7:01	Release = 2,000 cfs (due to rising pool)





Details of Decision Points – December 2021

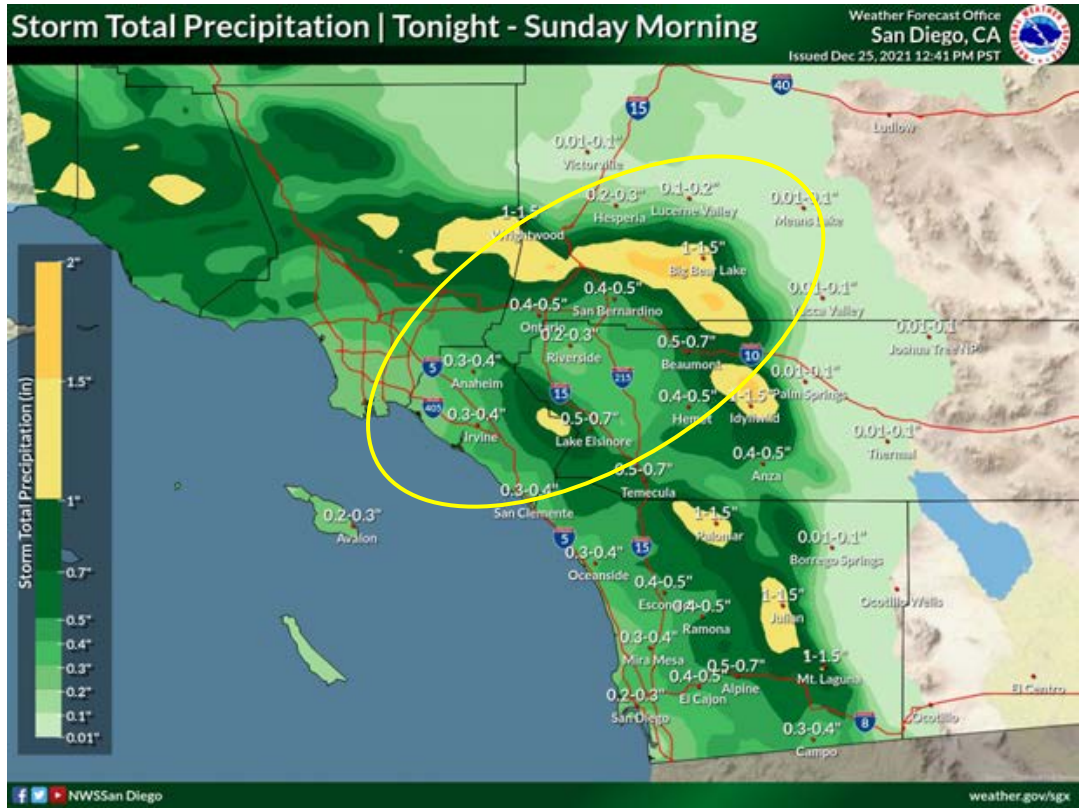
24 DEC 1500 Forecast

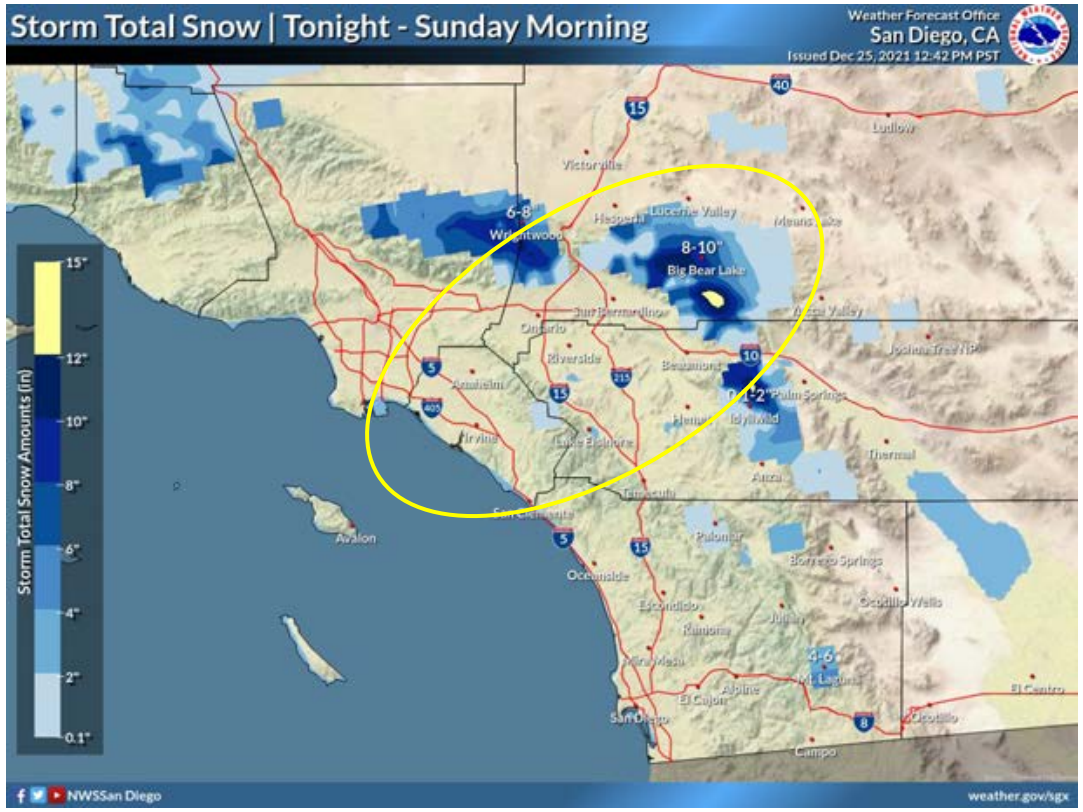


Details of Decision Points – December 2021

24-25 December 2021

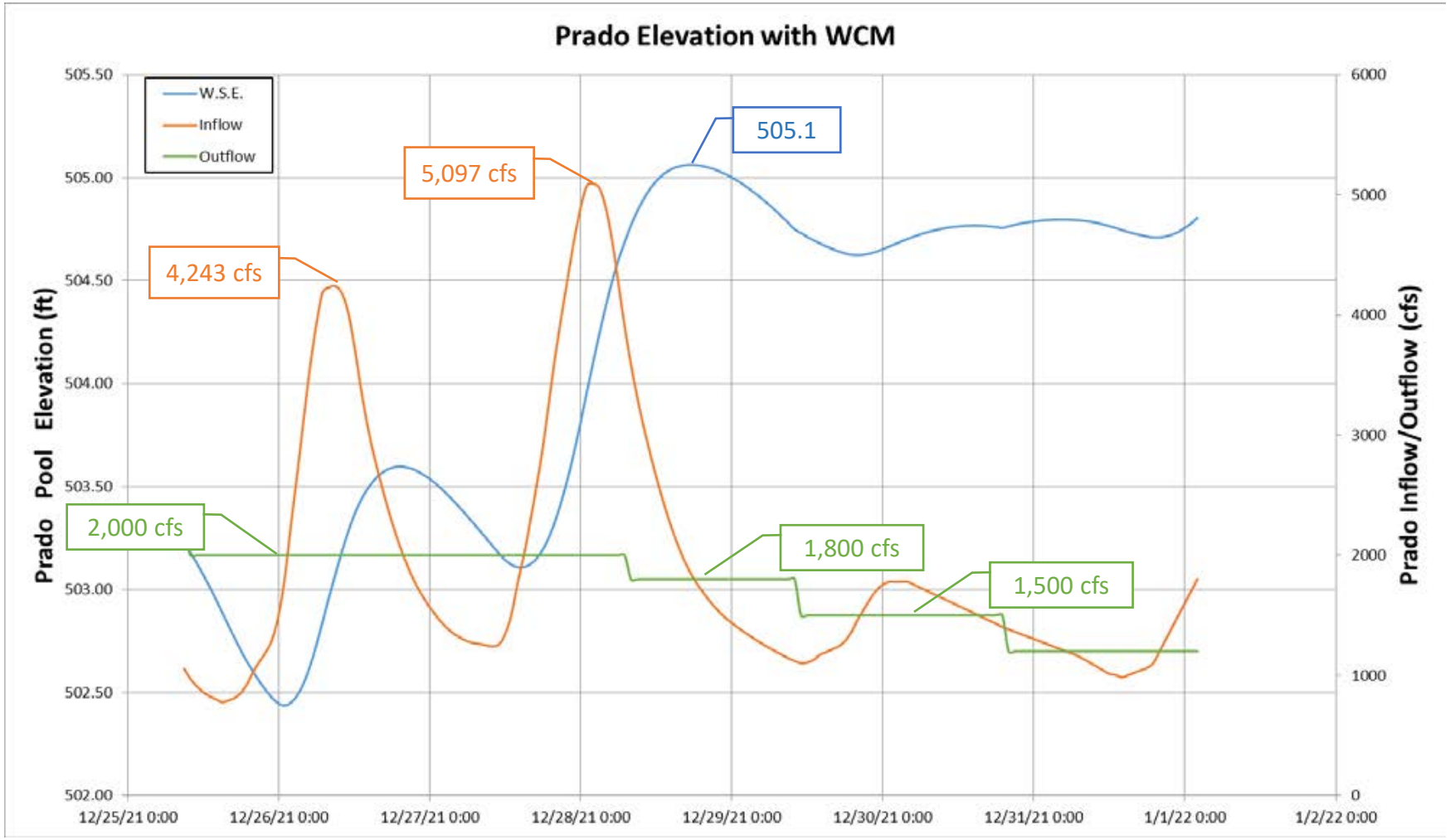
24-Dec	15:00	24 DEC 2021 1500 Forecast received and used for planning operations. Peak inflow = 10,832 cfs (24 DEC @ 1500) but 2 smaller peaks following with 5,819 cfs (26 DEC @ 0900) and 4,233 cfs (28 DEC @ 0100). Currently releasing 2,350 cfs. Plan to leave release at around 2,000 cfs.
24-Dec	15:05	Swift Water Rescue working on a retrieval in the lower Santa Ana River. Received call from OC Fire Authority. At this time, we have not been requested to adjust project operations.
25-Dec	0:15	Action 9. Gates pinched to limit outflow to about 2,000 cfs





Details of Decision Points – December 2021

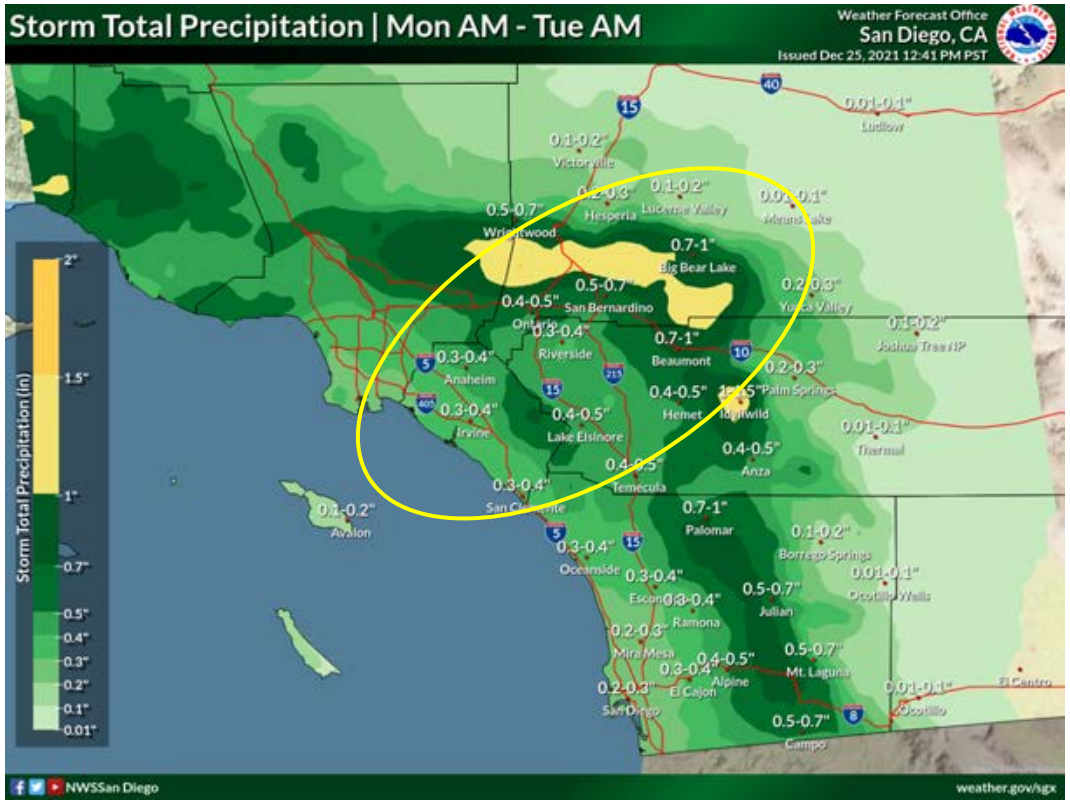
25 DEC 0900 Forecast

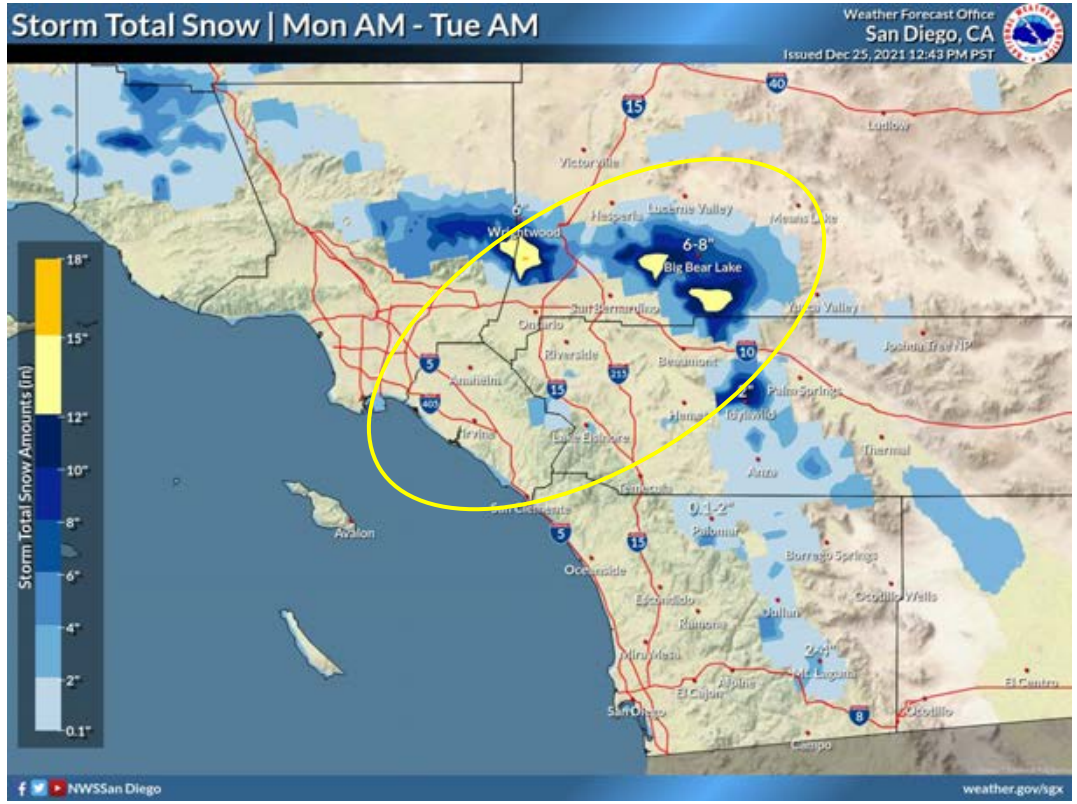


Details of Decision Points – December 2021

25 December 2021

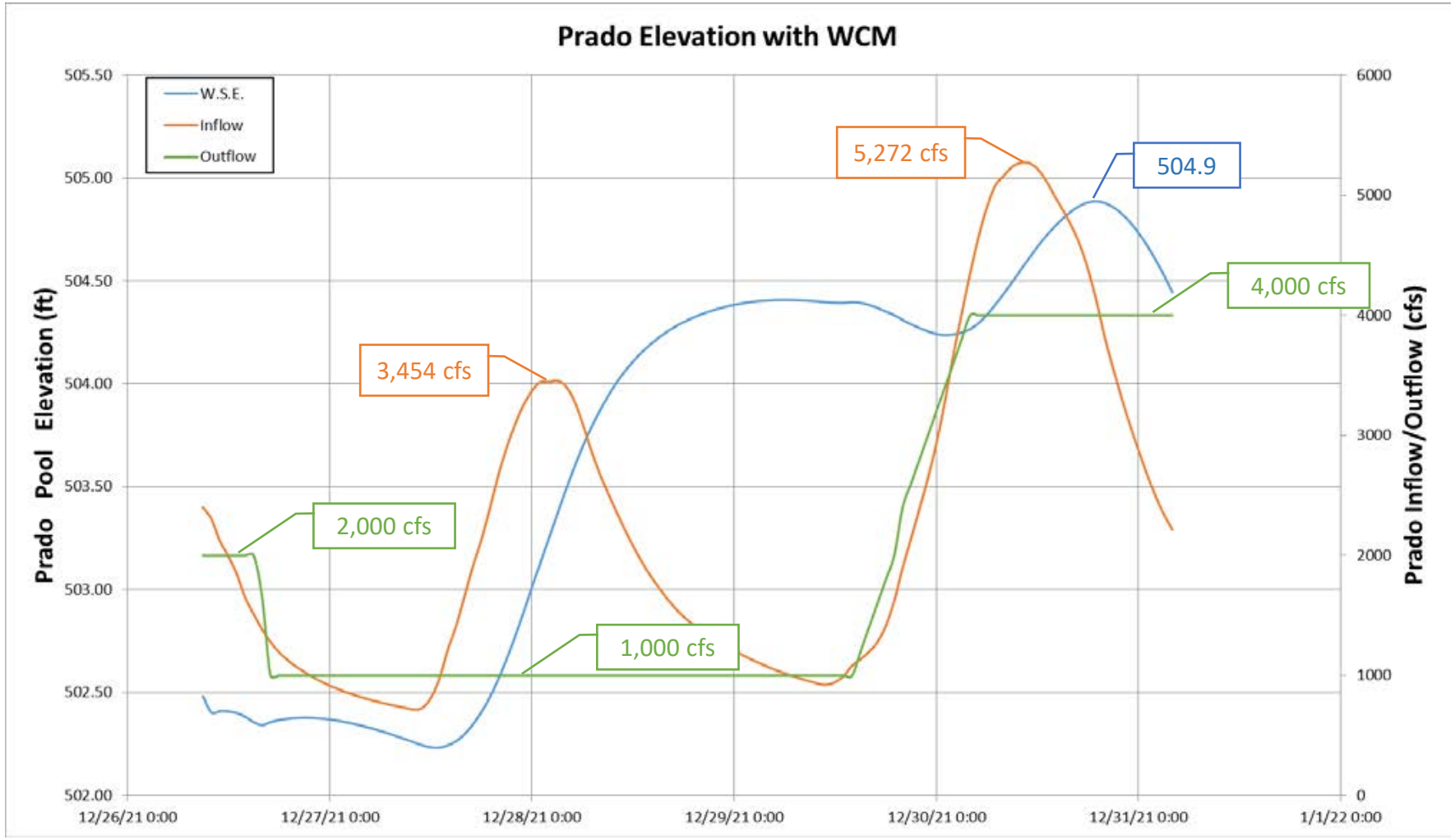
25-Dec	9:00	25 DEC 2021 0900 Forecast received and used for planning operations. Peak inflow = 4,243 (26 DEC @ 0900) and 5,097 cfs (28 DEC @ 0200). Currently releasing 2,000 cfs. Plan to reduce release to 1,800 cfs on 28-DEC at 08:00, then to 1,500 cfs on 29-DEC at 11:00.
25-Dec	1:15	Action 10. Gates raised a few inches
25-Dec	10:10	Action 11. Gates pinched to limit outflow





Details of Decision Points – December 2021

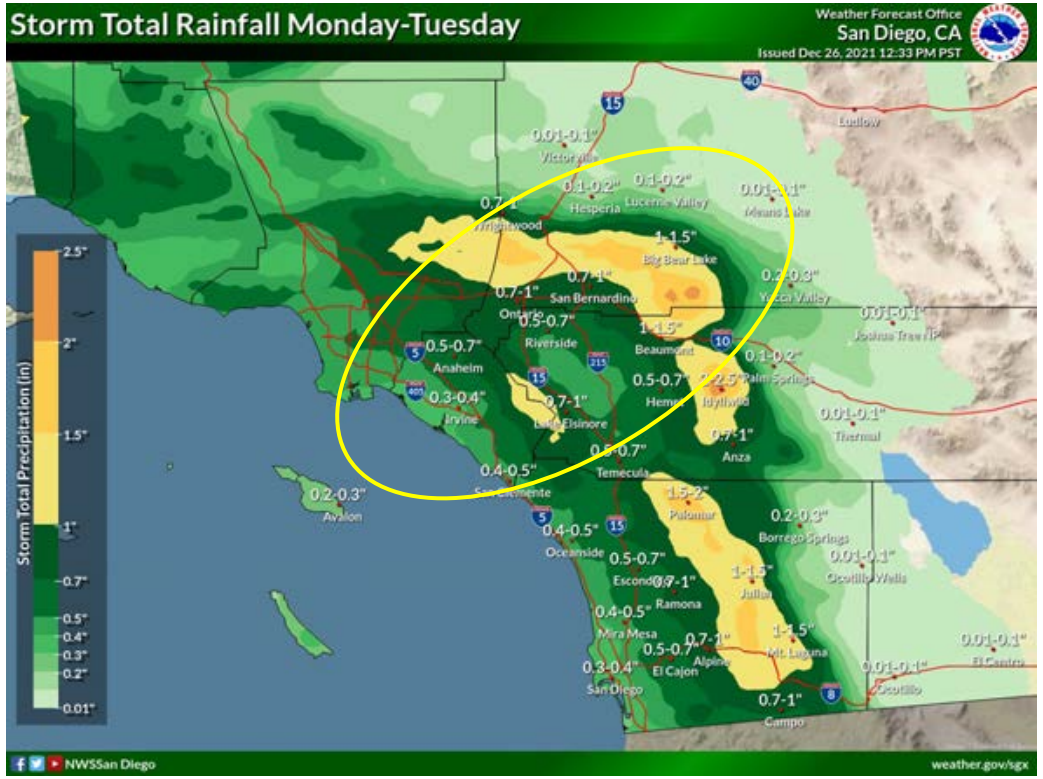
26 DEC 0900 Forecast

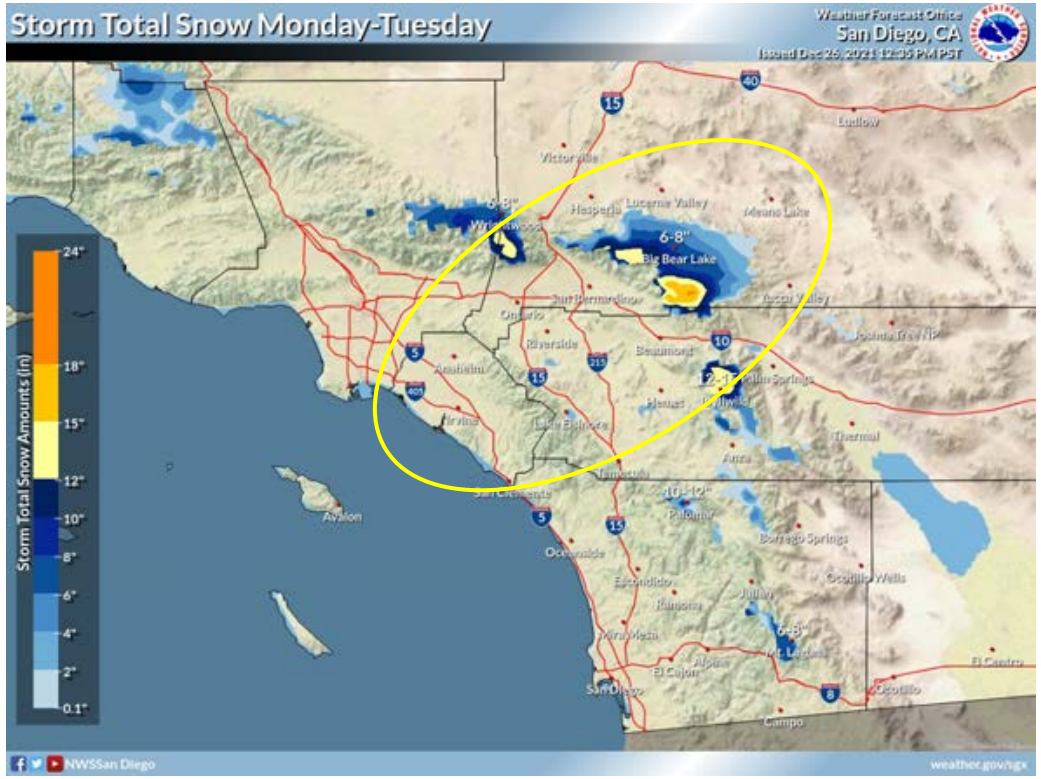


Details of Decision Points – December 2021

26-27 December 2021

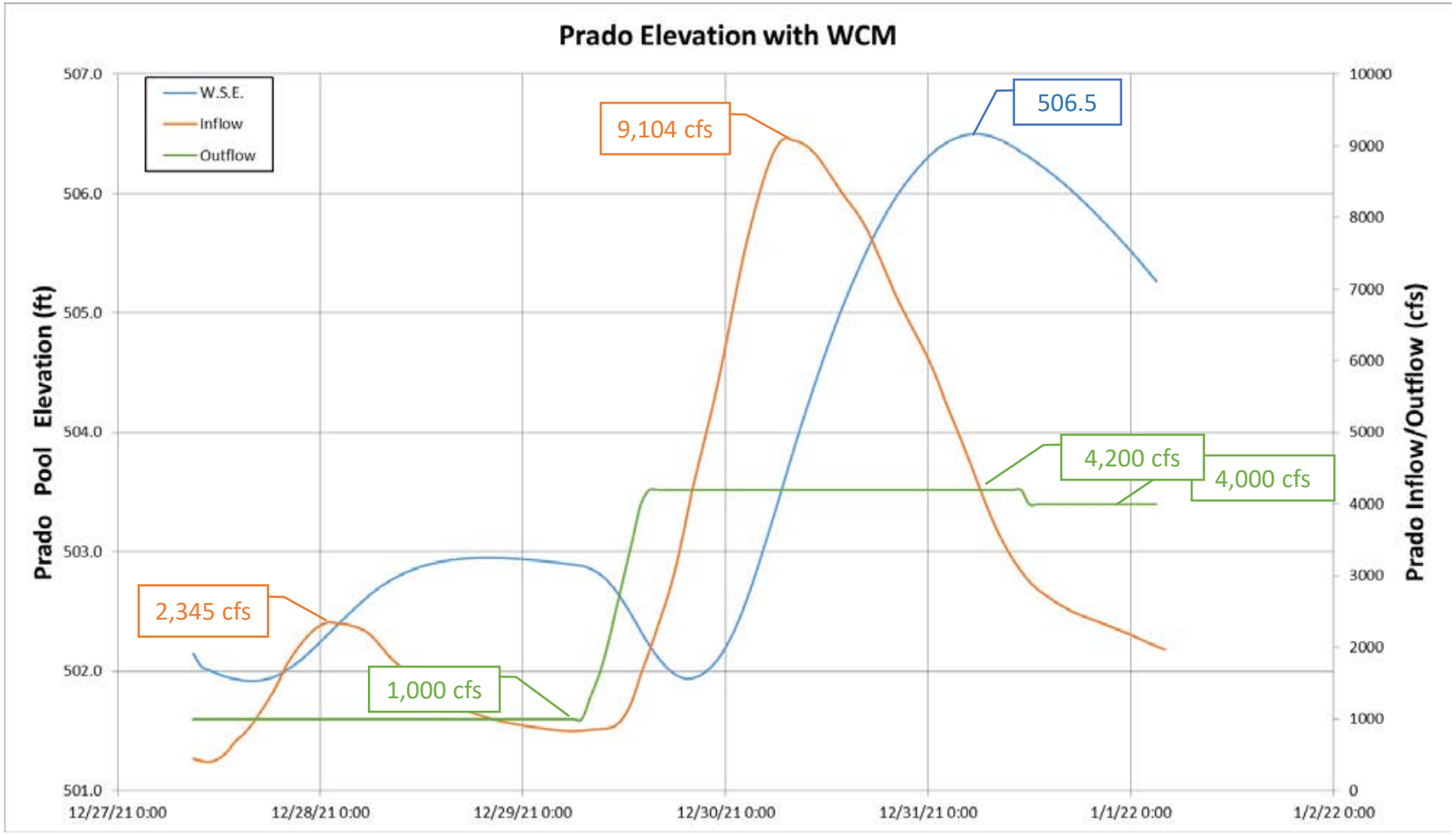
26-Dec	9:00	26 DEC 2021 0900 Forecast received and used for planning operations. Peak inflow = 3,454 (28 DEC @ 0300) and 5,272 cfs (30 DEC @ 1000). Currently releasing 1,000 cfs. Expecting to maintain 1,000 cfs and then increase to 4,000 cfs on 29-DEC at 15:00
26-Dec	16:09	Action 12. Notification to stakeholders - reduce release to 1,000 cfs at 18:00. Started reducing at 15:00 (1,000 cfs achieved at 18:00).
26-Dec	18:40	Action 13. ROC deactivated
27-Dec	7:39	Action 14. ROC activated, then deactivated a few hours later.





Details of Decision Points – December 2021

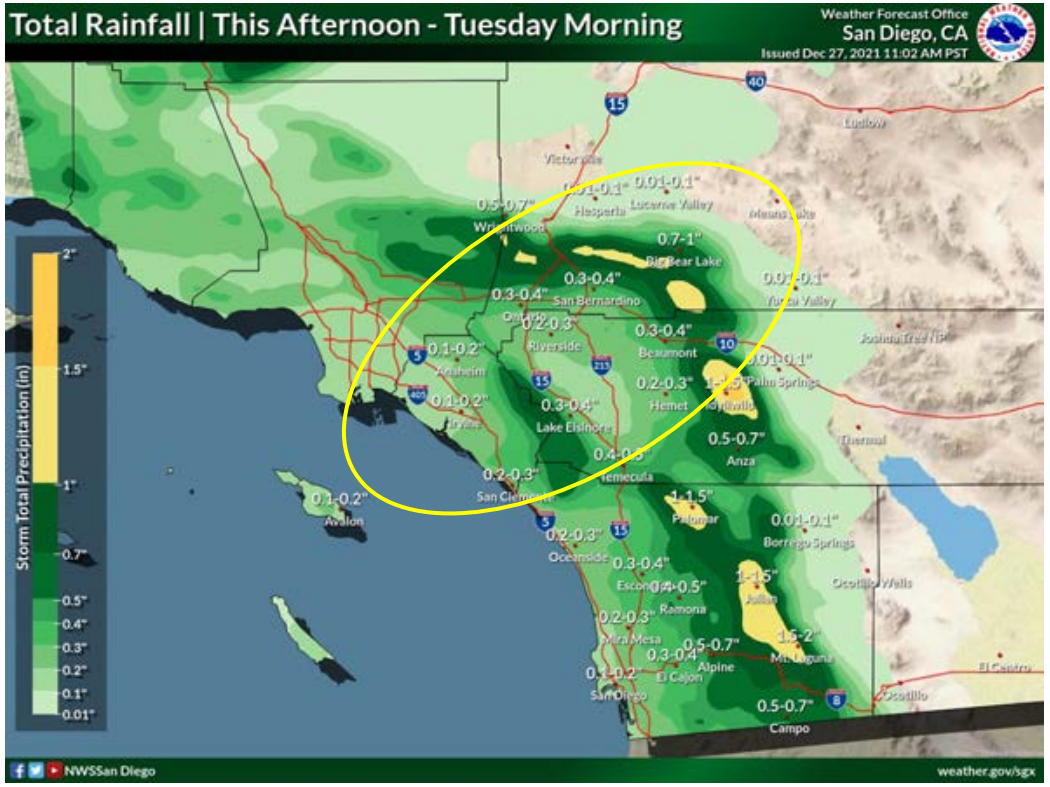
27 DEC 0900 Forecast

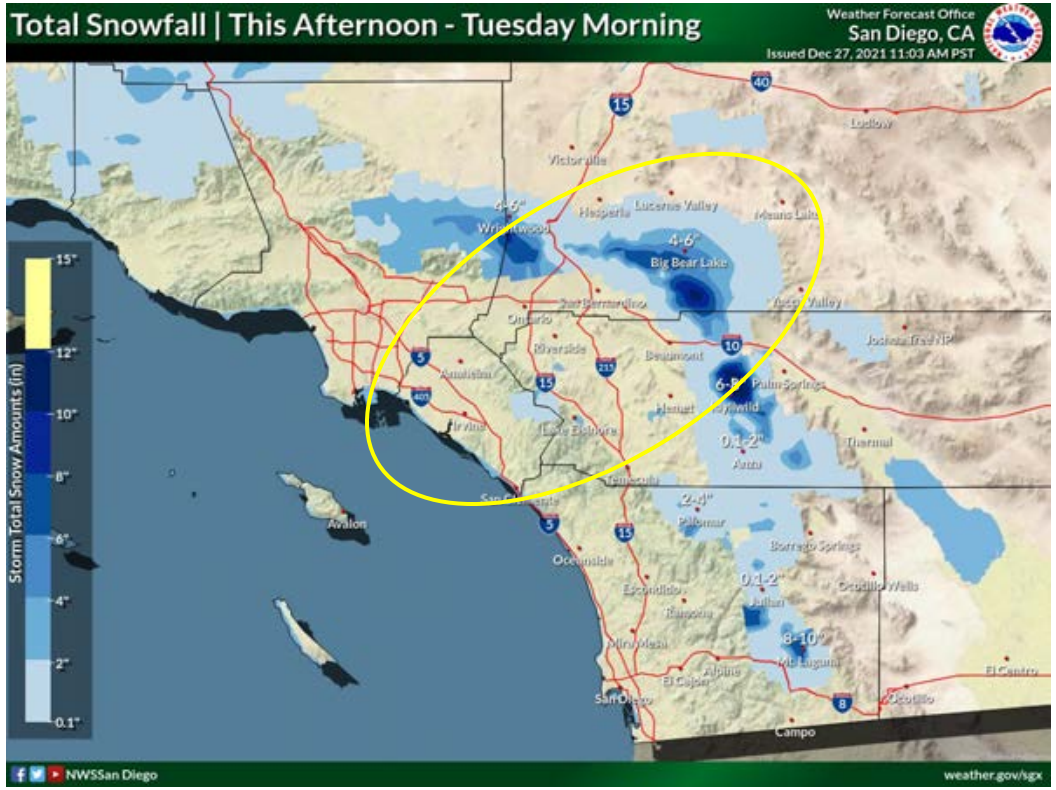


Details of Decision Points – December 2021

27-28 December 2021

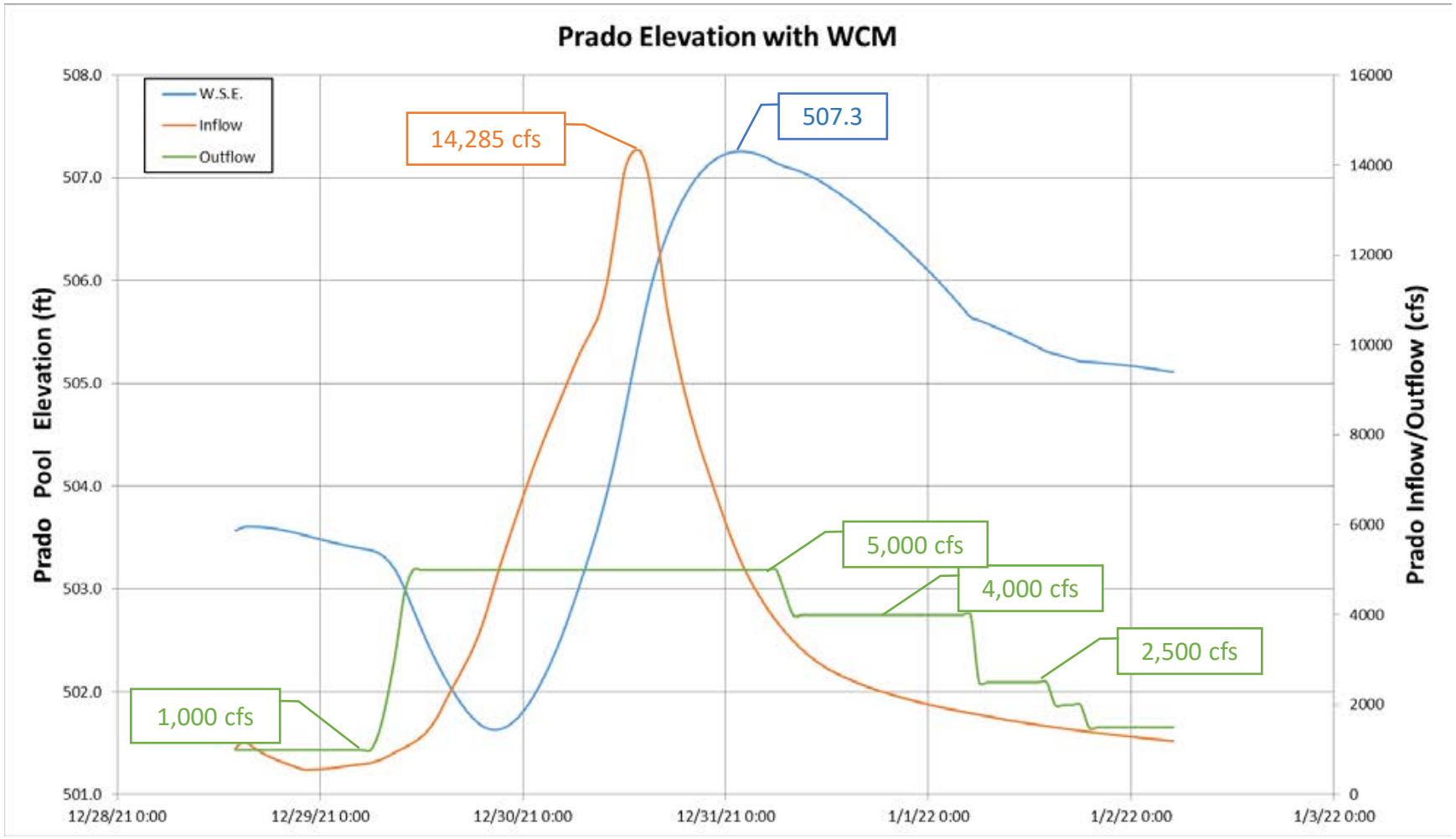
Date	Time	Plan / Action
27-Dec	9:00	27 DEC 2021 0900 Forecast received and used for planning operations. Peak inflow = 2,345 (28 DEC @ 0100) and 9,104 cfs (30 DEC @ 0700). Currently releasing 1,000 cfs. Expecting to maintain 1,000 cfs and then increase to 4,200 cfs on 29-DEC at 08:00, then reduce to 4,000 cfs on 31-DEC at 12:00.
28-Dec	11:09	Action 15. Notification to stakeholders - increase release to 5,000 cfs starting on 29-DEC at 07:00.
28-Dec		Action 16. Channel watch team preparing for activation on 29-DEC, to observe releases of 5,000 cfs.





Details of Decision Points – December 2021

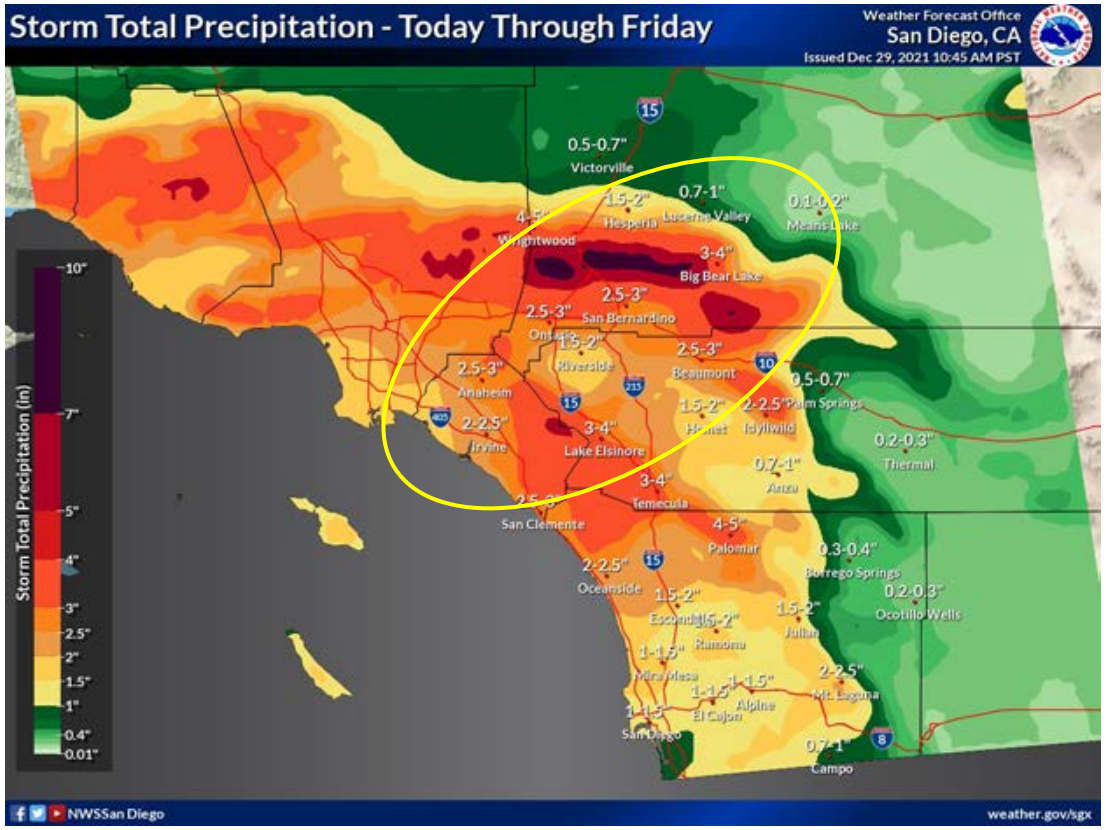
28 DEC 1400 Forecast

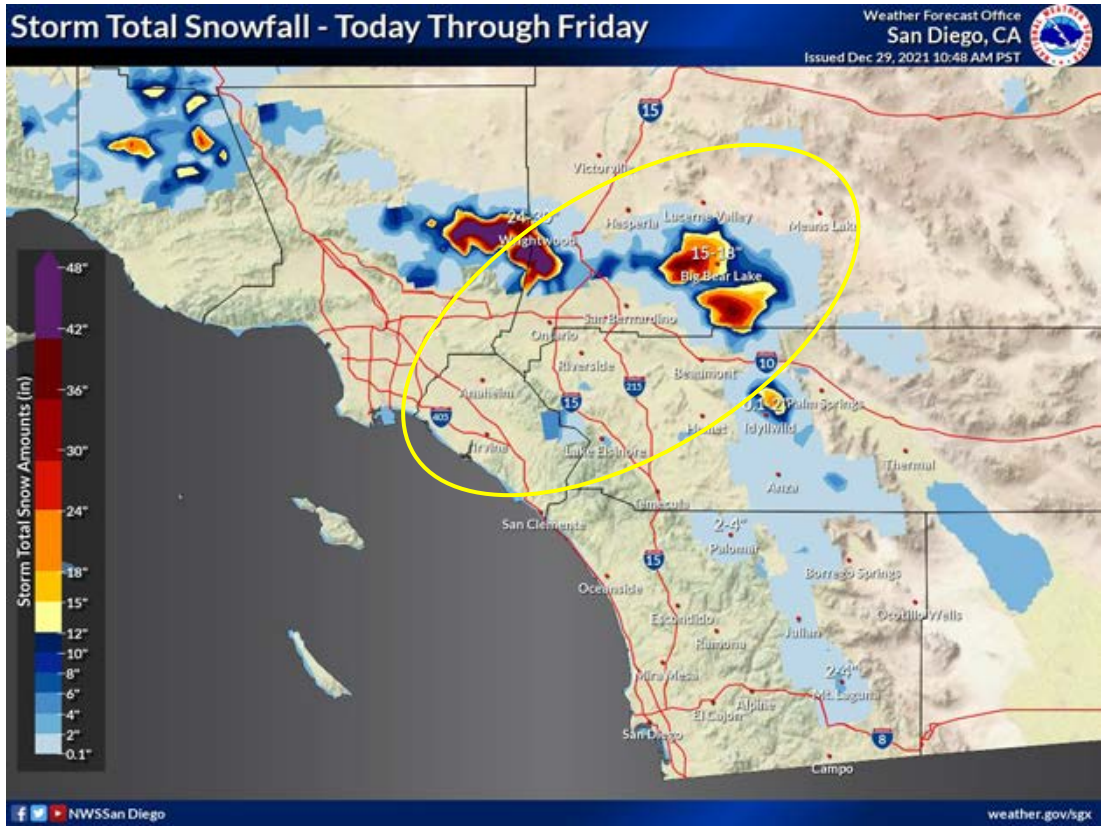


Details of Decision Points – December 2021

28-29 December 2021

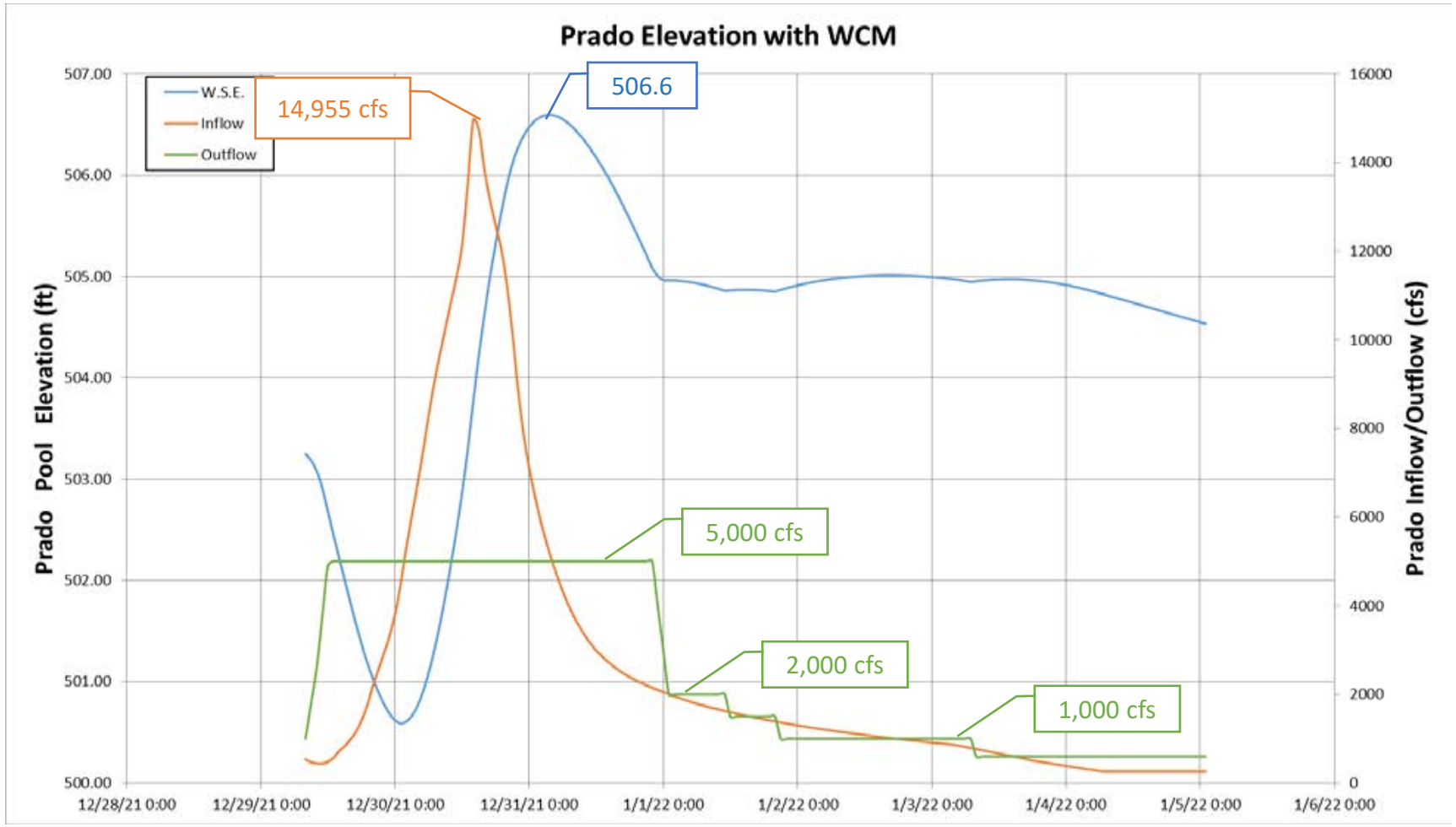
28-Dec	14:00	28 DEC 2021 1400 Forecast received and used for planning operations. Peak inflow = 14,285 (30 DEC @ 1300). Currently releasing 1,000 cfs. Expecting to maintain 1,000 cfs and then increase to 5,000 cfs on 29-DEC at 07:00, then reduce to 4,000 cfs on 31-DEC at 06:00, then to 2,500 cfs on 01-JAN at 06:00.
29-Dec	8:22	Action 17. ROC activated and release increased to 5,000 cfs





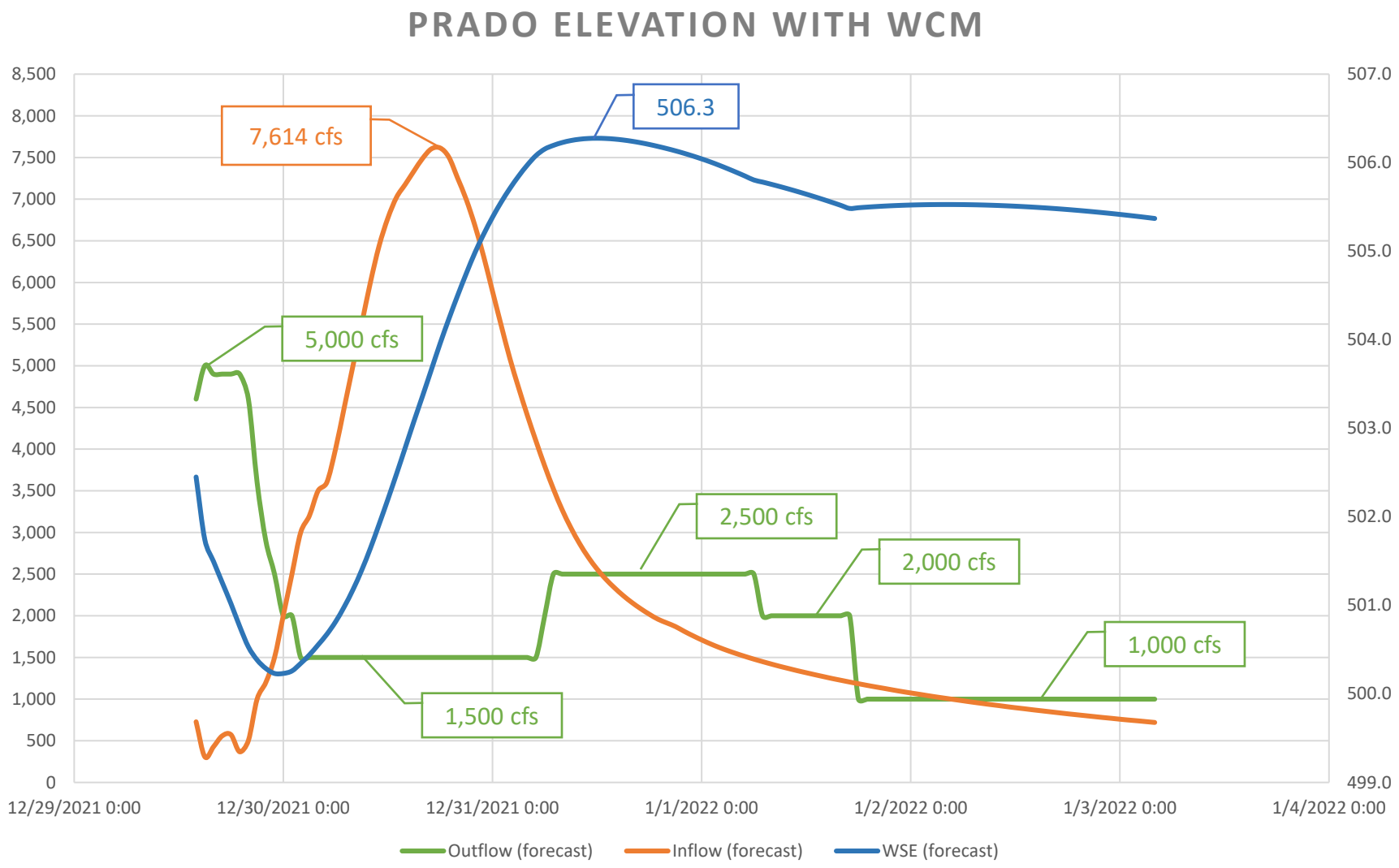
Details of Decision Points – December 2021

29 DEC 0900 Forecast



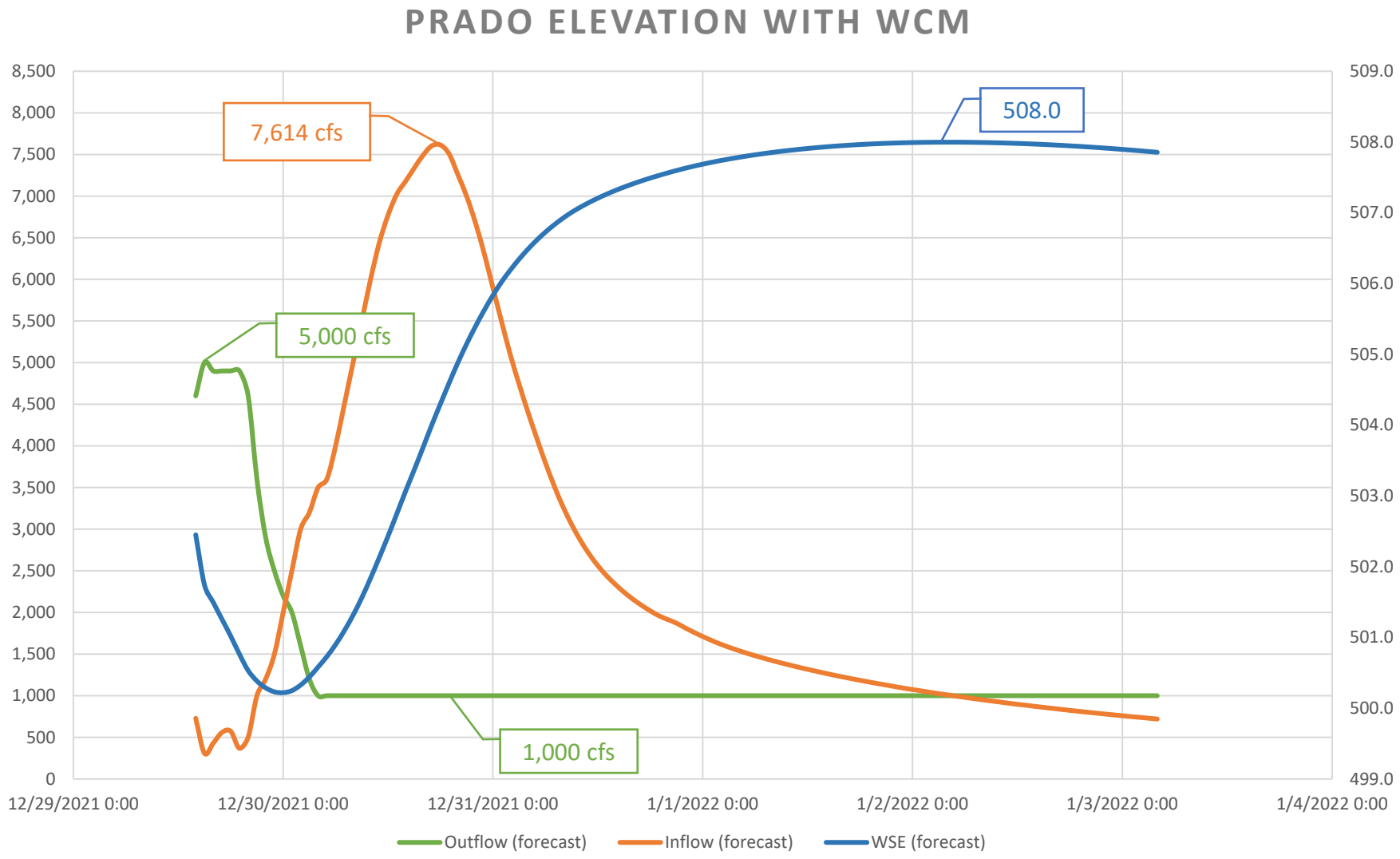
Details of Decision Points – December 2021

29 DEC 1400 Forecast



Details of Decision Points – December 2021

29 DEC 1400 Forecast



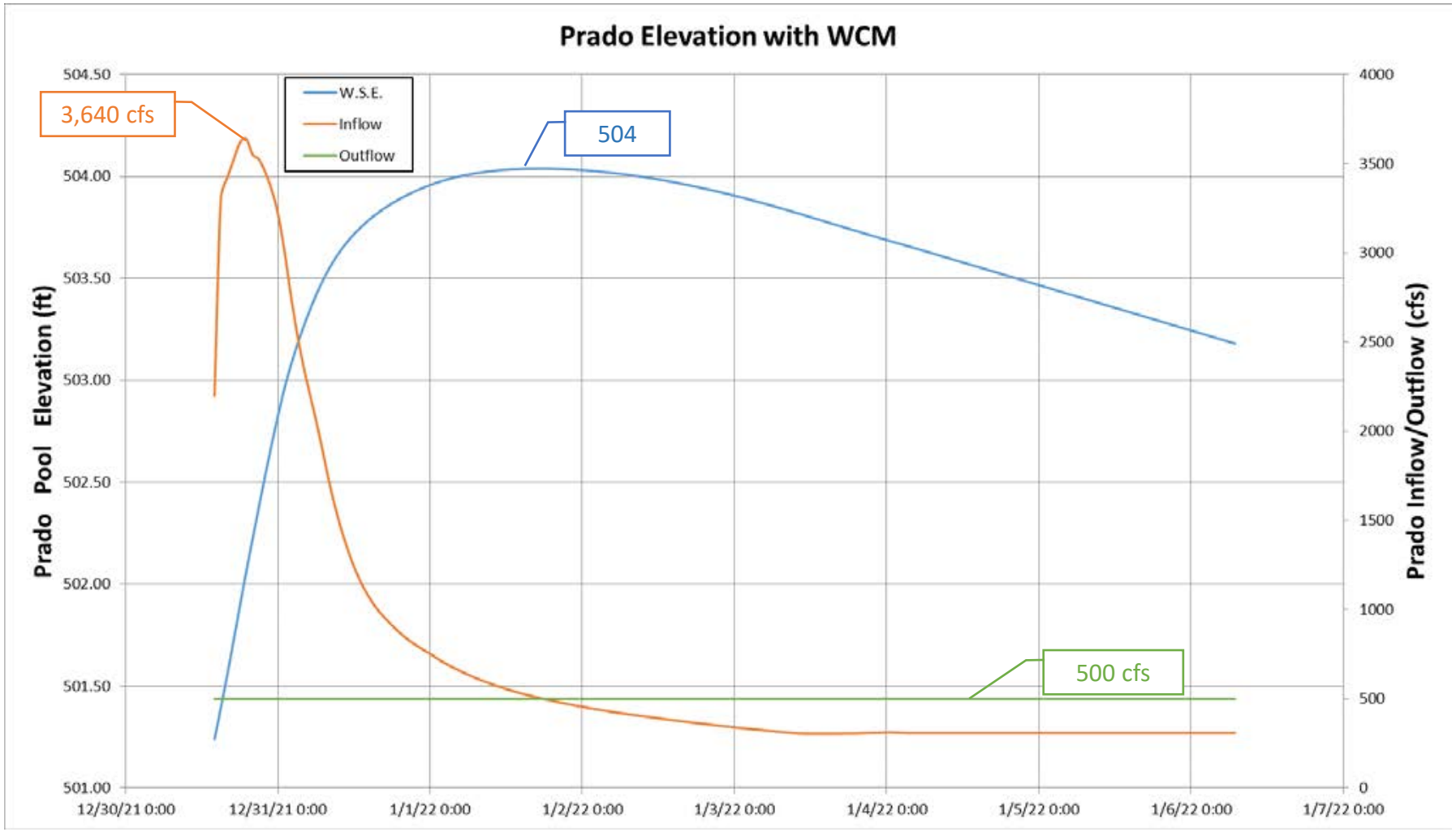
Details of Decision Points – December 2021

29-30 December 2021

29-Dec	9:00	29 DEC 2021 0900 Forecast received and used for planning operations. Peak inflow = 14,955 (30 DEC @ 1400). Currently releasing 1,000 cfs. Expecting to maintain 1,000 cfs and then increase to 5,000 cfs on 29-DEC at 07:00, then reduce to 4,000 cfs on 31-DEC at 06:00, then to 2,500 cfs on 01-JAN at 06:00.
29-Dec	14:00	29 DEC 2021 1400 Forecast received and used for planning operations. Peak inflow = 7,614 (30 DEC @ 1800). Currently releasing 5,000 cfs, immediate reduction to 1,500 cfs until 31-DEC at 05:00, then increase to 2,500 cfs until 01-JAN at 06:00, then to 2,000 cfs until 17:00, then to 1,000 cfs until further notice.
29-Dec	14:00	29 DEC 2021 1400 Forecast received and used for planning operations. Peak inflow = 7,614 (30 DEC @ 1800). Currently releasing 5,000 cfs, immediate reduction to 1,000 cfs until further notice.
29-Dec	19:20	Action 18. Notification to stakeholders - reduce release 3,000 cfs
29-Dec	21:59	Action 19. Notification to stakeholders - reduce release 2,500 cfs at 22:00, then to 2,000 cfs by 23:00.
29-Dec	22:19	
30-Dec	3:01	Action 20. Notification to stakeholders - reduce release 1,000 cfs
30-Dec	9:42	Action 21. Notification to stakeholders - reduce release 550 cfs

Details of Decision Points – December 2021

30 DEC 1400 Forecast



Details of Decision Points – December 2021

30 December 2021 – 01 January 2022

30-Dec	14:00	30 DEC 2021 1400 Forecast received and used for planning operations. Peak inflow = 3,640 (30 DEC @ 1900). Currently releasing 550 cfs. Expecting to decrease to 500 cfs and maintain that until futher notice.
1-Jan	22:20	Action 22. ROC deactivated

Prado Dam FIRO Decision Support Tools
Workshop #2
September 12, 2022
18700 Ward St, Laboratory conference room, L-1
Fountain Valley, CA

Join Zoom Meeting:
https://ucsd.zoom.us/j/96601086578

9:00-9:10	**Welcome and Introductions**
9:10-9:50	**Discussion of results of previous workshop (Chris Delaney)**
9:50-10:00	**Observations – Enhanced streamflow monitoring (Garrett McGurk)**
10:00-10:10	Discussion of Observations for Prado Dam FIRO
10:10-10:25	**Break**

ATMOSPHERIC TOOLS

10:25-10:55	**CW3E Atmospheric River Tools – Integrated Vapor Transport, AR Landfall, AR Scale (Brian Kawzenuk)**
10:55-11:05	Discussion of CW3E Atmospheric Tools for Prado Dam FIRO (Group)
11:05-11:35	**West-WRF (Rachel Weihs)**
11:35-11:45	Discussion of West-WRF for Prado Dam FIRO (Group)
11:45-12:00	**QPF Verification (Brett Whitin)**
12:00-12:10	Discussion of QPF Verification (Group)
12:10-12:50	**Lunch**

WATERSHED TOOLS

12:50-1:00	**CW3E Santa Ana River Precip Tool (Brian Kawzenuk)**
1:00-1:05	Discussion of CW3E Precip Tool for Prado Dam FIRO (Group)
1:05-1:25	**CW3E Regional QPF Comparison Tool (Rachel Weihs)**
1:25-1:35	Discussion of CW3E QPF Comparison Tool for Prado Dam FIRO (Group)
1:35-2:05	**GSSHA (Chuck Downer)**
2:05-2:15	Discussion of GSSHA for Prado Dam FIRO (Group)

2:15-2:45	**Discussion of DST needs to support FIRO implementation**
2:45-3:00	**Discuss agenda for Workshop #3 and wrap up**

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CW3E Atmospheric River Forecast Tools

Prado Dam FIRO DST Workshop | 12 September, 2022

http://cw3e.ucsd.edu

B. Kawzenuk (UCSD/SIO/CW3E)

On Behalf of the forecast and web-development team:
M. Ralph, J. Cordeira, B. Kawzenuk, C. Hecht, C. Castellano, J. Kalansky, M. DeFlorio, R. Hartman, among others

UC San Diego | SCRIPPS INSTITUTION OF OCEANOGRAPHY

CW3E Forecast Tools

Objectives:

- Diagnostics that enhance situational awareness of landfalling atmospheric rivers (ARs), including uncertainty, intensity, timing, duration, etc.
- Watershed forecasts that aid impact-based decision support of water resources management and FIRO
- Multi-model and ensemble forecasts that convey confidence and uncertainty
- High-resolution West-WRF forecasts that provide more accurate local forecasts
- Outlooks and updates from an experienced team of forecasters that describe high-impact events

https://upload.wikimedia.org/wikipedia/commons/f/f1/Oroville_dam_spillway_2017-02-11.jpg

CW3E Multi-Model Forecast Tools

Which objectives do these Multi-Model Forecast Tools meet?

- Diagnostics that enhance situational awareness of landfalling atmospheric rivers (ARs), including uncertainty, intensity, timing, duration, etc.
- High-resolution West-WRF (and other) forecasts that provide more accurate local forecasts

Summary of multi-model Forecast Tools:

Multi-Model	Tools and Frameworks	
GFS	Integrated Water Vapor (IWV)	Meteorology and/or AR focus Maps, Time Series Cross Sections Summative (e.g., Meteograms, AR Scale) Geospatial (e.g., watershed)
ECMWF	Integrated Water Vapor Transport (IVT)	
NAM	250-mb & 500-mb Height/Wind	
West WRF	850-mb Height/Wind/Temperature	
	Precipitation and Rate	
	Freezing Levels	

CW3E Multi-Model Forecast Tools

Multi-Model Forecasts (AR Focus):

Models
- ECMWF, GFS, NAM, West WRF (to ~7 days)

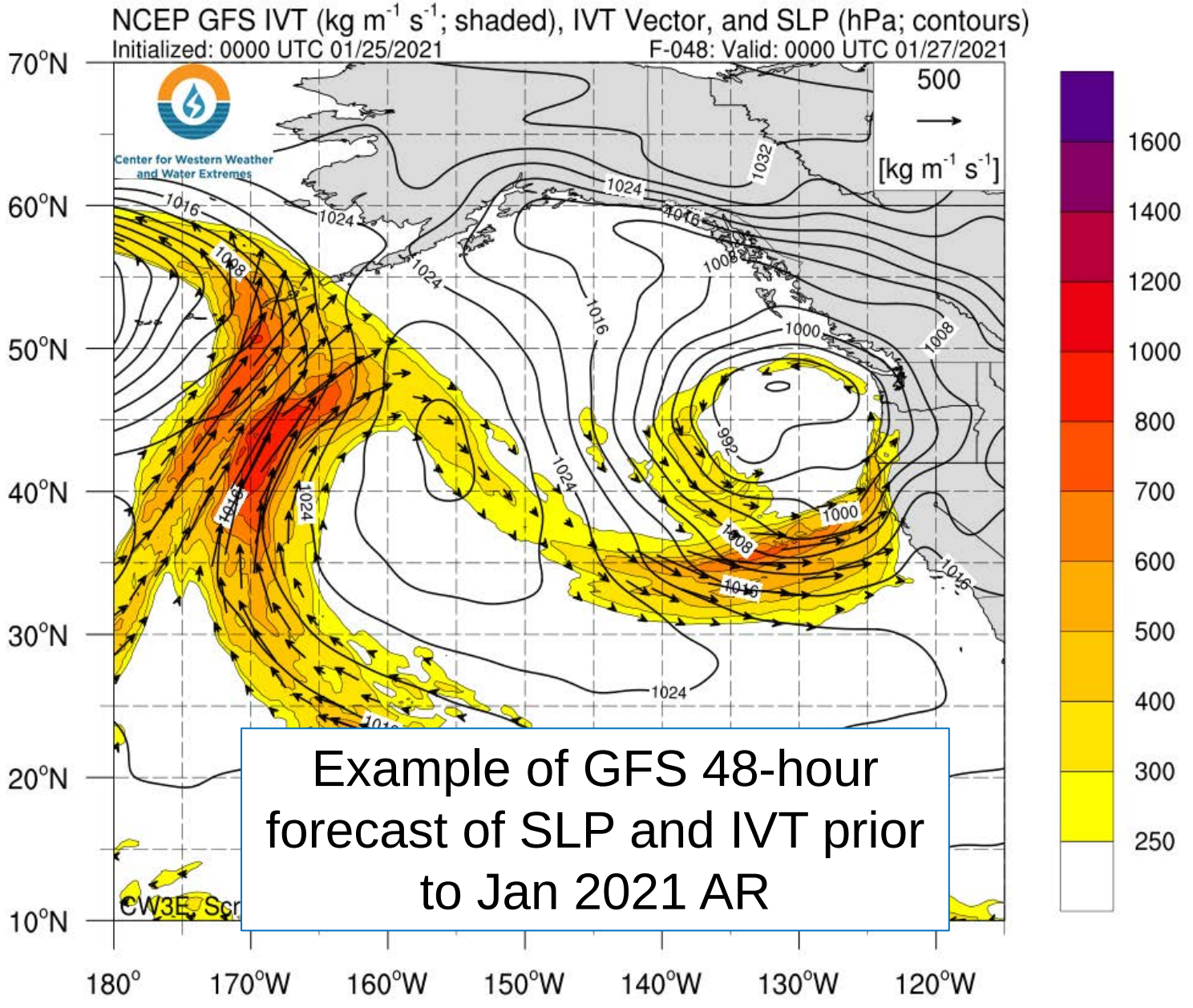
Products:
- Integrated Vapor Transport (IVT) with SLP
- Integrated Water Vapor (IWV) with SLP
- Precipitation (rate and totals) with SLP

Focus on ARs

- 250-mb Height/Wind
- 500-mb Height/Wind/Vorticity
- 850-mb Height/Wind/Temperature

Plan for WY23:
- Add diagnostic variables to aid in prediction of narrow cold frontal rain bands; e.g., frontogenesis, CAPE, shear, and lapse rates

GFS = **G**lobal **F**orecast **S**ystem
NAM = **N**orth **A**merican **M**esoscale Forecast System
ECMWF = **E**uropean **C**entre for **M**edium-Range **W**eather **F**orecasts
WRF = **W**eather **R**esearch and **F**orecasting Model



Example of GFS 48-hour forecast of SLP and IVT prior to Jan 2021 AR

CW3E Multi-Model Forecast Tools

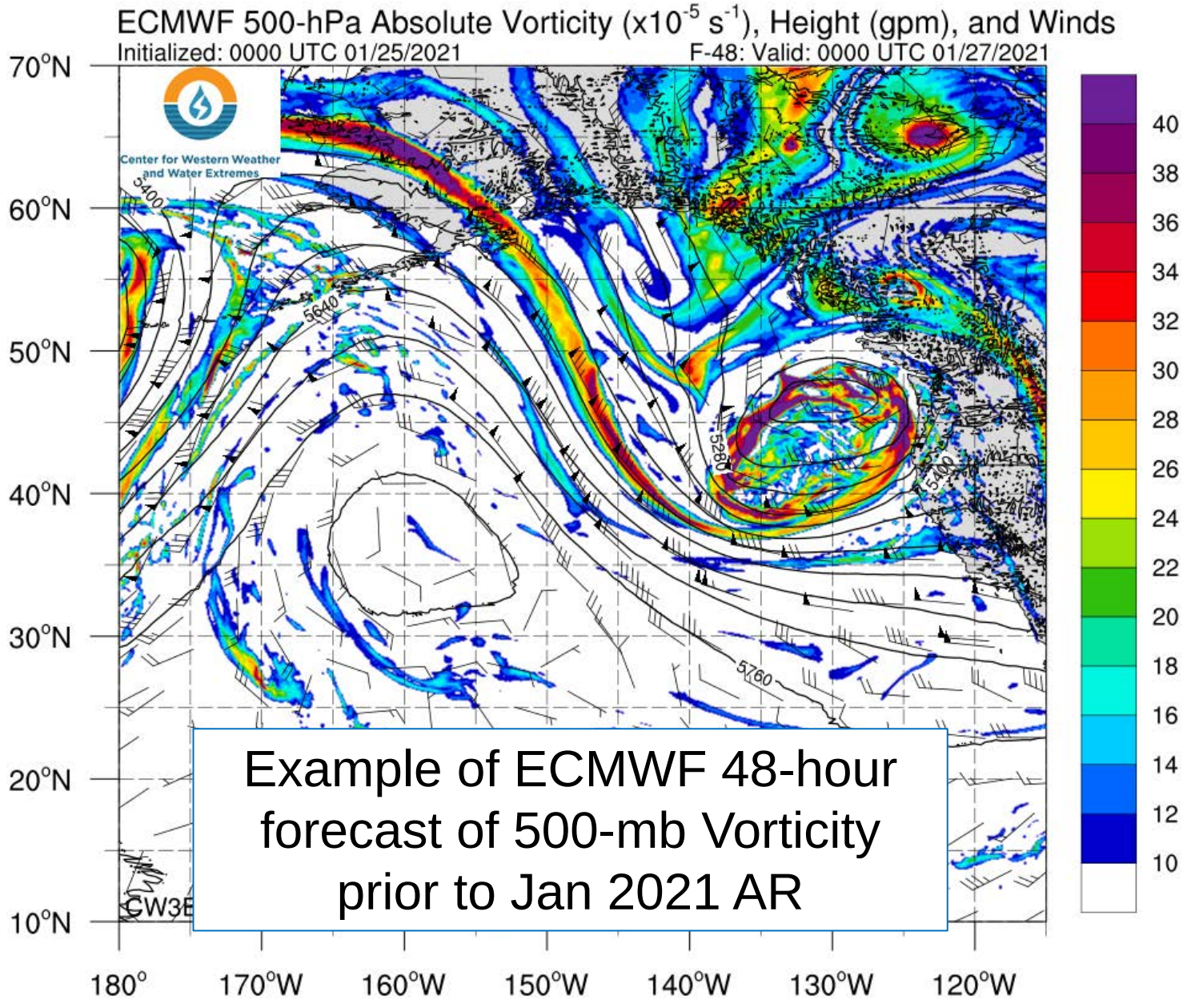
Multi-Model Forecasts (Meteorology):

Models
- ECMWF, GFS, NAM, West WRF (to ~7 days)

Products:
- Integrated Vapor Transport (IVT) with SLP
- Integrated Water Vapor (IWV) with SLP
- Precipitation (rate and totals) with SLP
- 250-mb Height/Wind
- 500-mb Height/Wind/Vorticity
- 850-mb Height/Wind/Temperature

Plan for WY23:
- Add diagnostic variables to aid in prediction of narrow cold frontal rain bands; e.g., frontogenesis, CAPE, shear, and lapse rates

GFS = **G**lobal **F**orecast **S**ystem
NAM = **N**orth **A**merican **M**esoscale Forecast System
ECMWF = **E**uropean **C**entre for **M**edium-Range **W**eather **F**orecasts
WRF = **W**eather **R**esearch and **F**orecasting Model



Example of ECMWF 48-hour forecast of 500-mb Vorticity prior to Jan 2021 AR

CW3E AR Ensemble Forecast Tools

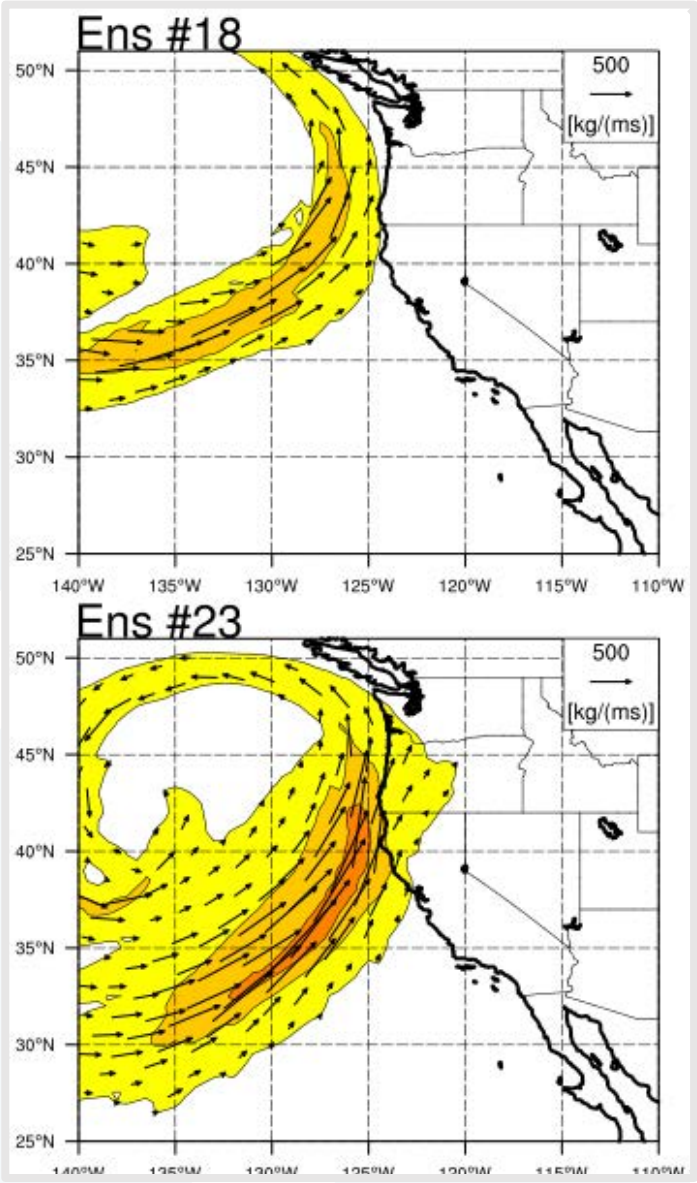
Which objectives do the ensemble tools meet?

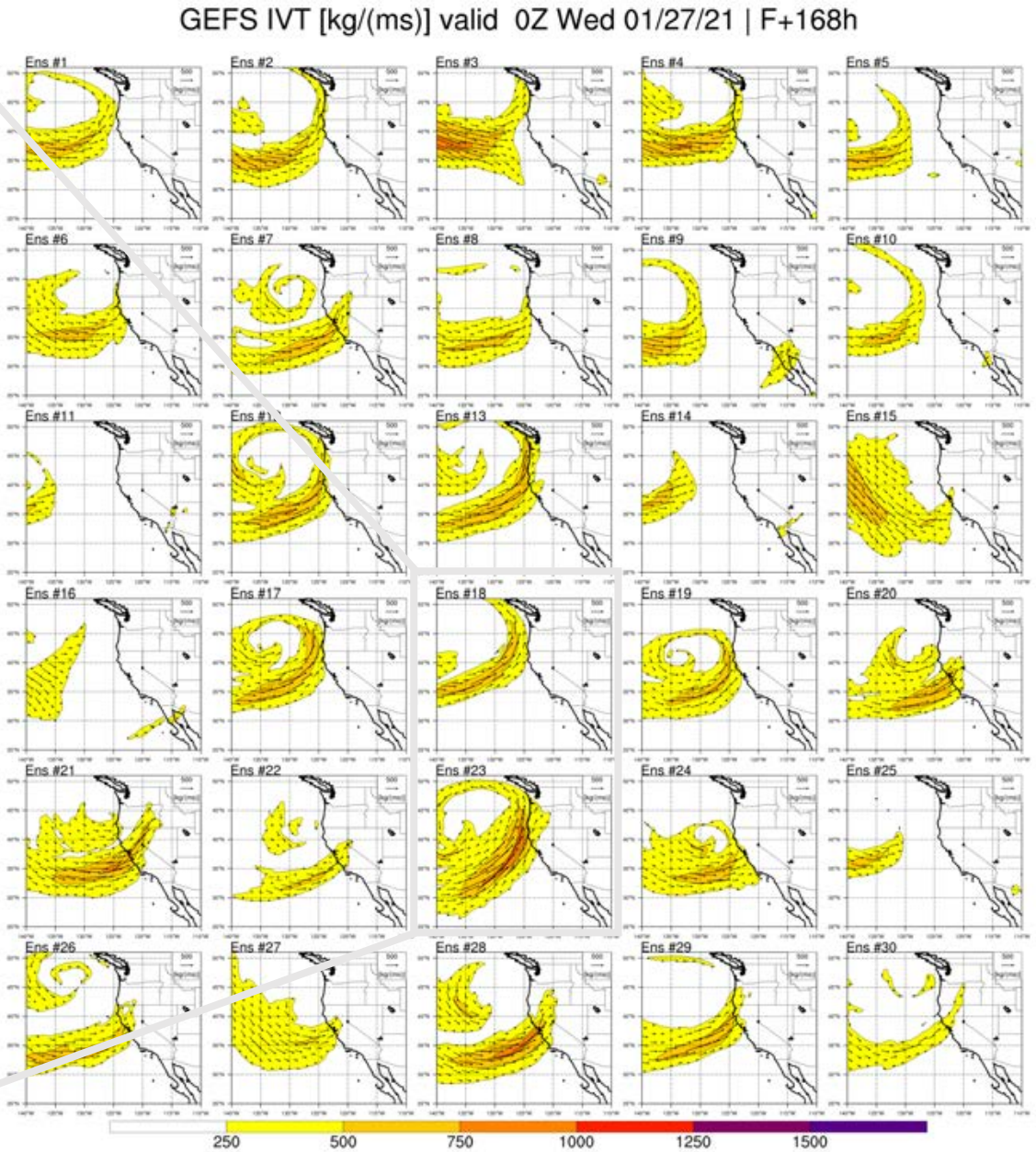
- Diagnostics that enhance situational awareness of landfalling atmospheric rivers (ARs), including uncertainty, intensity, timing, duration, etc.
- Multi-model and ensemble forecasts that convey confidence and uncertainty

Summary of CW3E AR-centric Ensemble Tools:

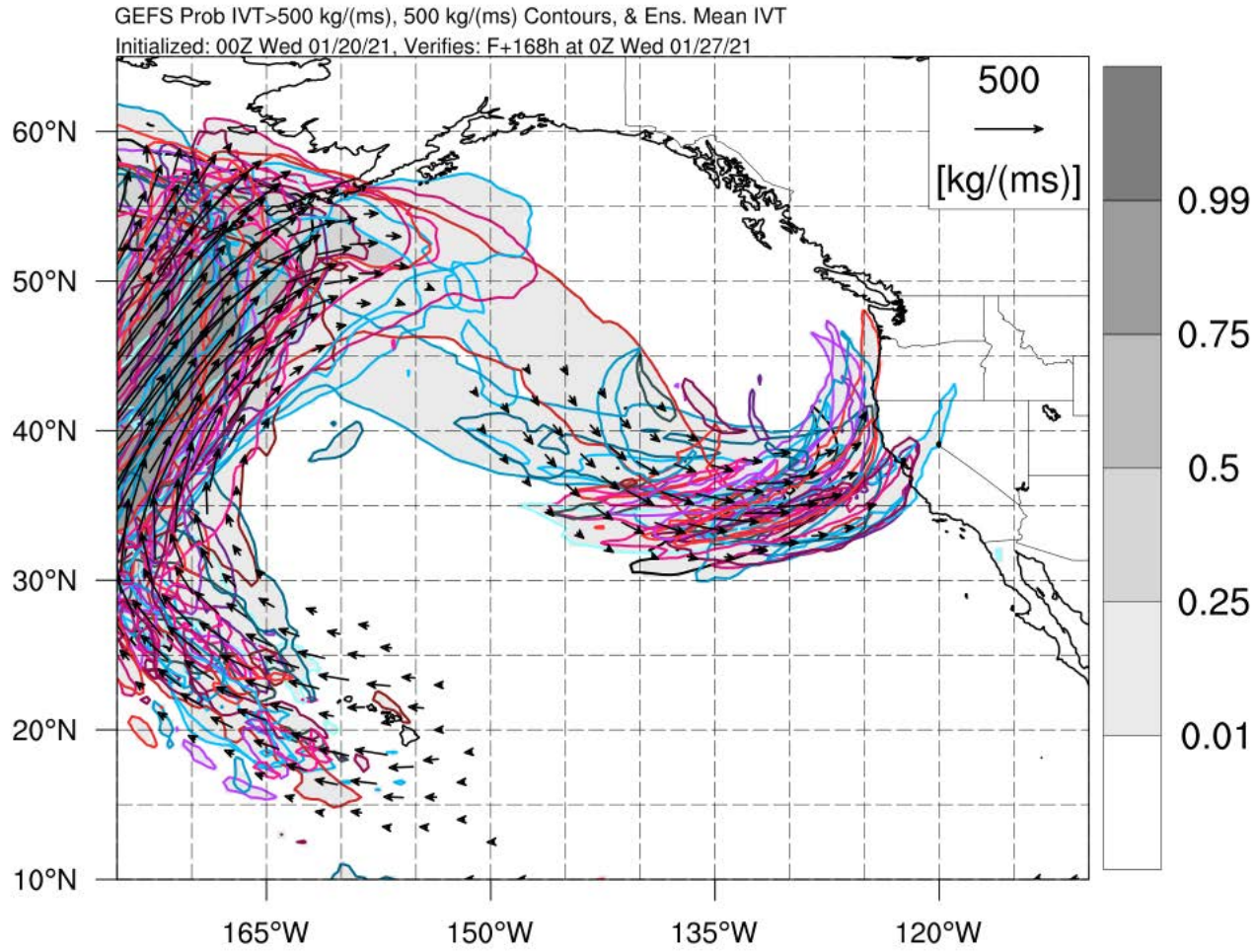
Multi-Model	AR-centric (Integrated Vapor Transport; IVT)	
GFS Ensemble	Landfall Tool	Prob. Over Thresh
ECMWF Ensemble	Probability Maps	
	Spaghetti Maps	
West WRF	Thumbnail Maps	Spatial Distribution
	Plume Diagrams	Time Series
	AR Scale	Spatial Distribution & Time Series

CW3E AR Ensemble Forecast Tools

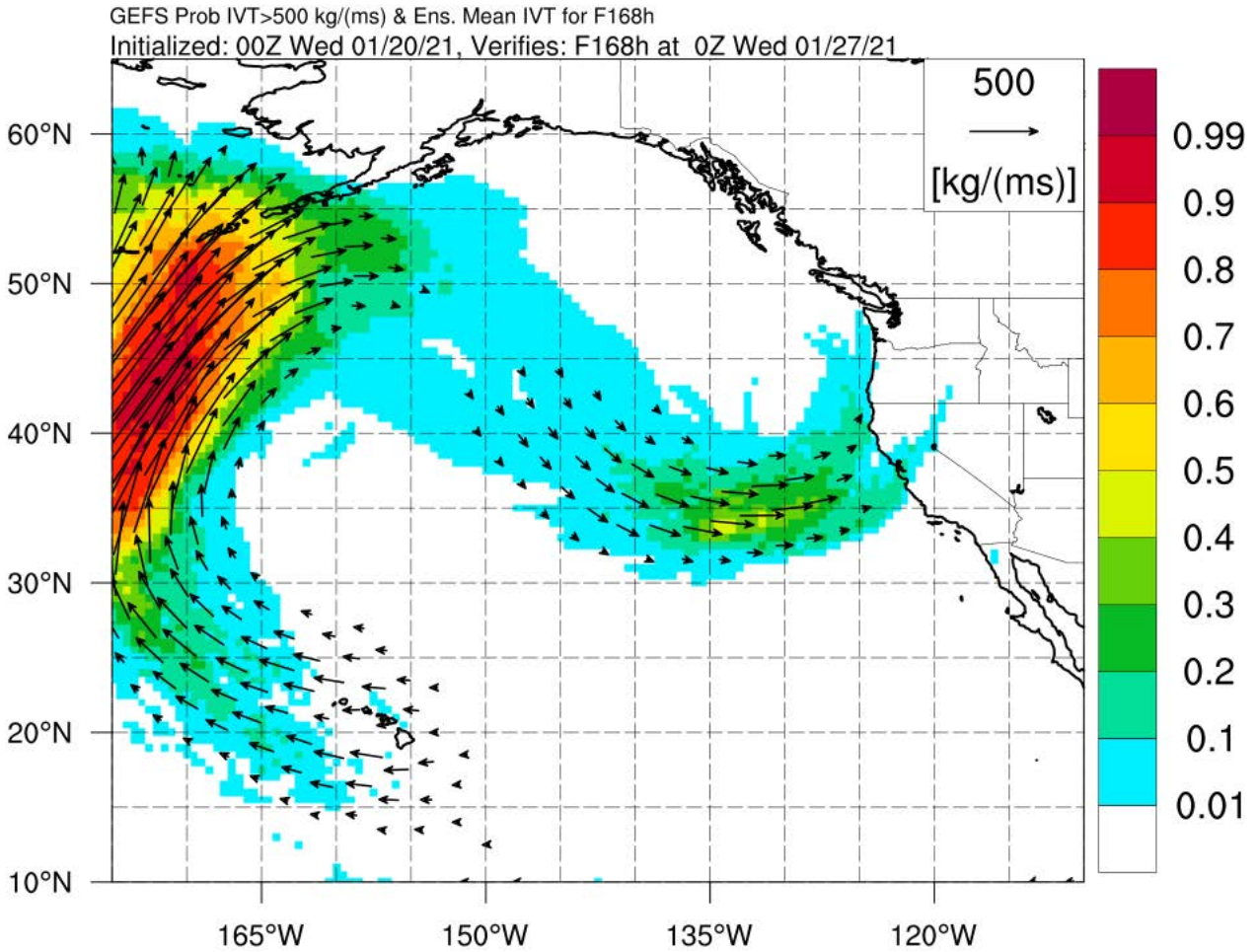




CW3E AR Ensemble Forecast Tools



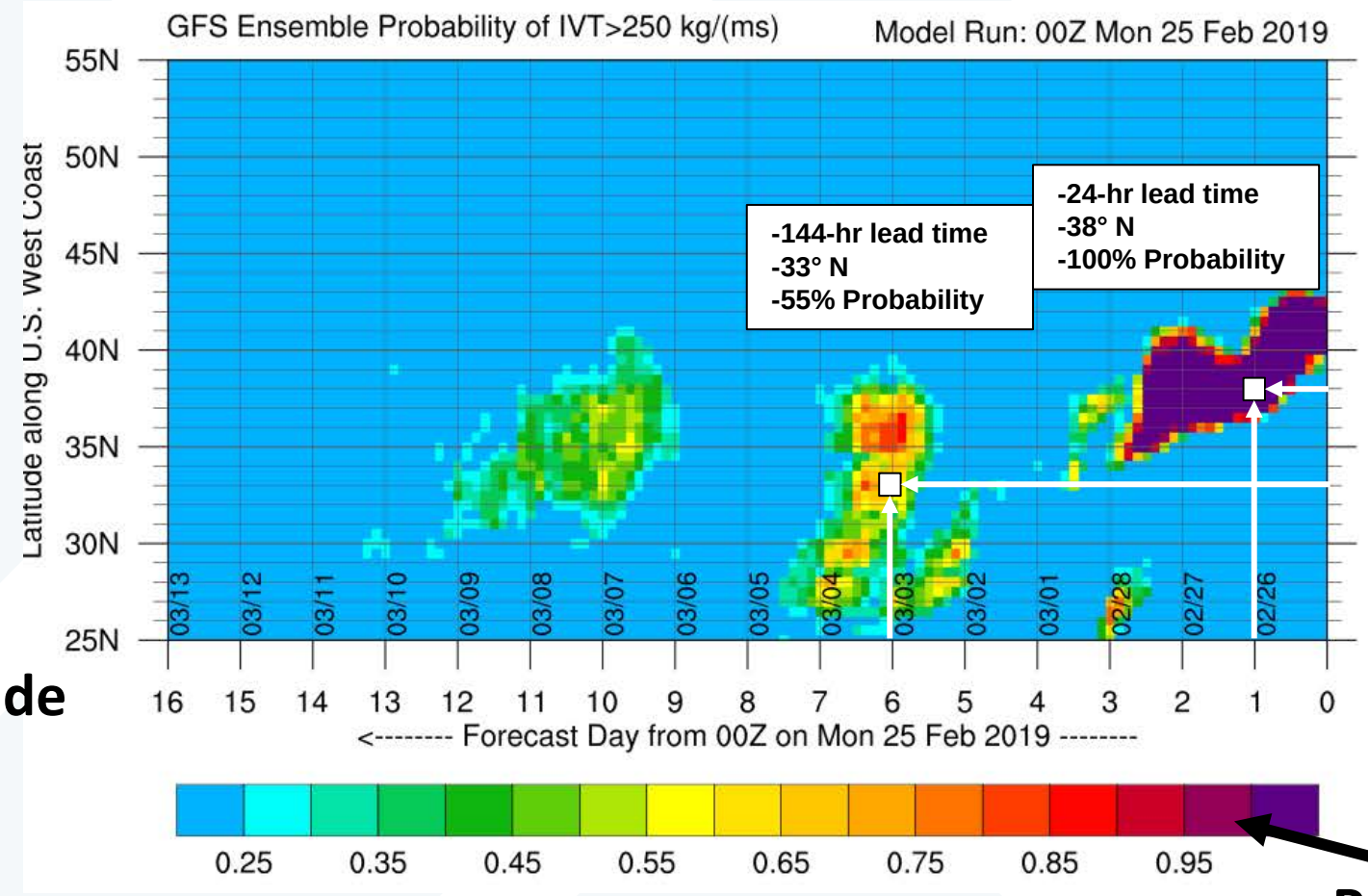
Spaghetti contours of IVT magnitudes highlight ensemble member differences in locations of AR corridor and possible landfall at given forecast hour

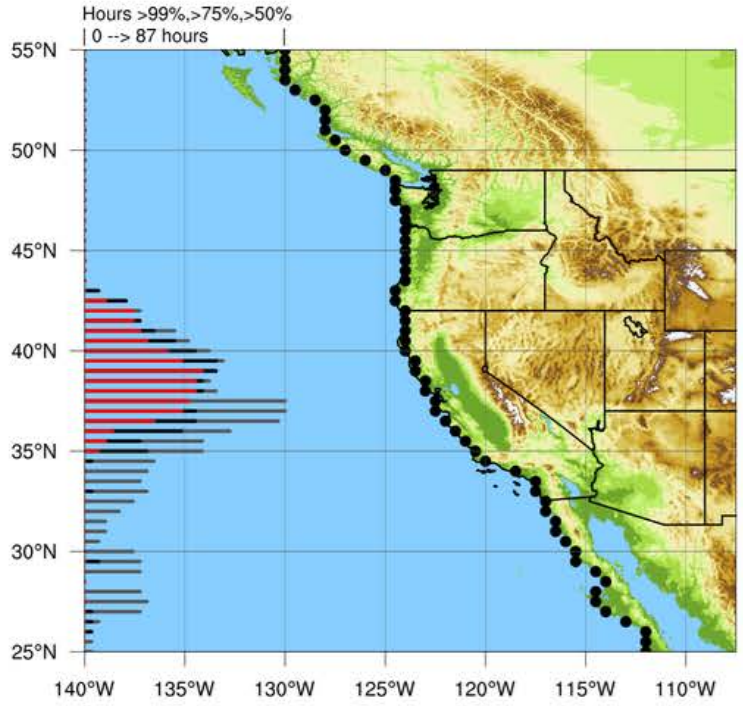


Probability of IVT magnitudes over a threshold highlight where moderate-to-strong ARs are most likely at the given forecast hour

CW3E AR Ensemble Forecast Tools

Ensemble Models: GEFS, ECMWF, West-WRF
CW3E AR Landfall Tool





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PLYMOUTH STATE METEOROLOGY

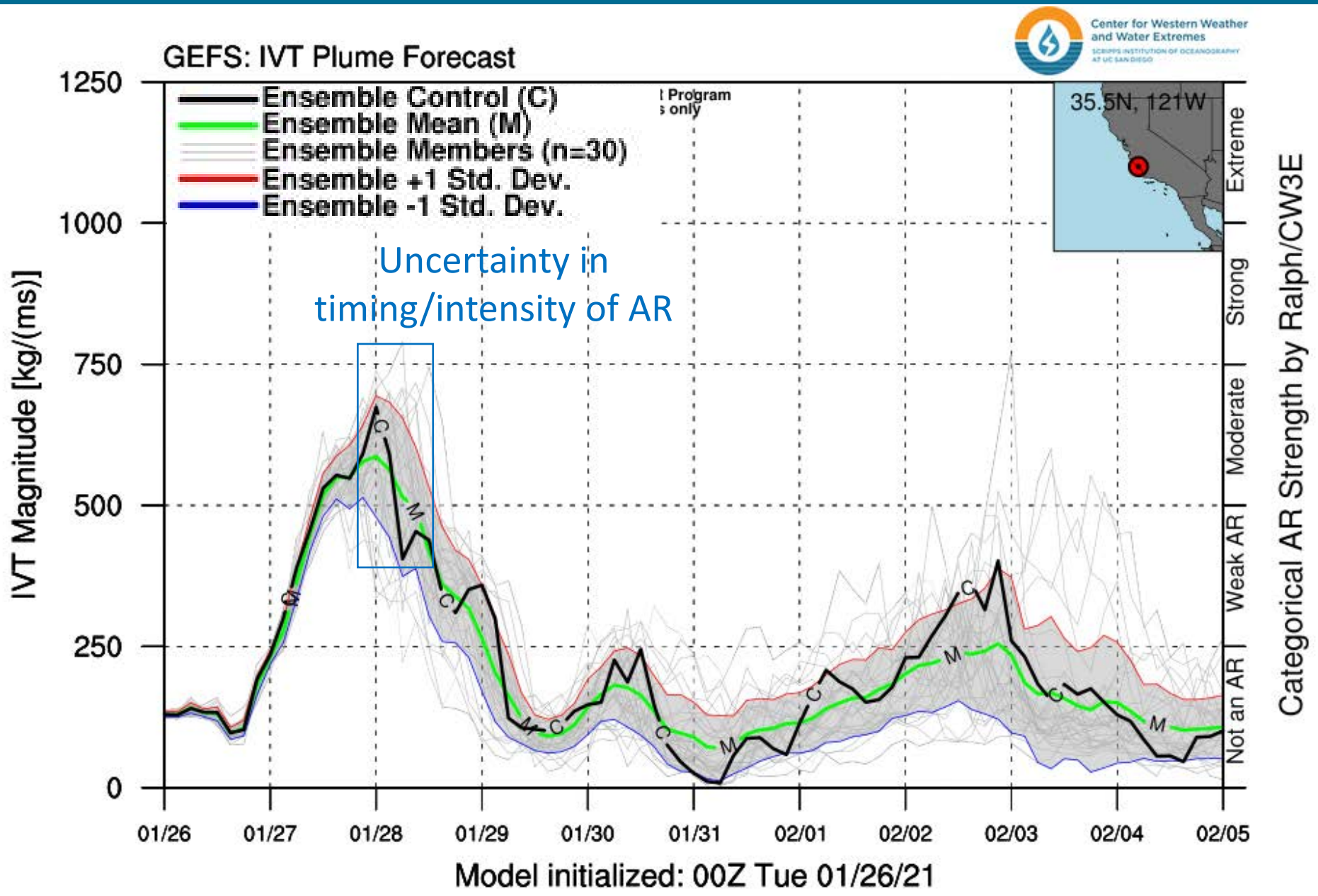
Latitude

Probability of IVT > 250 kg m^{-1} s^{-1}

Increasing Lead Time

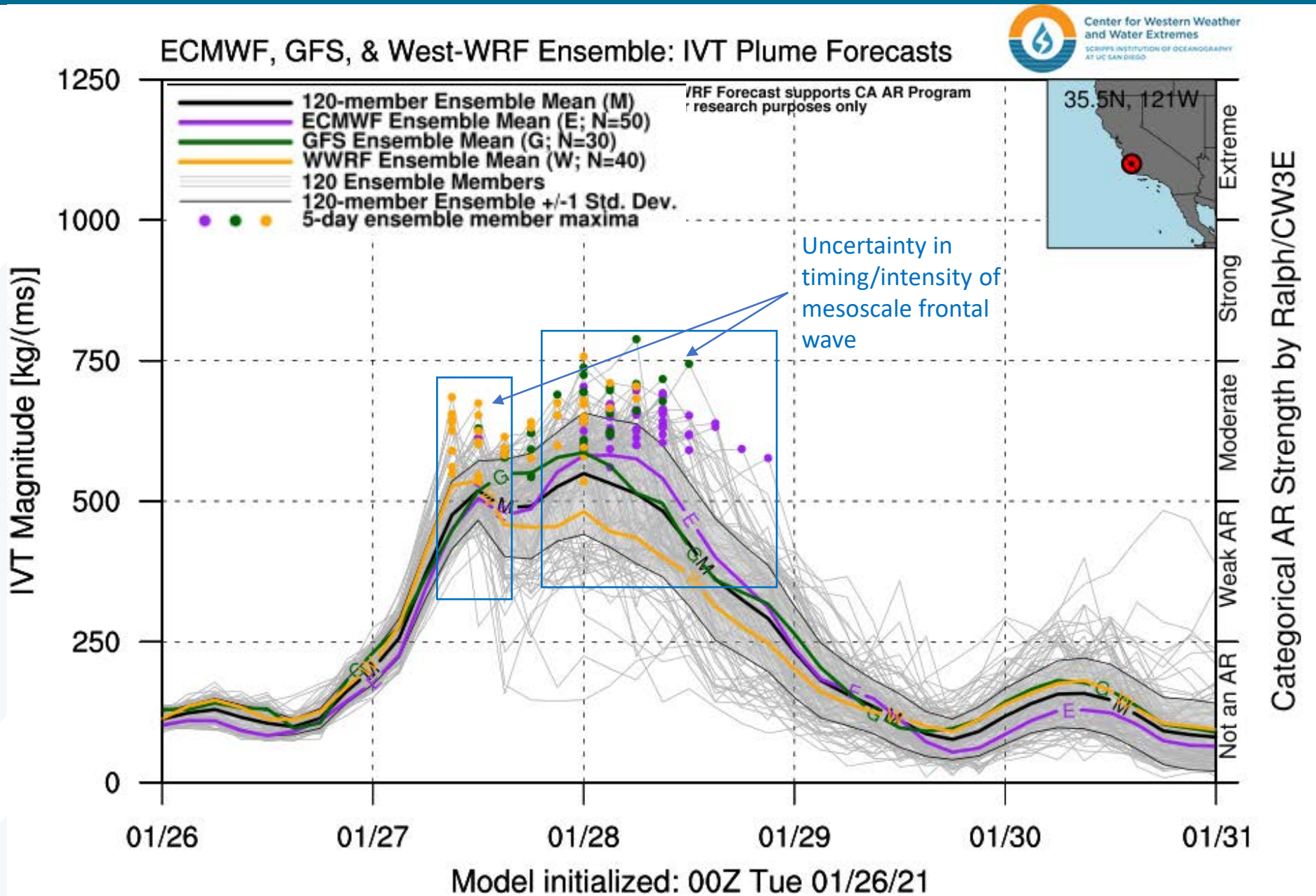
CW3E AR Ensemble Forecast Tools

- Designed to show ensemble uncertainty at a given point
- Plume characteristics can highlight uncertainty in timing, magnitude, and duration of landfalling AR
- Provides details on AR structure (e.g., mesoscale frontal waves)



CW3E AR Ensemble Forecast Tools

- Designed to multi-model distributions of IVT across GEFS, EPS, and West WRF
- Highlights where modeling centers details differ
- In this case from 2021, highlighted uncertainty in timing/intensity of the mesoscale frontal wave during AR landfall



CW3E AR Scale Forecast Tool

Which objectives does the AR Scale Forecast Tool meet?

- Diagnostics that enhance situational awareness of landfalling atmospheric rivers (ARs), including uncertainty, intensity, timing, duration, etc.
- Multi-model and ensemble forecasts that convey confidence and uncertainty

Summary of AR Scale Forecast Tool:

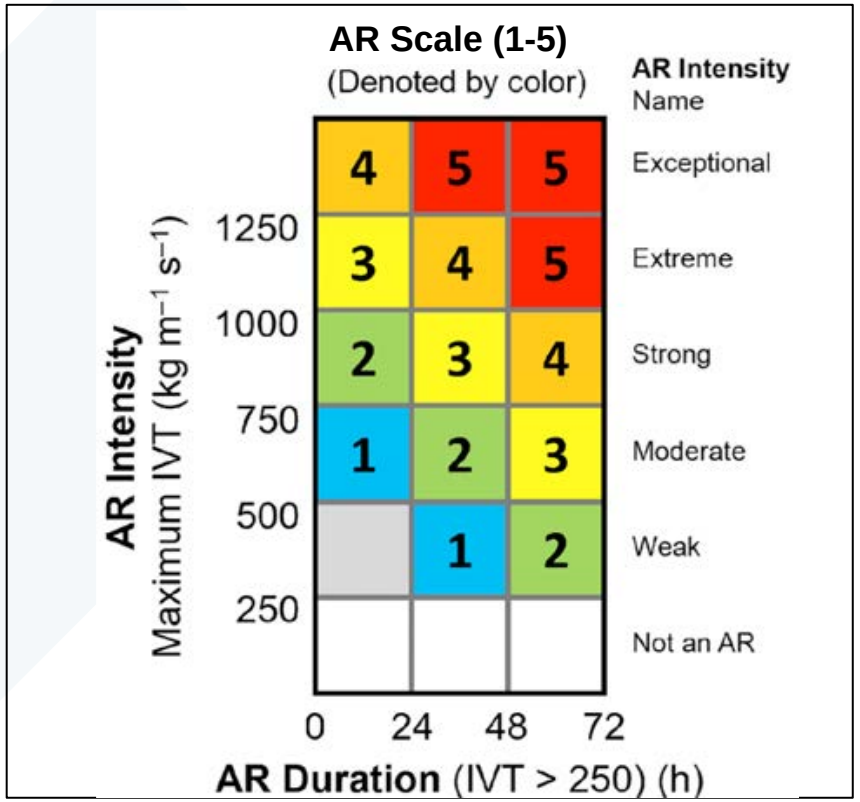
Multi-Model	Variables and Illustration	
GFS	AR Scale combines intensity and duration of AR (see next slide)	Time series
ECMWF		Multi-model and multi-member time series
West-WRF		Maps
		Uncertainty diagnostics

CW3E AR Scale Forecast Tool

http://cw3e.ucsd.edu/arscale

AR Scale: Ralph et al. (2019)

- Combines AR intensity (max IVT mag.) and AR duration (hours with IVT mag. >250 kg/ms) in order to convey benefit-hazard spectrum



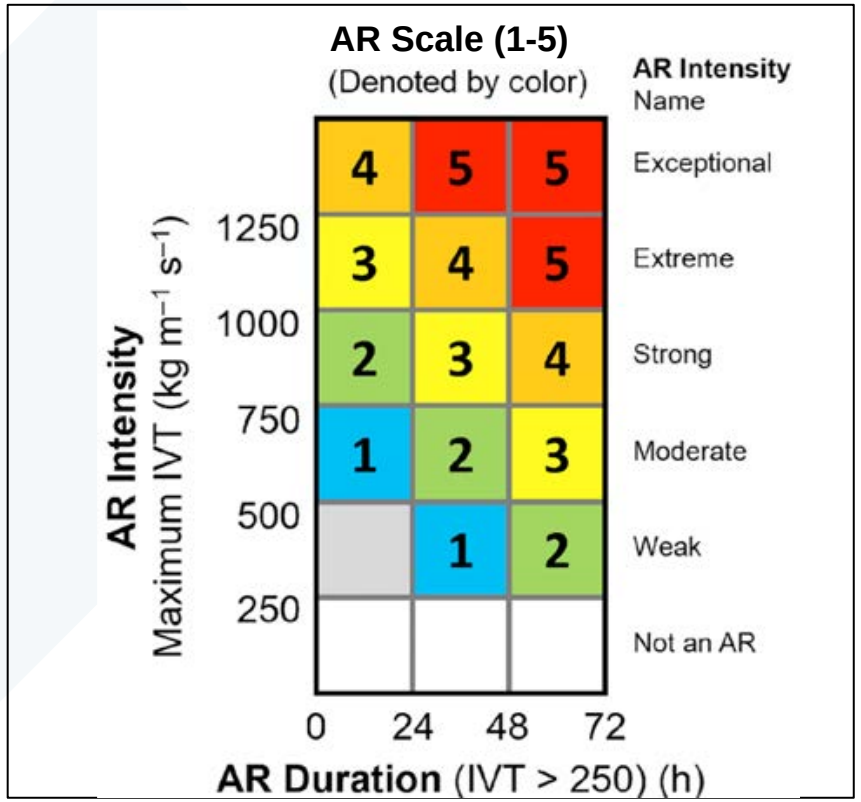
- AR 5 – Primarily hazardous
- AR 4 – Mostly hazardous, also beneficial
- AR 3 – Balance of beneficial and hazardous
- AR 2 – Mostly beneficial, also hazardous
- AR 1 – Primarily beneficial

CW3E AR Scale Forecast Tool

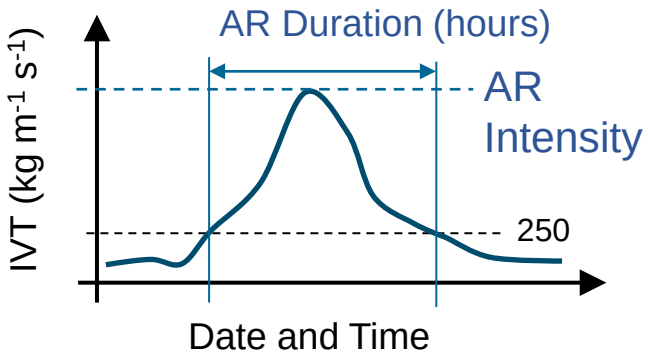
http://cw3e.ucsd.edu/arscale

AR Scale: Ralph et al. (2019)

- Combines AR intensity (max IVT mag.) and AR duration (hours with IVT mag. >250 kg/ms) in order to convey benefit-hazard spectrum
- Scale is derived for a location using observed or forecast data



- AR 5 – Primarily hazardous
- AR 4 – Mostly hazardous, also beneficial
- AR 3 – Balance of beneficial and hazardous
- AR 2 – Mostly beneficial, also hazardous
- AR 1 – Primarily beneficial



Determining Scale Value:

1. Pick a location
2. Identify periods with IVT>250 kg/ms in past or in forecast
3. AR Duration is continuous period with IVT>250 kg/ms
4. AR Intensity is maximum IVT magnitude during previously identified AR duration
5. AR Scale ranking is determined by AR Duration and AR Intensity on the AR Scale matrix.

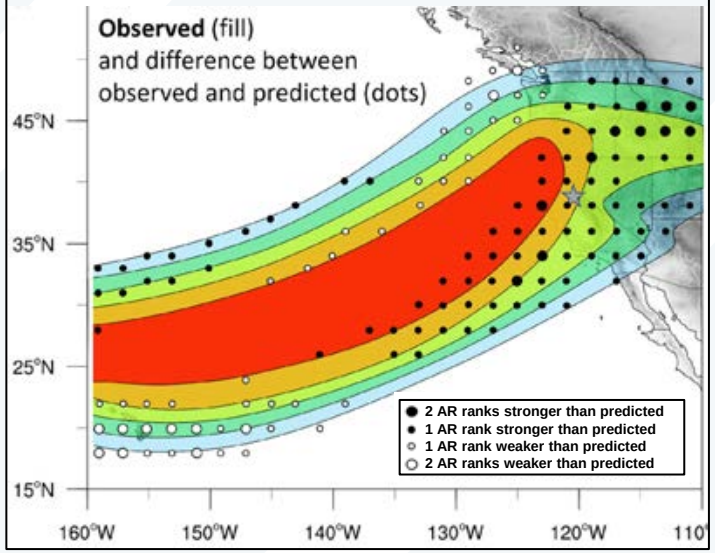
CW3E AR Scale Forecast Tool

http://cw3e.ucsd.edu/arscale

AR Scale: Ralph et al. (2019)

- Combines AR intensity (max IVT mag.) and AR duration (hours with IVT mag. >250 kg/ms) in order to convey benefit-hazard spectrum
- Scale is derived for a location using past or forecast data
- Scale can be mapped:

Maximum AR Scale for Oroville Event

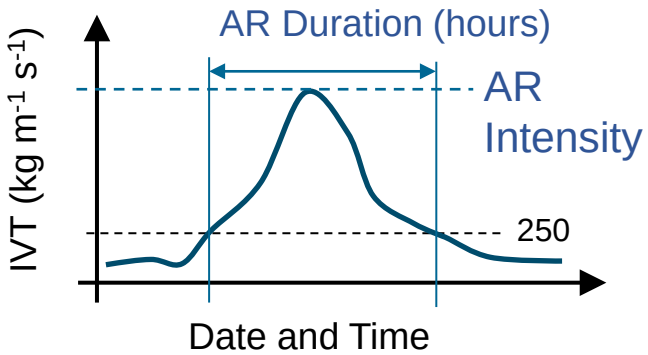


AR Scale (1-5)
(Denoted by color)

AR Intensity (Maximum IVT (kg m^{-1} s^{-1}))	0–24	24–48	48–72	AR Intensity Name
1250	4	5	5	Exceptional
1000	3	4	5	Extreme
750	2	3	4	Strong
500	1	2	3	Moderate
250		1	2	Weak
				Not an AR

AR Duration (IVT > 250) (h)

- AR 5 – Primarily hazardous
- AR 4 – Mostly hazardous, also beneficial
- AR 3 – Balance of beneficial and hazardous
- AR 2 – Mostly beneficial, also hazardous
- AR 1 – Primarily beneficial



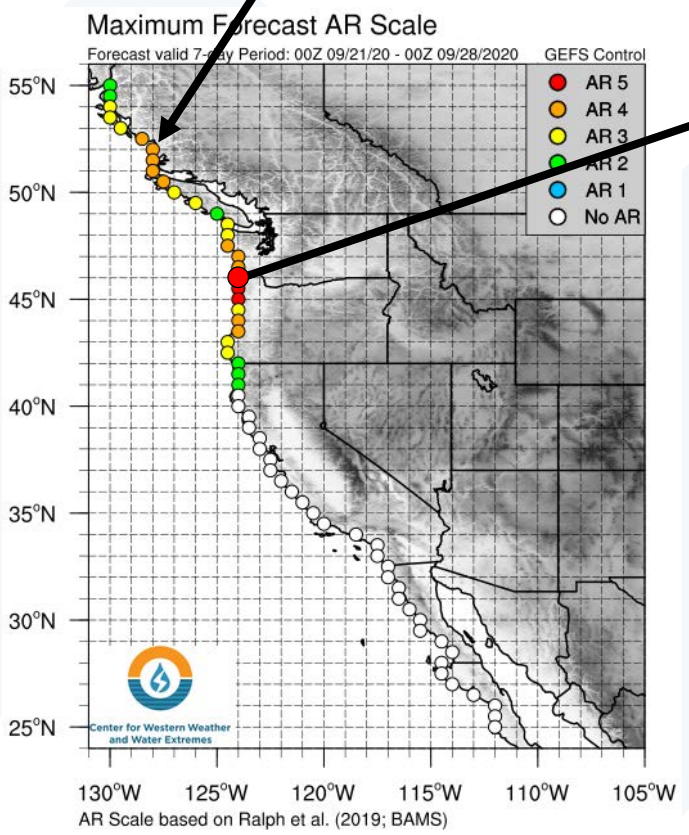
Determining Scale Value:

1. Pick a location
2. Identify periods with IVT>250 kg/ms in past or in forecast
3. AR Duration is continuous period with IVT>250 kg/ms
4. AR Intensity is maximum IVT magnitude during previously identified AR duration
5. AR Scale ranking is determined by AR Duration and AR Intensity on the AR Scale matrix.

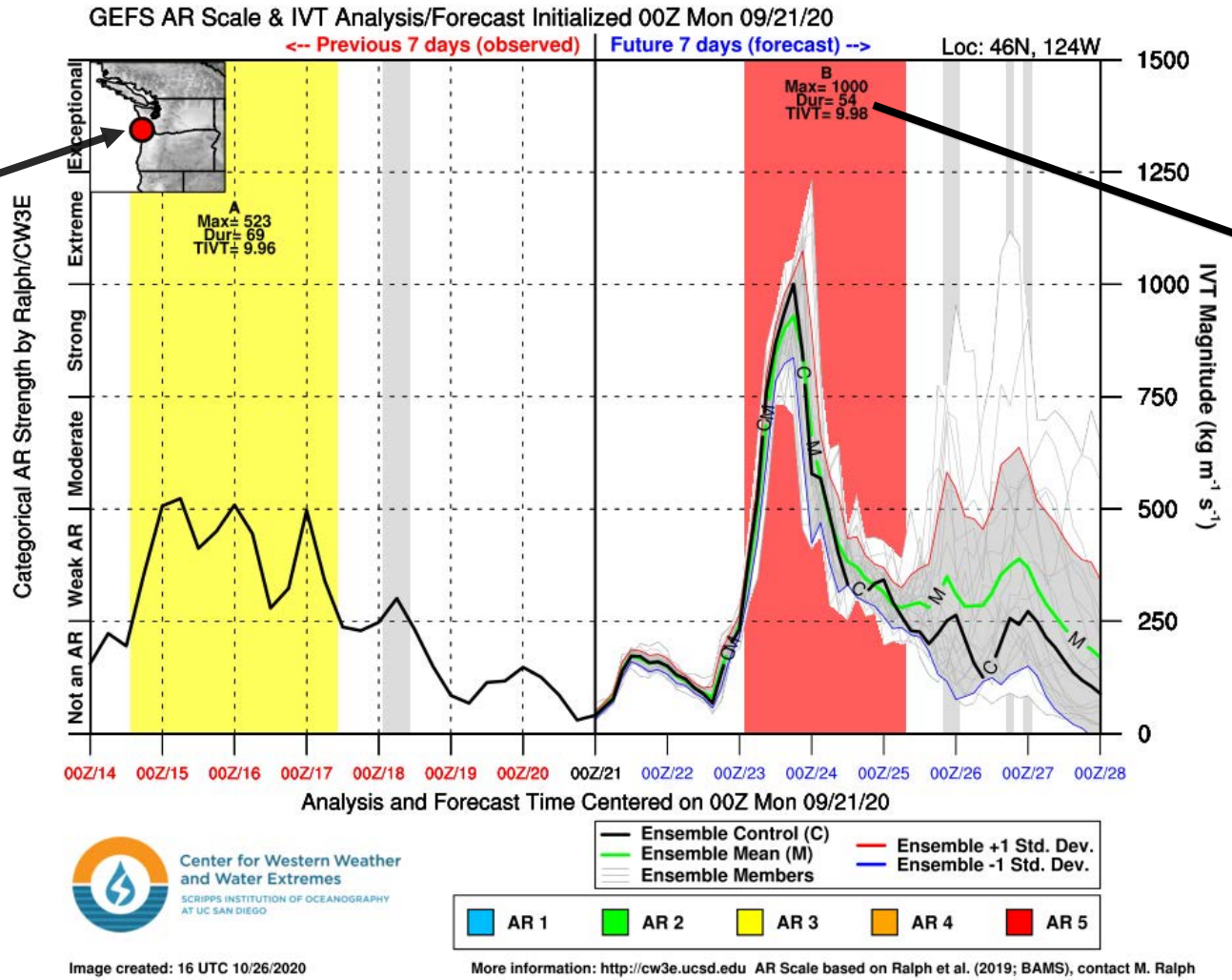
CW3E AR Scale Forecast Tool

http://cw3e.ucsd.edu/arscale

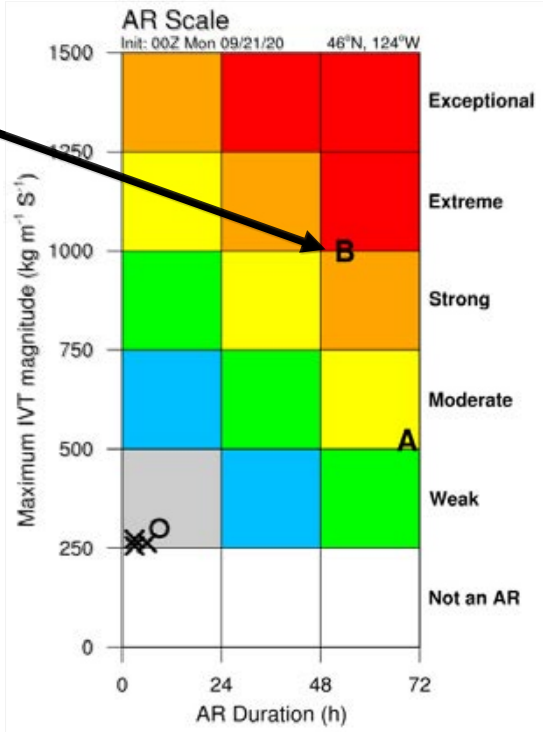
Forecasted AR Scale



Time series of IVT (observed and forecast) at each location



AR Scale at each location



Sign up to receive AR Scale alerts at https://cw3e.ucsd.edu/arscale_alerts/

CW3E Forecast Tools

Summary:

- Different tools at CW3E are constructed from multi-model global (GFS/ECMWF) and regional (NAM/WRF) numerical weather prediction models for the primary purpose of providing enhanced situational awareness of landfalling atmospheric rivers (ARs; e.g., including uncertainty, intensity, timing, duration).

- Multi-model and ensemble forecasts convey confidence and uncertainty, which aid in decision support applications during AR Reconnaissance and FIRO, among others

- Summative diagnostics aid in communicating potential for hazardous weather (e.g., AR Scale, Landfall Tool), with peer-reviewed relationships with flood-related damages and NWS watches/warnings

https://upload.wikimedia.org/wikipedia/commons/f/f1/Oroville_dam_spillway_2017-02-11.jpg

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CW3E Watershed Precipitation Forecast Tools

Prado Dam FIRO DST Workshop | 12 September, 2022

http://cw3e.ucsd.edu

B. Kawzenuk (UCSD/SIO/CW3E)

On Behalf of the forecast and web-development team:
M. Ralph, J. Cordeira, B. Kawzenuk, C. Hecht, C. Castellano, J. Kalansky, M. DeFlorio, R. Hartman, among others

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CW3E Watershed Forecast Tools

Which objectives do the ensemble tools meet?

- Watershed forecasts that aid impact-based decision support of water resources management & FIRO
- Multi-model and ensemble forecasts that convey confidence and uncertainty

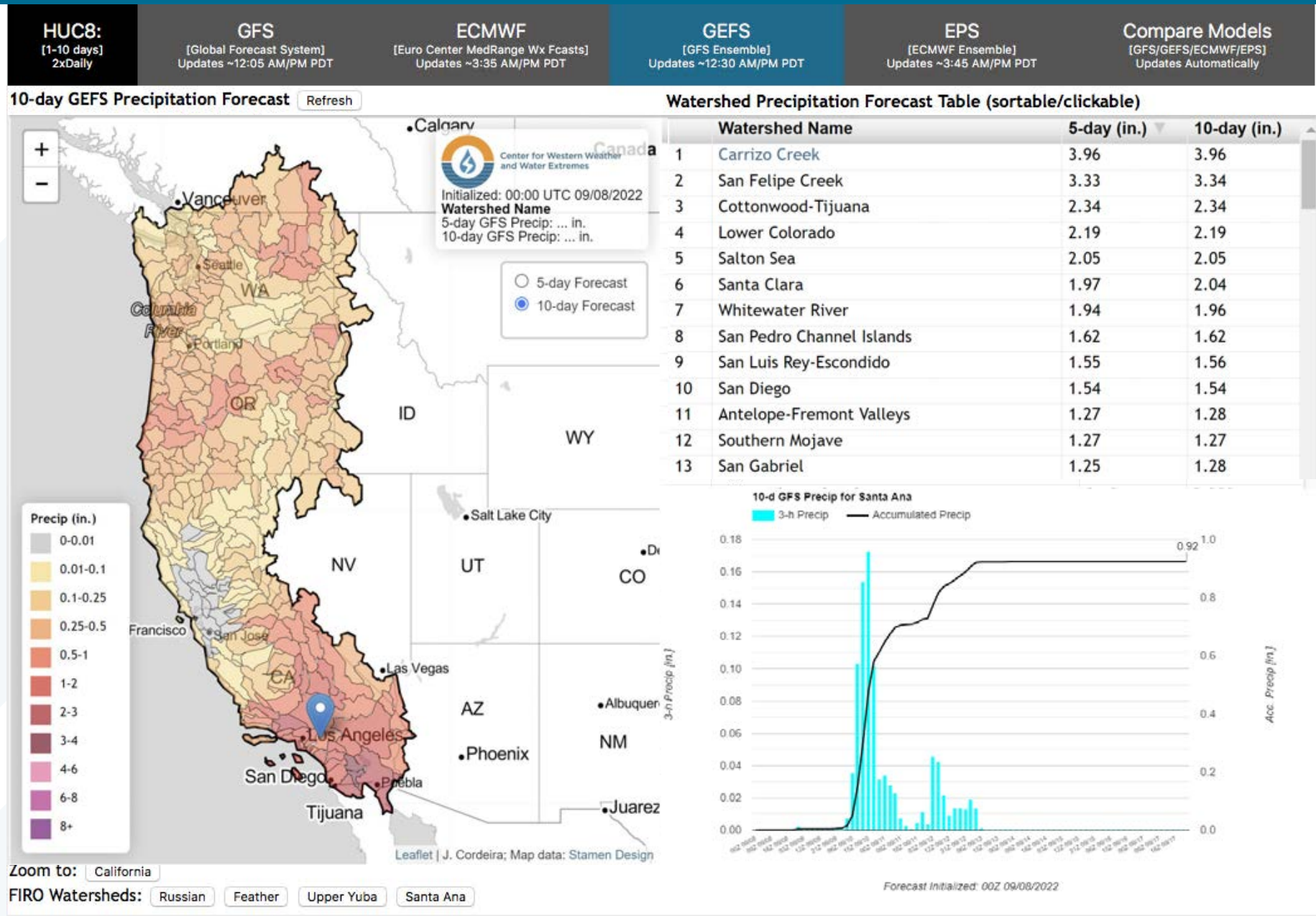
Summary of CW3E Watershed-centric Ensemble Tools:

	Multi-Model	Watershed-centric	
*	GFS Ensemble	HUC-8 & HUC-10 QPF*	Spatial Distribution
*	ECMWF Ensemble		Time Series
**	West WRF	HUC-8 Freezing Level	Spatial Distribution
**	HRRR		Time Series
**	WPC		
**	CNRFC		

* Operational In an Experimental Capacity WY22
** In Dev. for WY23 (case-by-case in WY22)

Watershed-centric | QPF

- Showcase multi-model mean-areal precipitation among global NWP models and their ensembles (e.g., GFS/GEFS and ECMWF/EPS)
- Enhance data interactivity in order to optimize situational awareness
- Build toward quantifying risk of hazardous precipitation



	Watershed Name	5-day (in.)	10-day (in.)
1	Carrizo Creek	3.96	3.96
2	San Felipe Creek	3.33	3.34
3	Cottonwood-Tijuana	2.34	2.34
4	Lower Colorado	2.19	2.19
5	Salton Sea	2.05	2.05
6	Santa Clara	1.97	2.04
7	Whitewater River	1.94	1.96
8	San Pedro Channel Islands	1.62	1.62
9	San Luis Rey-Escondido	1.55	1.56
10	San Diego	1.54	1.54
11	Antelope-Fremont Valleys	1.27	1.28
12	Southern Mojave	1.27	1.27
13	San Gabriel	1.25	1.28

Watershed-centric | QPF

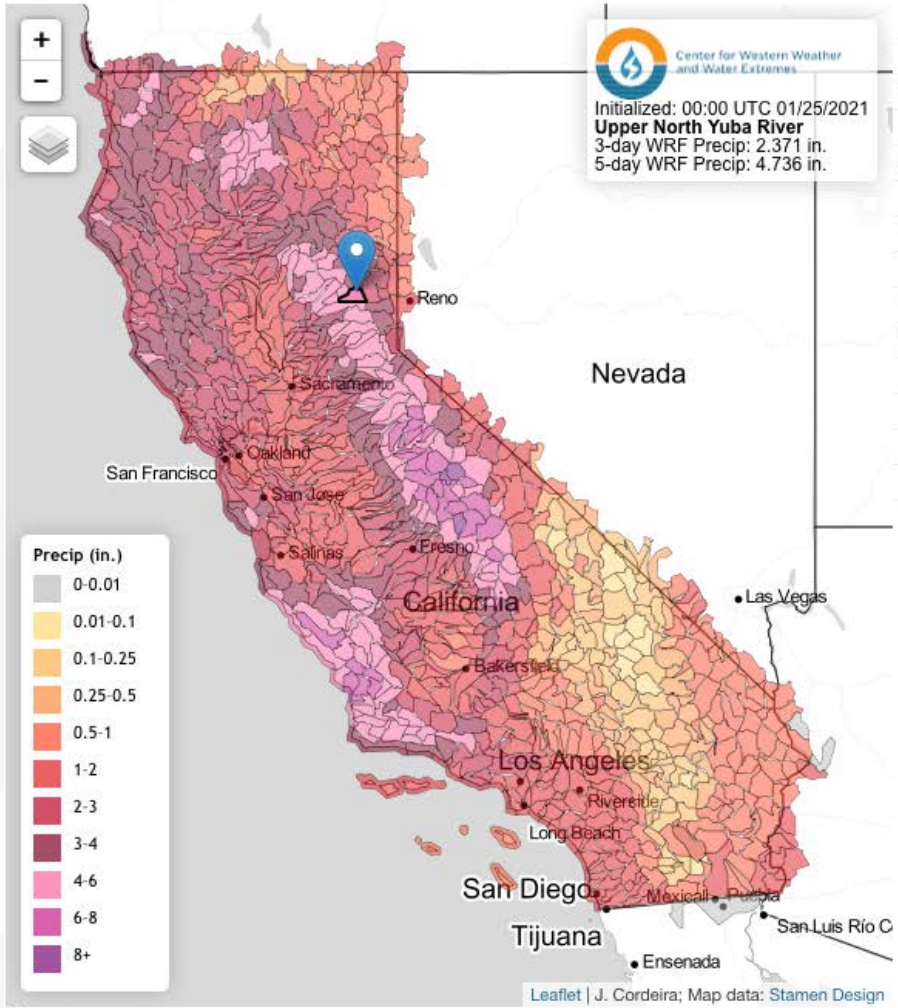
- Showcase multi-model mean-areal precipitation among global NWP models and their ensembles (e.g., GFS/GEFS and ECMWF/EPS)
- Enhance data interactivity in order to optimize situational awareness
- Build toward quantifying risk of hazardous precipitation

Watershed-centric | QPF

- Illustrate mean-areal precipitation on sub-HUC10 watershed scales
- Requires higher resolution NWP, some additional computing resources
- Bringing online west-WRF, CNRFC, and HRRR HUC10 QPF visualizations using a similar framework
- Example: West-WRF Jan 2021

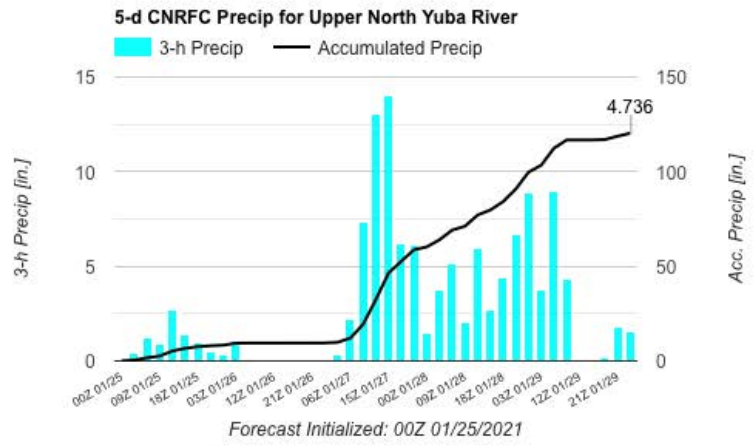
HUC10: [1-5 days] | WRF [CW3E West WRF] | CNRFC [CA/NV River Fcast Ctr] | [To Be Added] | [To Be Added] | [WRF/CNRFC/HRRR]

West WRF Precipitation Forecast Refresh



Watershed Precipitation Forecast Table (sortable/clickable)

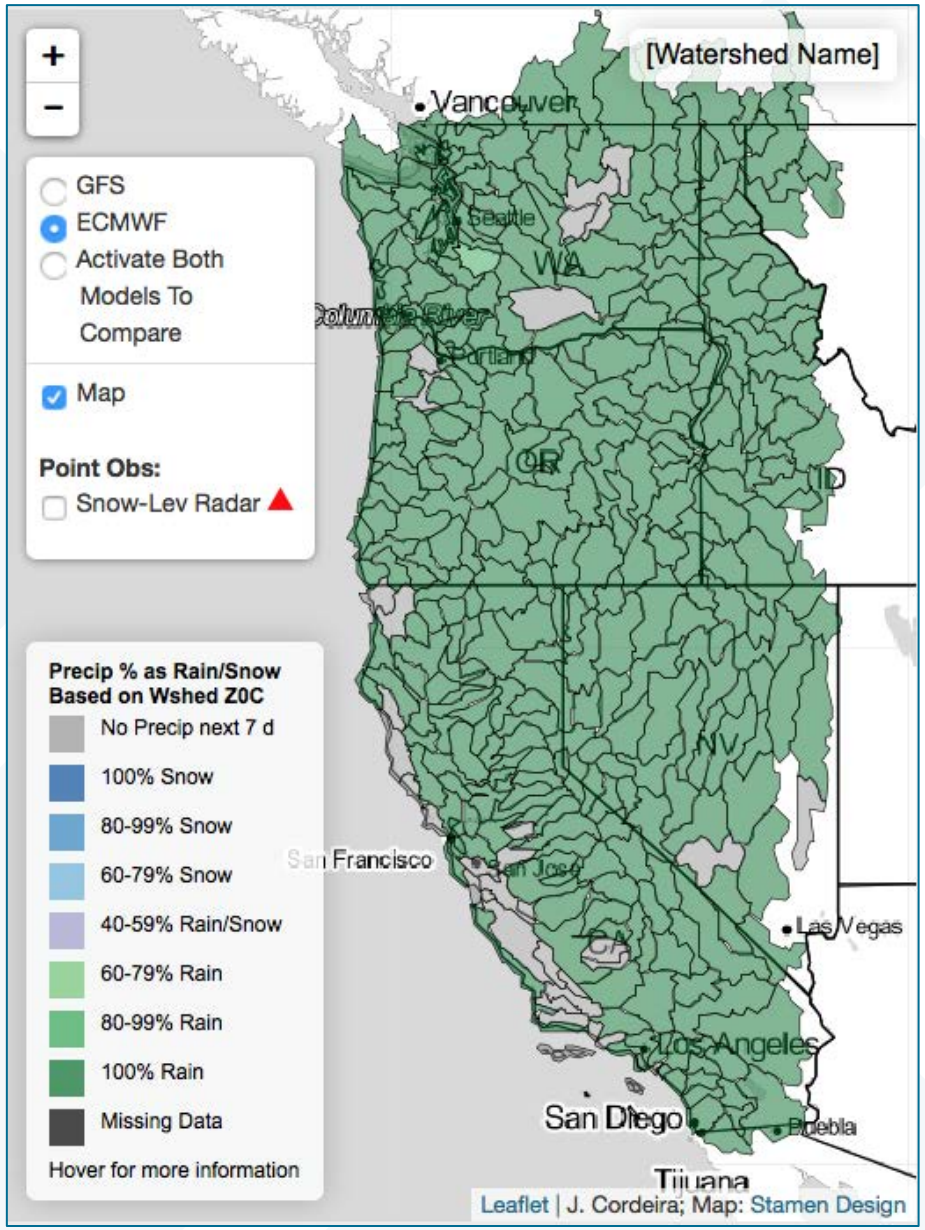
	Watershed Name	3-day (in.)	5-day (in.)
1	Granite Creek	3.41	8.62
2	Middle Fork San Joaquin River	3.33	8.59
3	Dinkey Creek	3.29	8.25
4	Willow Creek	2.9	7.89
5	South Fork Merced River	3.01	7.89
6	Chiquito Creek	3.23	7.87
7	Arroyo Grande Creek	2.37	7.63
8	North Fork Kings River	3.18	7.6
9	Roaring River	3.34	7.48
10	Big Creek	3.12	7.38
11	Cherry Creek	2.82	7.24
12	Yosemite Creek-Merced River	2.67	7.2
13	South Fork Tuolumne River	2.64	7.19

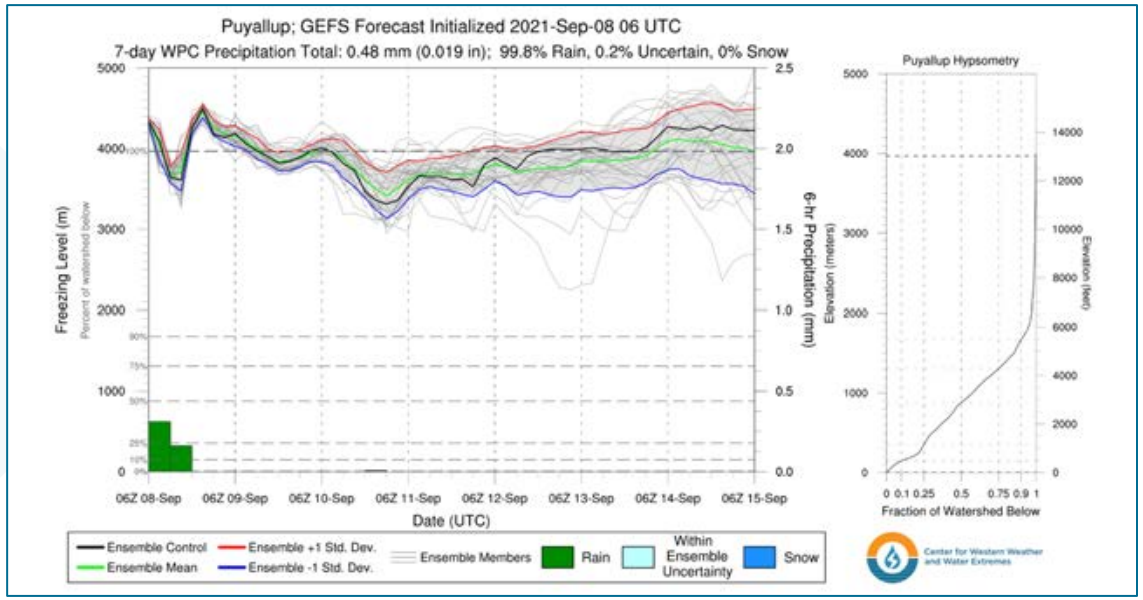


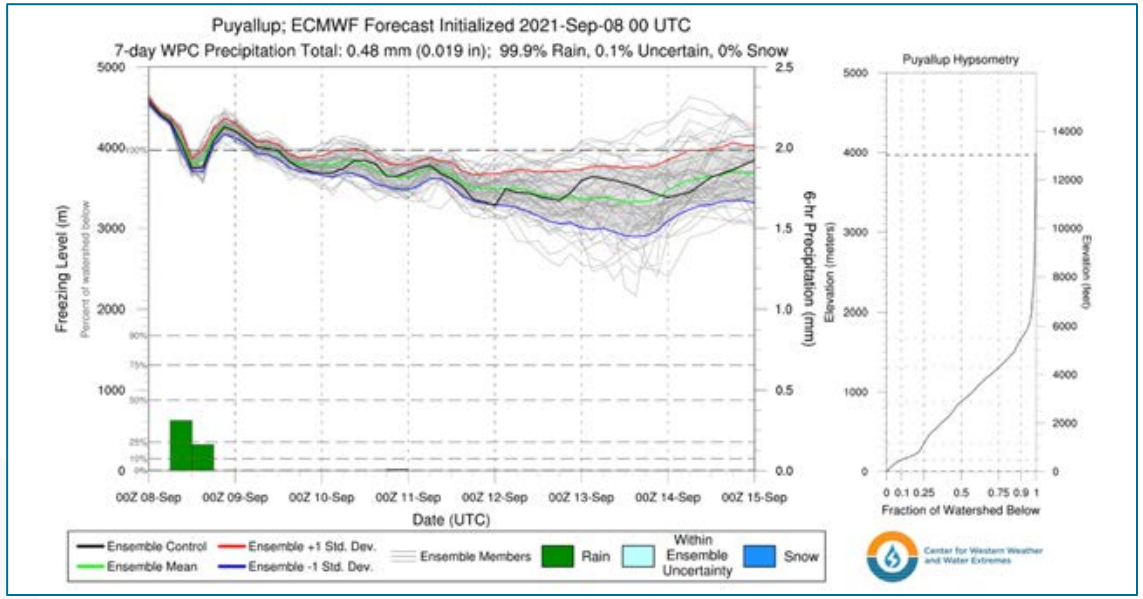
Data look old? Try a refresh.

Zoom to:
Full Domain: California
FIRO Watersheds:
Russian - East Fork | Feather - Lower Middle Fork | Yuba - Lower North | Santa Ana - Middle

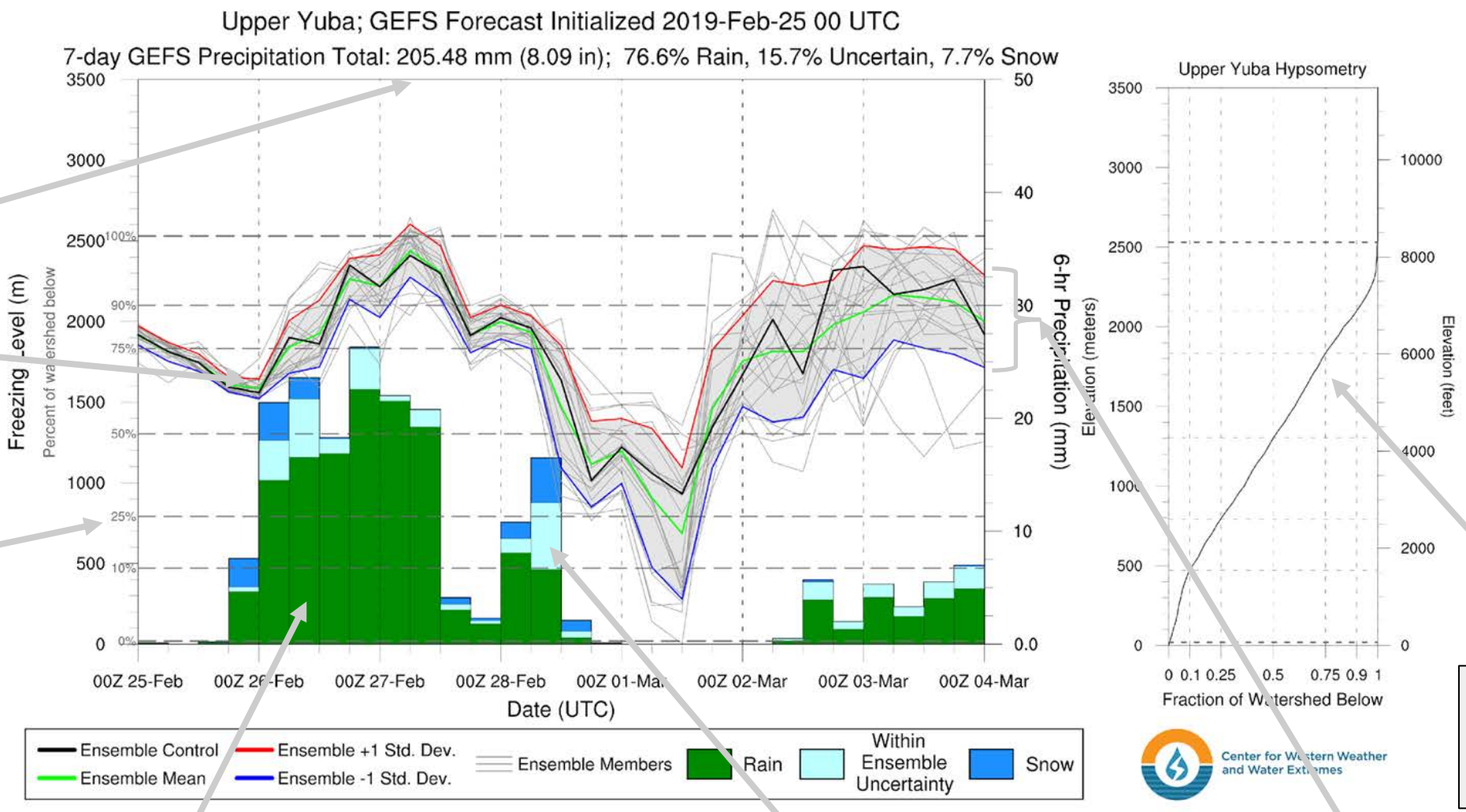
Watershed-centric | Freezing Levels







Watershed-centric | Freezing Levels



7-day total precip

Forecast freezing level

Percent of watershed terrain above or below each level

Topography within watershed

6-h forecast of mean areal precip over watershed

Shading represents percent of watershed to receive rain vs snow

Uncertainty in ensemble freezing level

Center for Western Weather and Water Extremes
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September 12, 2022

Prado Dam FIRO Final Viability Assess Decision Support Tools Workshop #2

Chris Delaney, Research Engineer
Robert Hartman, Consultant
Rachel Weihs, Mesoscale Modeler
Brian Kawzenuk, Applications Programmer
Duncan Axisa, FIRO Program Manager
Arleen O'Donnell, ERG
David Reynolds, Consultant

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Workshop #2 Agenda

9:00-9:10	**Welcome and Introductions**
9:10-9:50	**Discussion of results of previous workshop (Chris Delaney)**
9:50-10:00	**Observations – Enhanced streamflow monitoring (Garrett McGurk)**
10:00-10:10	Discussion of Observations for Prado Dam FIRO
10:10-10:25	**Break**
ATMOSPHERIC TOOLS	
10:25-10:55	**CW3E Atmospheric River Tools – Integrated Vapor Transport, AR Landfall, AR Scale (Brian Kawzenuk)**
10:55-11:05	Discussion of CW3E Atmospheric Tools for Prado Dam FIRO (Group)
11:05-11:35	**West-WRF (Rachel Weihs)**
11:35-11:45	Discussion of West-WRF for Prado Dam FIRO (Group)
11:45-12:00	**QPF Verification (Brett Whitin)**
12:00-12:10	Discussion of QPF Verification (Group)
12:10-12:50	**Lunch**
WATERSHED TOOLS	
12:50-1:00	**CW3E Santa Ana River Precip Tool (Brian Kawzenuk)**
1:00-1:05	Discussion of CW3E Precip Tool for Prado Dam FIRO (Group)
1:05-1:25	**CW3E Regional QPF Comparison Tool (Rachel Weihs)**
1:25-1:35	Discussion of CW3E QPF Comparison Tool for Prado Dam FIRO (Group)
1:35-2:05	**GSSHA (Chuck Downer)**
2:05-2:15	Discussion of GSSHA for Prado Dam FIRO (Group)
2:15-2:45	**Discussion of DST needs to support FIRO implementation**
2:45-3:00	**Discuss agenda for Workshop #3 and wrap up**

DST Workshops

- **Workshop 1 (Completed 8/16/22):** Review Corps existing tools and operations for Prado Dam
  - Historical storm events: February 2019 and December 2021
  - Facilitate learning of existing operational practices and constraints
- **Workshop 2 (9/12/22):** Review atmospheric river and watershed tools that could support FIRO
  - Demonstration of CW3E and ERDC tools
- **Workshop 3 (10/19/22):** Review operational tools that could support FIRO

Overview of Workshop #1

- Overview of existing tools used by LAD
- February 2019 Case Study
- December 2021 Case Study
- Identification of key needs to implement FIRO at Prado Dam

2 Case Studies

- **February 2019**
  - Atmospheric River event
  - Under forecast
  - Operated to a forecasted peak pool elevation of ~513’
- **December 2021**
  - 3 events back-to-back
  - Last event was over forecasted cutoff low
  - Operated to a lower forecasted peak pool elevation of ~507’
  - Very challenging for operations

Overview of Existing Tools

- Site Access Coordination
- Orange Book and Notification Software
- Quantitative Precipitation Forecasts (QPF)
- RFC Inflow Forecasts
- Reservoir Regulation Website
- Corps Water Management System (CWMS & CAVI)

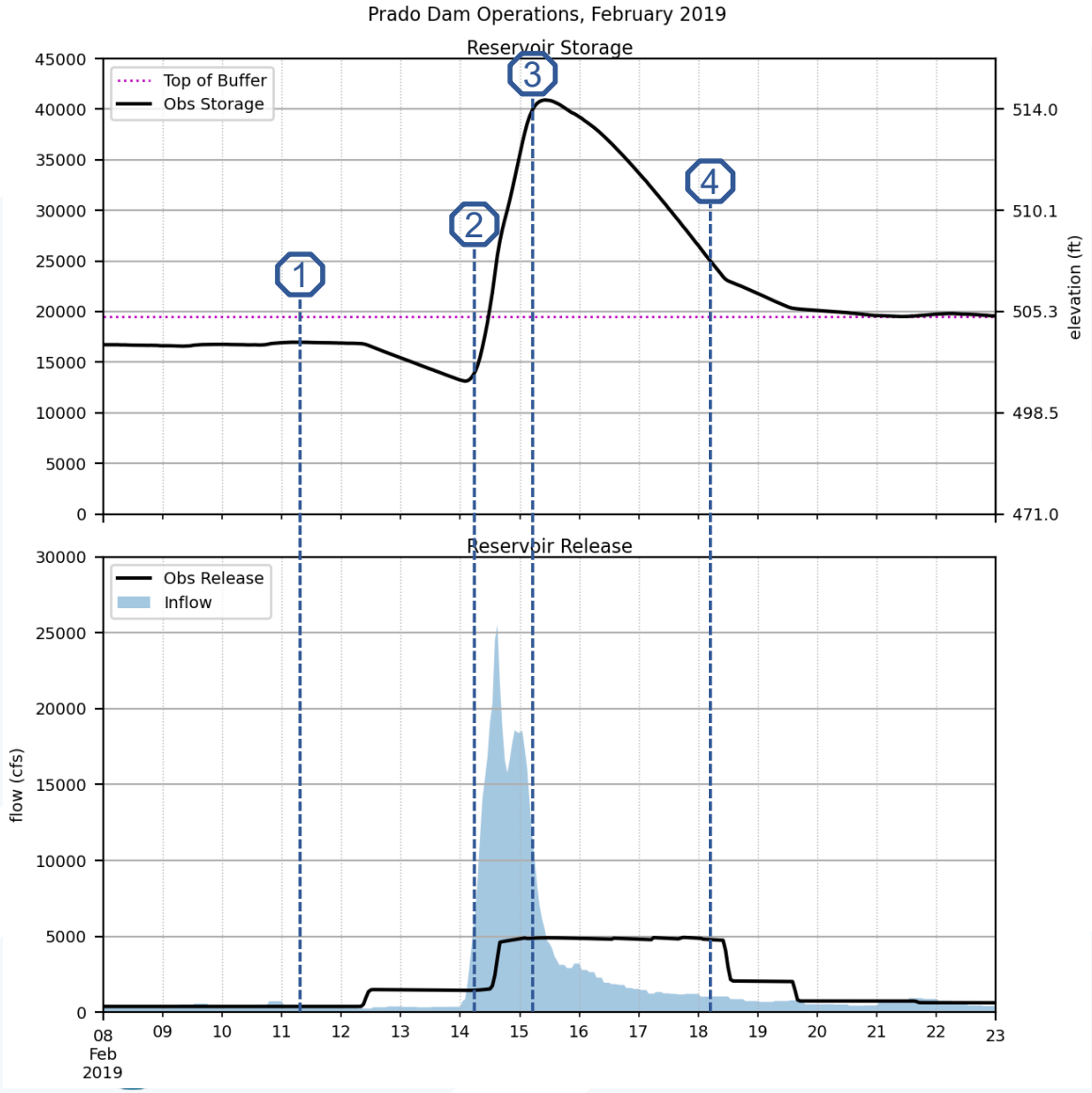
Site Access Coordination and Orange Book

- **Site Access Coordination Form**
  - Provided to entities working within reservoir and downstream
  - Forms include notification requirements
  - Many entities doing work without completing forms
- **Orange Book (Internal Use)**
  - Lists impacted properties within reservoir and downstream
  - Identifies by elevation and/or flow thresholds
  - Permanent notifications – updated annually
  - Release changes can be delayed by 3-4 hours
  - 5,000 cfs release typically results in 20-30 notifications
- **Notification Tool**
  - Software to log when notifications are made

Quantitative Precipitation Forecasts (QPF)

- FOX Weather
  - Hourly QPF w/ 3-day lead time
  - HEC Meteorological Forecast Processor (MFP) for 15-minute
  - QPF can be routed through CWMS
    - ❖ Provides another estimate of inflow (assess forecast uncertainty)
    - ❖ Previous attempts have shown that this overestimates inflows
- National Weather Service (NWS)
  - 6-hour QPF w/ 3-day lead time
  - Forecast discussions also utilized
- Used for situations awareness and operations
  - Help inform ROC activation and deactivation
  - Site access coordination
  - Notifications
  - Support release decisions

Quantitative Precipitation Forecasts (QPF)
February 2019 Case Study

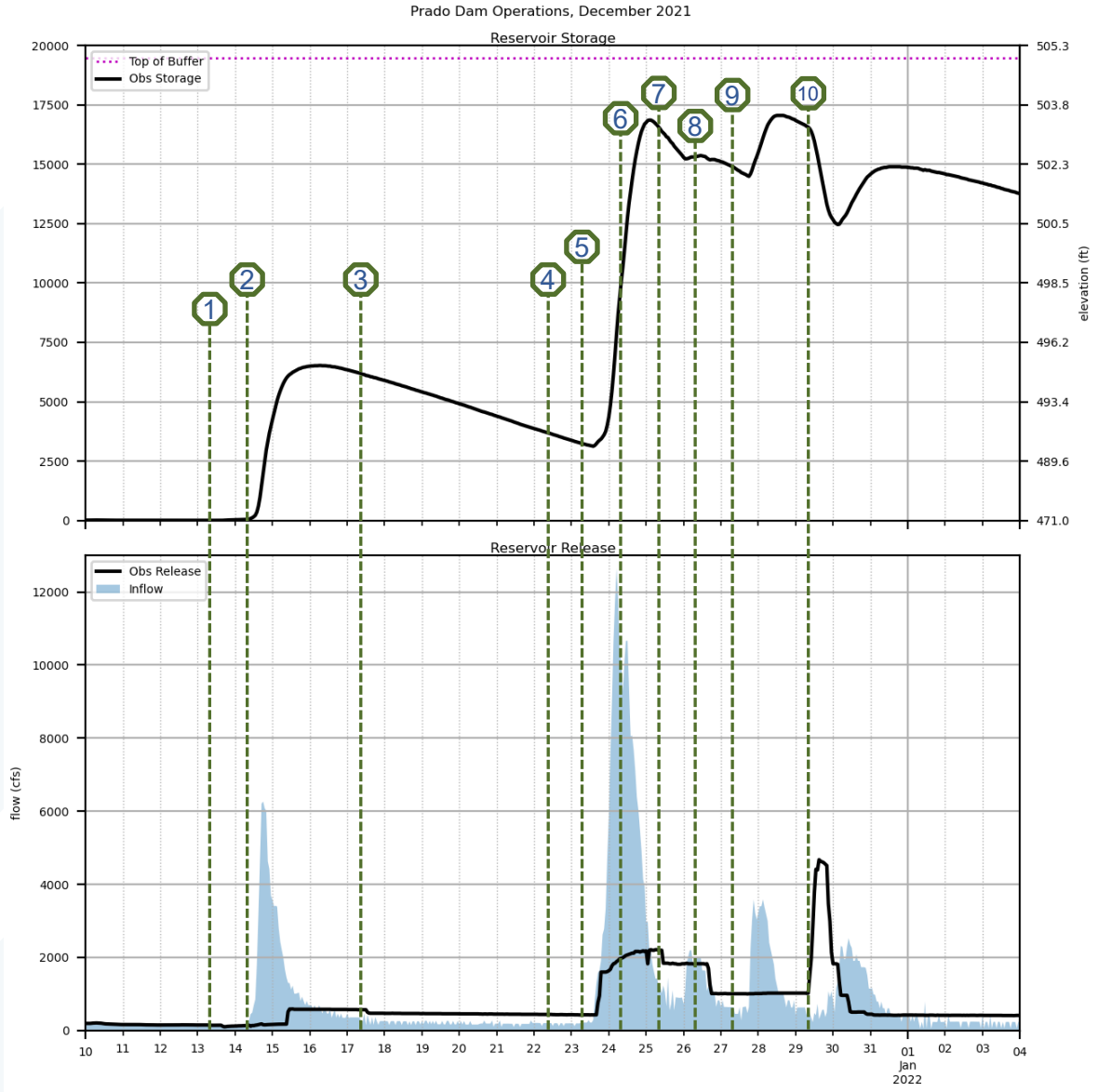


February 2019 Event

1) 2/11 – NWS: 1-1.5”
2) 2/14 – FOX: 0.3-1.0”
3) 2/15 – FOX: 0-0.3”
4) 2/18 – 2/25
    1) Notification of release reductions
    2) ROC Deactivation

❖ QPF = Situational Awareness

Quantitative Precipitation Forecasts (QPF)
December 2021 Case Study



December 2021 Event

1) 12/13: 1-4”
   - ROC Activated
2) 12/14: 1-3” Forecast reduced
   - ROC Deactivated
3) 12/17: 0.5-1” in 3 days
4) 12/22: 1-4” in 2 days
5) 12/23: 2-3” in 1 day
   - ROC Activated
6) 12/24: 1-3” in 2 days
7) 12/25: 0.4-1” in 1 day
8) 12/26: 0.4-1.5” in 2 days
   - ROC Deactivated
9) 12/27: 0.3-1” in 1 day
10) **12/29: 2-7” in 3 days**
    - **Over forecast**
    - **ROC Activated**

NWS QPF primarily used for this event

At lower storage levels QPF is used to inform ROC activation and deactivation and release notifications

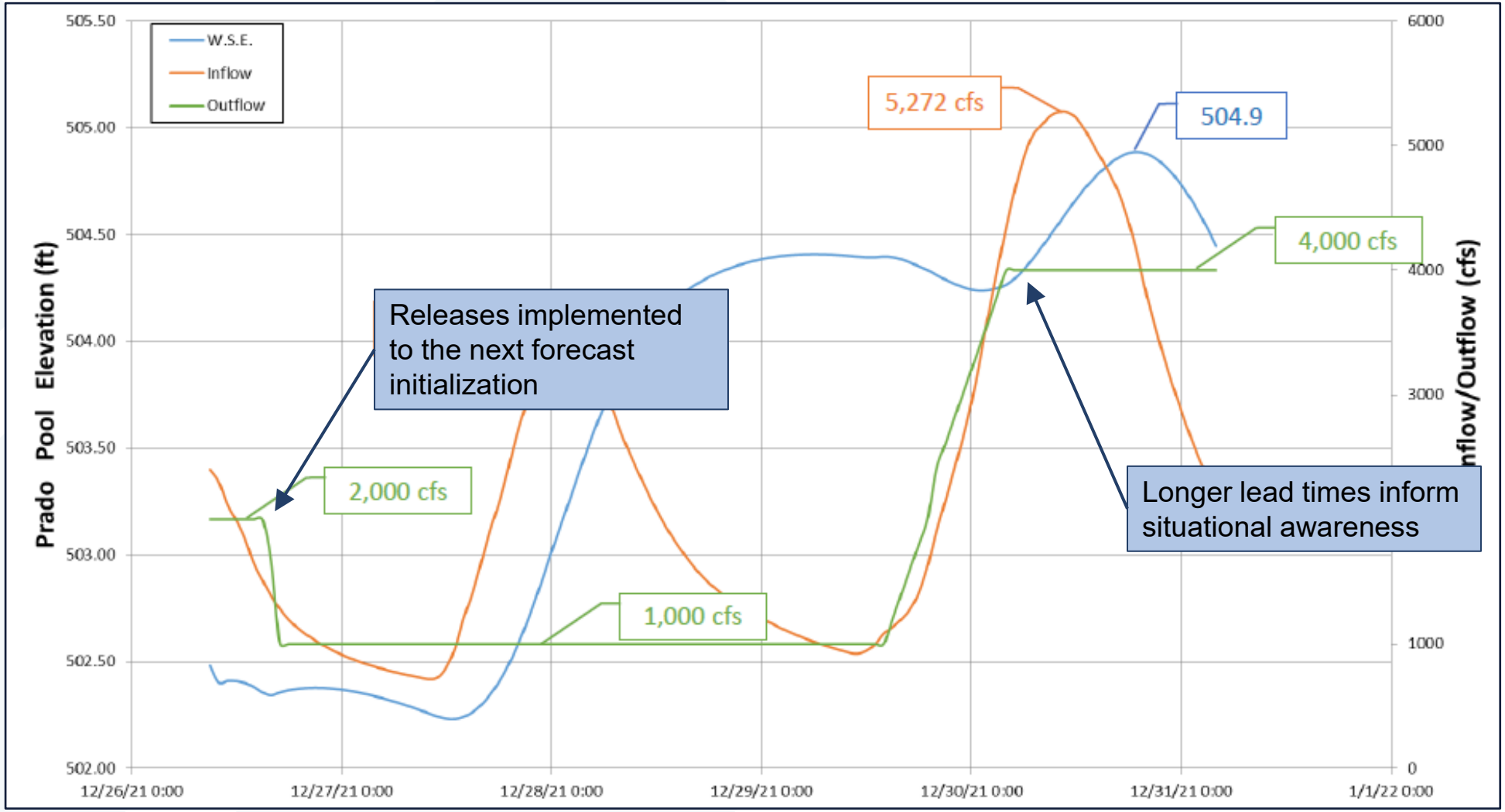
At higher storage levels QPF is used for situational awareness to support ROC activation and deactivation however spreadsheet tool is also used for these purposes.

CNRFC Inflow Forecast & Corps Spreadsheet Tool

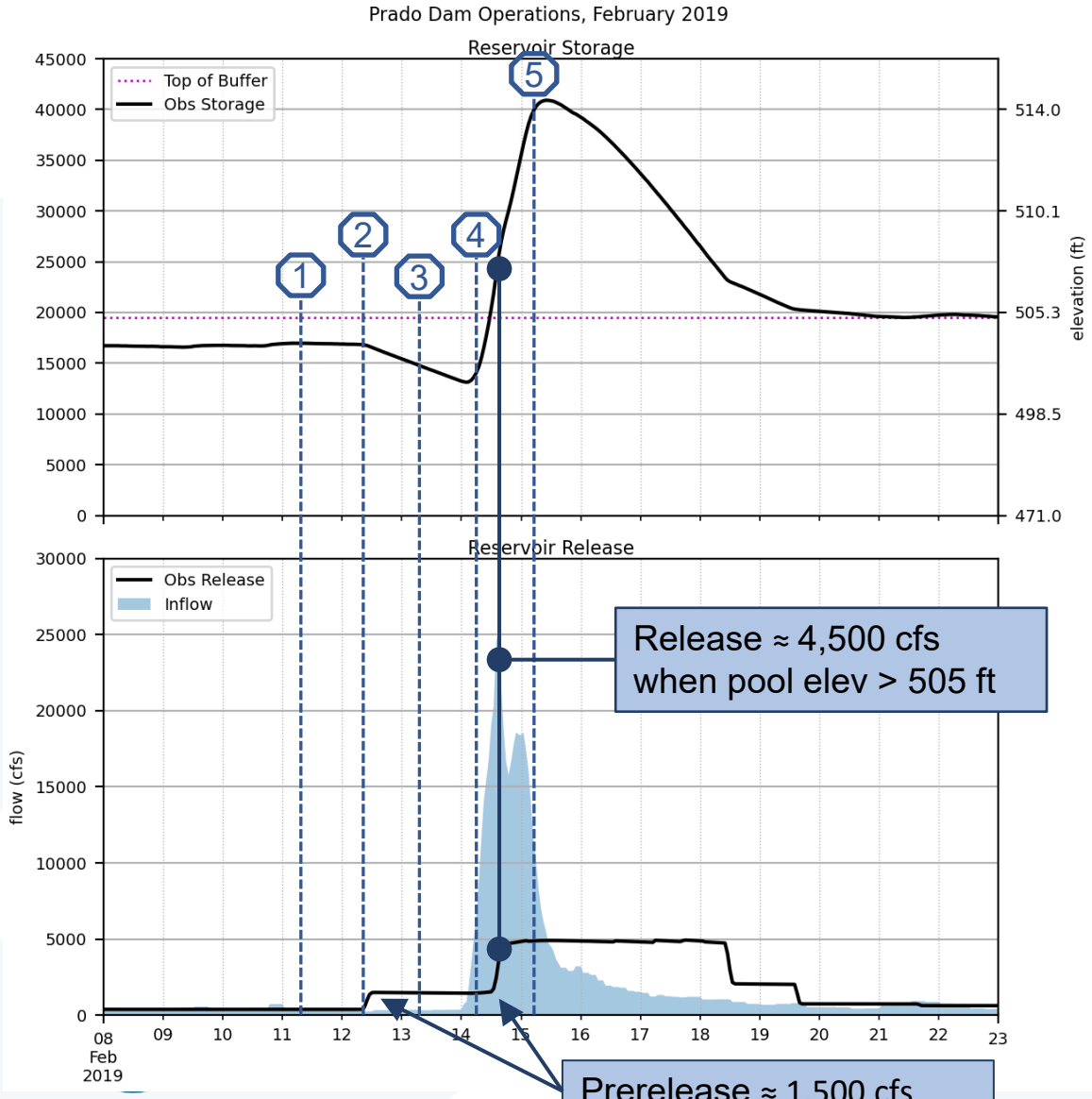
- Use deterministic inflow forecasts (4-day lead time)
- Calculate reservoir elevation w/ spreadsheet tool
  - Rolling horizon approach - update spreadsheet forecasts with each deterministic forecast cycle to 4-day lead time
  - Often run multiple release schedule alternatives to inform release decision

Spreadsheet tool is used to formulate release decisions

- **Release schedules formulated for the 4-day lead time to manage to a targeted peak pool elevation**
  - **Management strategy results in prereleases**
  - **Elevation target may vary depending on forecast strength**



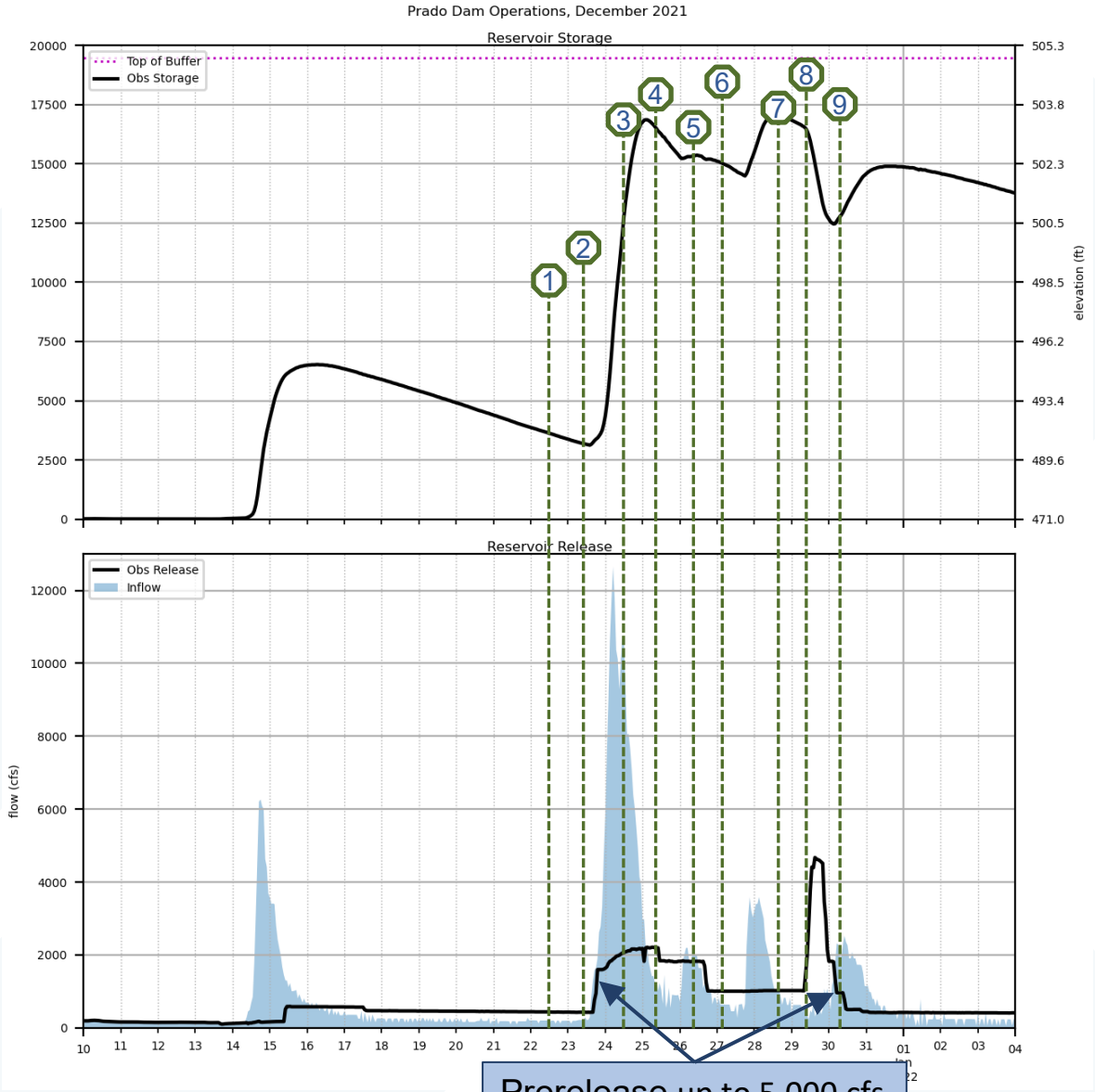
CNRFC Inflow Forecasts Spreadsheet Tool – February 2019 Case Study



Decision Point	Date	Time	Peak Inflow	Release Change From	Release Change To	Long Range Release	Forecasted Peak Pool
			(cfs)	*(cfs)*		*(cfs)*	*(feet)*
1	11-Feb	0900	8,670	350	1,400	1,500	509.6
2a	12-Feb	0900	10,510	1,400	1,400	1,400	510.2
2b		1500	11,340	1,400	1,400	1,400	511
3a	13-Feb	0900	30,680	1,400	1,500	1,500	516.9
3b		1400	28,290	1,500	1,500	5,000	512.8
3c		2100	27,390	1,500	1,500	4,500	513.8
4a	14-Feb	0200	28,340	1,500	1,500	4,500	513.1
4b		0900	25,795	1,500	4,500	4,500	512.7
5	15-Feb	0400	14,200	4,800	4,800	4,800	514.3

Hedging forecasted pool elev to maintain stable release schedule

CNRFC Inflow Forecasts
Spreadsheet Tool – December 2021 Case Study



Decision Point	Date	Time	Forecasted Peak Inflow	Release Change From	Release Change To	Long Range Release	Forecasted Peak Pool
			(cfs)	*(cfs)*		*(cfs)*	*(feet)*
1	22-Dec	0900	8,425	470	1,000	400	504.5
2a	23-Dec	0900	10,585	470	2,000	2,000	504.7
2b		1500	11,215	470	2,000	500	504.9
3	24-Dec	1500	10,832	2,000	2,000	2,000	506.8
4	25-Dec	0900	5,097	2,000	2,000	1,200	505.1
5	26-Dec	0900	5,272	2,000	1,000	5,000	504.9
6	27-Dec	0900	9,104	1,000	1,000	4,200	506.5
7	28-Dec	1400	14,285	1,000	5,000	2,500	507.3
8a	29-Dec	0900	14,955	1,000	5,000	1,000	506.6
8b		1400	7,614	5,000	1,000	1,000	508
9	30-Dec	1400	3,640	500	500	500	504

Prerelease up to 5,000 cfs

More conservative hedging of pool elev & more aggressive prereleases

Reservoir Regulation Website

- Google Maps
  - Elevation
  - Streamflow
  - Precipitation
- Gages color coded to established thresholds
- Alert system to contact reservoir regulation staff if thresholds are exceeded

Corps Water Management Systems (CWMS)

- **Incorporates multiple models**
  - HEC-HMS, HEC-ResSim, HEC-RAS, and HEC-FIA
  - Can generate inflow forecasts using QPF as input to HEC-HMS
  - RAS and FIA rarely used for operations due to long simulations times
- **ResSim is the primary model used**
  - Currently use deterministic inflow forecasts from CNRFC
  - Runs existing operations rule set
  - Alternatives are defined that hold releases at different rates
    - 1K, 2K and 5K cfs
  - Elevation results are evaluated for the alternatives to aid in the formulation of a release schedule
- **Control Acquisition Visualization Interface (CAVI)**
  - Desktop software for CWMS
- **Corps requirement to use CWMS for operations**

Current Alignment of Tools to Operational Needs

Types of Operations

Activation of ROC staff

- Forecasts to provide lead time for staffing needs

Notifications

- Site access coordination
- Orange Book

Reservoir Release Decisions

Current Tools

Weather

- FOX QPF
- NWS

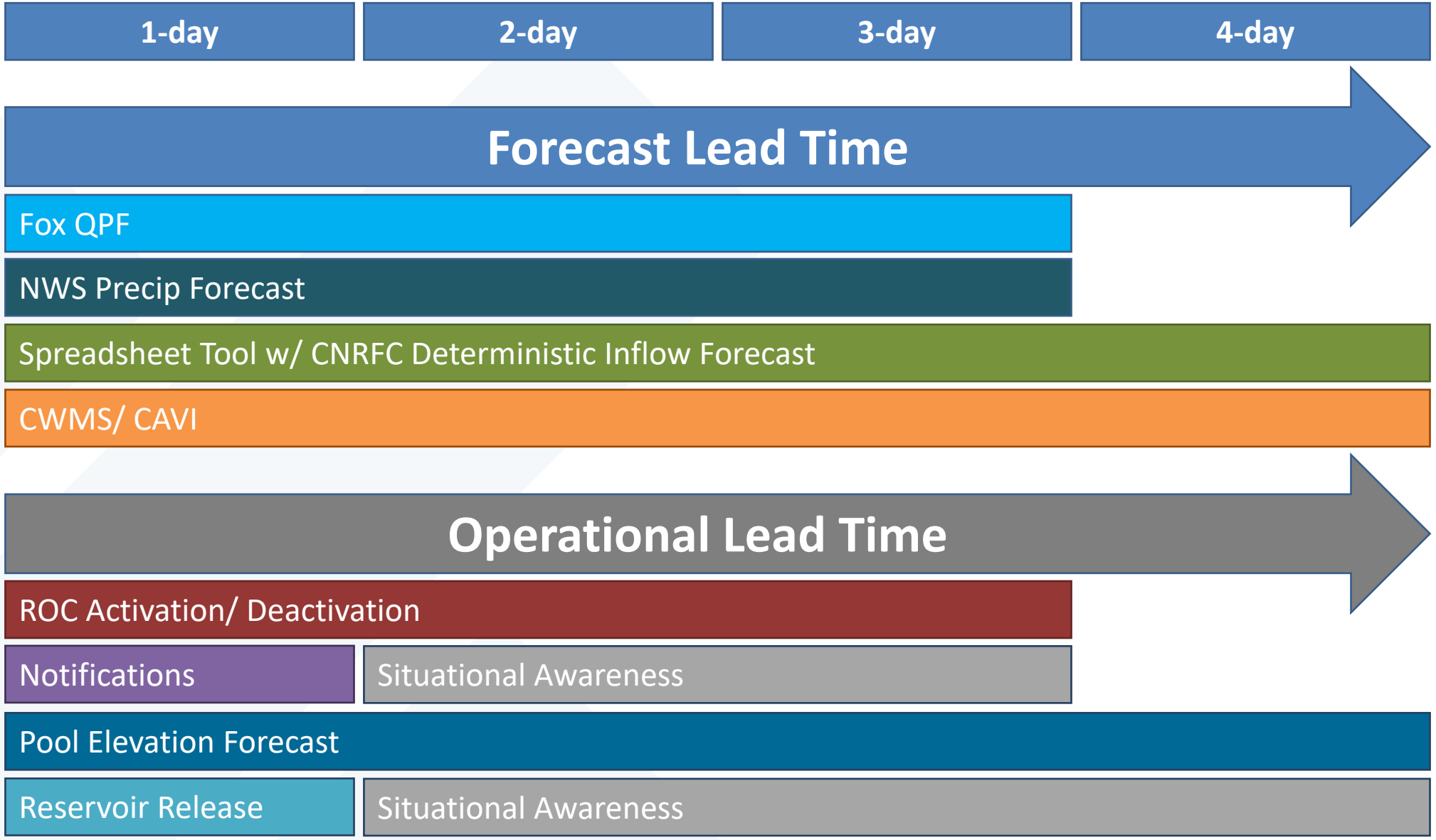
Hydrologic

- CNRFC Deterministic Inflow
- HEC-HMS

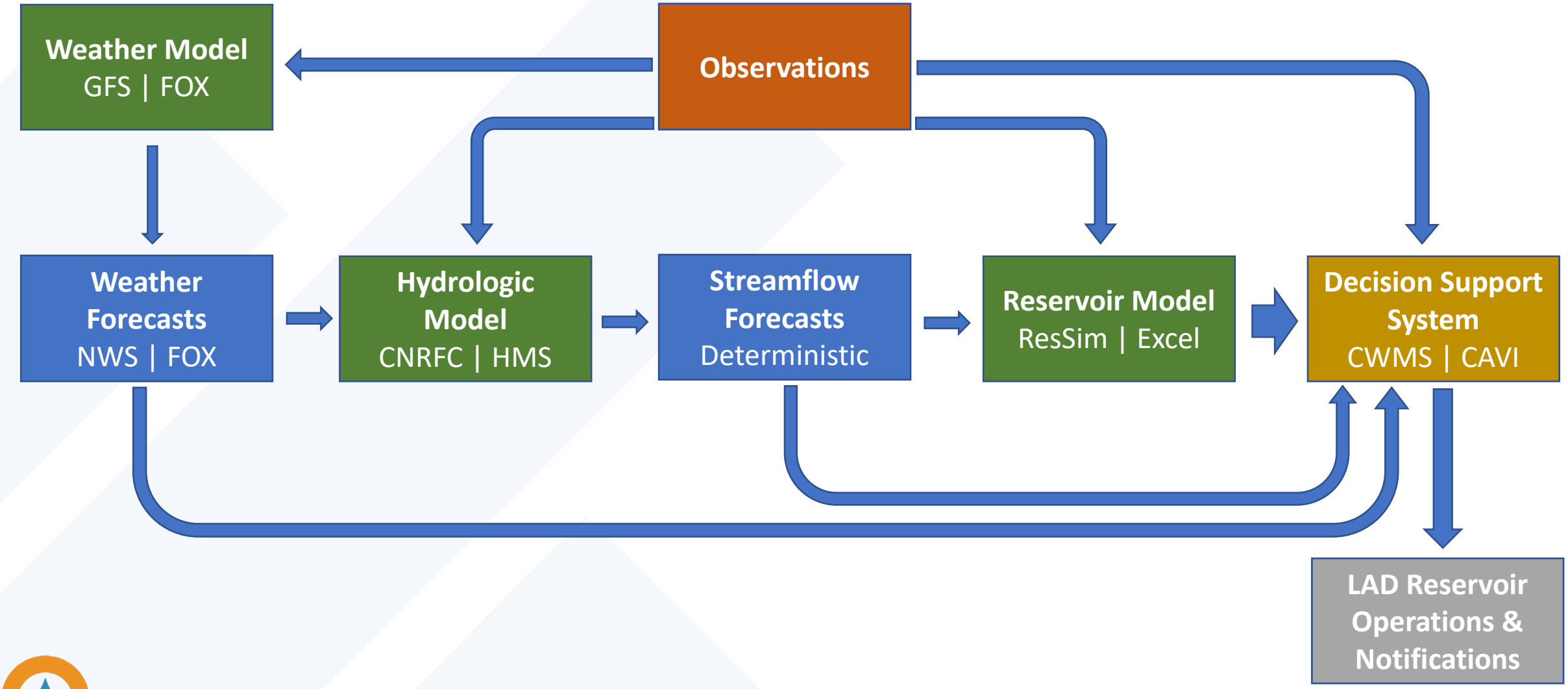
Operations

- **Spreadsheet**
- CWMS/ CAVI
- Reservoir Regulation Website

Current Tools to Inform Operational Lead Times



Existing Decision Support System Framework



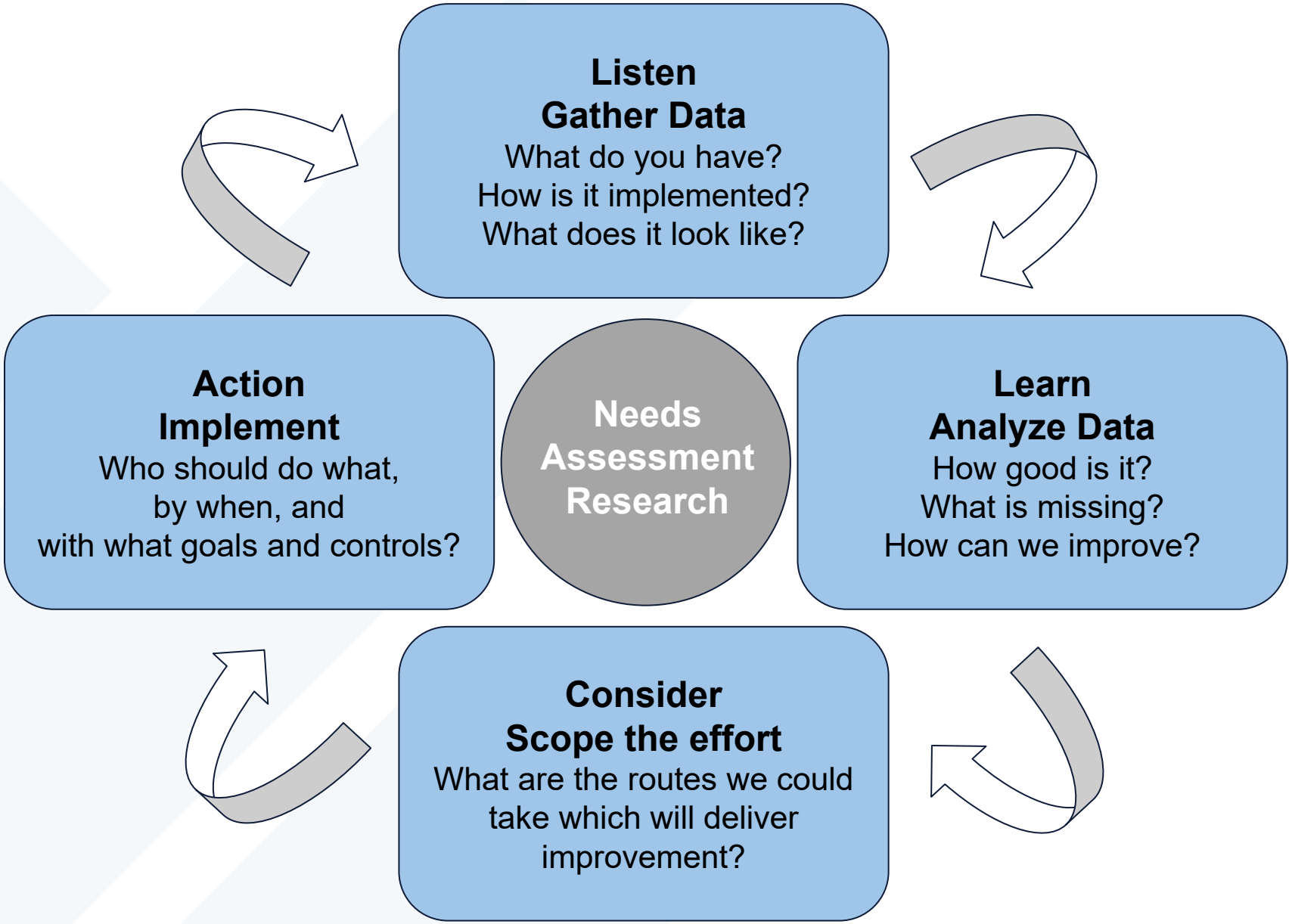
List of Decision Support Tool Needs from Workshop 1

- **More information is not necessarily better**
  - Limited time to process and evaluate different sources of information during real-time operations.
  - During a large storm event operations must focus on multiple systems not just Prado Dam.
- **Incorporating ensemble streamflow forecasts to account for forecast uncertainty could help with decision making**
  - Currently deterministic inflow forecast is sometimes scaled to account for forecast uncertainty
  - Incorporate into spreadsheet model | incorporate EFO model
- **Tools with thresholds of forecast information to inform operational decisions**
  - Precipitation thresholds (i.e. X inches in Y hours)
  - Pool elevation thresholds
- **Explicit FIRO water control plan**
  - Consistency of how forecast information is evaluated to inform decision making
- **FIRO-based operations framework to integrate with CWMS**
- **Assessment of QPF – conditioned based on storm type (AR vs. non-AR)**
- **Evaluate differences in FOX and CNRFC QPF in real-time**
- **Streamline notification process**
  - AR tools could be used to provide more lead time with notifications for AR events

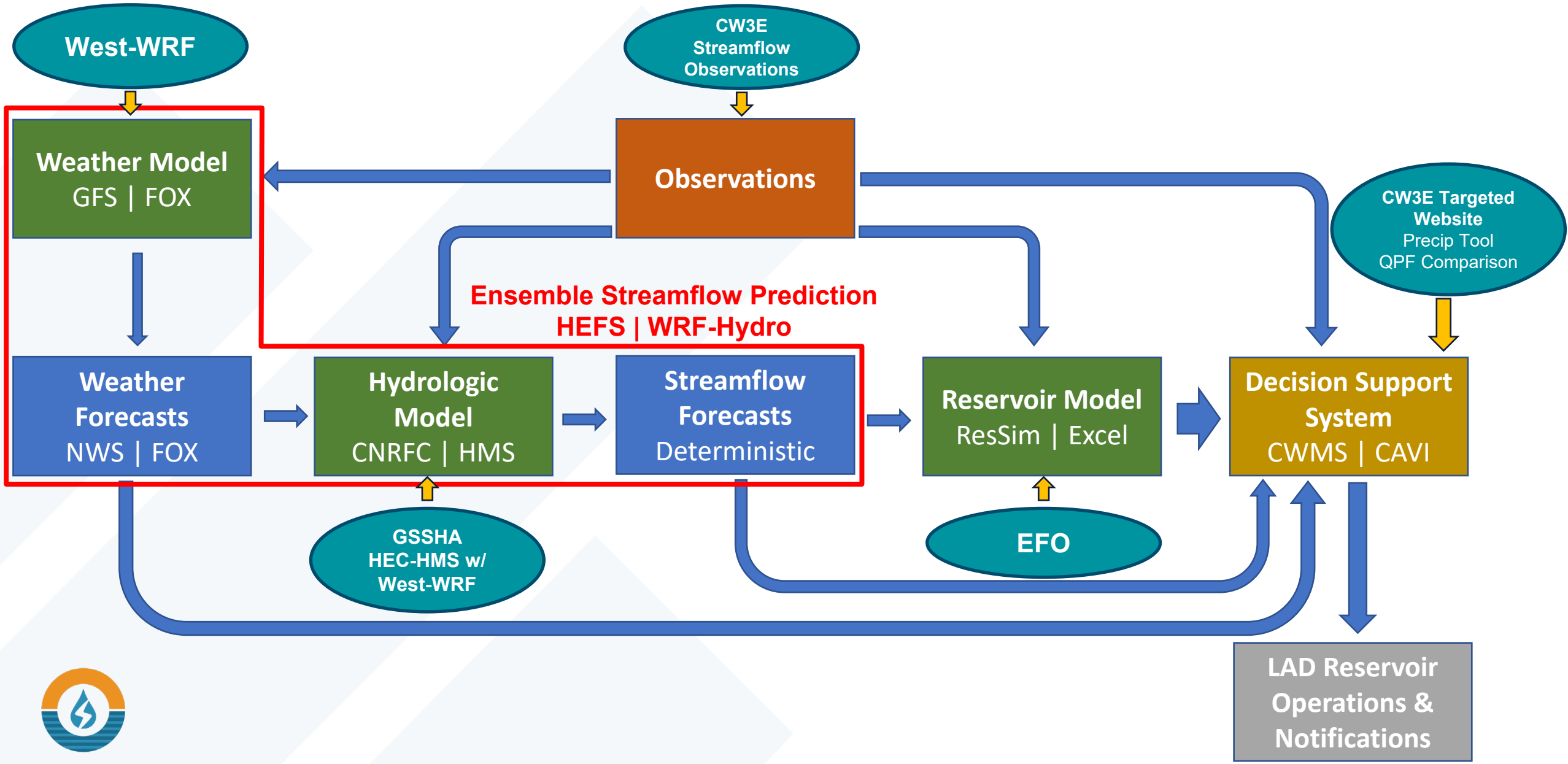
Things Learned from Workshop 1

- **QPF is used for situational awareness and can be applied as a source for alternative hydrologic inflow forecasts**
  - Activation/ Deactivation of ROC staff
  - Support notifications and release decisions
- **Spreadsheet tool w/ CNRFC Inflow forecasts is the primary tool used for decision making**
  - Forecast pool elevations to inform preleases (releases made based on forecasted storage conditions)
  - Notifications are tied to thresholds of release and pool elevation
- **Spreadsheet tool forecasts are updated frequently during large events**
  - Updated for each forecast cycle
  - Release schedule implemented to next forecast initialization
  - Multiple release alternatives are often evaluated before a decision is made
- **Elevation target for water management varied by forecast strength**
  - **2019:** *Target peak elevation ≈ 513' | Max prerelease ≈ 1,500 cfs*
  - **2021:** *Target peak elevation ≈ 507' | Max prerelease ≈ 5,000 cfs*
- **Additional situational awareness tools could provide helpful lead time for large events**

Needs Assessment Analysis



Possible Enhancements to Decision Support System Framework



Questions to Consider

- Does the information provided by these tools this help you streamline your process?
- Would this information increase your confidence and/or reduce the risk in making critical decisions beyond your current set of tools?
- Do you have any suggestions on how the information is presented with these tools?
- Given your current decision-making process, when in this process do you see these tools having the most impact?

Thank You

Prado Dam FIRO Decision Support Tools
Workshop #3
November 2, 2022
U.S. Army Corps of Engineers Base Yard
Building 2 Conference Room
645 N Durfee Avenue
South El Monte, CA 91733

Join Zoom Meeting:
https://ucsd.zoom.us/j/96842254213

9:00-9:10	**Welcome and Introductions**
9:10-9:40	**Overview of results of results of Workshop #2**
9:40-10:20	**Ensemble Forecasting – The importance of forecast uncertainty in decision making (Rob Hartman)**
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1:30-2:00	**Discuss of needs to support FIRO implementation**

Prado Dam FIRO Decision Support Tools
Workshop #3
November 2, 2022
U.S. Army Corps of Engineers Base Yard
Building 2 Conference Room
645 N Durfee Avenue
South El Monte, CA 91733

Materials can be found here

Attendance:

CW3E: Chris Delaney, Duncan Axisa, Janel Mayo, Garrett McGurk, Rob Hartman, Brian Kawzenuk, Rachel Weihs, Anna Wilson

USACE: Beth Faber, Evan Heisman, Joe Forbis, Fauwaz Hanbali, Kat Feingold, Jose Paradez, Julia Kim, Steve Turnbull, Amanda Walsh, Ken Lawler

OCWD: Adam Hutchinson, Greg Woodside, Ben Smith

CHL: Eric Bird

NOAA: Brett Whitin

Dave Reynolds

Action Items:

- **Chris to schedule DST Workshop #4 - Tuesday Jan 24th or 25th, fully virtual**
- **Chris to email links to HEFS documentation/resources & Lake Mendocino paper to participants after workshop**
- **Beth to create slides to capture what was shown in her presentation.**
- **Chris Next DST Monthly Meeting is Nov 11 - canceled, will just have the meeting in December**
- **Chris/Rob to schedule briefing of Prado virtual operations to OCWD, when ready (next 4-6 weeks)**
- **Rob: Need to work with the LA Water district on addressing delays in real-time operations support, as well as a ramp-up schedule formal vs. informal (John).**
- **Updating maximum release schedule chart, to reflect desire to not exceed 5,000 cfs for pre-releases.**
- **Rob/Chris: Form sub-group to address how to integrate EFO into CWMS**

- **Follow-up meeting needed in December**

Welcome and Introductions

Introductions.

Review of past Workshops #1 and #2. Workshop #3: Review operational tools xx. Workshop #4: Not yet scheduled, sometime in January, potentially all virtual.

Review of agenda

Ensemble Forecasting – The importance of forecast uncertainty in decision making (Rob Hartman) Slides are located here

Background on why we want to be using uncertainty and ensembles in decision-making.
Ensemble forecast basics.
    Forecast users need to manage their risk.
Fundamentals of uncertainty, probability, risk.
How might we estimate hydrologic forecast uncertainty?
    Error propagations, ensemble
Examples and applications of risk mitigation using ensembles.
    FIRO!
    Sources of uncertainty in hydrologic forecasts: many sources, forecast precipitation are the dominant source, but other sources may become more important depending on time of year, other factors.
    Ensemble streamflow prediction process:
        Using CHPS models, set of ensemble forecasts
    Available at most river forecast locations.
    15-day regulated, updated up to 4x a day. [regulated forecasts include reservoir operations regulations included as a part of the model - part of the CNRFC coordinated reservoir operations site, is then integrated into the models]
    365-day unregulated, updated daily. [unregulated doesn't include information on diversion/outflow]
    Multiple graphics and .csv - available online: CNRFC's website
Interpretation of Ensemble Forecasts
    Every individual ensemble member is equally likely. Probability of a variety of outcomes can be estimated.
    Normally an empirical distribution is assumed and applied. A theoretical distribution often works best with tails.
Questions:

So the differences in the forecast are just the different forcings? Yes.
Ken would like a tutorial on different variables.
YouTube videos and tutorials are available and documentation. (Chris to send out after)
    Brett Whitin, from chat: https://cnrfc.noaa.gov/hefs.php
        "HEFS Informational Videos" and the "HEFS at CNRFC" are what was referenced.
Review of emergency response examples.
FIRO is paving the way for forecast-informed emergency response.
Situational awareness/emergency response could be integrated into a FIRO dashboard to help inform decisions and be defensible.
Review of water management examples.
    The spread of what we see in the model (Santa Ana River) includes historic forecasts and historic observations - large spread. The thing that is not integrated in HEFS - would require further research. A function of all of the forecasts and all of the obs at a particular period of time, ex.: all observations and forecasts from 1990 on during a 60 day window of the year. Not associated with one particular weather phenomenon -> not integrated into the uncertainty. If we had data on particular weather phenomena, we could integrate that in - limitations may come from available data.
We could have guidance of what the forecast skill is with a product such as HEFS based on the meteorological feature associated with the event.
Some indications of level of uncertainty - could be based on type of feature, etc. How to quantify this is uncharted territory? - but would be worth exploring.
How do we solve this problem? Weighting ensembles based on conditional uncertainty in the past - how to quantify is the tricky part.

Things to consider for reservoir operations:
    Ensemble forecast reliability
    Specifics on weather feature that affect predictability
        Ensemble spread is based on average predictability
    Need a modeling framework to properly assess the risk
        Spreadsheet tool (ensemble-enabled)
        Ensemble Forecasts Operations Model (EFO)
        Some other variant
    Evaluation of risks and benefit - balance
    Understand lead time requirements
    Practice with simulated events to build confidence

Enhanced Spreadsheet Tool w/ Ensembles (Beth Faber)
Beth to make slides after the fact.
Walk through 2/2019 example:
    Enter in starting elevation - tracking of the reservoir by tracking inflow and release.

Tab: Paste ensemble - includes ensemble forecast trace. Average ensemble forecast is not continuous - plotted as dots (hourly)
Ensemble compute - can compute reservoir storage routing for each of the ensemble members (not suggesting decisions - descriptive vs. prescriptive) "what could occur with the decisions we currently have planned?" How much of the ensemble outcome should we plan for? We need to consider both directions spanning high end (consequences = drafting water out of buffer pool) spanning low end (making sure we don't draft more than we have to)
This spreadsheet is an intermediate step before making decisions with the ensemble - allows for visualization.

Ensemble Forecast Operations (EFO) (Chris Delaney) Slides are located here

EFO background
We developed this approach to incorporate how we use forecast in our daily lives in order to inform decision-making. Forecast uncertainty and management uncertainty increases with lead time.
EFO Risk tolerance curve accounts for forecast uncertainty: central to methodology.
Published paper for study done at Lake Mendocino - provides a lot of detail into how the methodology works. A lot of the methods in this paper apply for Prado Dam. [Link to article]
Hydrologic Ensemble Forecast System (HEFS)
What is currently being used as an operational forecast ensemble. One important component is the hindcasts - which has been key in allowing modeling for FIRO.
Hindcast for Prado being extended to 2019.
CNRFC -> model -> Storage Forecast -> Risk Analysis -> Flood Release
(Repeat with each forecast cycle)
Prado Dam PVA Results
Five alternatives were considered
January 5, 2005 example review (100 yr event):
*For hindcast period for Prado: limited data on extreme events
Forecasted risk is the main component for informing decision-making (based on risk guide curve)
Risk guide curve: optimization approach - scoring different curve shapes based on FIRO objective metrics calculated from hindcast simulation results.
Will be improving upon this for the FVA.
All of the FIRO alternatives show increased benefits compared to baseline (reduced flood risk)
Operations that were developed for the PVA did not incorporate responding to flooding at the airport - will be considered in the FVA
Seeing an increase in flooding with all FIRO alternatives - need a way to respond to flooding.
February 2019 Case Study

Dual objective FIRO: Reduce frequency of flooding at airport, with no reduction in water supply reliability.

Build upon EFO developed in the PVA: will still consider risk of exceeding the spillway, but will also now include the risk of exceeding the airport.

Built in assumptions in Dual Objective EFO (DUO 515):

- Buffer pool elevation 508'
- Max FIRO pre-release 5,000 cfs
- No delay on release decisions (in real time there is delay in implementing decisions - may skew results to appear a bit better)

December 2021 Case Study

DUO 515 model (if it was used operationally at the time) recovers storage from over forecast. If we're evaluating at every forecast cycle there's opportunities to adjust to changing forecast and recover storage.

Combined Findings:

This tool demonstrates skillful operation for both events

Management of pool to minimize airport flooding

Management to reduce risk of spills for extreme events (100 & 200 yr), evaluated in PVA and further evaluated in FVA

Can provide both situation awareness and release recommendations.

HEFS forecasts evolved very rapidly for both events.

Will go over the volume-based approach at another time.

Next steps and feedback:

Multiple dual objective EFO alternatives will be evaluated in the FVA

Multiple buffer pool levels (508 to 515 ft.)

Further explore volume-based approach

Currently developing real-time virtual EFO model

Dual objective alternatives: 508' buffer pool and 515' flood stage

Simulate in real-time if EFO alternative were implemented

Could attempt to incorporate actual operational delays in the simulation of FIRO alternatives for the FVA.

Can we look at the airport flooding on the one hand and the release rate on another, considering that flood risk is low?

Chris: Absolutely it can be developed and incorporated. It would be great to get feedback from the Corps on constraints of pre-releases.

What consequence modeling has been done?

There hasn't been any done to date. If there is some sort of quantified cost as a function of flooding, that's something that it could be done in the future - but not sure we want probability x consequency to inform decision-making? It's conceptual at this point.

USACE has FIA which has information about quantifiable amounts for these metrics.

Status of the Corps Water Management System to incorporate ensemble streamflow predictions (Fauwaz Hanbali on behalf of Evan Heisman) Slides will be placed here

- HEC Software Options - Existing and Underway
  - ResSim Ensemble Compute
  - CWMS (Corps Water Management System)
    - Control and visualization interface (CAVI), integrates real-time data acquisition data visualization and modeling tools.
  - Ensemble Data Management Options
    - DSS Storage and API
      - Ensemble data identifiers and versioning
      - Plot versioned forecasts together
      - Read/Write API for ensemble data exchanges between models
    - CWMSVue Versioning in Oracle Database
      - Has direct access to CWMS database
      - Versioning
      - Plot aggregate to show latest values for a given time
    - SQLite and API
      - Note yet integrated in CAVI real-time forecasting
      - Already integrated in HEC-WAT planning models
      - Shared Java API (can use the same code against DSS or SQLite)
  - Ensemble compute options in CAVI
    - (Existing) CAVI Ensemble Extract Editor
      - Currently supports DSS only
      - Can access local and/or remote DSS files
    - (Existing) CAVI Ensemble Forecast Run
      - Distributed computes using each ensemble member
      - Feeding ResSim directly
      - Aggregated results into a master forecast dss file
      - Scripting applications for post processing analysis and visualization of results
    - (Existing/Underway) Ensemble Forecast Pre-processor
      - Pretty operational, is in progress to be used in the CAVI
      - New standalone program
      - Calculate metrics from forecast ensemble datasets
      - Also serves as a plugin progrram for both CAVI and HEC-WAT
      - (Future) CAVI Cloud Computing and Ensemble Computes across the various programs
      - CAVI cloud computing designs are at initial stage
      - Looking to expand ensemble computer to at least HEC-MetVue and HEC-HMS in addition to HEC-ResSim
  - Ensemble forecast pre-processor
    - summarized ensemble forecasts into understandable metrics in modeling environment
    - Intended to be an in between for ensemble and forecast operations

Take the ensemble and get the summary metric to pass to operations.

If EFO was used, the pre-processor would not be needed.

What output options does the EFO model have that could be integrated into CWMS or ResSim?

In the past we've just used .csv which can be set up to be used in DSS. There's other possibilities too for direct DSS output for using the Corps' tools.

Is the SQLite up and available?

Yes it is up and running with the HEC-WAT, but could be set up with CAVI.

It would be a great way to couple the stuff we're working on with CWMS, most of our stuff is in Python, so it would be a nice way to integrate.

FIRO Libraries

Through FIRO funding the team built a set of libraries that can support the needs of FIRO studies, These are designed to be used in both CWMS and WAT.

Data storage and access, statistical analysis, visualization, plugins for WAT and CWMS

Can evaluate results, and drive operations.

HEC-WAT is reliant on the forecast processor to convert the ensembles to metrics.

FVA:

The plan is to figure out how to adapt the models to CWMS and adapt that in real-time.

Reviewed workflow concepts (simple, and EFO-like)

Questions:

Can the forecast processor interact with ResSim parameters, rule sets, states to create metrics that have regulation outcomes associated with them? Feedback mechanism between forecast processor and ResSim?

Yes. Sequential process, not dynamic in one run.

What about the option of using the pre processor to link with EFO?

I think that could be done, seems like a good tie in. As long as it's in a database that the preprocessor can process.

The forecast processor tool is operational within the WAT, for CWMS we have a foundation that we can use it as a plugin but there's a little bit of work to link it to ResSim? Depends on what you're trying to do now, real time?

Supporting real time operations, direct coupling is needed.

RAS in forecast mode to evaluate forecasting consequences?

We don't have downstream consequences for Prado. Could be useful because impacts of flooding downstream could be large. There could be issues with the time it would take to run RAS. There's other ways (RIM) tool is a good substitute - you can build library of static maps, pick something that looks really close. Districts are supposed to have capability to create event specific inundation map. Would not be efficient in the moment. Would need to populate library.

Is that matching inundation maps with distributions of rainfall?

Based on depth, range for depths, not flow specific but footprint of dam area.

If you have questions, email Beth and Evan.

Discuss of needs to support FIRO implementation

Duncan: how are we doing with this exercise, are we on track, what are you desired next steps and outcomes?

In terms of progress, lots of good progress is made. Would the Corps have interest or benefit in trialing this this year?

Open to it, we would have to figure out resources involved.

Rob: we're on track to be able to have virtual operations EFO model up and working soon..

Chris: not up to real-time yet, working with Chad at CW3E - hopefully before December.

Rob: Once that is live, we can do an online demo/tutorial for interpreting the information. We can password protect this if wanted.

Steve Turnbull: ERDC is shooting to have our tool built and working by the next workshop.

Duncan: How much of that can be daylighted for Workshop #4 -

Chris: We can present that in the next workshop, it's very close right now. One of the things - it may not be interesting if we don't get interesting weather. One of the main goals for the next workshop is to present a needs assessment.

Rob: Reminder: Pencils down 2/14/2023 for the FVA. We want to spend some time in the next workshop converging on the alternatives.

Center for Western Weather and Water Extremes
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November 2, 2022

Prado Dam FIRO Final Viability Assessment Decision Support Tools Workshop #3

Verizon MiFi-8800L-A1CA
WiFi Password: bba5d89e

Chris Delaney, Research Engineer
Robert Hartman, Consultant
Beth Faber, HEC
Evan Heisman, HEC
Duncan Axisa, FIRO Program Manager
Arleen O'Donnell, ERG

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DST Workshops

- **Workshop 1 (Completed 8/16/22):** Review Corps existing tools and operations for Prado Dam
  - Historical storm events: February 2019 and December 2021
  - Facilitate learning of existing operational practices and constraints
- **Workshop 2 (Completed 9/12/22):** Review atmospheric river and watershed tools that could support FIRO
  - Demonstration of CW3E and ERDC tools
- **Workshop 3 (11/2/22):** Review operational tools that could support FIRO
- **Workshop 4 (TBD):** Presentation of needs assessment

Workshop #3 Agenda

9:00-9:10	**Welcome and Introductions**
9:10-9:40	**Overview of results of results of Workshop #2**
9:40-10:20	**Ensemble Forecasting – The importance of forecast uncertainty in decision making (Rob Hartman)**
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1:20-1:30	Discussion of CWMS (Group)
1:30-2:00	**Discuss of needs to support FIRO implementation**

Overview of Workshop #2

- **Observations – Enhanced Streamflow Monitoring (Garret McGurk)**
- **Atmospheric Tools:**
  - Atmospheric River Tools (Brian Kawzenuk)
  - West WRF (Rachel Weihs)
  - QPF Verification (Brett Whitin)
- **Watershed Tools:**
  - Santa Ana River Precip Tool (Brian Kawzenuk)
  - Regional QPF Comparison (Rachel Weihs)
  - GSSHA (Chuck Downer)
- **Discussion of FIRO need to support implementation**

Key Takeaways from Workshop 2

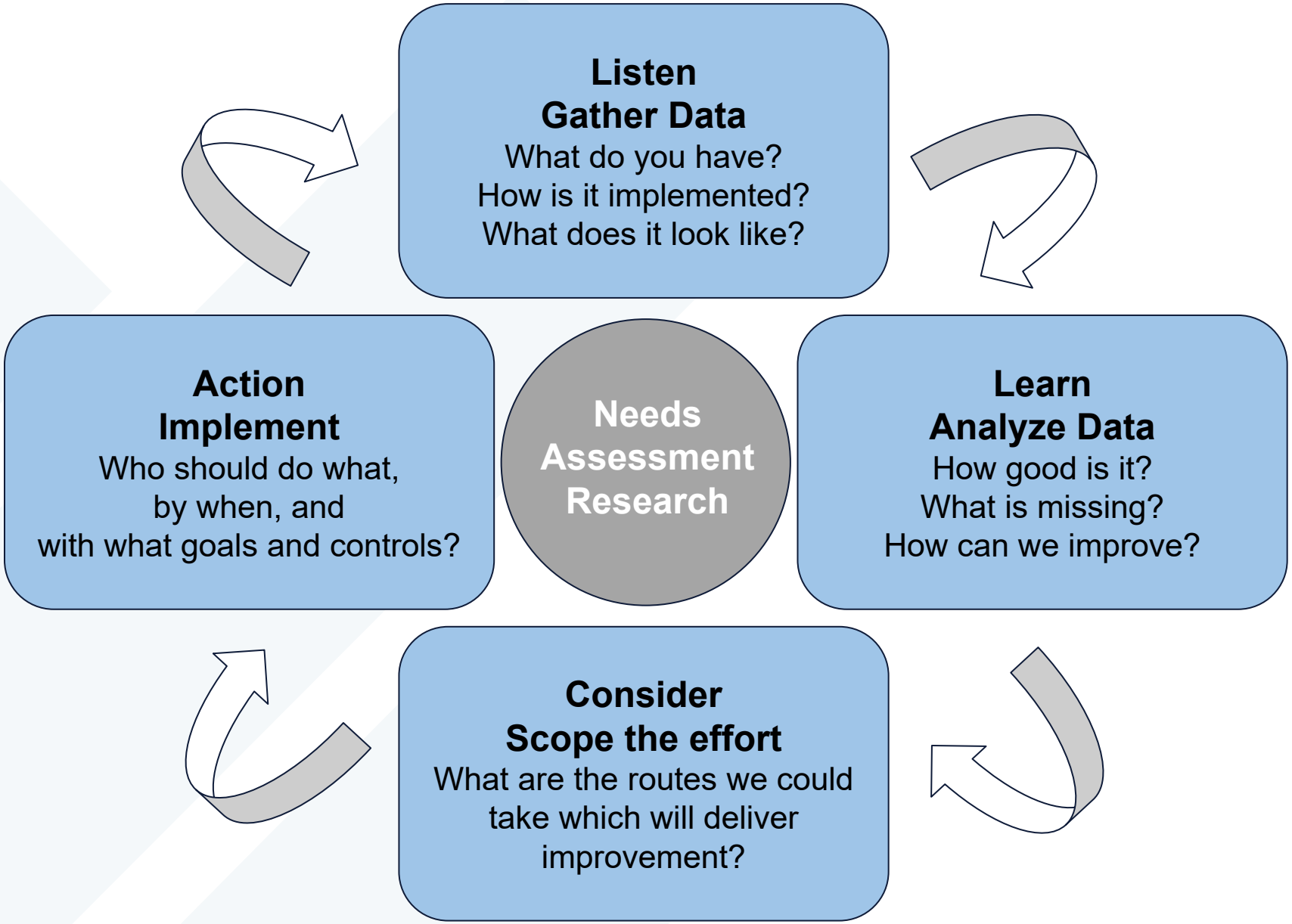
- **Relevant information is best.**
  - This can be adjusted as FIRO evolves, but don't want too much information to process in real-time.
  - Development of tools focused for the watershed would be useful.
- **A FIRO DSS must enable implementation of a FIRO water control plan (WCP).**
  - Once a FIRO WCP is developed what additional information and tools do operators need to manage according to the WCP?
  - Want to avoid a paradigm where FIRO is not adequately supported with decision support tools.
  - Desired to formulate a WCP with flexibility in how forecasts are used.
  - Initial implementation will be influenced by the selected alternative of the FVA.
    - NOAA Hydrologic Ensemble Forecast System (HEFS) will be used initially – all FVA alternatives use this.
- **How will the information be provided?**
  - Simple summaries to minimize delays in decision making?
  - More complex? – would require additional resources from USACE to support real-time operations.
- **Forecasters and tool developers will require ongoing feedback to support tool refinement.**
- **Decision support tools should be integrated into CWMS and CAVI.**
  - Will be the primary tool for decision making.

Questions to Consider for Today's Workshop

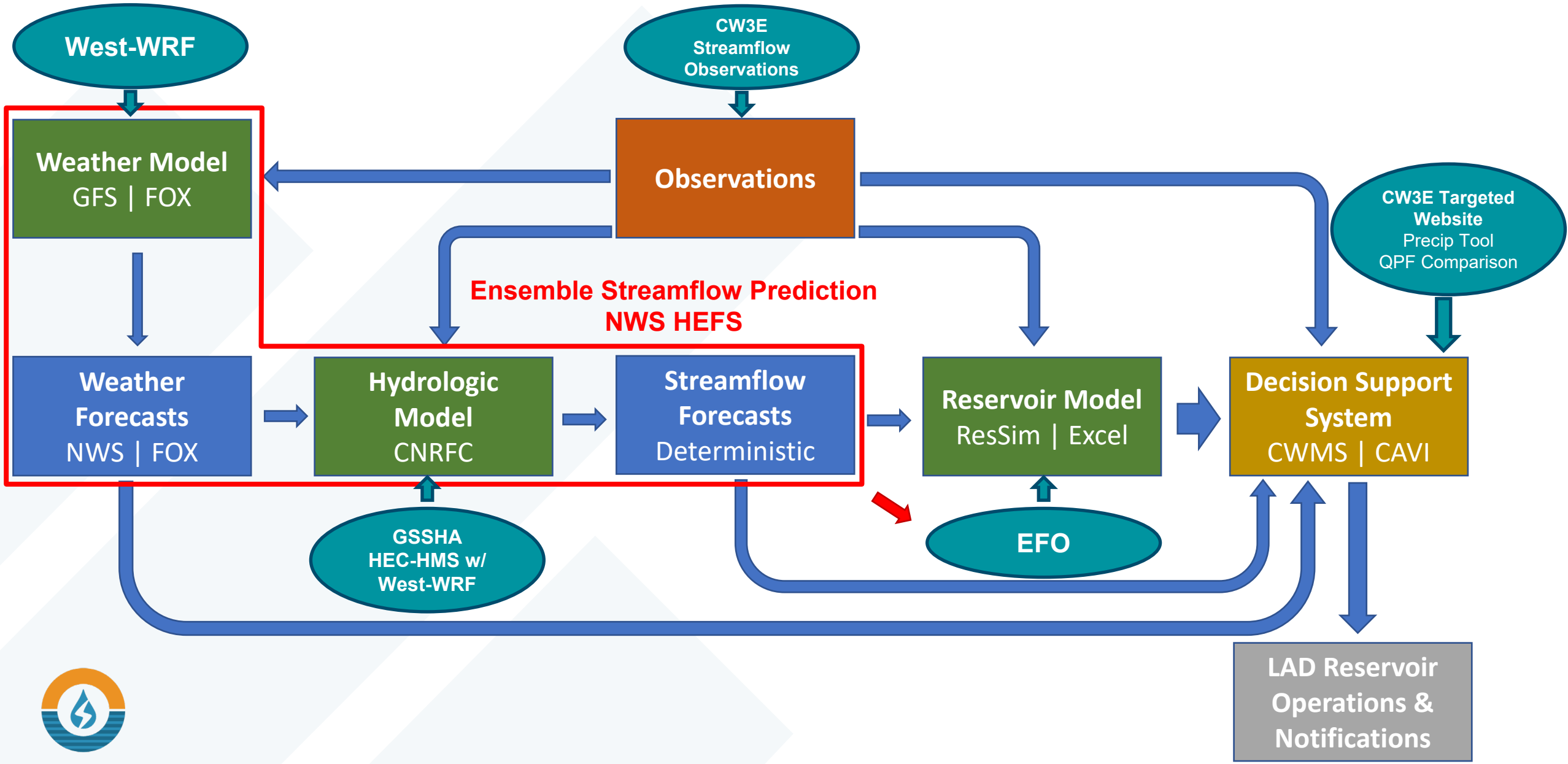
- Does the information provided by these tools help to enable the implementation of FIRO?
- Would this information increase your confidence and/or reduce the risk in making critical decisions beyond your current set of tools?
- Do you have any suggestions on how the information is presented with these tools?

Thank You

Needs Assessment Analysis



Possible Enhancements to Decision Support System Framework



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Prado Dam FIRO Decision Support Tools Workshop #3 Ensemble Forecast Operations

11/2/2022

Chris Delany, Research Engineer
Center for Western Weather and Water Extremes

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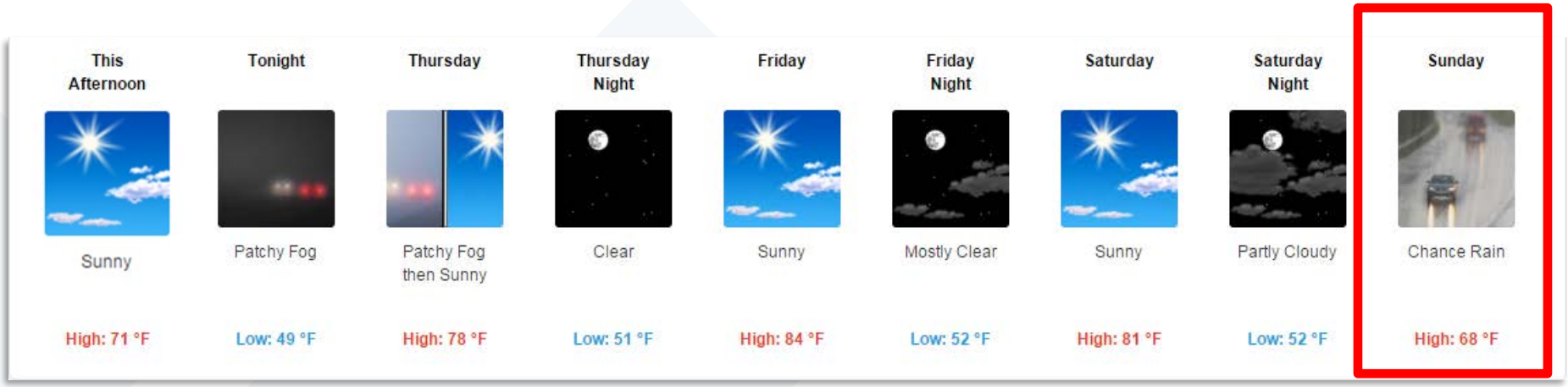
Presentation Overview

1. **Ensemble Forecast Operations Background**
2. Prado Dam Preliminary Viability Assessment
3. February 2019 Case Study
4. December 2021 Case Study
5. Volume Based EFO Approach
6. Next Steps and Feedback

We account for forecast uncertainty in our daily lives.



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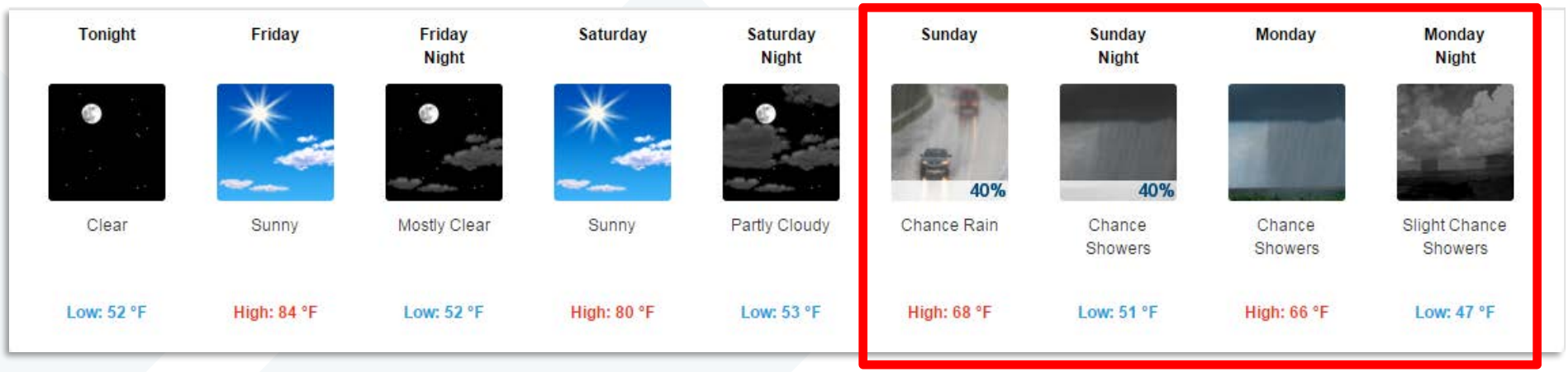

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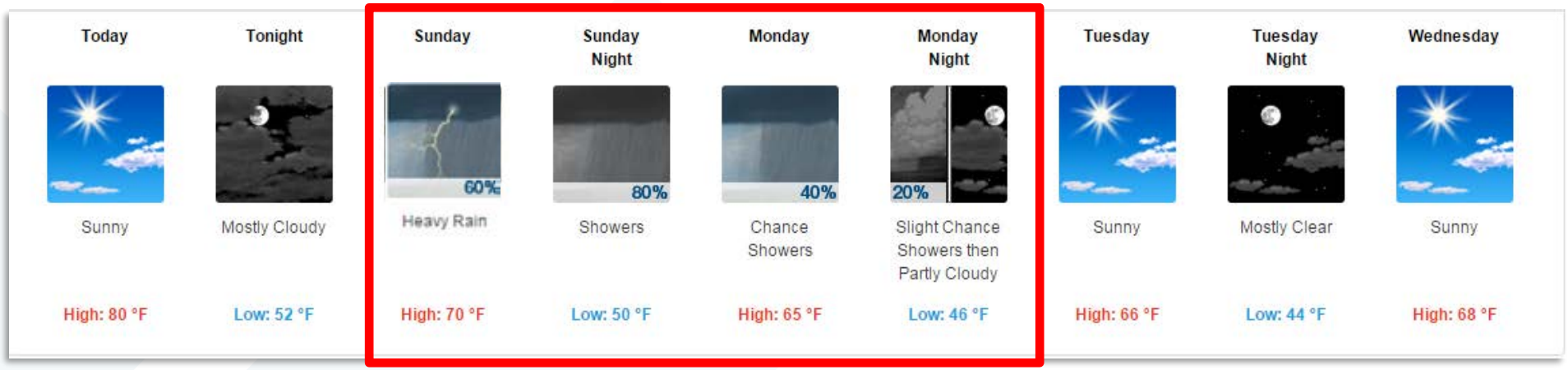
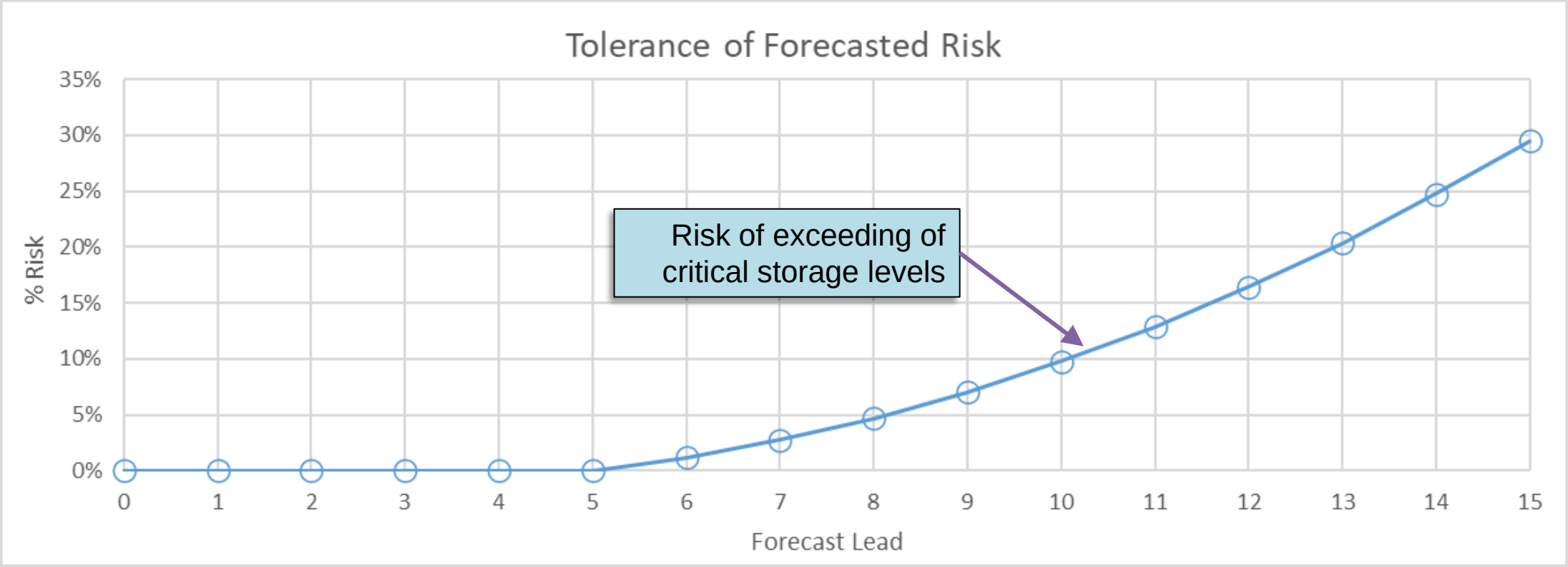


EFO Risk Tolerance Curve Accounts for Forecast Uncertainty



Water Resources Research

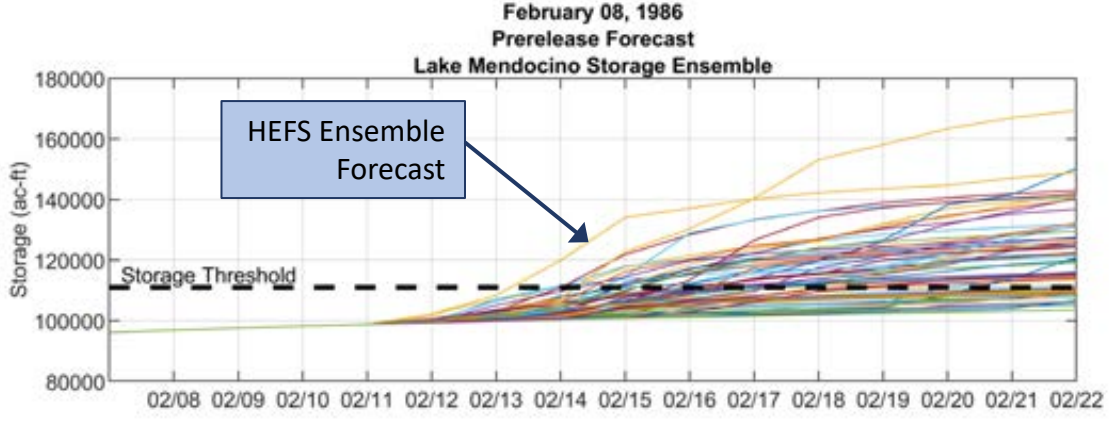
Forecast Informed Reservoir Operations
Using Ensemble Streamflow Predictions for a Multi-Purpose Reservoir in Northern California

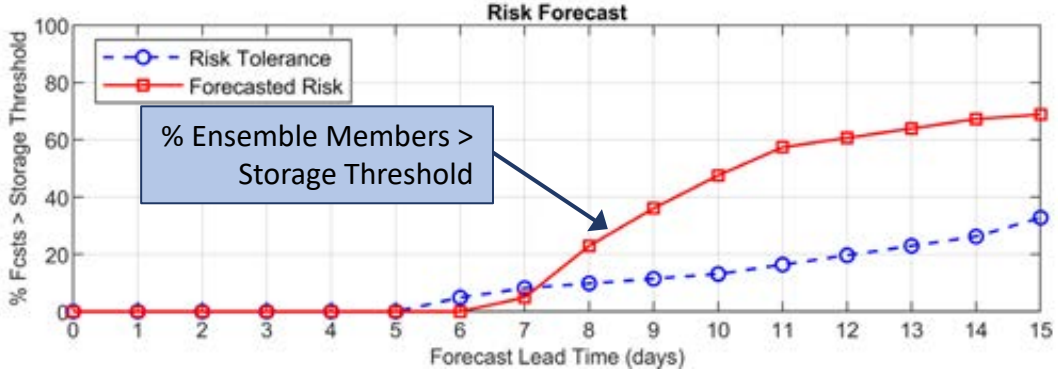
10.1029/2019WR026604

Chris J. Delaney[1], Robert K. Hartman[2], John Mendoza[1], Michael Dettinger[3], Luca Delle Monache[3], Jay Jasperse[1], F. Martin Ralph[3], Cary Talbot[4], James Brown[5], David Reynolds[6], Simone Evett[7]

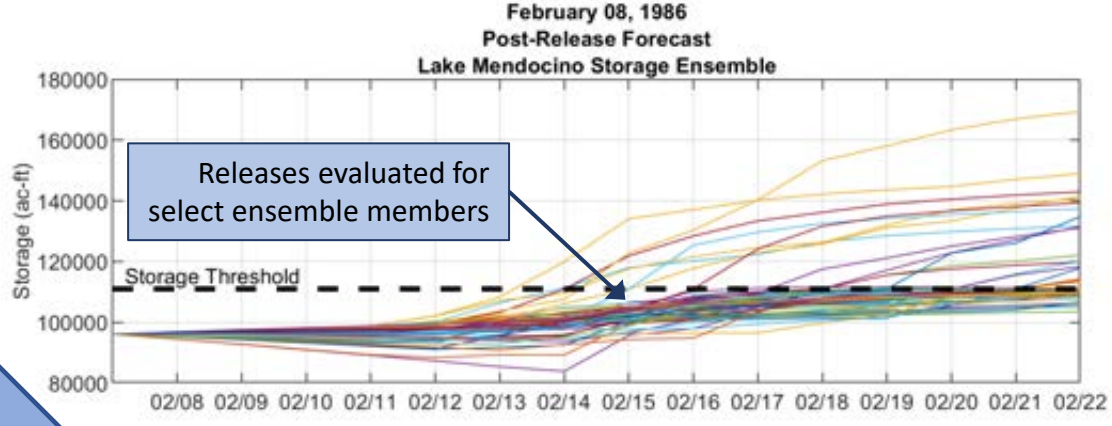
[1] Sonoma Water
[2] RKH Consulting Services
[3] University of California San Diego
[4] U.S. Army Corps of Engineers
[5] Hydrologic Solutions Ltd.
[6] University of Colorado
[7] Independent Researcher

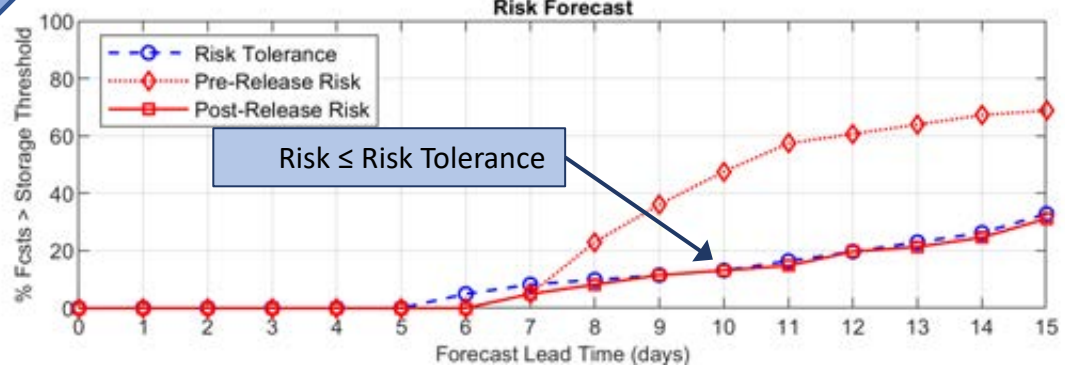
- Ensemble Forecast Operations is probabilistic decision support system for reservoir flood control operations.
- Utilizes ensemble streamflow predictions (ESPs), which account for forecast variability, to manage to forecasted risk of exceeding critical storage levels.
- Demonstrates improved reservoir storage reliability for water supply and ecosystems.





Release mitigates risk





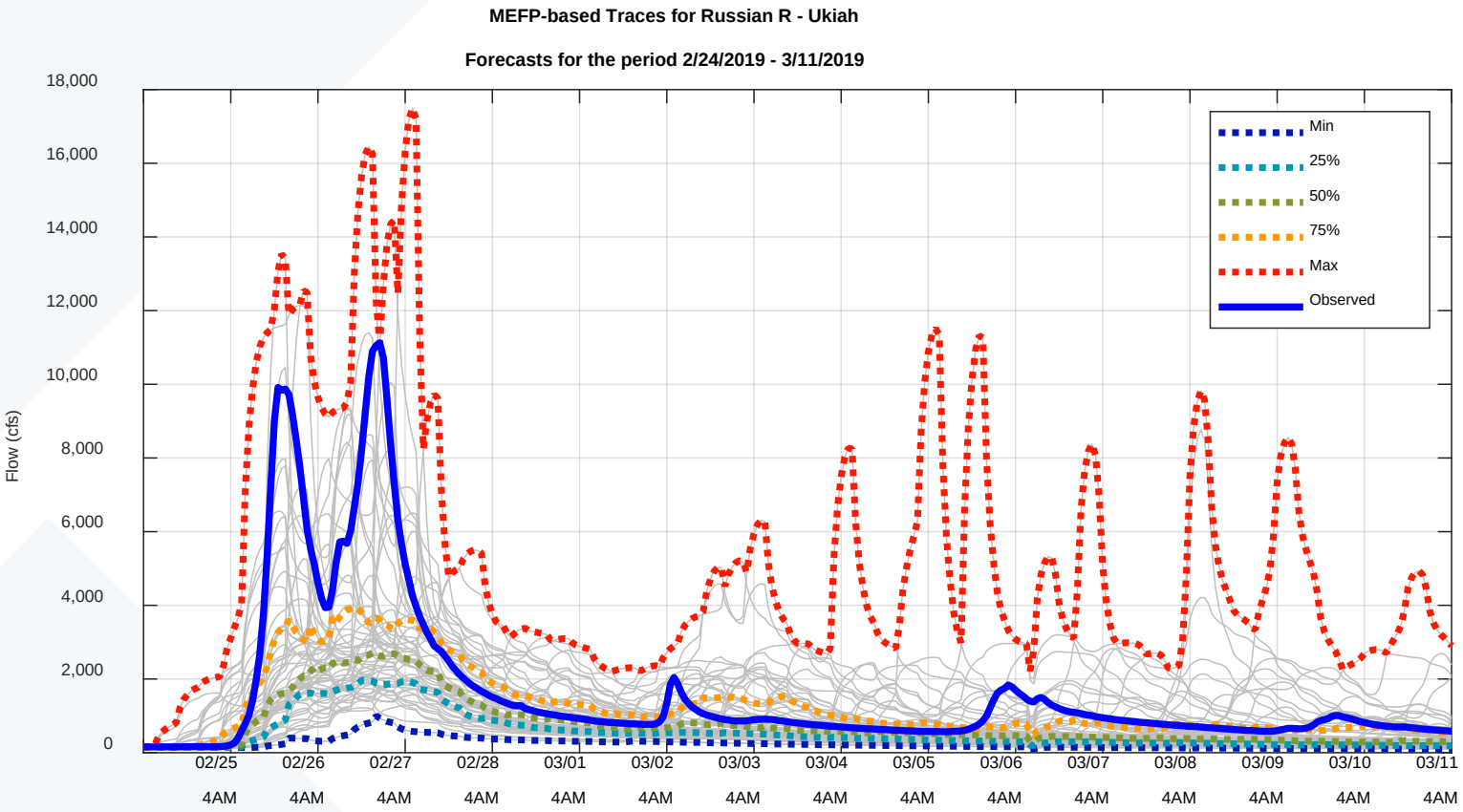
Hydrologic Ensemble Forecast System (HEFS)

HEFS Hindcast

- **Lake Mendocino FVA**
  - 1985 - 2017
  - 68 members
  - 15-day lead time
  - Scaled 200 and 500-year events
- **Prado Dam PVA**
  - 1985 - 2011
  - 68 members
  - 15-day lead time
  - Scaled 100 and 200-year events
- **Yuba-Feather System FVA**
  - Scaled 1986 & 1997 Events
  - 62 members
  - 14-day lead time

CNRFC

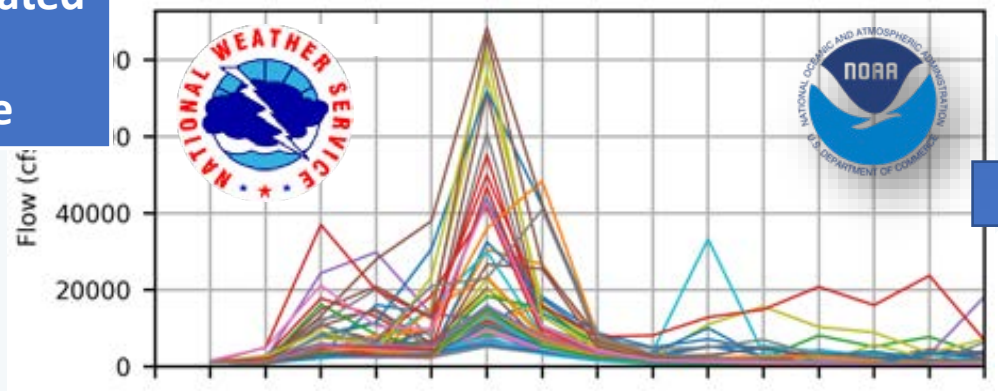
California Nevada River Forecast Center



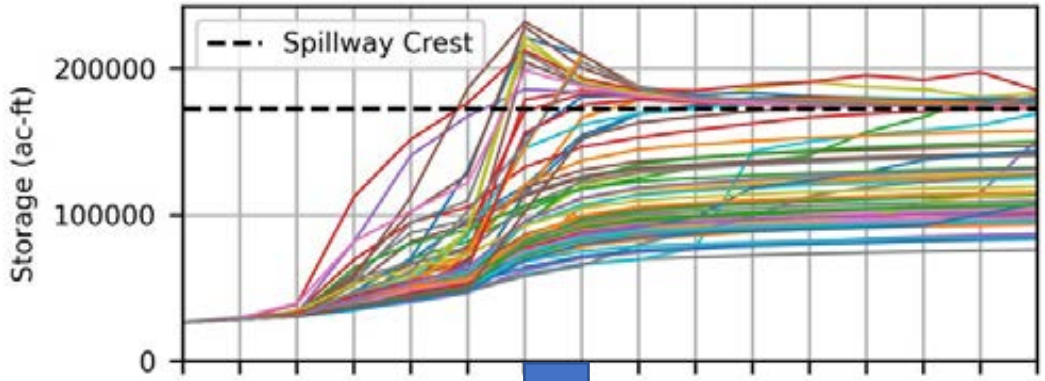
Ensemble Forecast Operations (EFO)

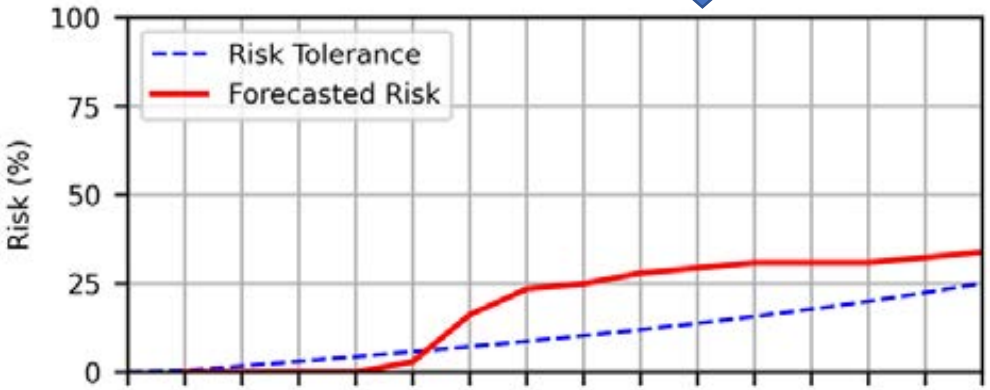
Process repeated with each forecast cycle

CA-NV River Forecast Center
Ensemble Inflow Forecast



Storage Forecast





Flood Risk Analysis

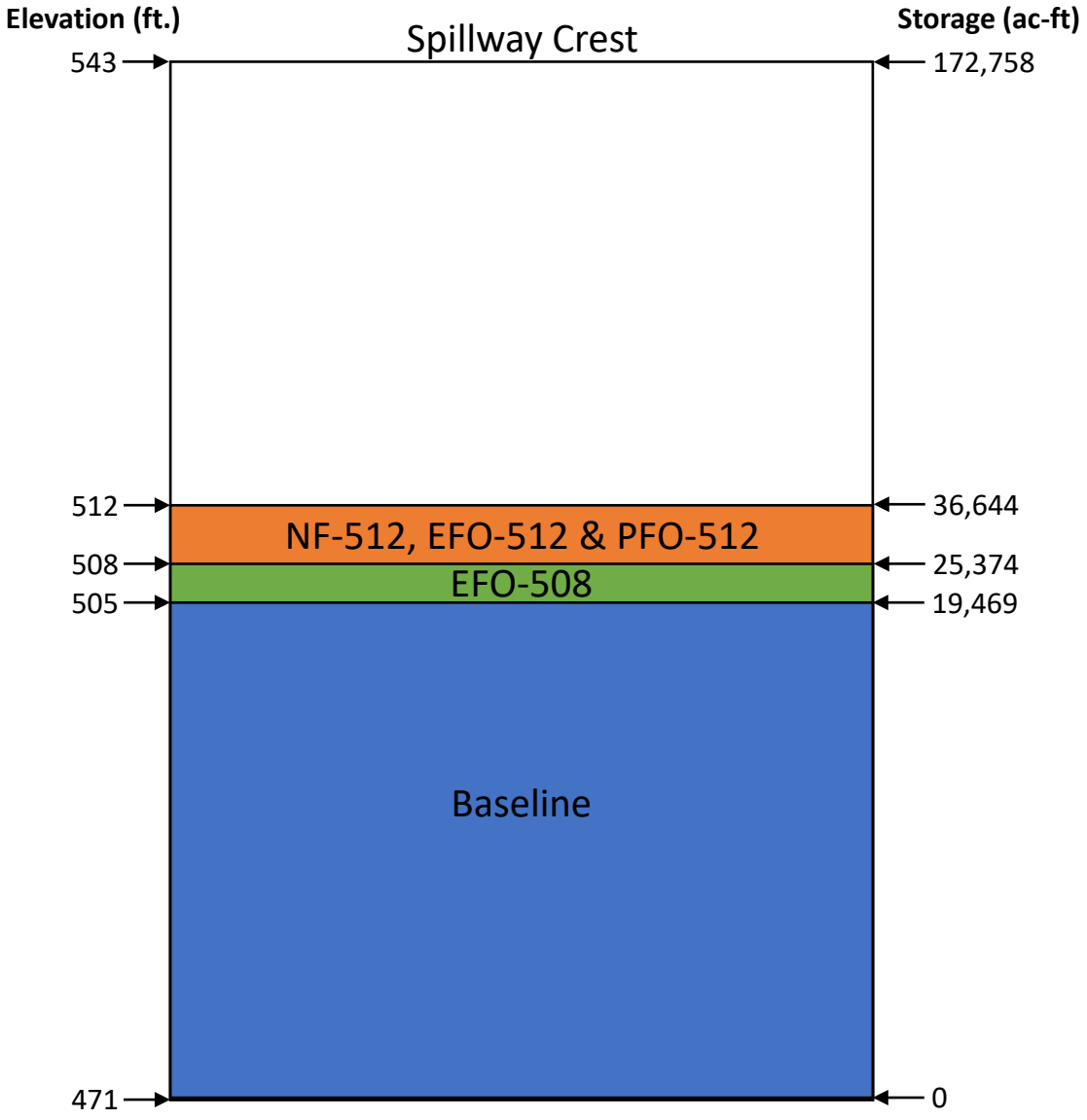
Flood Release

Presentation Overview

1. Ensemble Forecast Operations Background
2. **Prado Dam Preliminary Viability Assessment**
3. February 2019 Case Study
4. December 2021 Case Study
5. Volume Based EFO Approach
6. Next Steps and Feedback

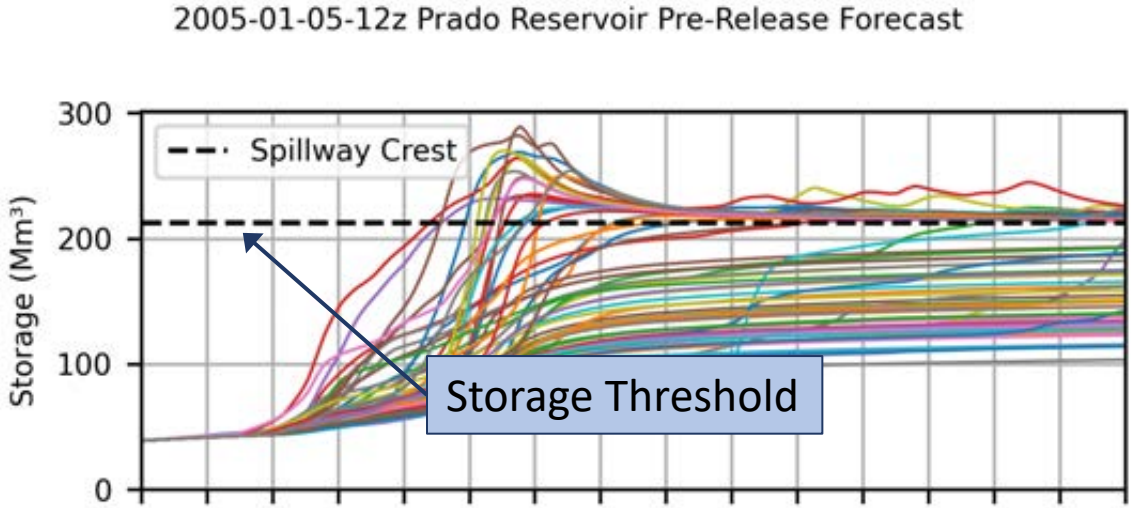
Prado PVA Flood Control Alternatives

#	Alternative	Buffer Pool (feet)	Flood Operations
1	Baseline	505	Major Devation
2	NF-512	512	no FIRO
3	EFO-508	508	Ensemble Forecast Operations
4	EFO-512	512	Ensemble Forecast Operations
5	PFO-512	512	Perfect Forecast Operations

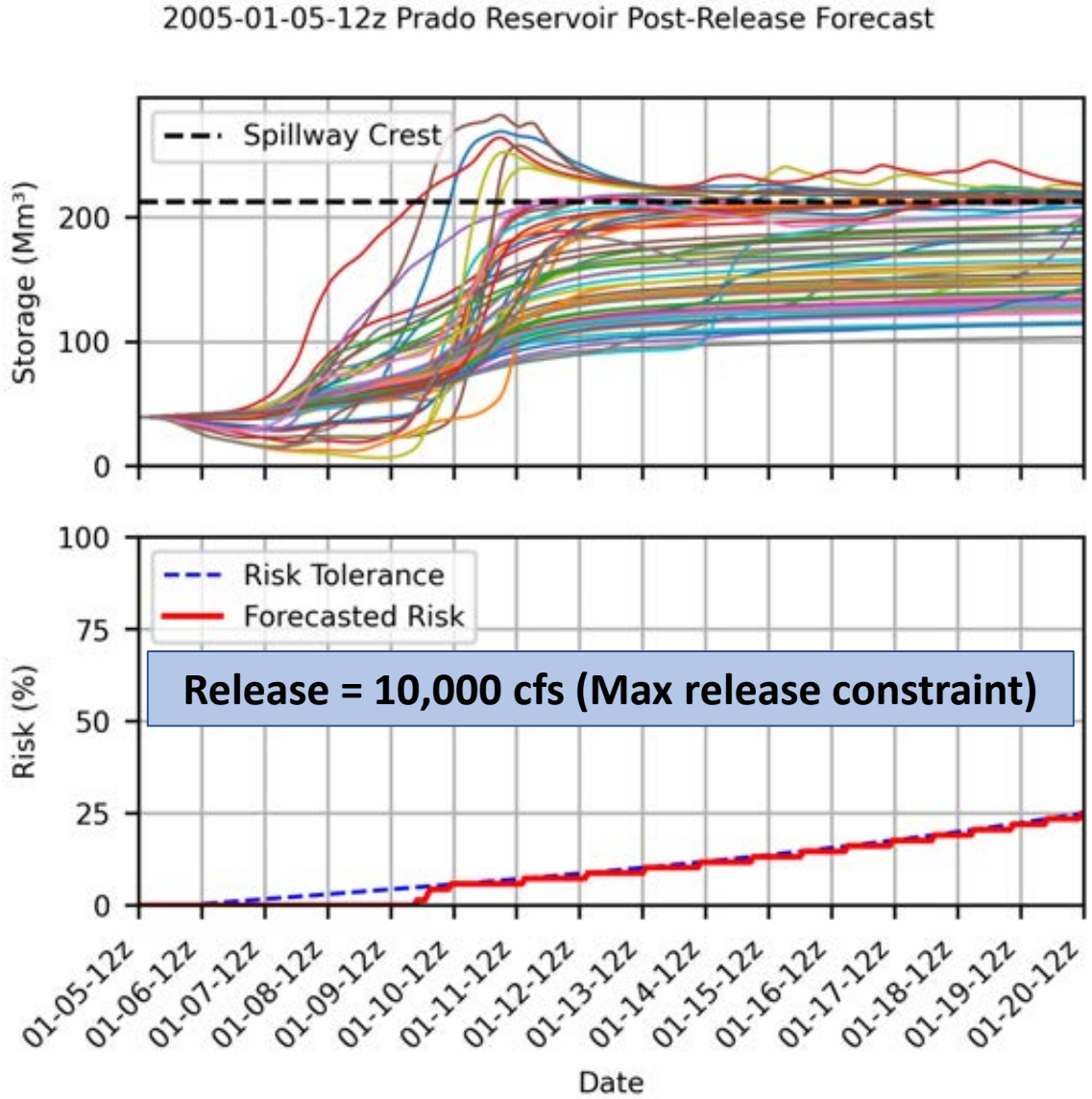


How EFO Works – January 5, 2005 Example

Pre-Release Forecast (0 cfs)



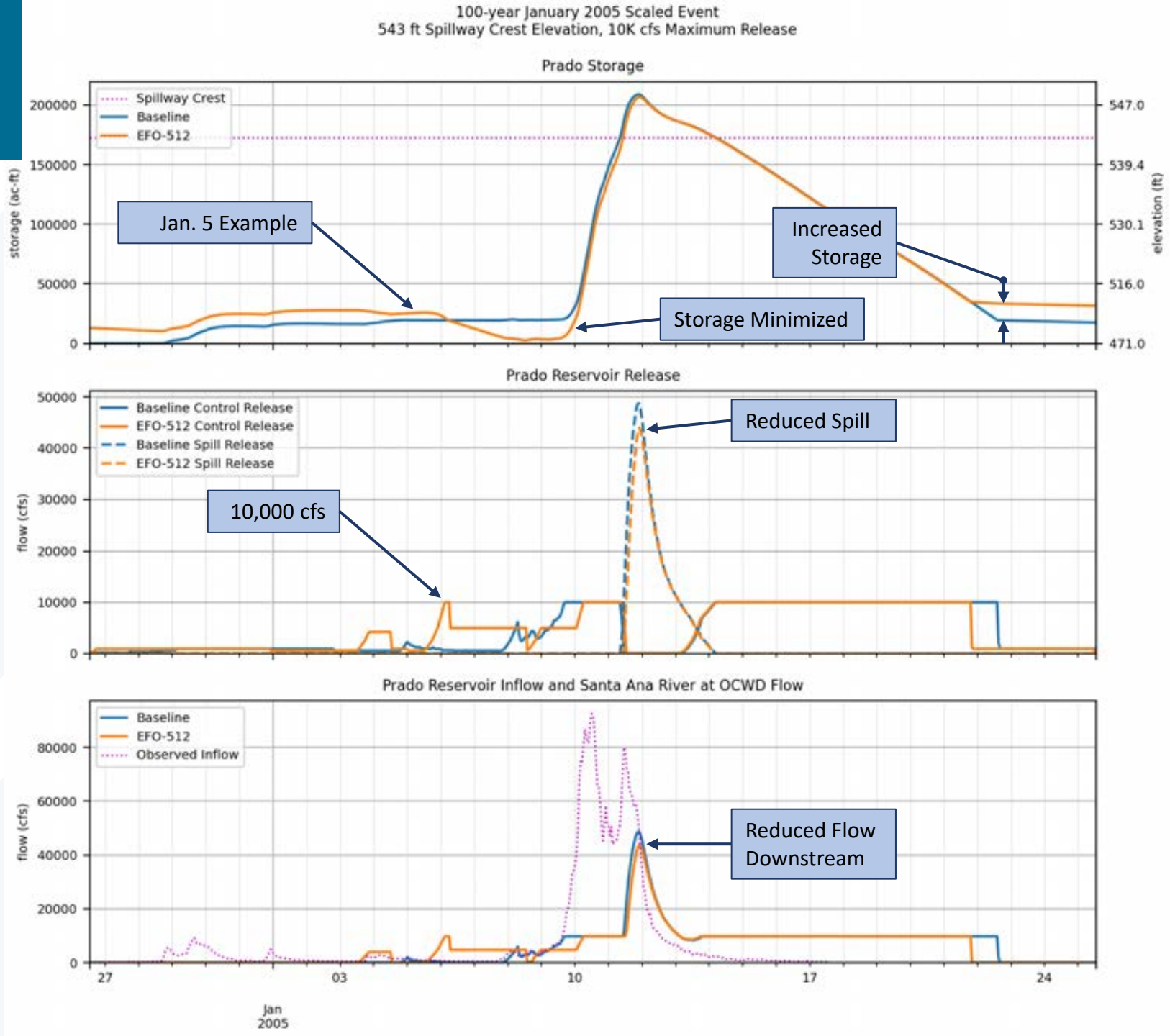
Post-Release Forecast



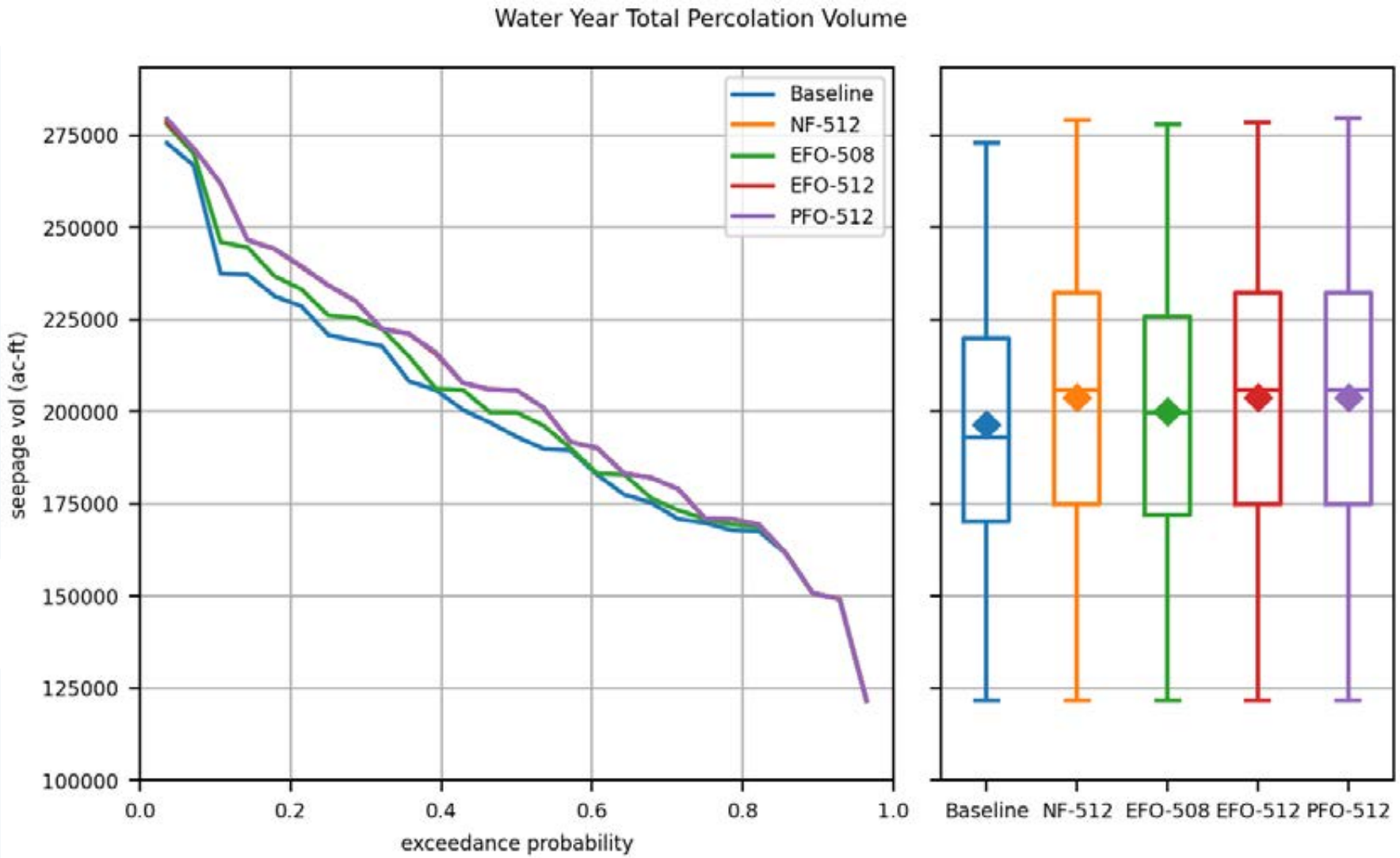
Risk Guide Curve

Prado EFO Results

100-year 2005 Event



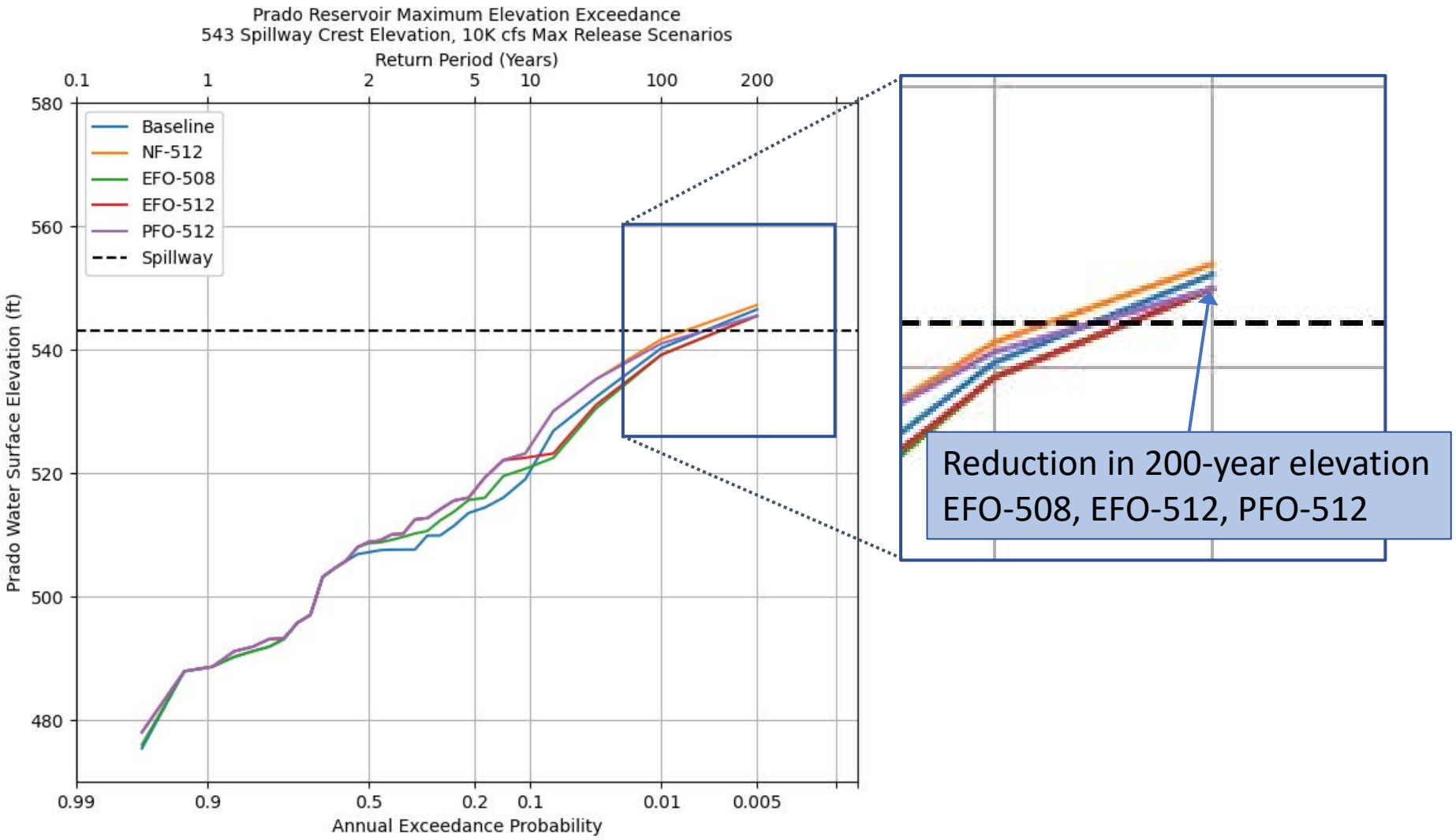
Prado PVA Results



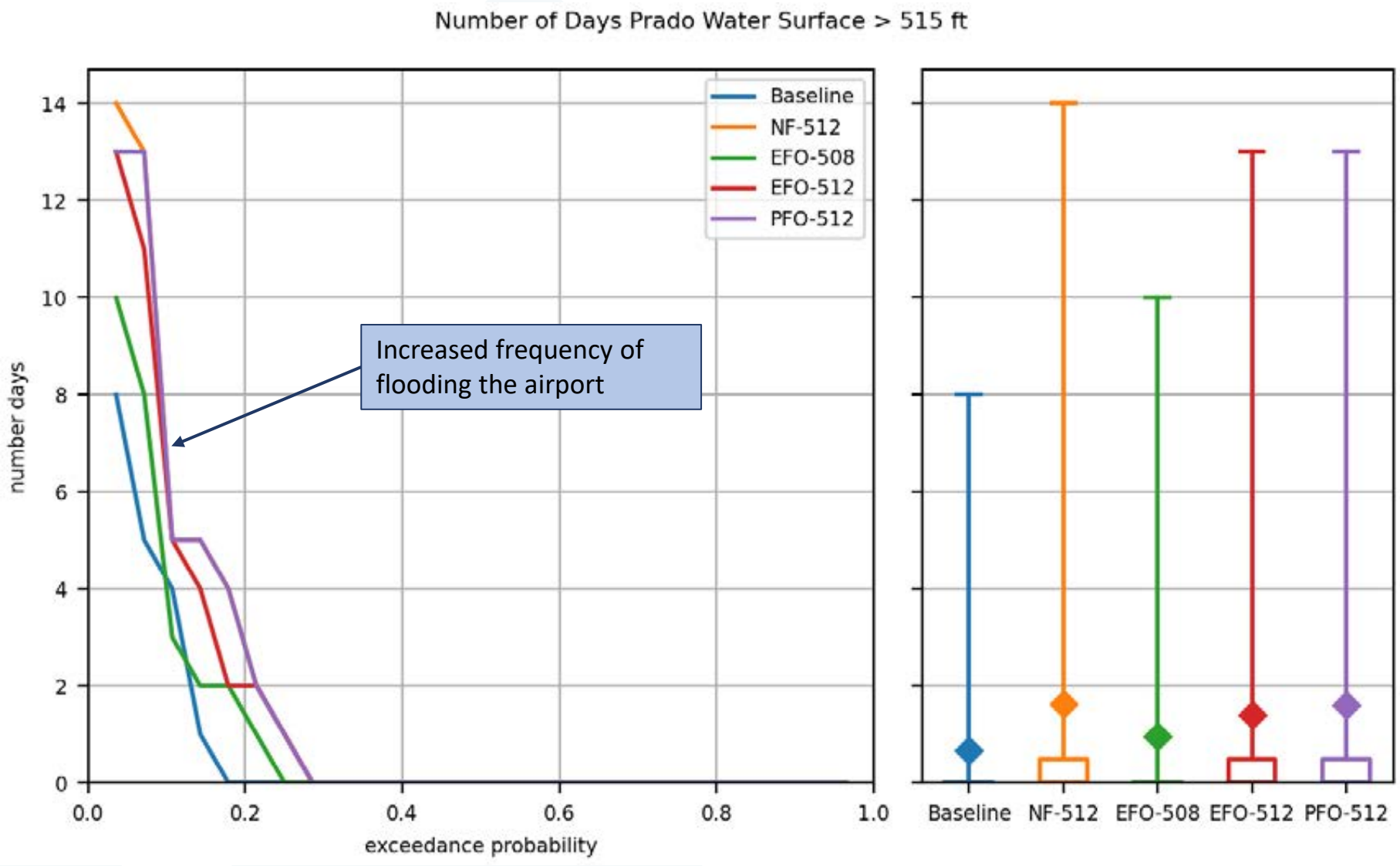
% Increase in Median from Baseline	
EFO-512, NF-512, PFO-512:	6.5%
EFO-508:	3.4%

% Increase in Mean from Baseline	
EFO-512, NF-512, PFO-512:	3.7%
EFO-508:	1.7%

Prado Dam PVA Results



Increased Frequency of Flooding Airport



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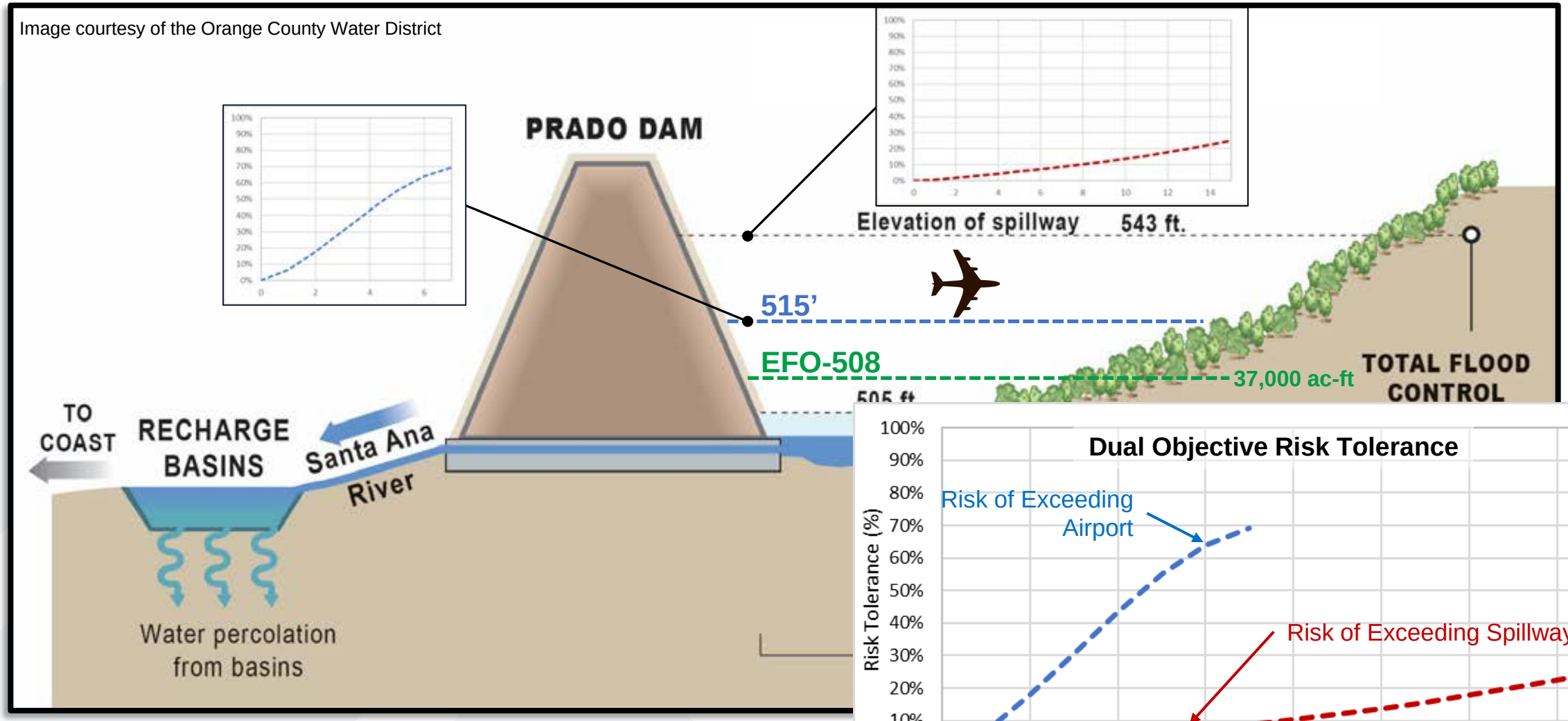
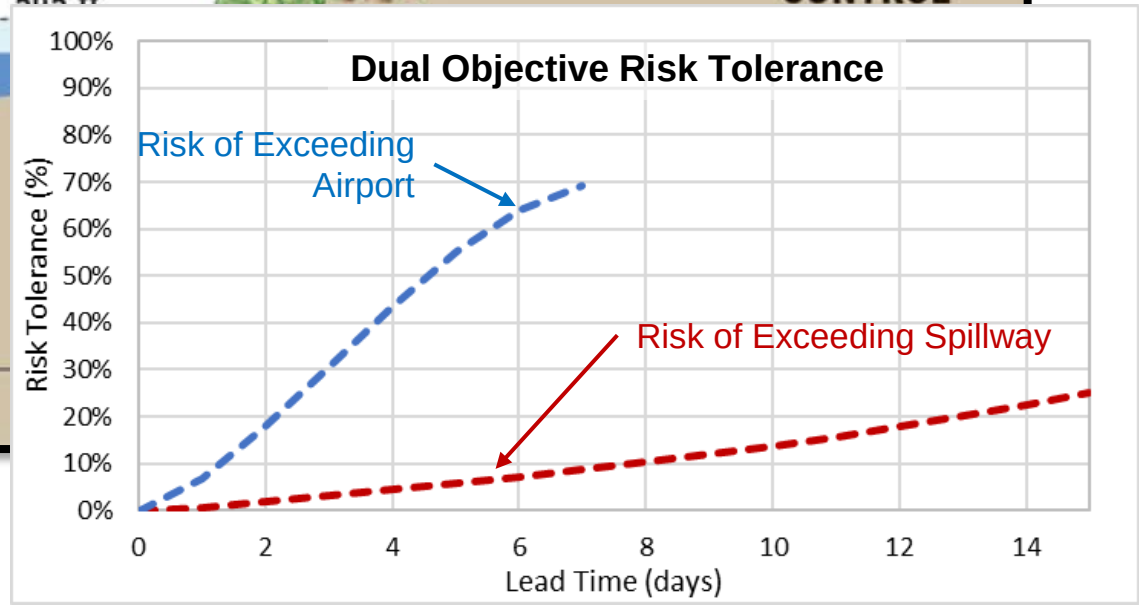
Dual Objective FIRO





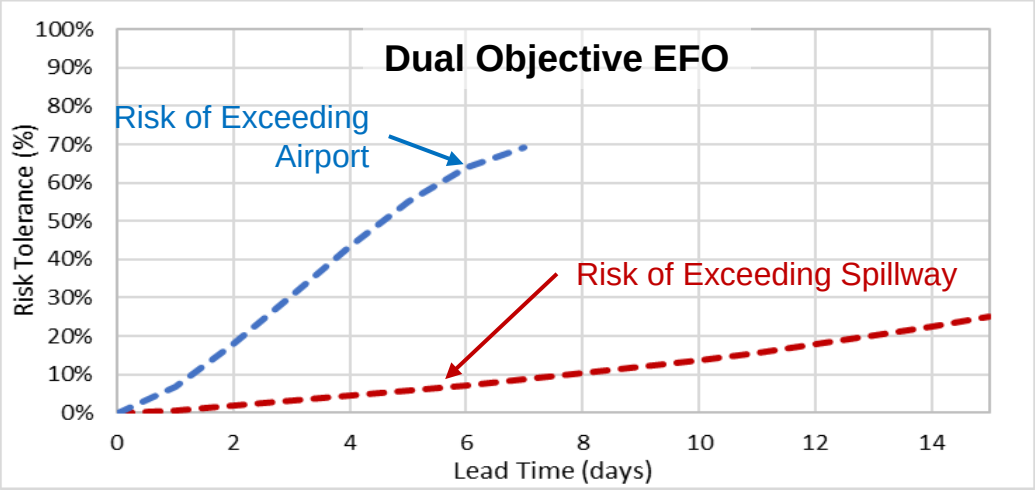
Challenge:

- Reduce flood frequency of airport
- No reduction in water supply reliability that FIRO provides

February 2019 Case Study Demonstration

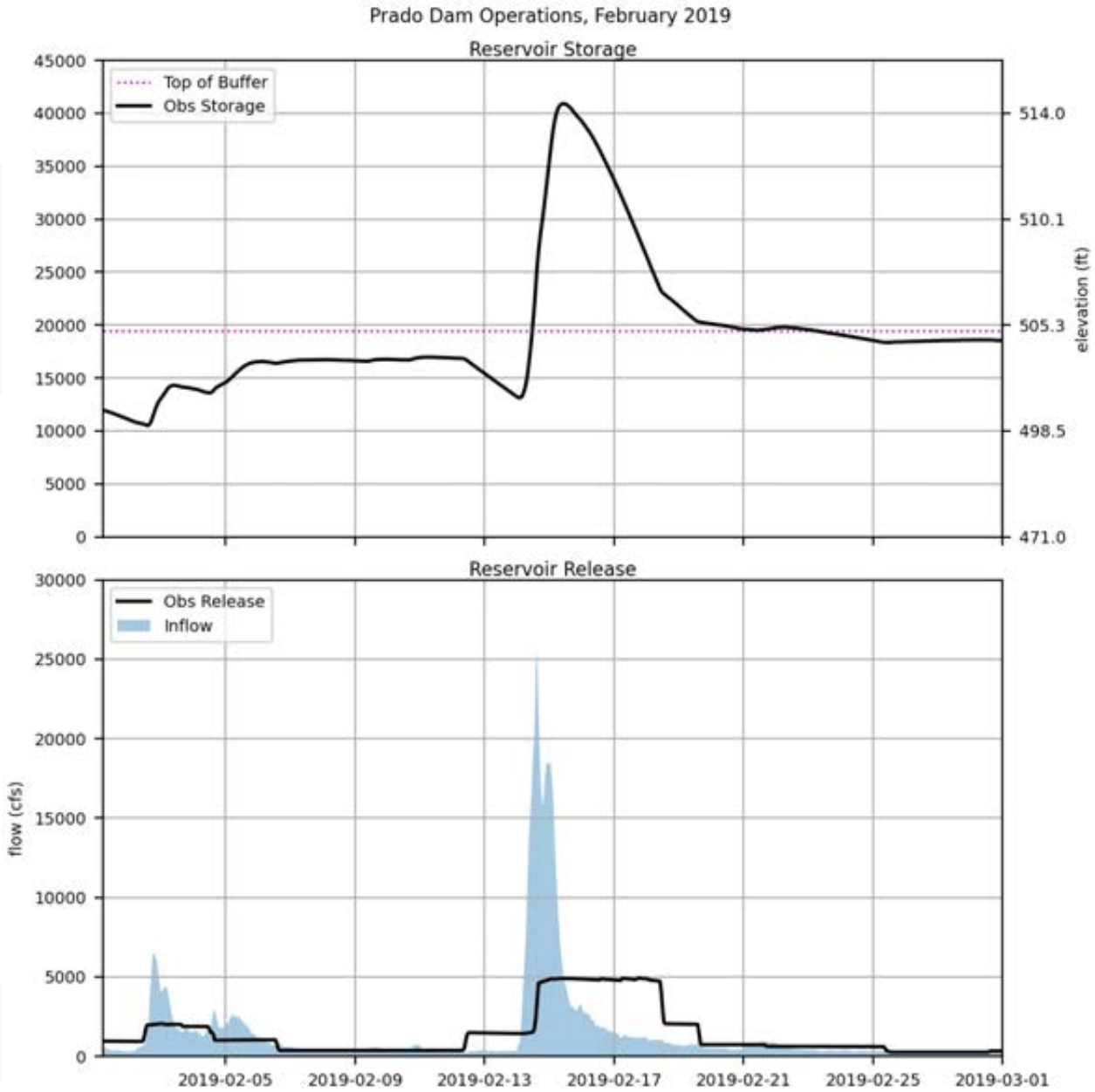
Scenarios:

- Actual Operations
- Dual Objective EFO (DUO-515)

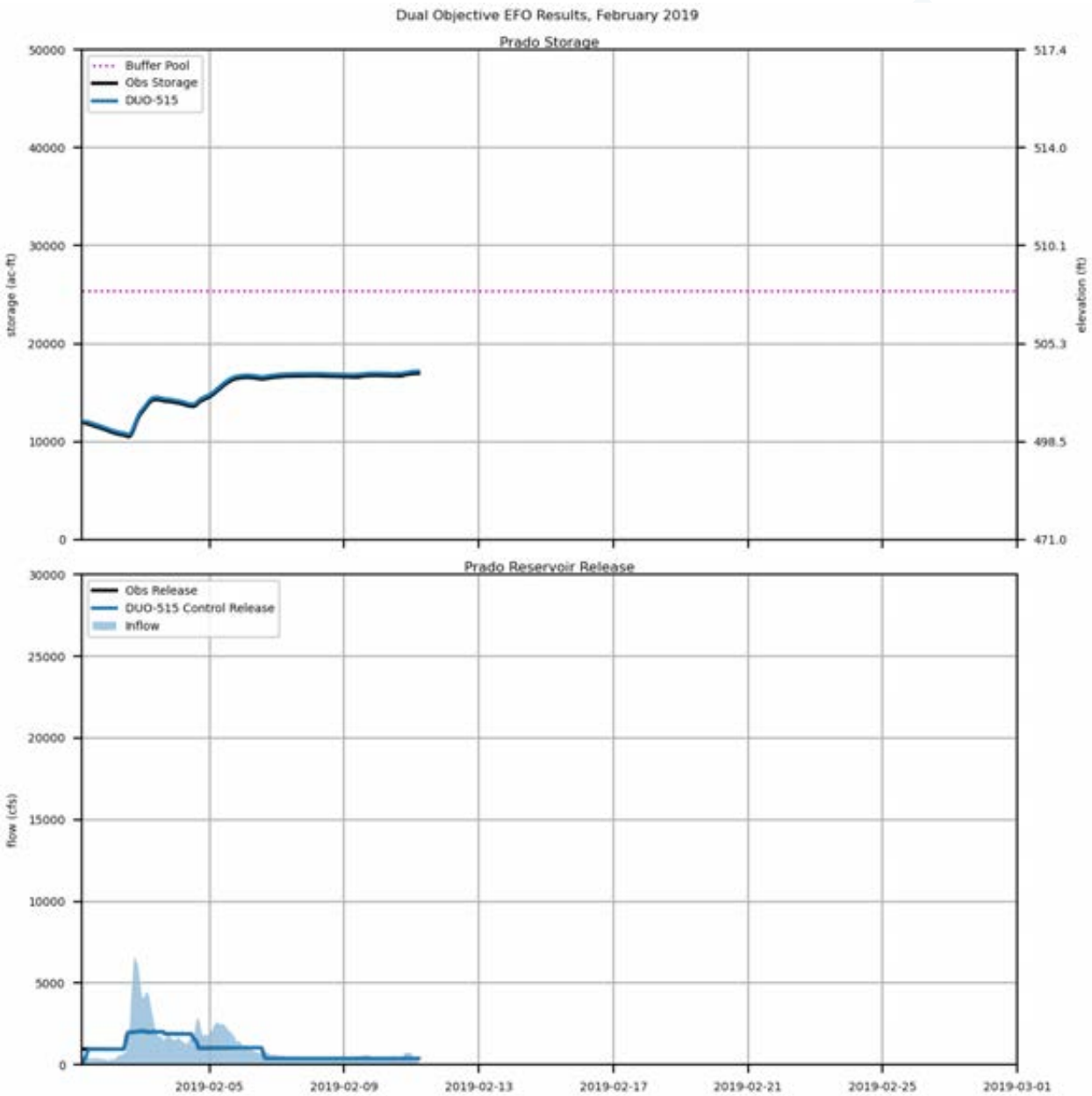


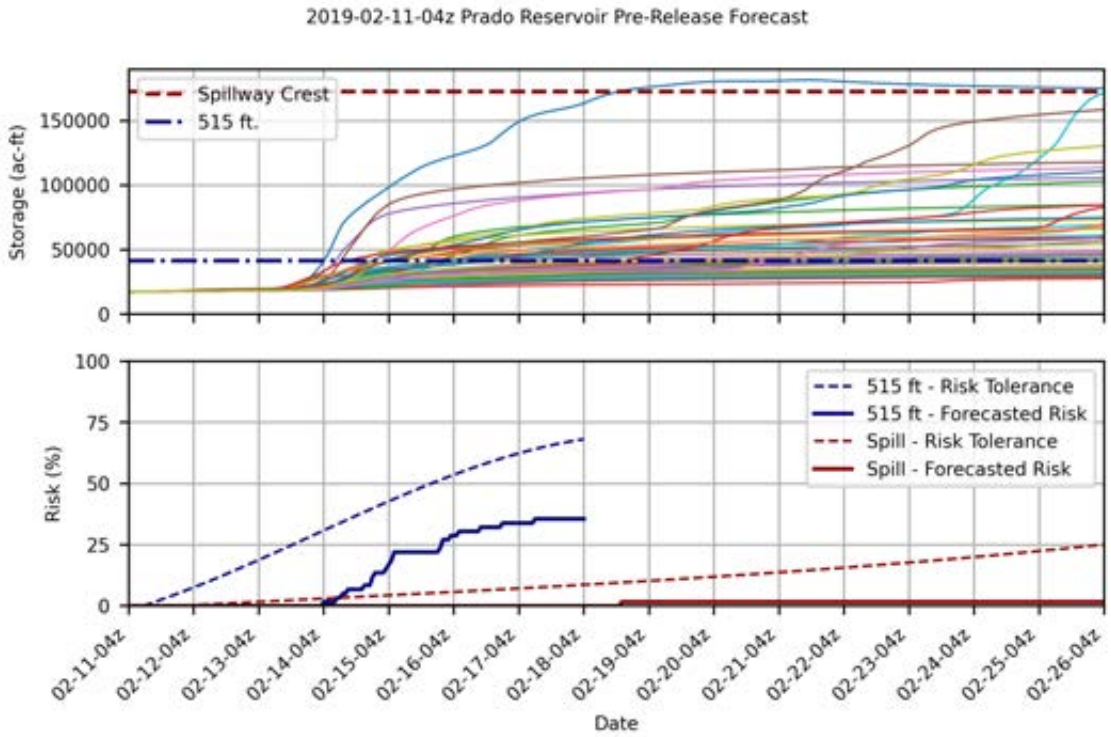
Dual Objective EFO Assumptions:

- Buffer pool elevation: 508’
- Max FIRO pre-release: 5,000 cfs
- No delay on release decisions



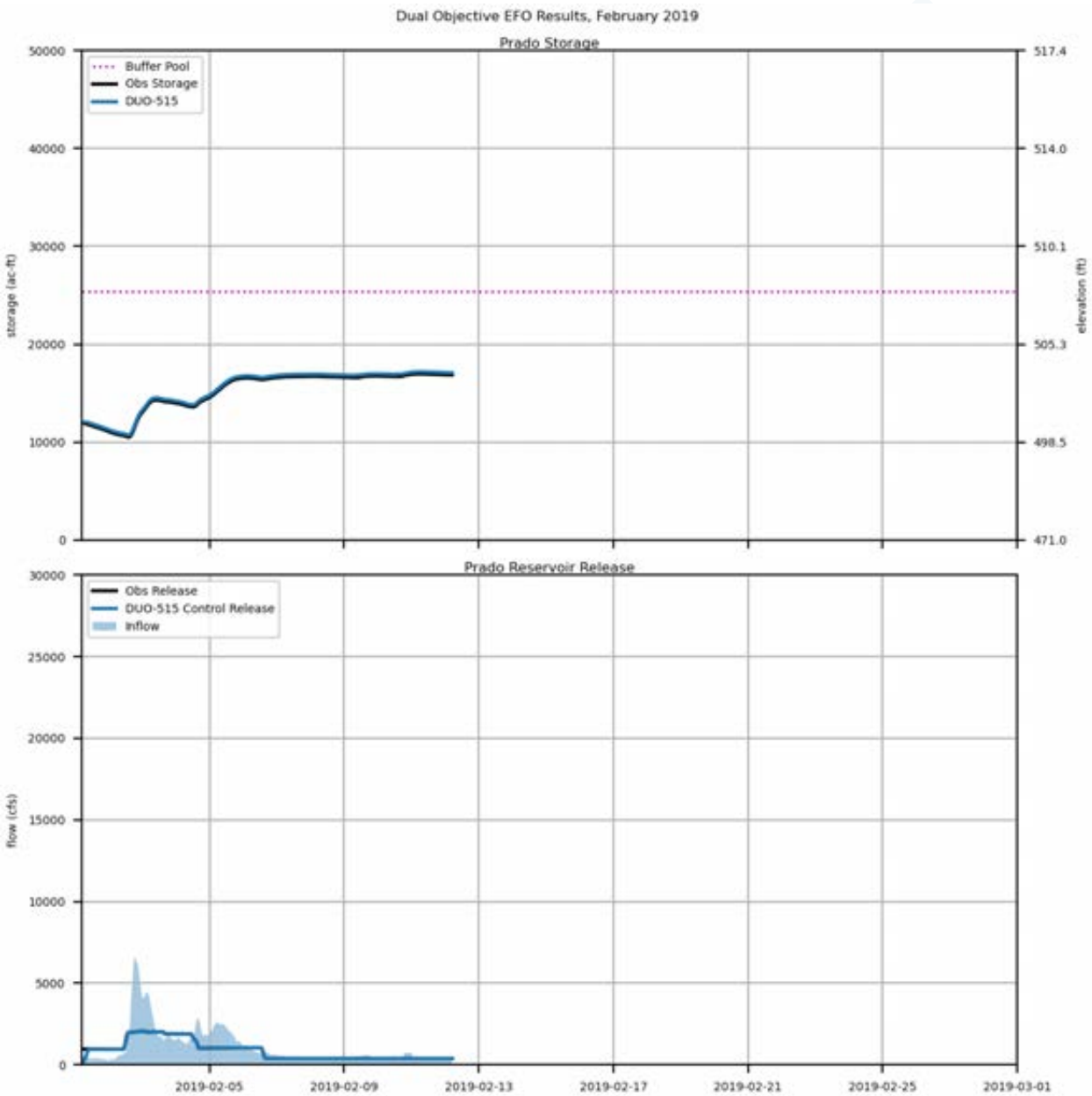
February 2019 Case Study – February 11, 4 am – EFO Forecast

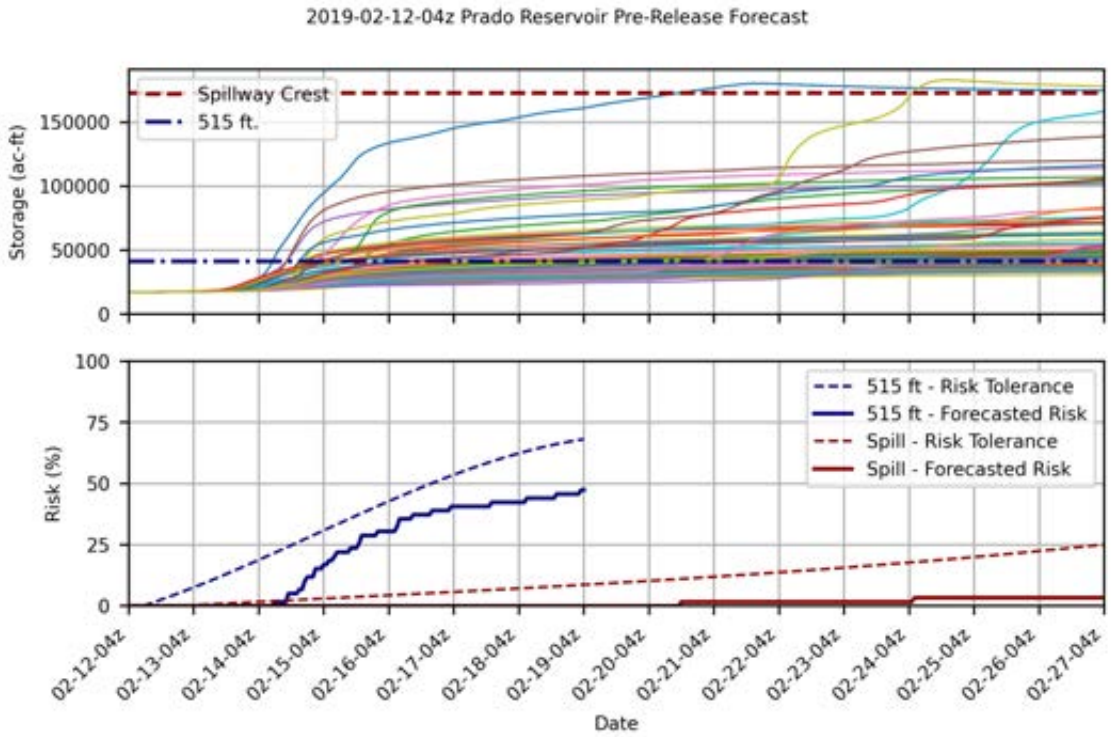




- **Proposed EFO Operation:**
  - No Flood Control Release
- **Actual Operations:**
  - Recommended release increase to 1,500 cfs on 2/12/19

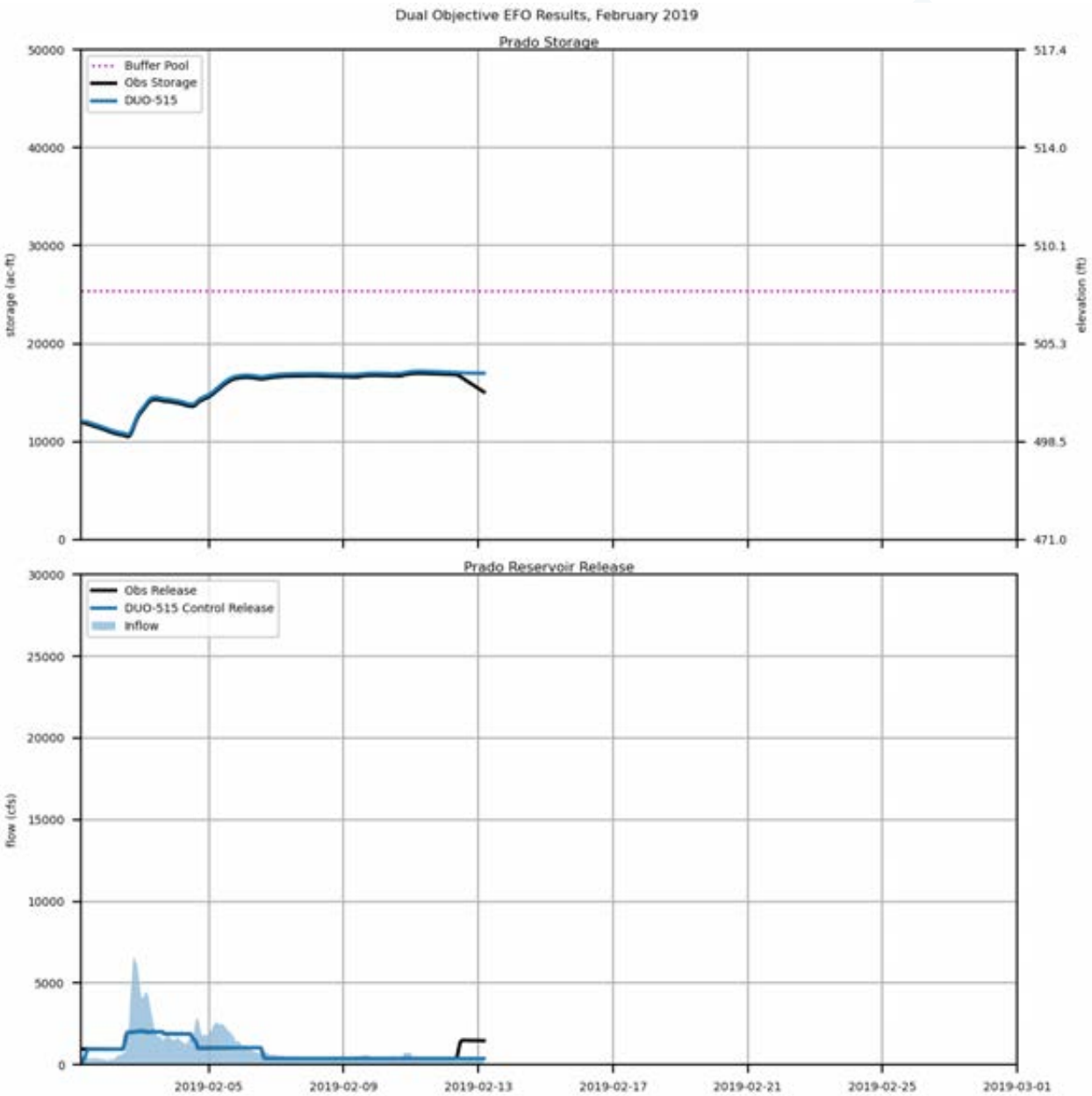
February 2019 Case Study – February 12, 4 am – EFO Forecast

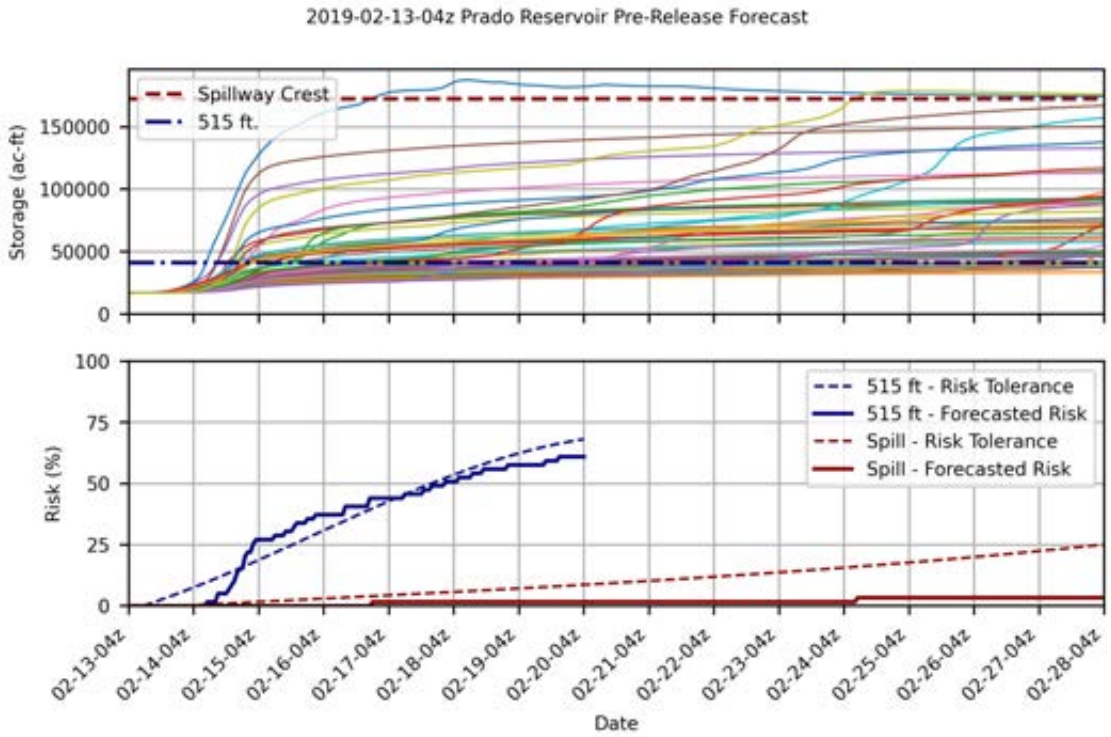




- **Proposed EFO Operation:**
  - No Flood Control Release
- **Actual Operations:**
  - Started release increase to 1,500 cfs

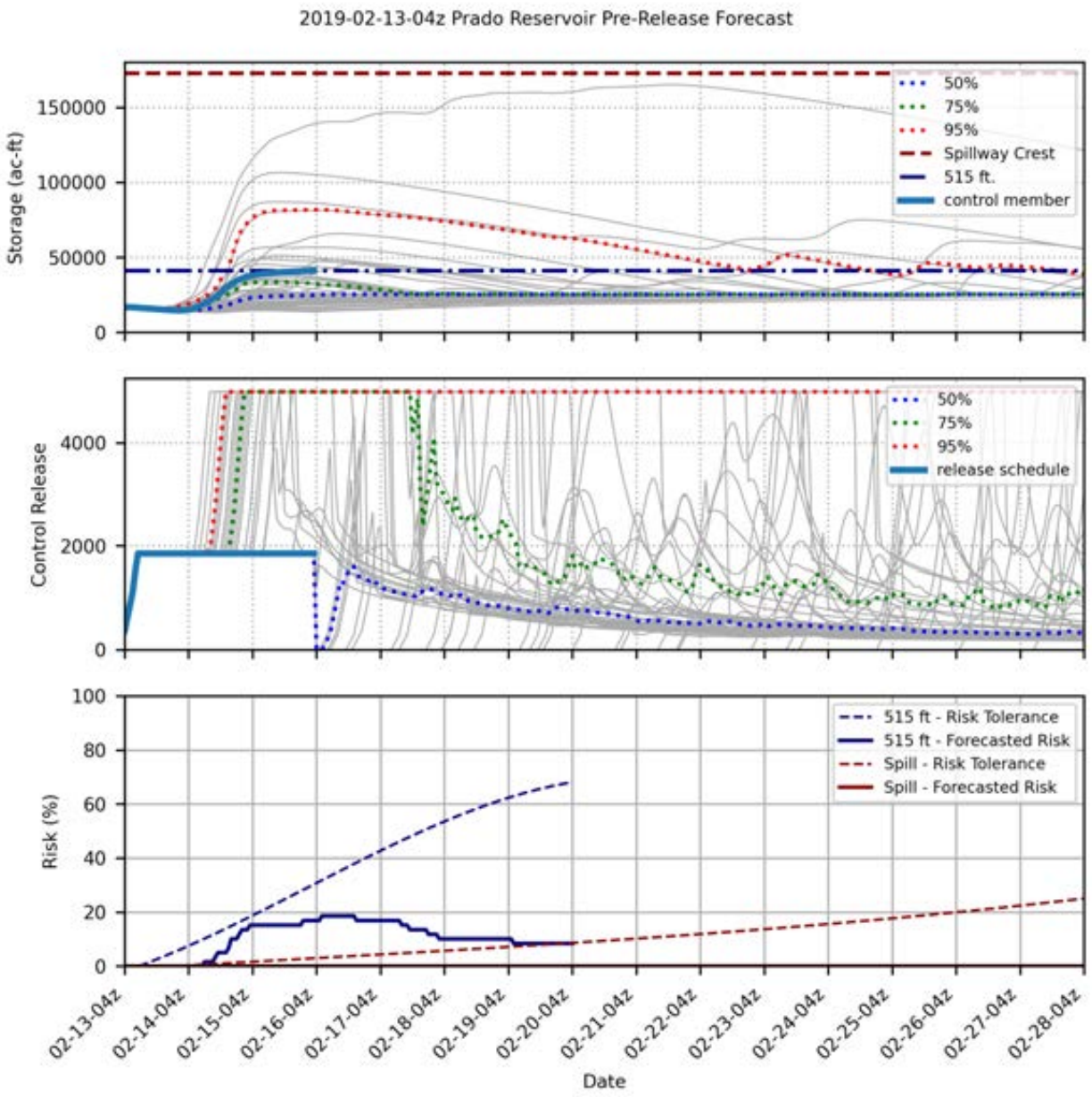
February 2019 Case Study – February 13, 4 am – EFO Forecast



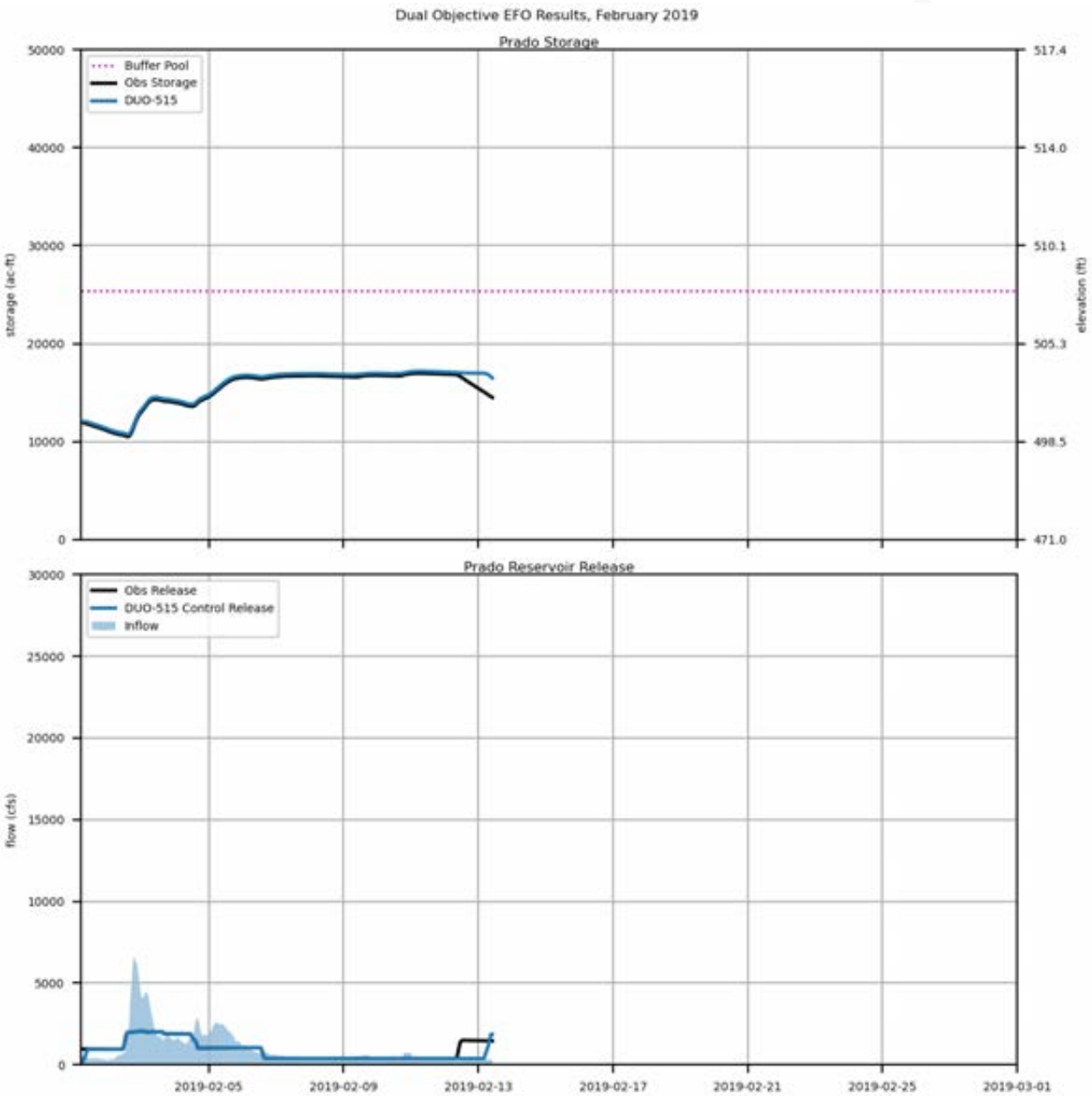


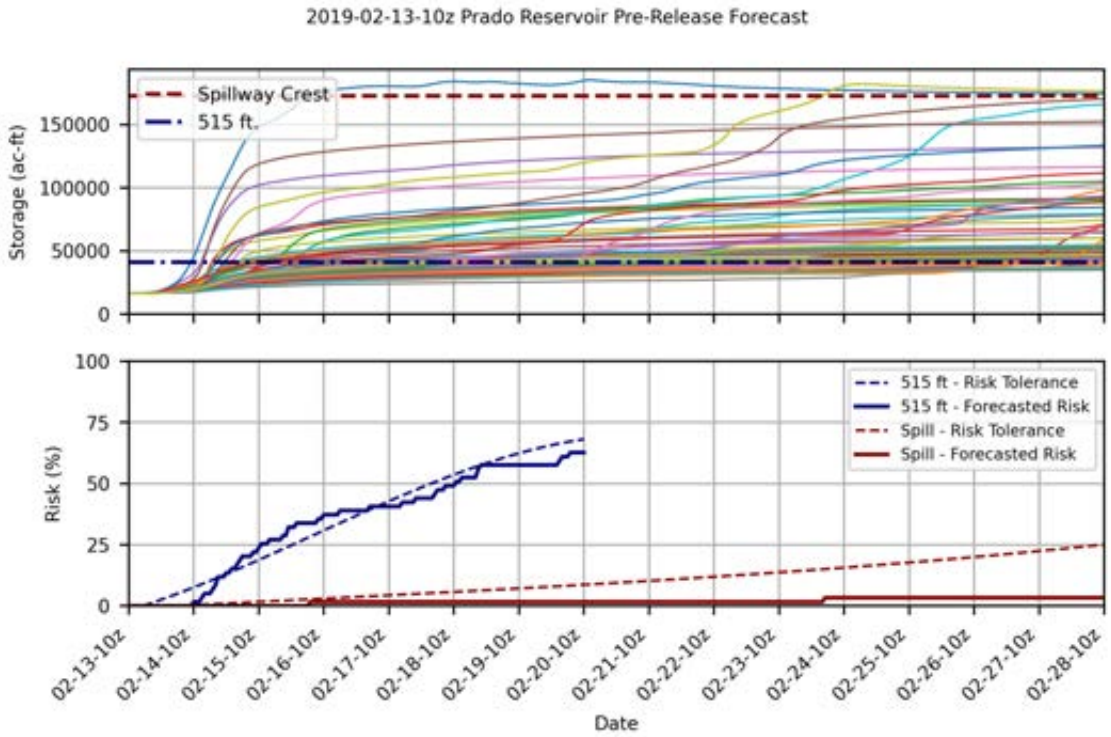
- **Proposed EFO Operation:**
  - Increase release to 1,856 cfs
- **Actual Operations:**
  - Release maintained at 1,500 cfs

February 13, 4 am – EFO Post Release Forecast



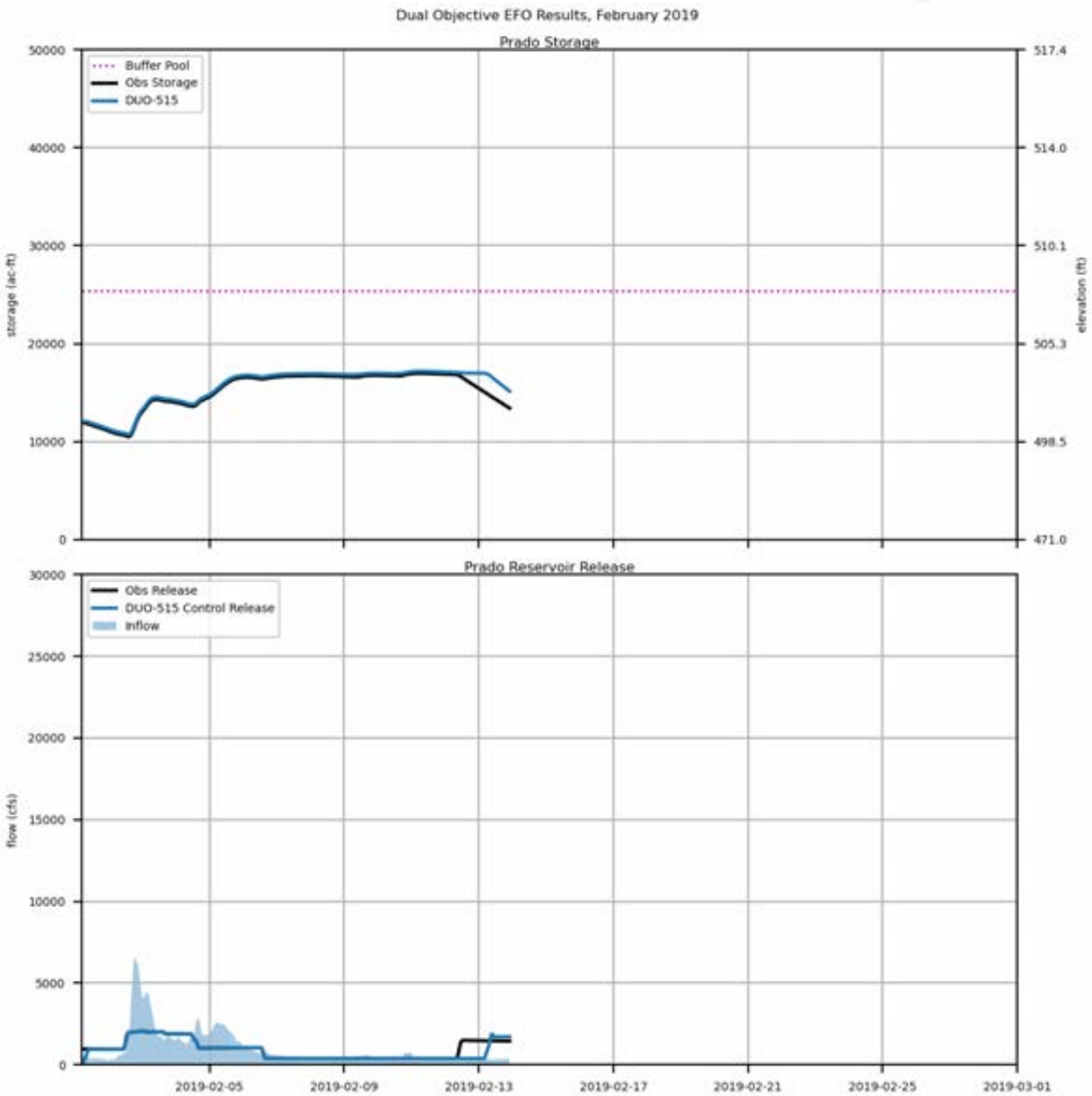
February 2019 Case Study – February 13, 10 am – EFO Forecast

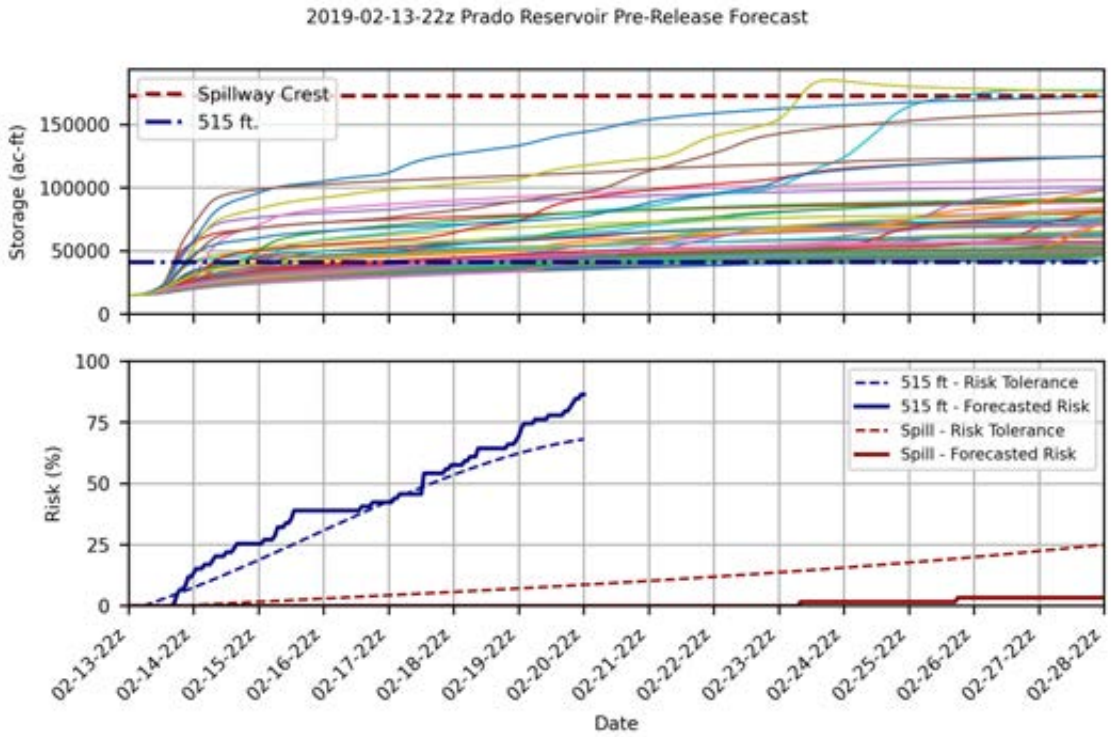




- **Proposed EFO Operation:**
  - Decrease release to 1,710 cfs
- **Actual Operations:**
  - Release maintained at 1,500 cfs

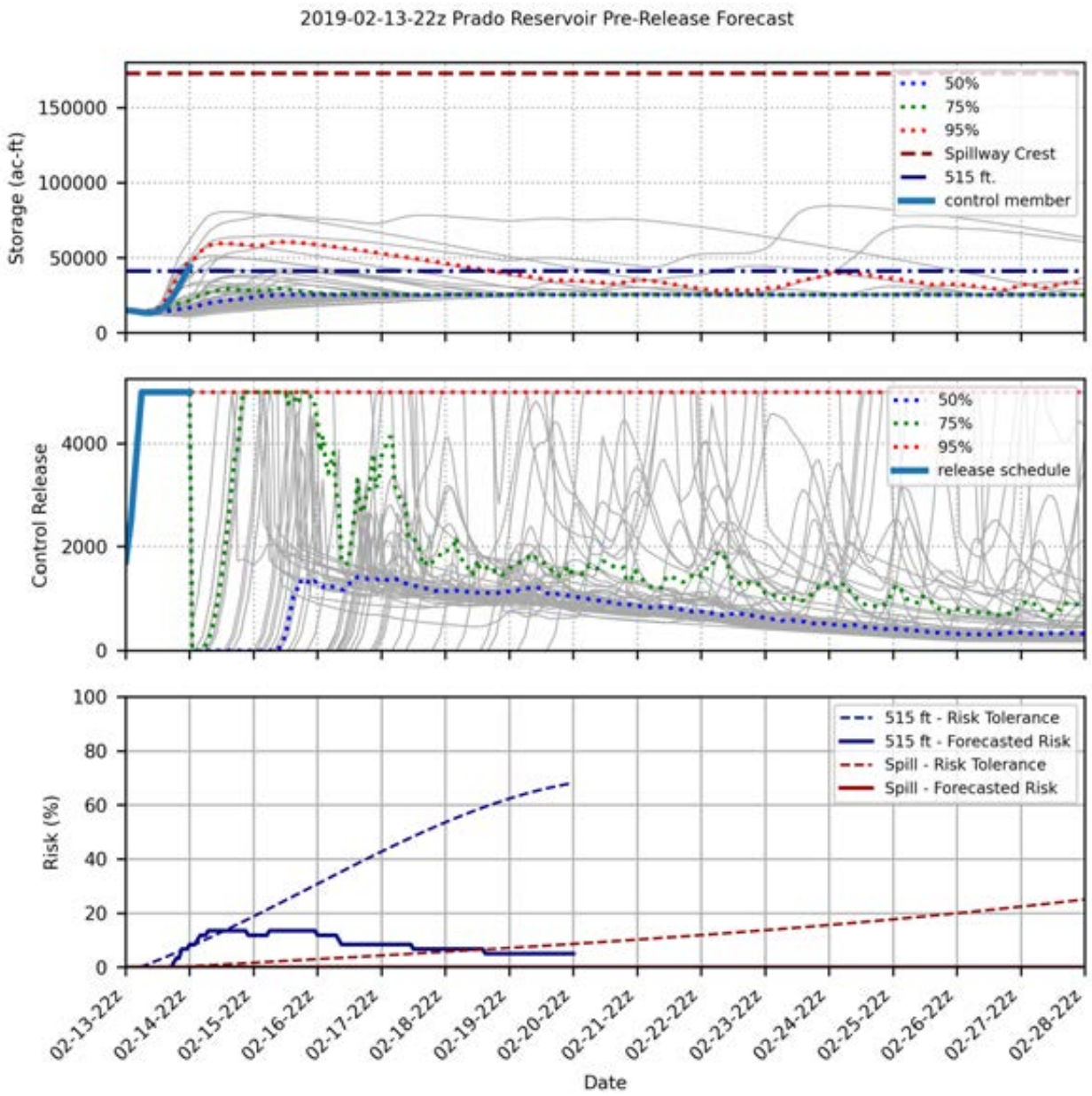
February 2019 Case Study – February 13, 10 pm – EFO Forecast



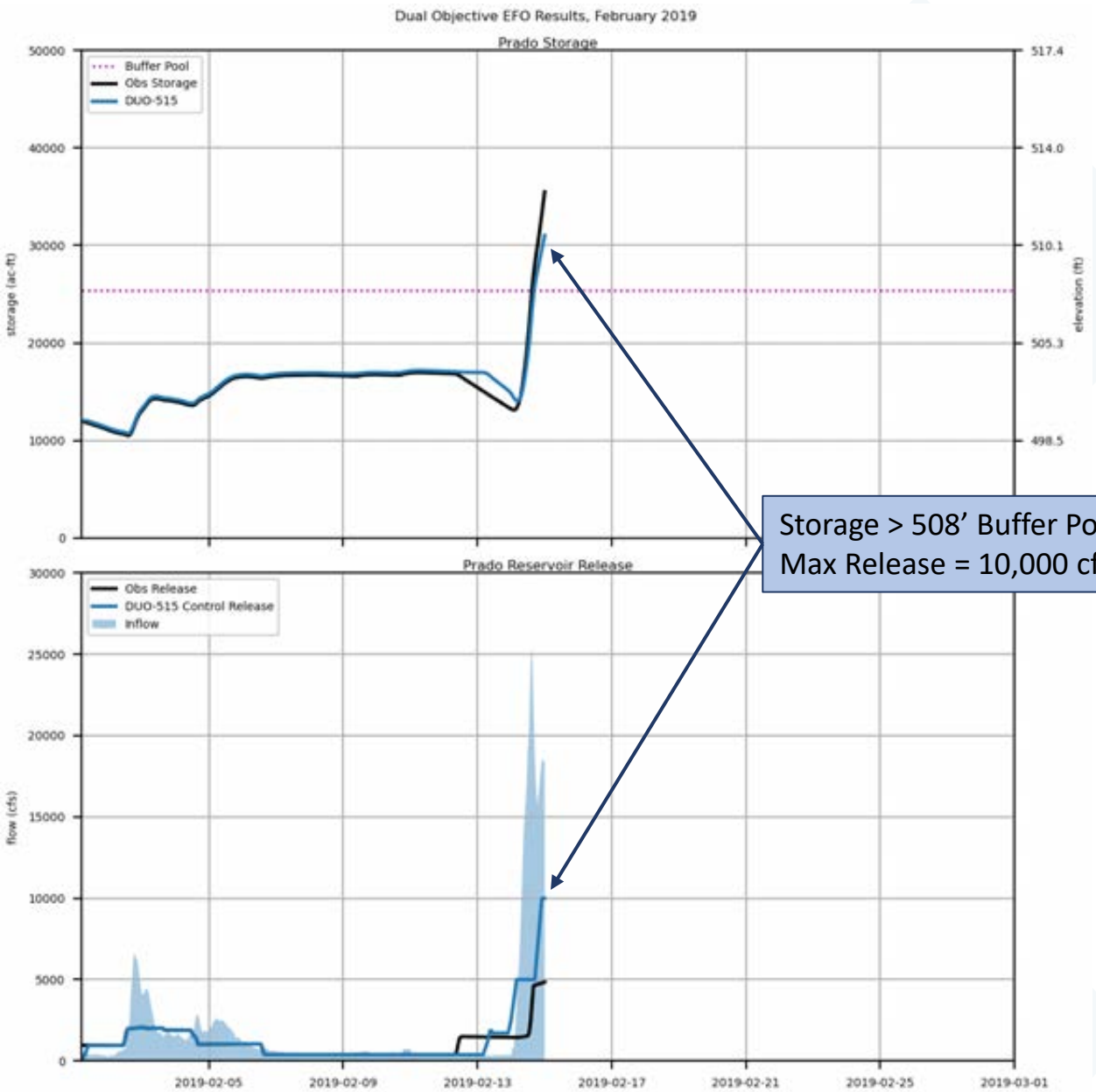


- **Proposed EFO Operation:**
  - Increase release to 5,000 cfs
- **Actual Operations:**
  - Release maintained at 1,500 cfs

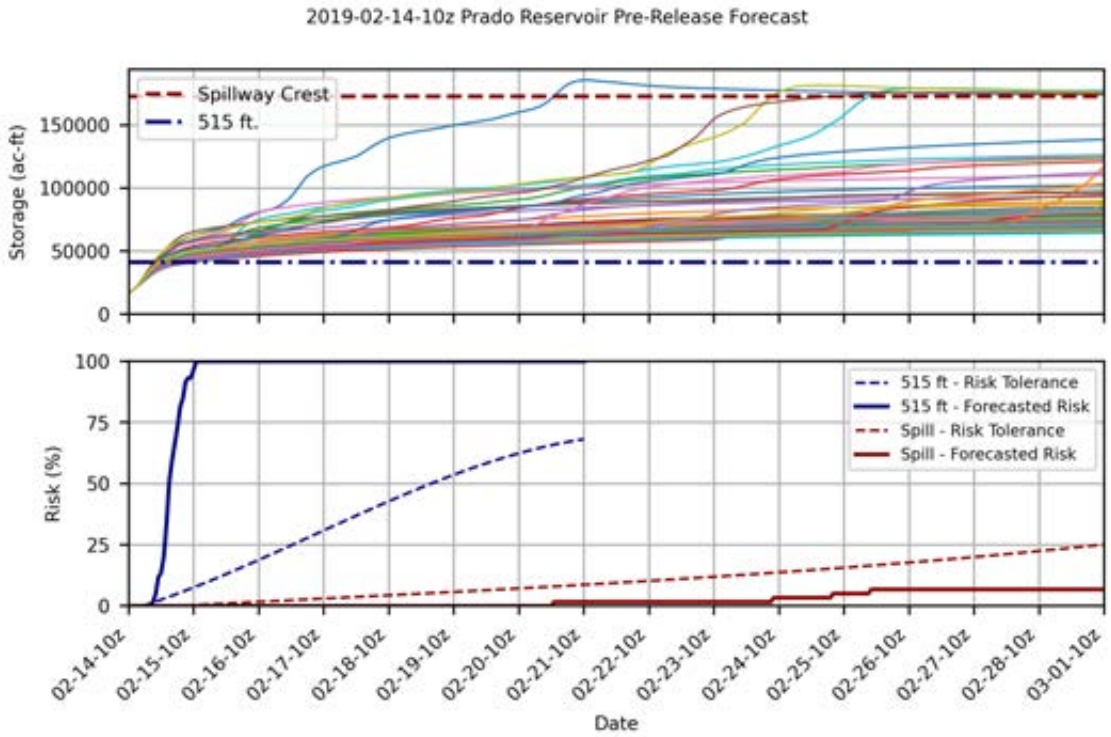
February 13, 10 pm – EFO Post Release Forecast



February 2019 Case Study – February 14, 12 pm – EFO Forecast

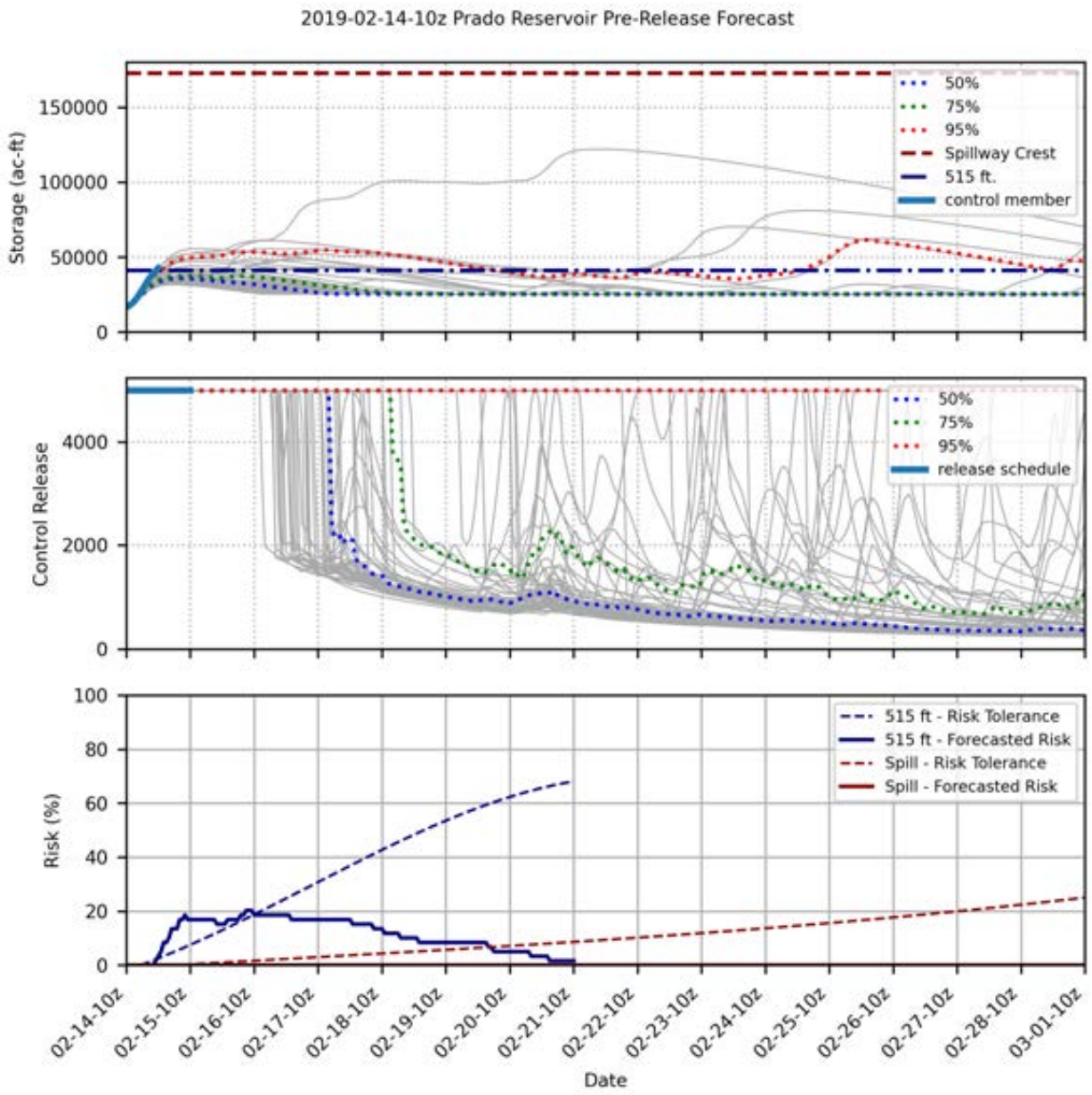


Storage > 508' Buffer Pool
Max Release = 10,000 cfs



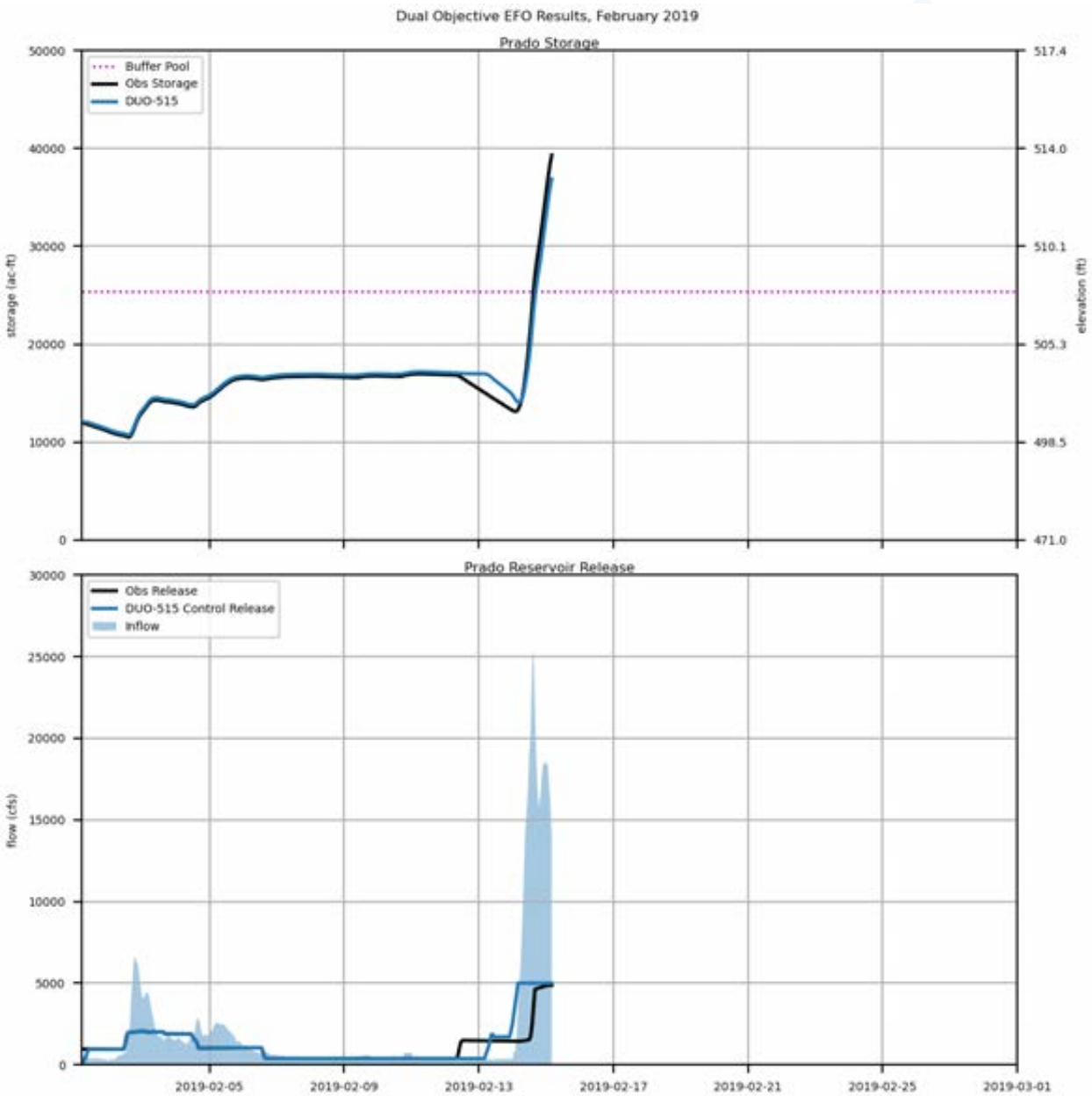
- **Proposed EFO Operation:**
  - Maintain release at 5,000 cfs
- **Water Control Manual Operation:**
  - Release increased to 10,000 cfs
- **Actual Operations:**
  - Release increased to ~5,000 cfs

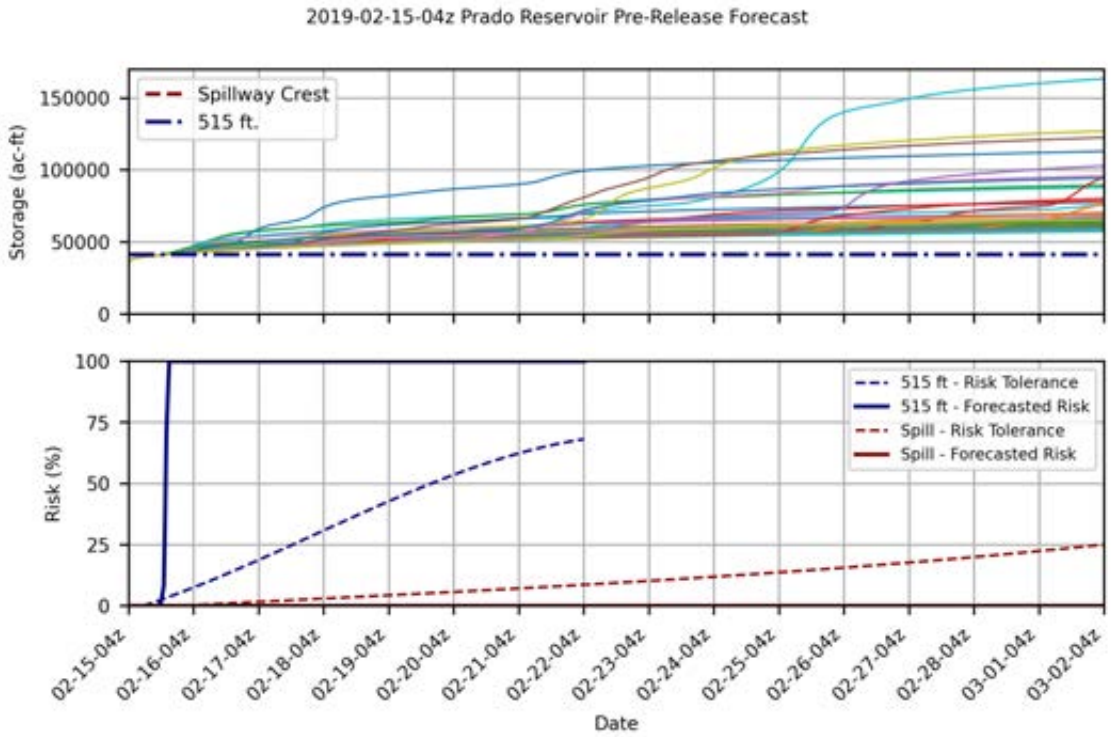
February 14, 10 am – EFO Post Release Forecast



Forecasts support holding release at 5,000 cfs

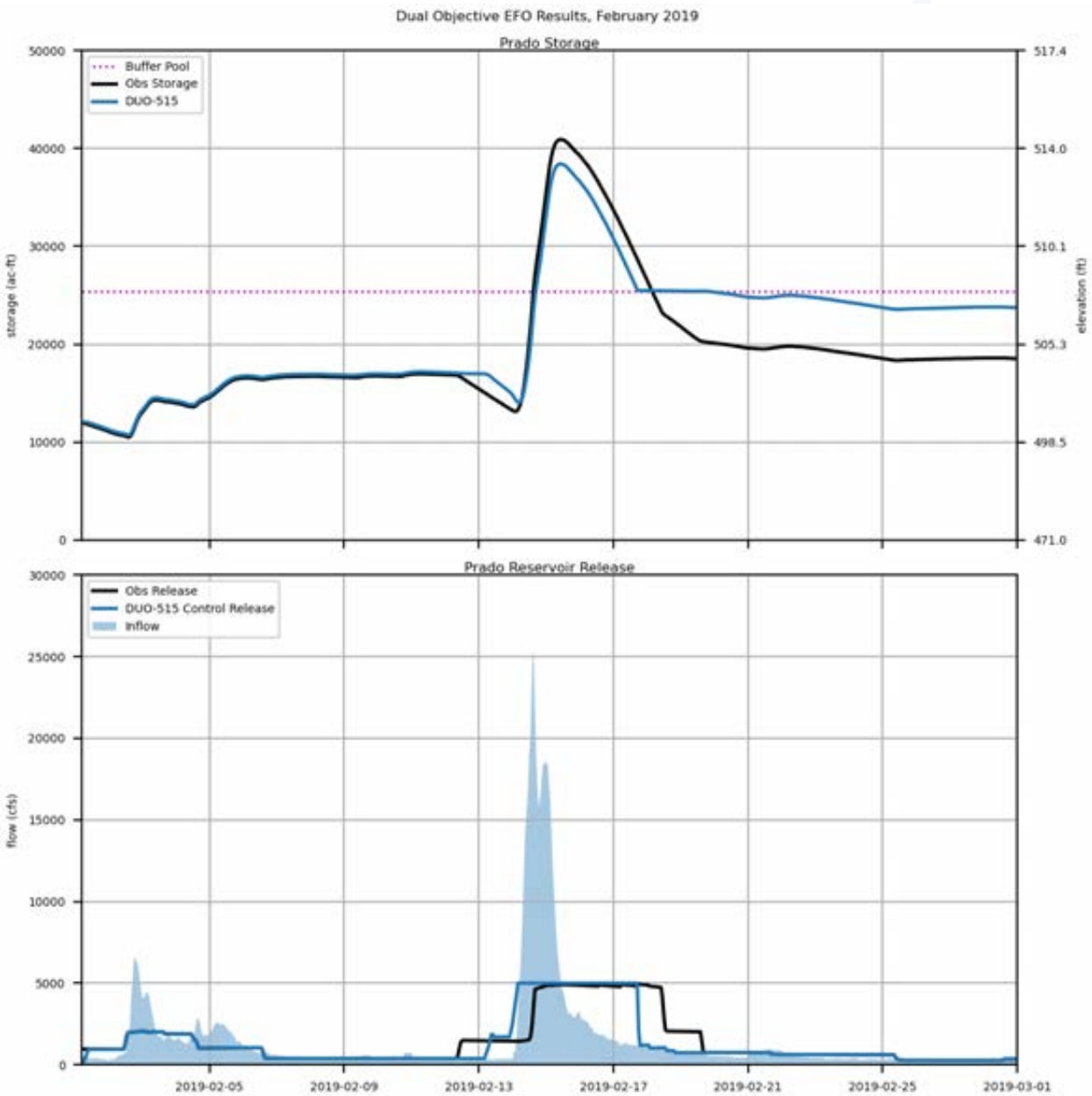
February 2019 Case Study – February 15, 4 am – EFO Forecast





- **Proposed EFO Operation:**
  - Decrease release to 2,430 cfs
- **Flood Control Operation:**
  - Maintain release at 5,000 cfs
- **Actual Operations:**
  - Release increased to ~5,000 cfs

February 2019 Case Study – Findings



- **EFO simulations show similar trends to actual operations.**
  - Actual operations began prereleases earlier.
  - EFO increased to 5,000 cfs earlier.
- **EFO results could be used to support maintaining a release of 5,000 cfs when storage is encroached into flood pool.**
- **Case study limitation:**
  - Model simulation did not incorporate operational delays in making release changes.

Presentation Overview

1. Ensemble Forecast Operations Background
2. Prado Dam Preliminary Viability Assessment
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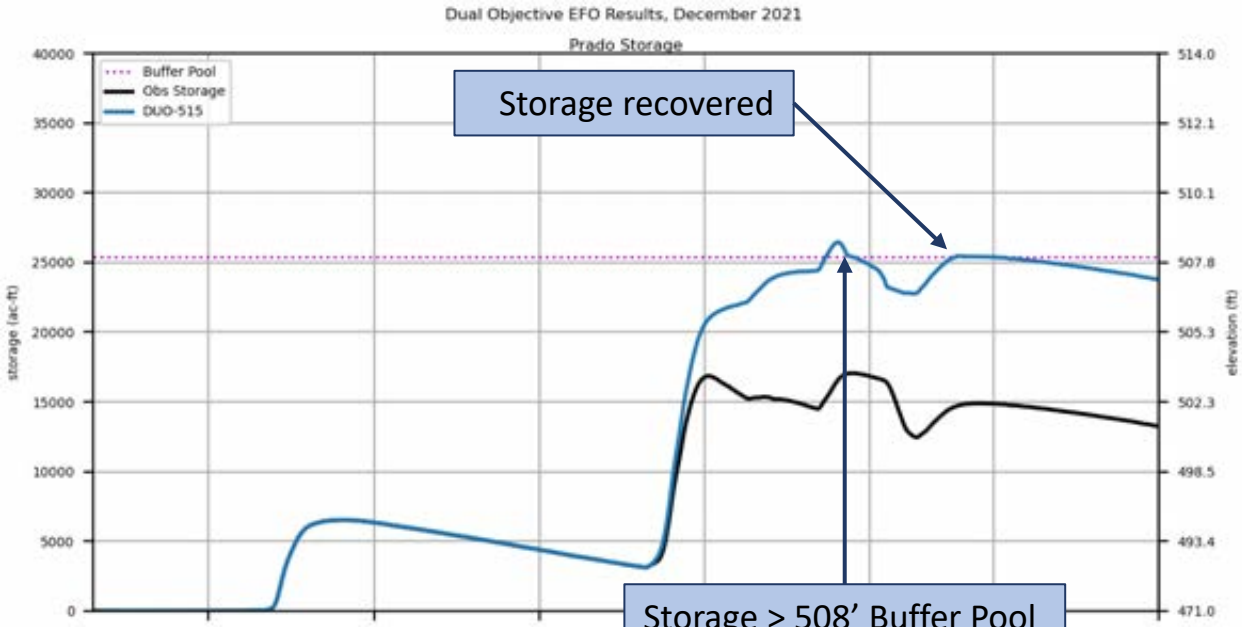
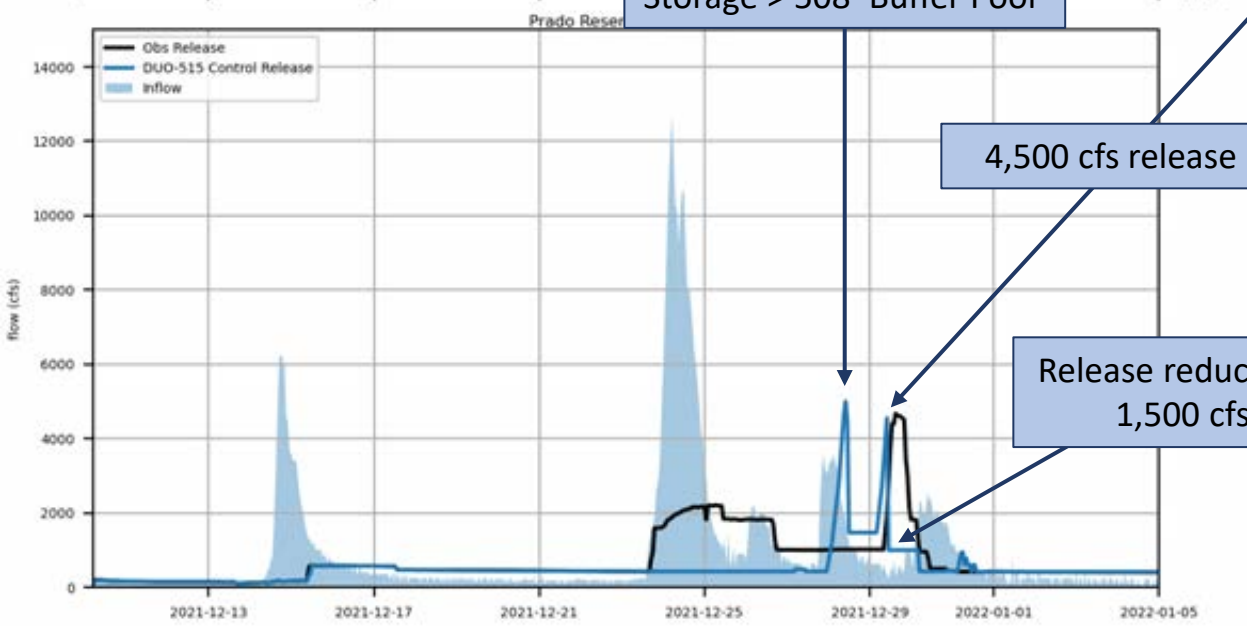
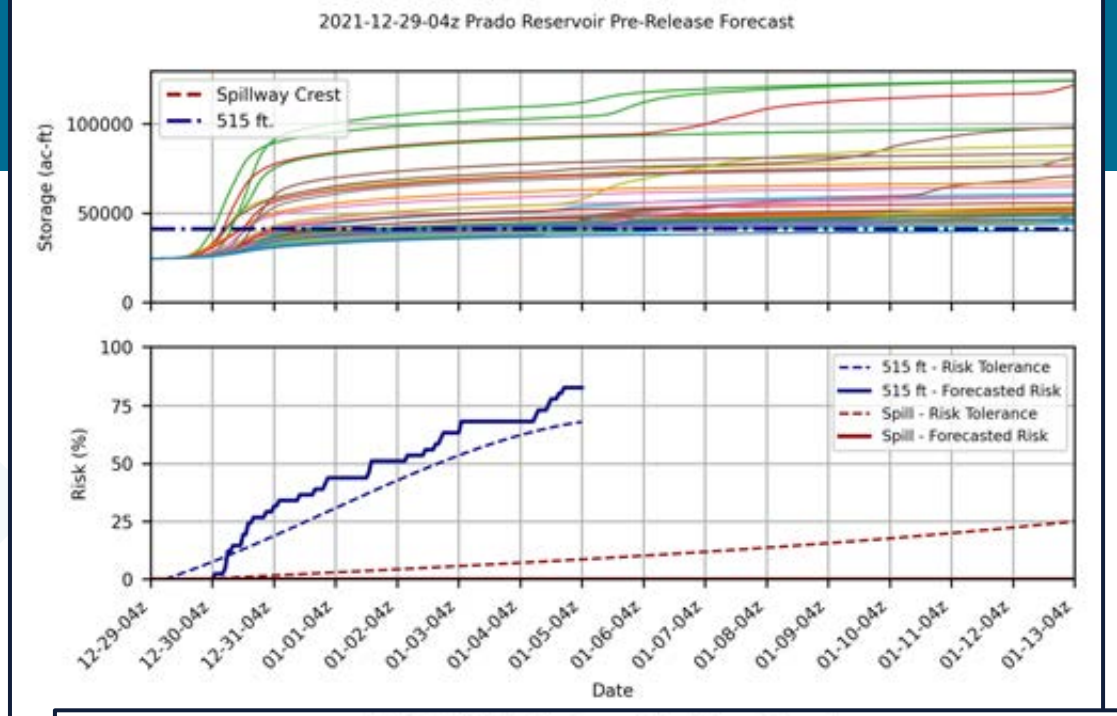
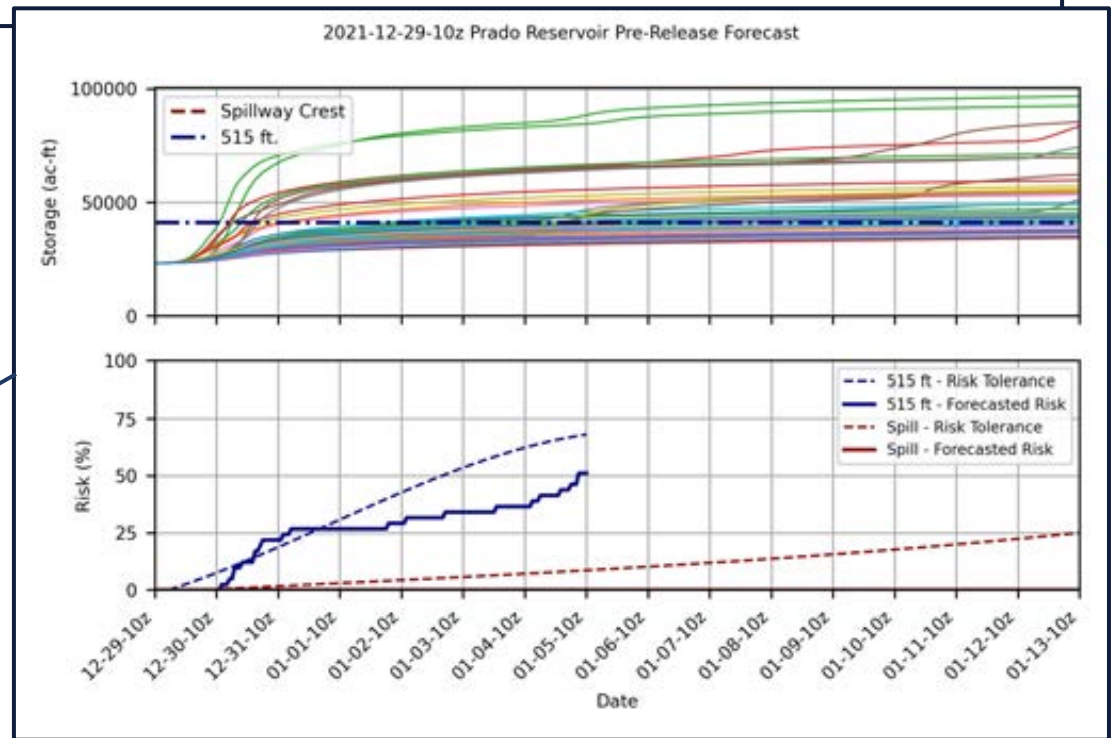
4. **December 2021 Case Study**
5. Volume Based EFO Approach
6. Next Steps and Feedback

December 2021 Case Study

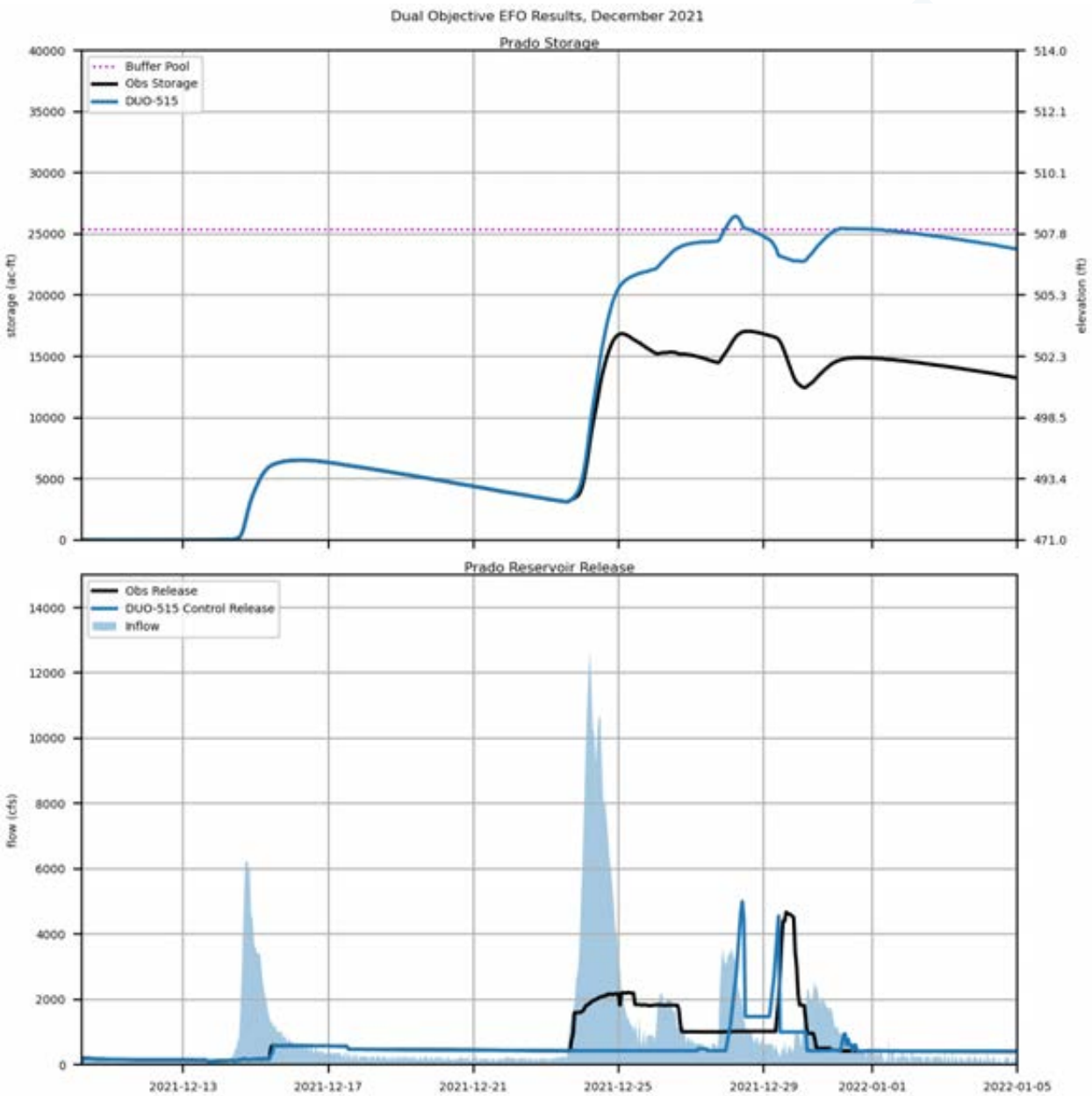








February 2019 Case Study – Findings



- **EFO managing to higher flood elevation than actual operations.**
  - ➢ EFO managing to minimize airport flooding.
  - ➢ Actual operations target peak was ~507’ .
- **EFO over released water in response to over forecast of December 31 event.**
  - ➢ Actual operations also showed similar challenges.
- **Case study limitation:**
  - ➢ Model simulation did not incorporate operational delays in making release changes.

Combined Findings

- **EFO demonstrated skillful operation for both Feb 2019 and Dec 2021.**
  - Management of pool to minimize airport flooding.
  - Management to reduce risk of spills for extreme events (100 & 200 year) was evaluated in PVA and further evaluated in FVA.
- **EFO can provide both situational awareness and release recommendations.**
  - EFO dashboards provide situational awareness for upcoming events.
  - Release recommendations are formulated forecasted risk exceeds risk tolerance.
- **HEFS forecasts evolved very rapidly for both events.**
  - Feb 2019 was under forecasted until 1-day lead.
  - Dec 2021 was over forecasted until less that 1-day lead.
- **Case study limitations:**
  - Model simulation did not incorporate operational delays in making release changes.
  - This limitation can be significant for actual operations.

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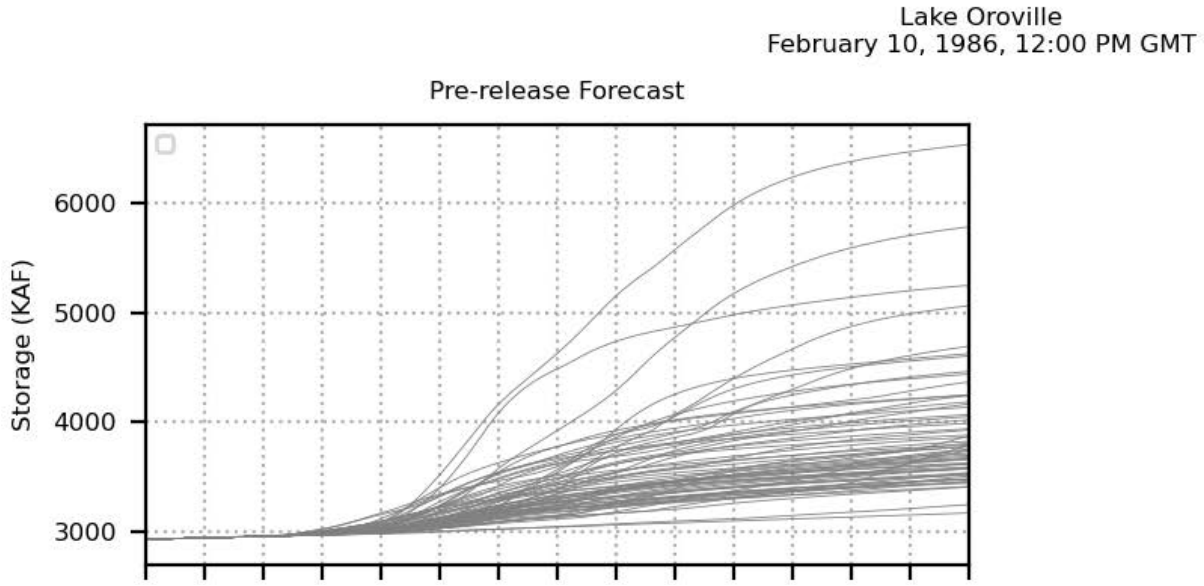
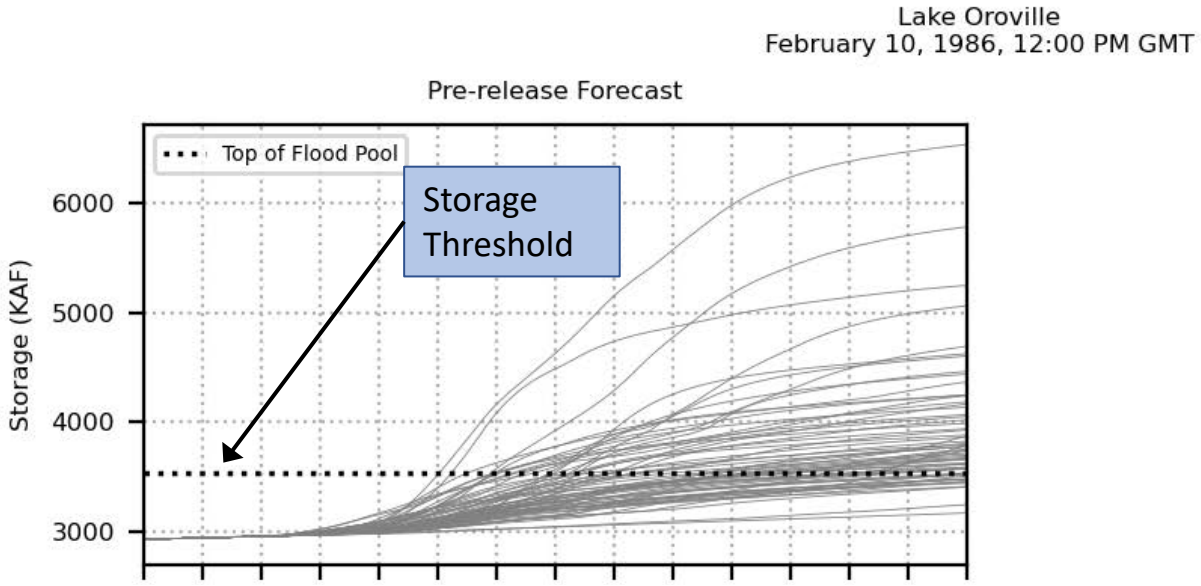
4. December 2021 Case Study
5. **Volume Based EFO Approach**
6. Next Steps and Feedback

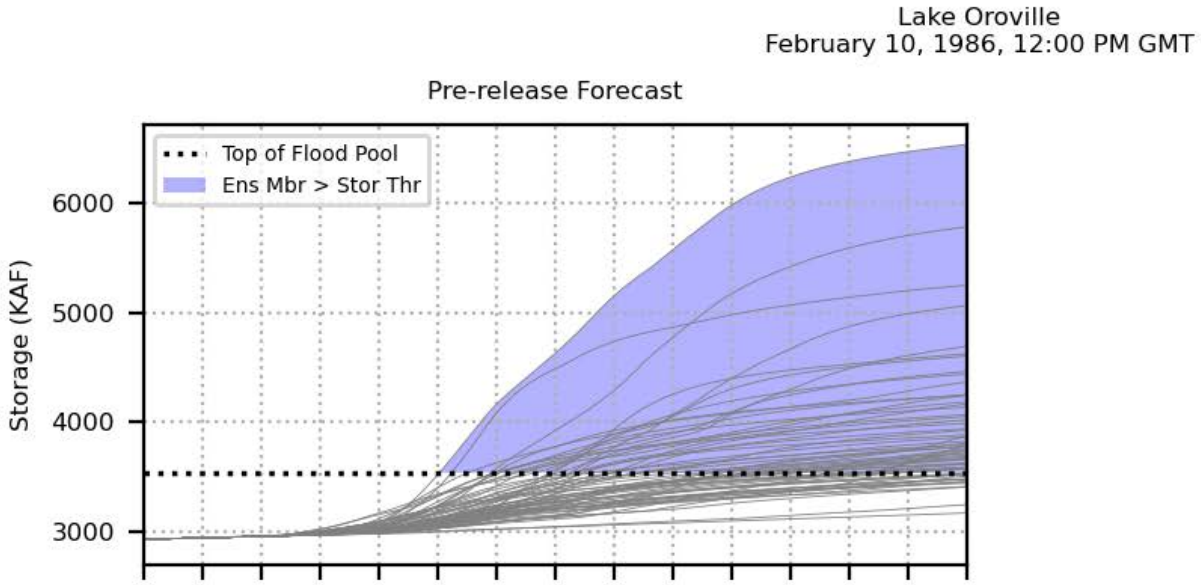
Volume Based EFO – Lake Oroville Example



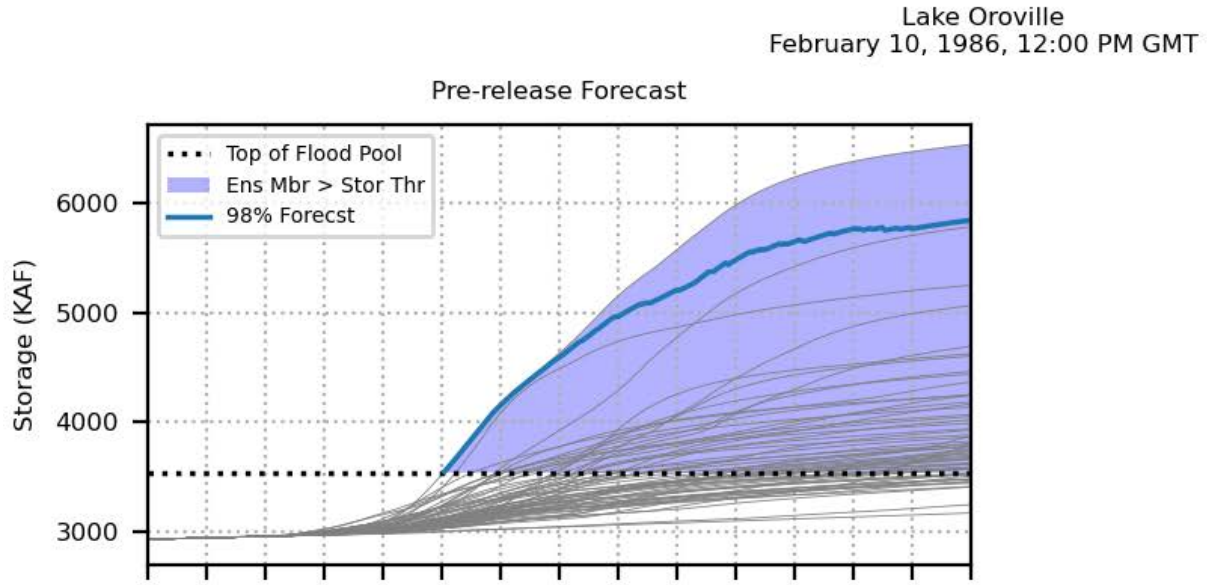
Volume Based EFO – Lake Oroville Example



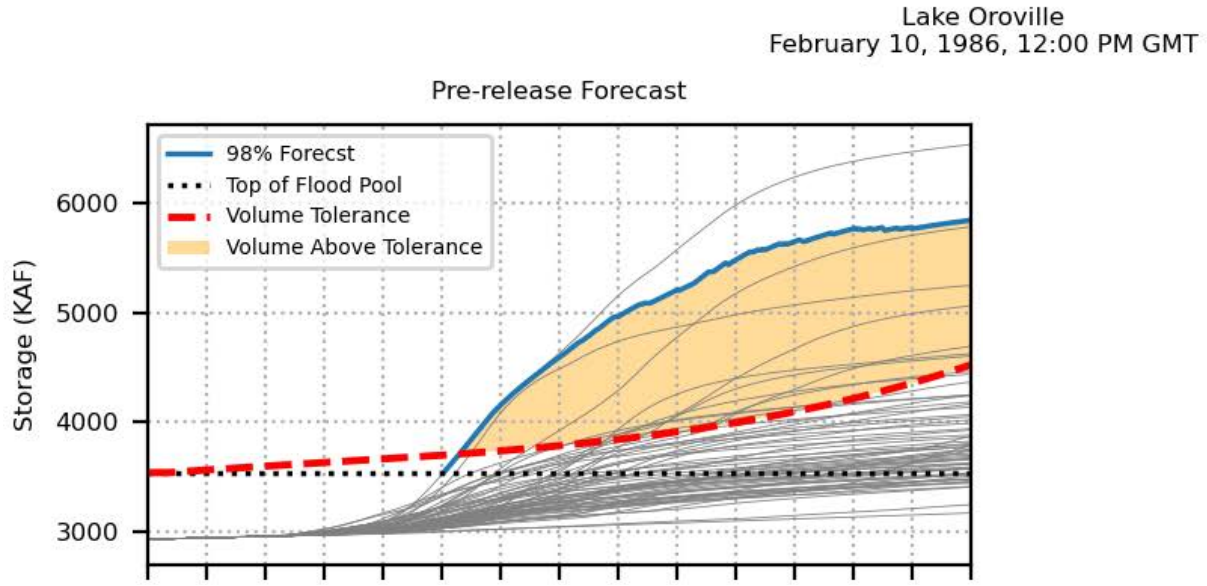
Volume Based EFO – Lake Oroville Example



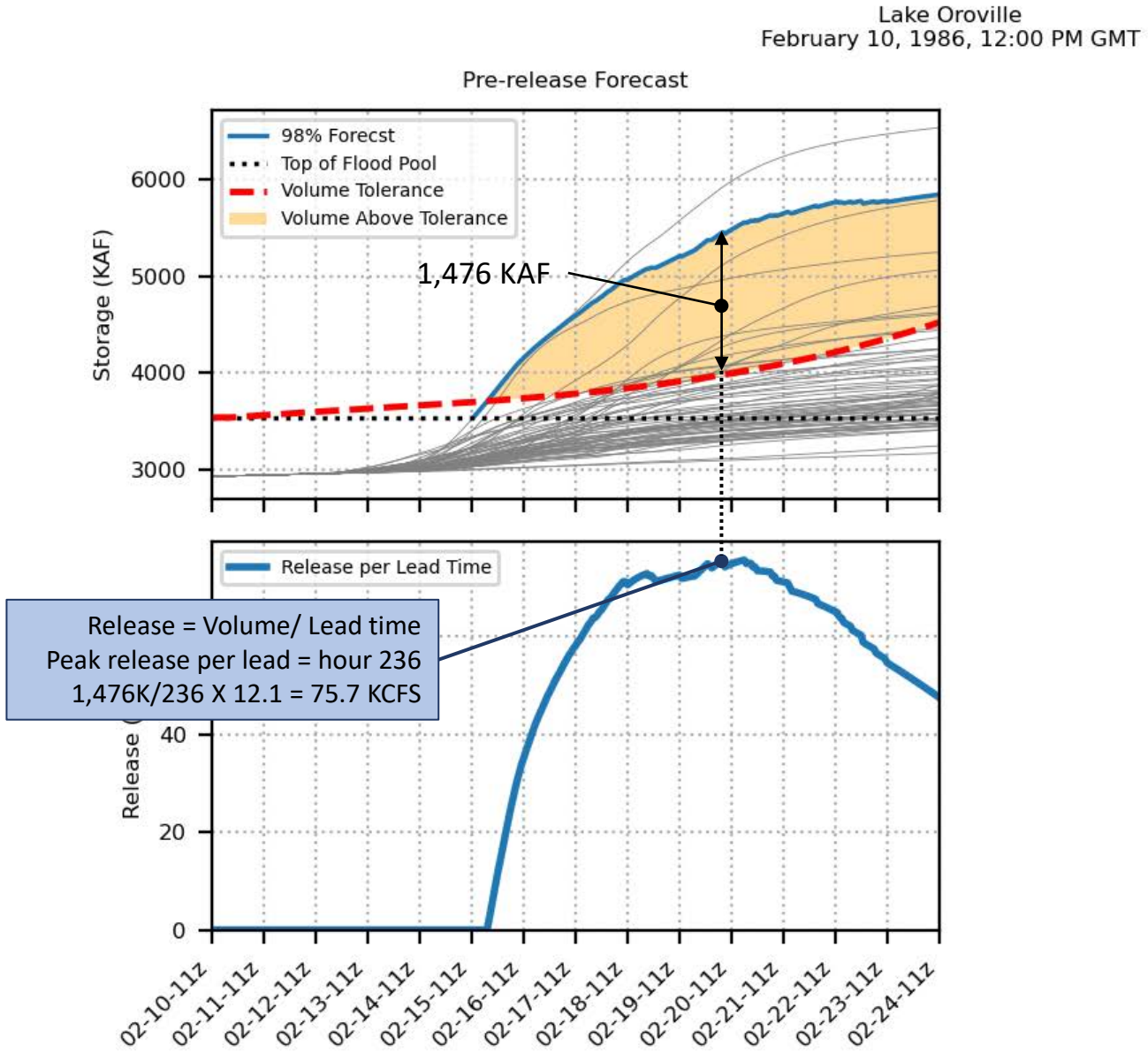
Volume Based EFO – Lake Oroville Example



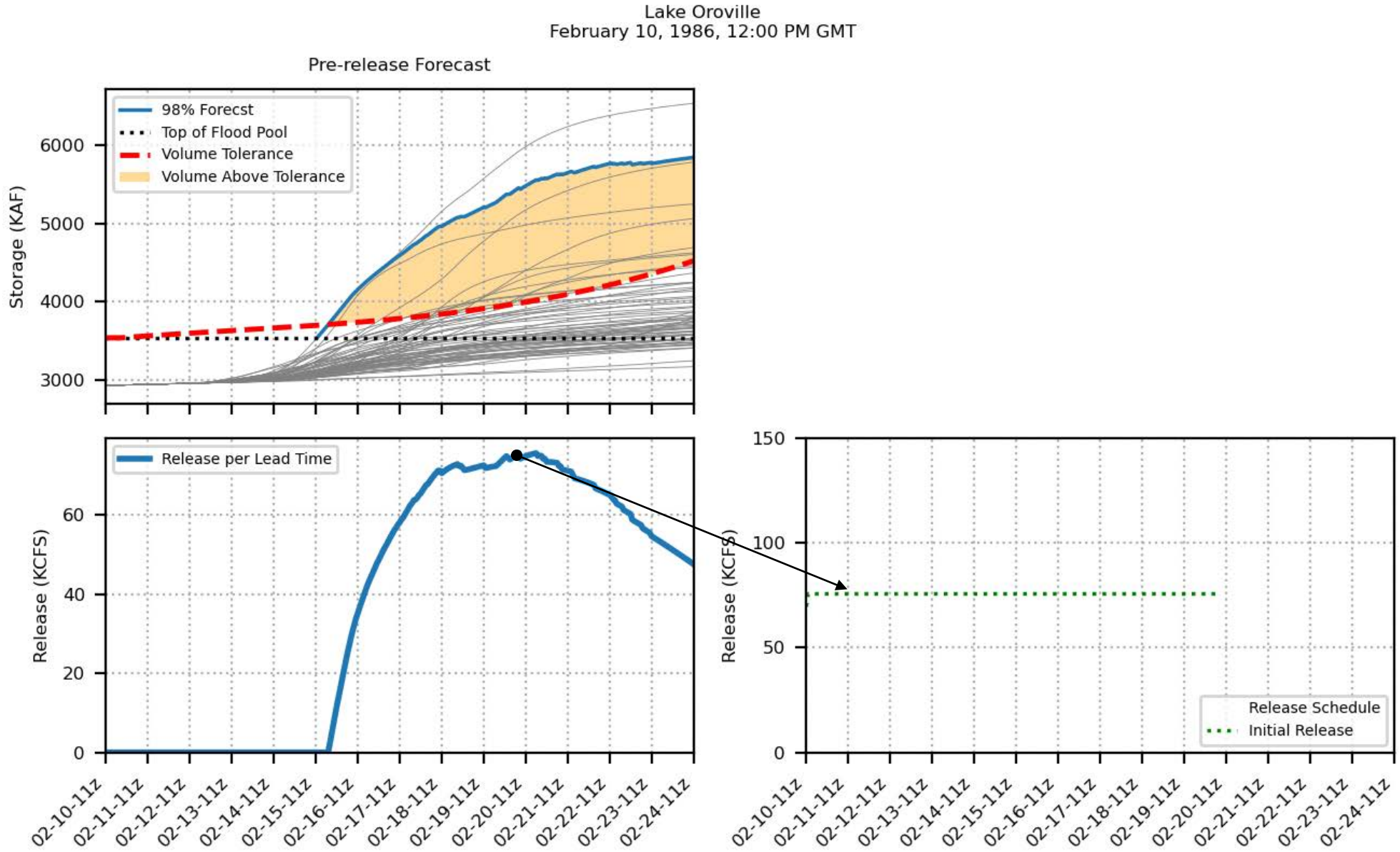
Volume Based EFO – Lake Oroville Example



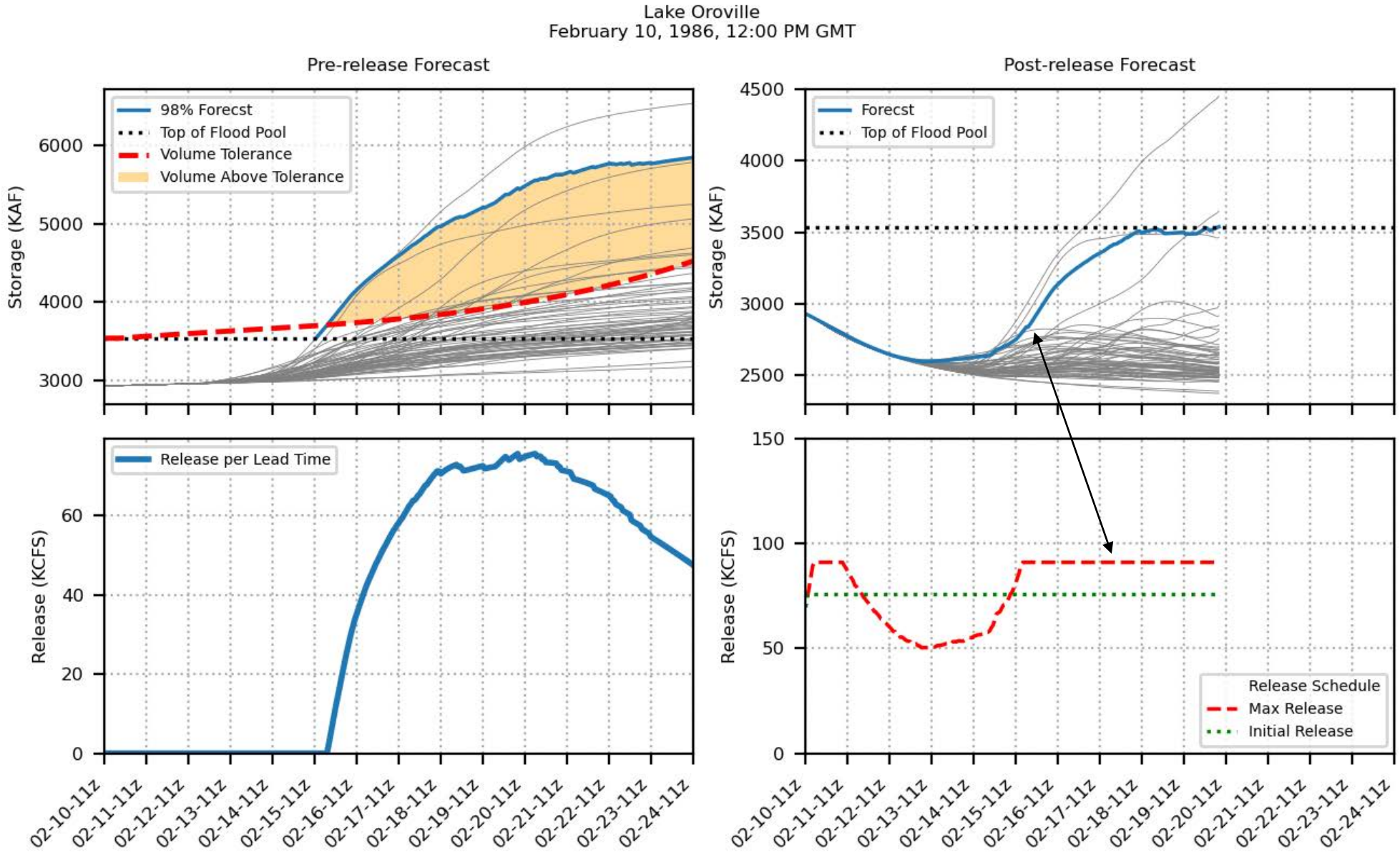
Volume Based EFO – Lake Oroville Example



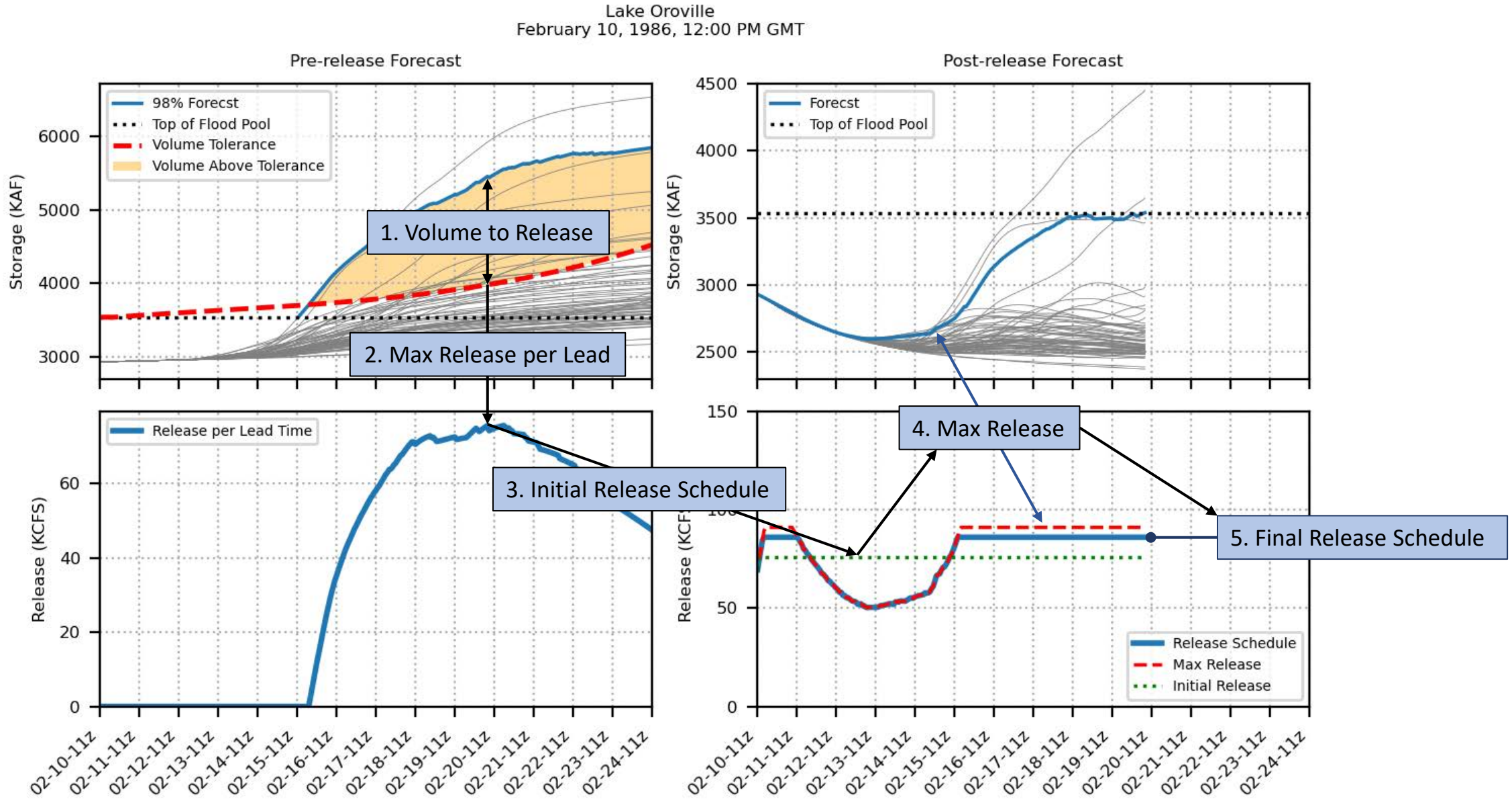
Volume Based EFO – Lake Oroville Example



Volume Based EFO – Lake Oroville Example



Volume Based EFO – Lake Oroville Example



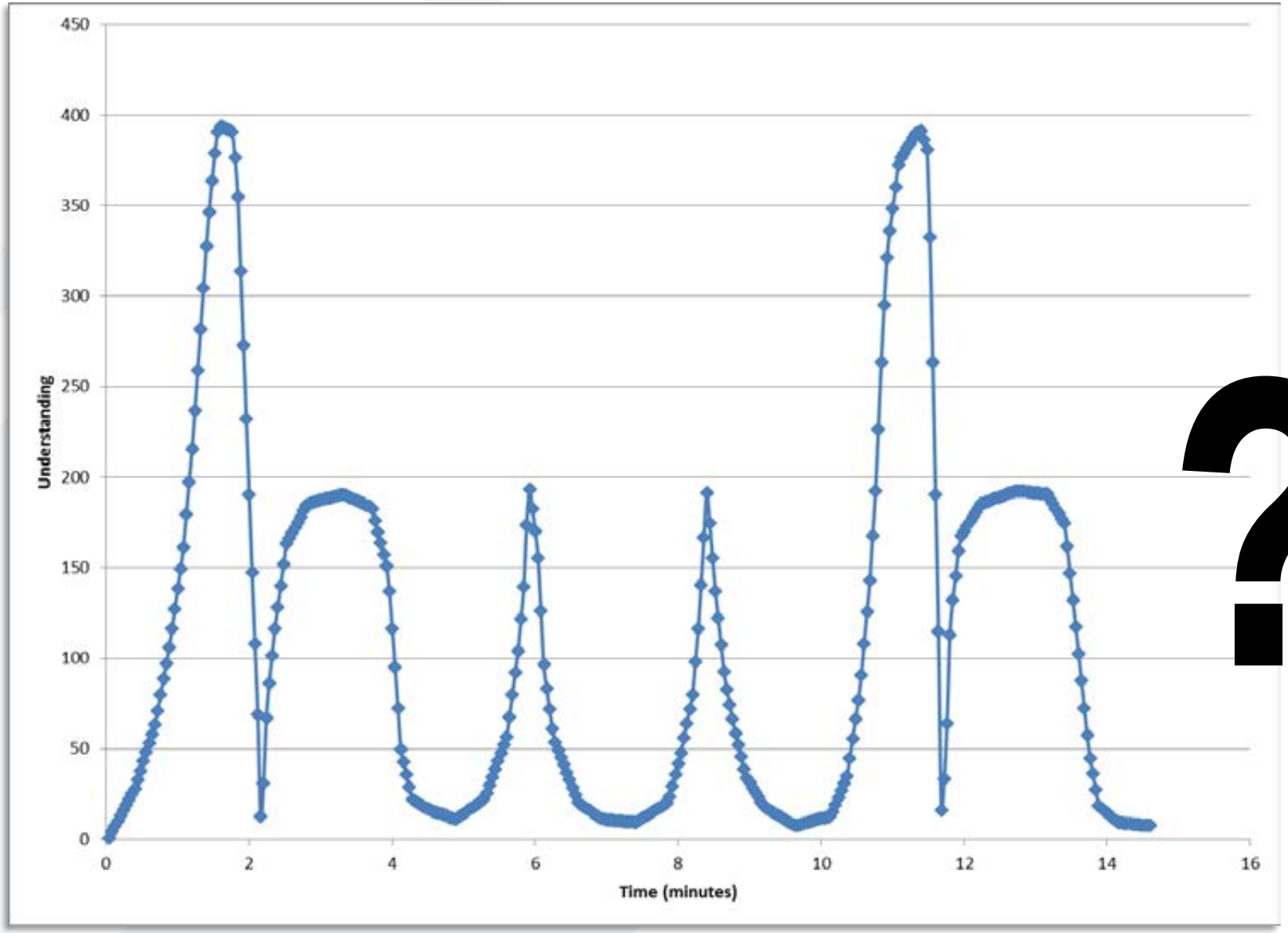
Presentation Overview

1. Ensemble Forecast Operations Background
2. Prado Dam Preliminary Viability Assessment
3. February 2019 Case Study
4. December 2021 Case Study
5. Volume Based EFO Approach
6. **Next Steps and Feedback**

Next Steps & Feedback

- **Multiple dual objective EFO alternatives will be evaluated in the FVA.**
  - Multiple buffer pool levels (508 to 515 feet).
  - Further explore volume-based approach.
- **Currently developing a real-time virtual EFO model.**
  - Dual objective alternatives: 508’ buffer pool and 515’ flood stage.
  - Simulate in real-time if EFO alternative were implemented.
- **Could attempt to incorporate actual operational delays in the simulation of FIRO alternatives for the FVA.**

Questions?


450
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16
Time (minutes)

?

Prado Dam FIRO Decision Support Tools
Workshop #4
February 8, 2023
Orange County Water District, Room C-2
18700 Ward St.
Fountain Valley, CA

Join Zoom Meeting:
https://ucsd.zoom.us/j/94961107055

9:00-9:10	**Welcome and Introductions**
9:10-9:50	**Overview of LA District operations during January 2023 (Jon Sweeten, Amanda Walsh)**
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Prado Dam FIRO Decision Support Tools
Workshop #4
February 8, 2023
Orange County Water District, Room C-2
18700 Ward St.
Fountain Valley, CA

Attendance:

(In person)
Duncan Axisa, CW3E
Arleen ODonnell, ERG
Rob Hartman, RKHC
Garrett Mcgurk, CW3E
Joe Forbis, USACE
Chris Delaney, CW3E
Amanda Walsh, USACE
Adam Hutchinson, OCWD
Jon Sweeten, USACE
Ken Lawler, USACE
Janel Mayo, CW3E
Steve Turnbull, USACE

(Zoom)
Rachel Weihs, CW3E
Brett Whitin, NOAA
Greg Woodside, OCWD
Chuck Downer, USACE ERDC
Kim Gilbert, USACE
David Reynolds,
Brian Kawzenuk, CW3E
Julia Kim, USACE
Beth Faber, USACE HEC

Action Items:

- Within the scope of Seven Oaks FIRO, the hydro team should explore "model susceptibility to simulation errors associated with direct runoff"
- Within the scope of Prado FVA: in coordination with Forecast Verification team, explore: recession rates associated with a larger runoff event
- **Adam H.:** To disseminate the rating table for diversion/infiltration and release rates.
- **Chris and DST team** to sync up with folks at HEC (Beth + team) to ensure there is more streamlined communication with the group working on CWMS. Regularly scheduled meetings would be good.

Welcome and Introductions

Chris led introductions, recapped previous meetings, and reviewed the agenda.

CNRFC Deterministic and Ensemble Forecasts from January 2023 (Brett Whitin)

Reviewed Prado Inflow forecasts from late December 2022 through January 2023 - ensemble vs deterministic forecast vs observations.

Q: Do we still use MBM? A: WPC relies on MBM for their forecast. We take most models into account, we don't know the exact makeup of all of the models, but could find out.

Dec 30 - Deterministic was right around the 50% exceedance

Jan 4 - Deterministic right between 25%-50% exceedance

Jan 9 event: Observations came in at the lower end of the ensembles, there were members that were much larger. Dug in deeper to San Bernardino at E-Street. For the heaviest period of

precipitation, the deterministic forecast was around 1in, for ensembles it was around 2.5in - which is within reason.
POR for RFC is based on the difference between prediction and observations from 2010-now. GEFS POR is from 2000-2019. It appears there's enough data to derive a reliable distribution to sample from. Ran the model with GEFS only (no RFC QPF), showed a very dry forecast, the range was larger compared to the RFC, still not unreasonable. When run through hydro models with GEFS only, the deterministic was at the top of the ensemble (GEFS was a lot drier of a model compared to RFC for this event). It doesn't appear there's a sampling issue. The large members aren't coming from a large precipitation sampling, but there are members showing the runoff response.
Q: Why is the POR you looked at for GEFS only back until 2000? A: Quality of the GEFS forecast was different prior to 2000, we didn't want to introduce that inconsistency. Focused on forecasts that were of similar origin.

Less extreme events for this watershed, maybe having a larger dataset would outweigh issues with inconsistent forecast origin? Right now I'm not confident that adding another 10 years is going to improve the distribution, not to say more data is not helpful. We've talked about synthetically derived forecasts, this would allow us to generate hindcasts for a longer period of time, increase the dataset, not a lot of large events with the RFC POR, we rely on the GEFS for the larger events.

Rob H.: There's an opportunity here to huddle about hindcasts, if we could agree to skill metrics associated with hindcasts, we could run some simulations and look for the most efficient way to move forward. Maybe this summer.

Maybe something we can adjust post-processing, if we see something that doesn't fit with historical outcomes we could stop it. I think we need to understand the QPF sequence. It didn't verify. It's a QPF issue for sure. It would be interesting to diagnose the issue for this event.

Every summer we recalibrate hydro, we're focusing on central coast and southern CA this summer. We may need to focus on Prado. We can revisit.

The soil moisture profile is brought forward on a 6hr time step, it would have naturally gotten wetter, there's no dialing. There are potential adjustments to the soil moisture states that the forecaster can put into the system if they see the flow is not matching the model.

One thing that might be good to add to these slides, would be to run the hydro model with the observed data to see what is model error.

The key difference is that the forecaster sits in front of the display and sees how the model runs and what the forecast has been, and if something doesn't seem right you adjust the model. The ensembles are run after the deterministic forecast. Some of the behavior with the high ensemble models, and you saturate the soil and get direct runoff, it probably happens more in the model than it does in reality. This is a learning exercise, we have the opportunity make changes.

Can we turn these into recommendations for future work? (Is the model susceptible to simulation errors associated with direct runoff)
Yes we can do that likely with CNRFC and CW3E working collaboratively. Maybe Seven Oaks FIRO, it would be a good task for the 7O hydro team to explore.

Overview of LA District operations during January 2023 (Jon Sweeten, Amanda Walsh)

Evolution of thinking with more flexibility instead of “505 glass ceiling” - allowing to go up to 506, giving an additional 1800 ac ft, this helps avoid yo-yoing to maintain 505’ and gives a “soft landing”’. Conversations were had with USFWS about allowing up to 506’ - birds aren’t currently nesting.

Trying to avoid deflating a rubber dam, rather be at 4,000 cfs or 400 cfs - one or the other. Adam: We have a rating table to know how much we can divert at which release rates.

Reviewed operations in late December through mid-January. Activated the ROC 4 different times ~2 days at a time for the first 3, and ~5 days for last activation. Discharges were coordinated with OCWD. There was some mental bias that forecasts were trending high. Notifications are made with 24 hour notice. Last event(s) required 4,000 cfs releases - assumption this wouldn’t impact the golf course/access road to golf course facility, there’s a wave effect at 4,000 cfs that impacts the access road- but there was a wedding event, they needed to shut down the access road and evacuate everyone safely. ~3,800 cfs is a safer release limit for not impacting the golf course.

Maybe there should be an update to the USFWS operations plan - to make sure it’s a better reflection of what’s happening today and reflect the correct seasonality correlated to nesting.

There may be benefits to having a variable pool - there should be conversations with USFWS about optimization - creating habitat.

EFO Virtual Operations (Chris Delaney)

Evaluation of EFO operations during January.
Real time EFO: always initialized to current observed storage and release.
Virtual operations: simulates storage and release outcomes for 2 FVA alternatives (DUO-514 w/ 508’ buffer pool). Baseline = ops according to current water control diagram
Reviewed Jan 10 AR event: model “spun off” into a virtual operation/diverged from the observed around the Jan 10 AR event. Virtual EFO lost about ~4000 ac ft in storage due to over forecast.

Jan 14-16 Events: Did much better than the Jan 10 event. Had 5,300 ac-ft above observed at the end.

Are the v12 hindcasts consistent with real-time operations?
Analyzed 2 day inflow volumes, compared obs 2-day inflow volumes to max ensemble member, then calculated how much of an over forecast = 730% over forecast.

Looked at the overforcast percentage for the entire hindcast period, but was filtered for difference over 20,000 ac ft (1990-2019). Main takeaway is that we don't see this over forecast in the hindcast - EFO is designed to account for forecast uncertainty.

Do we see significant over releases in the EFO model simulations?

Address simulation of large over forecasted events (2021 and 2023) in the FVA to quantify risk to water supply.
Possible Solutions for operations:
Modify ensemble inflow forecasts
Adjust risk tolerance calibration to favor water supply
Modify EFO rule
Do nothing - accept risk to water supply

Calibration of EFO Risk Tolerance. We have methodology = we generate 1000's of risk tolerance curves, simulate for POR, evaluate performance of each curve, identify/enhance tolerance curve. Interpolate through multiple to reduce overfitting. Methodology is completely dependent on the hindcast. The fact that we don't see these over forecasts in the POR is concerning. Currently bringing in scaled events, extreme events, we want to also include over forecasted events.

Objective function could be formulated differently - currently 50/50 water supply v flood risk. Toying with 60/40 water supply risk given higher weight.

Reduce maximum release for FIRO pre-release

Mitigate risk of storage recovery - conceptual at the moment.

CW3E Atmospheric River and Precip Tools (Brian Kawzenuk)

Reviewed ARs Dec-Jan, summary of landfall locations, IVT and time series, mesoscale characteristics, precipitation summary.

S2S Products: Water year to date precip / odds of 100% of WY normal precip.
Dynamical models: NCEP, ECMWF, ECCC -> pretty decent signal of AR activity at a 3 week lead.

AR Landfall tool (forecast out to 16 days), deterministic models GEFS - stepping through each of the 9 AR forecasts with reference to Prado.

GFS and ECMWF were tracking pretty well together.

Latitude: from a longer range the models were predicting further north > could be either an error in landfall location/how fast they dissipated or timing issues.

West-WRF Forecasts (Rachel Weihs)

Mean Areal precipitation error

Precipitation skill across CA: West-WRF forecasts show skill greater than 4 days in the Santa Ana Basin when predicting P >1 inch.

Q: Do you think orographic precipitation is being captured better? A: Yes, working hypothesis is that throughout the Santa Ana basin there are enough grid cells to accurately capture the orographic precipitation.

Ensemble mean fields - ensemble mean forecasts NRT has lowest RMSE.

Comparison of West-WRF and GFS landfall position error; on average West-WRF improved landfall position by 36km

AR Intensity Error

Q: is the plan to relate this to the AR catalog and see where the IVT errors identify with features of the ARs? A: Yes. One of the issues with this is sample size, over a 10 year period we ended up with less than 30 landfalling ARs in Southern California.

Q: Have you tried to correlate IVT errors with the MAP errors? So, how does an IVT duration, intensity, and timing correlate with the MAP in the watershed? A: They are weakly correlated. The theory is there is a timing delay in the onset of the IVT.

Q: How do you correct for orientation of the AR making landfall vs AR scale? A: Mostly addressed by the MOE, a measure of the aerial extent and overlap, it's not directly addressed but folded into positional error. That's why it's important that we include a whole list of measurements when we're assessing ARs.

There are some improvements that can be made with the addition of dropsonde data. Targeting specific processes within the AR -> Would need to look over a series of storms to detect patterns in the improvement of forecast w/ AR recon.

Prado Dam Outflow Observations (Garrett McGurk)

Computer Vision Stream Gage at USGS Prado Gage House

(Space Time Image Velocimetry) STIV below Prado Dam, co-located with USGS gage

NRT CVSG Dashboard

Working with USGS to improve the velocities rating curve, ADCPs are used to measure depth.

Camera is providing useful data and is a good tool to resolve inconsistencies with the flow data. Would hopefully apply this to MWD crossing in the future.

Q: What are the next steps? A: We need to decide as a group if we're comfortable with this technology, but the idea is to add to the observations of inflow at Prado (MWD crossing).

Q: is this being evaluated at other CW3E sites? A: Not currently. We do have support from Xylem.

Discussion of lessons learned from the January 2023 events and how this affects FIRO implementation.

It would be nice to see the information discussed today AR by AR, for future reference - would be more illuminating.

Discussion of DST section of the FVA and DST team recommendations.

Description of Existing DSTs used for operations
[needs to be documented, this is the baseline]
- Atmospheric
- Hydrologic
- Operations

Gaps Analysis
[don't have that much room in the FVA to go too in depth, needs to be polished and refined]
- What are the gaps to implement FIRO

How to we resolve gaps
- Roadmap to develop a DSS

(once we know the gaps, how do we get there to get a DSS developed, functional specifications - not sure that level of commitment will be feasible in FVA scope)
- Envision laying out general tasks of filling the gap
- How do we get the existing tools that are developed and/or being developed integrated in CWMS / CAVI

It may be a missed opportunity in the FVA if we don't make the connection with the USACE's efforts to use CWMS for real-time water management. The best we can do within these FIRO projects is to support that reality, this will make it easier to implement CWMS - so there aren't incompatible sets of tools.

Chris and DST team to sync up with folks at HEC to ensure there is more streamlined communication with the group working on CWMS. Regularly scheduled meetings would be good.

HEC's work (using Prado as a case study) will likely help fill the gap of the questions being addressed by DST in the FVA.

We need to show initiative to align with CWMS (corps is investing/implementing)

There will need to be a process for vetting this section with the group - potentially 2 drafts, feedback, then a final

Greg thanked Chris on setting up and trialing the virtual EFO.

Chris: Moving forward we'll be working on the DST section of the FVA, I'll be reaching out to folks on language and overall structure and content of this section.

Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

February 8, 2023

Prado Dam FIRO Final Viability Assessment Decision Support Tools Workshop #4

Join Zoom Meeting:
https://ucsd.zoom.us/j/94961107055

UC San Diego | SCRIPPS INSTITUTION OF OCEANOGRAPHY

DST Workshops

- **Workshop 1 (Completed 8/16/22):** Review Corps existing tools and operations for Prado Dam
  - Historical storm events: February 2019 and December 2021
  - Facilitate learning of existing operational practices and constraints
- **Workshop 2 (Completed 9/12/22):** Review atmospheric river and watershed tools that could support FIRO
  - Demonstration of CW3E and ERDC tools
- **Workshop 3 (11/2/22):** Review operational tools that could support FIRO
- **Workshop 4 (2/8/2023):** ~~Presentation of needs assessment~~

  Review of forecasts and operations during the January 2023 AR Events

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DSTs in the FVA

- **Description of Existing DSTs used for operations**
  - Atmospheric
  - Hydrologic
  - Operations
- **Gaps Analysis**
  - What are the gaps to implement FIRO
- **How do we resolve gaps**
  - Roadmap to develop a DSS

Center for Western Weather and Water Extremes
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Prado Dam FIRO Decision Support Tools Workshop #4 EFO Real Time Operations

2/8/2023

Chris Delany, Research Engineer
Center for Western Weather and Water Extremes

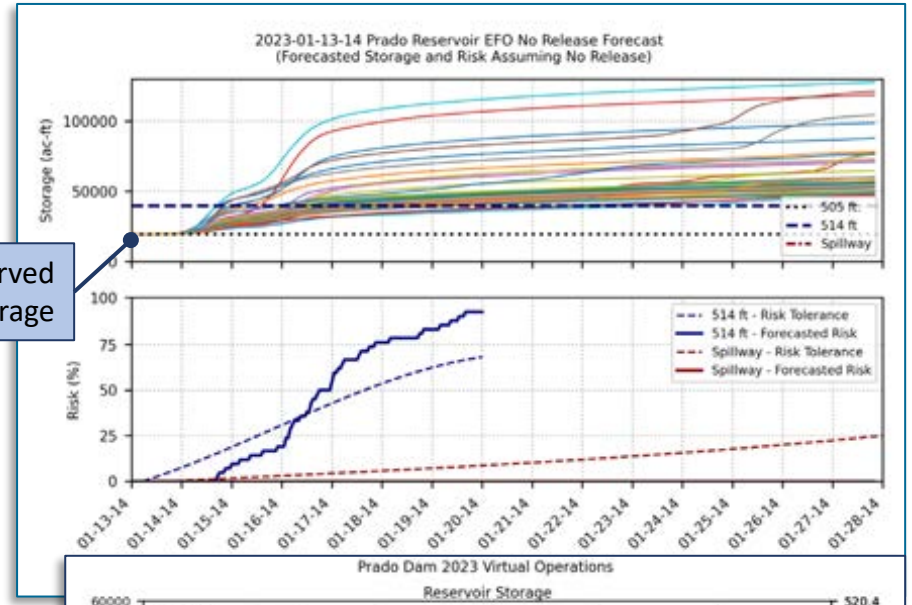
UC San Diego | SCRIPPS INSTITUTION OF OCEANOGRAPHY

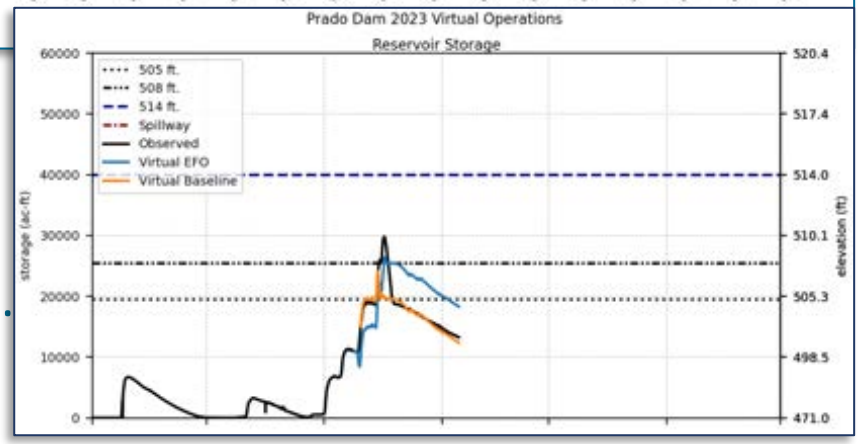
Presentation Overview

1. **Evaluation of January EFO Virtual Operations**
2. Are the V12 hindcasts consistent with real time operations?
3. Management challenges using HEFS forecasts for Prado and ways to address those challenges.

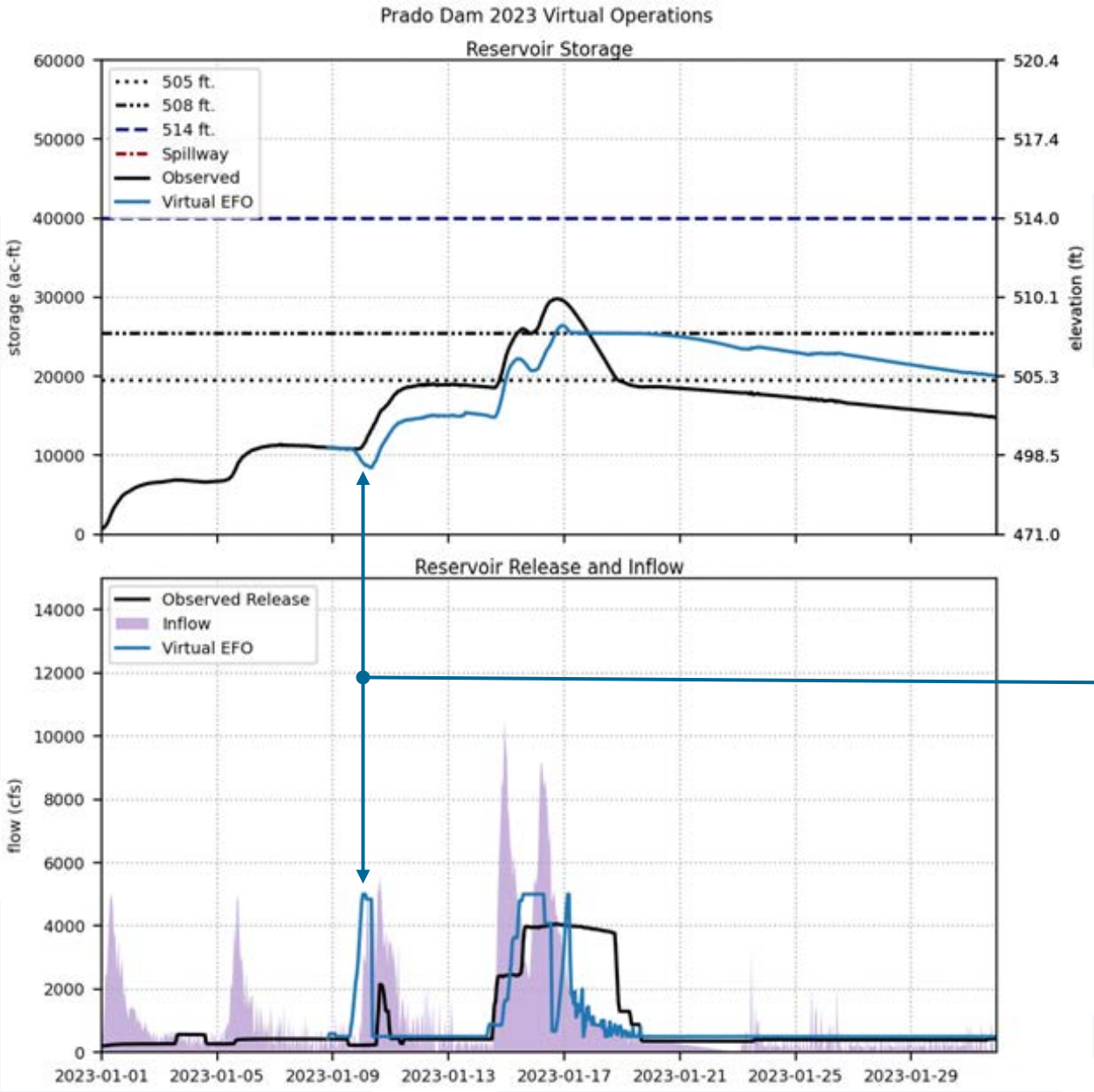
Real Time Ensemble Forecast Operations – What does this provide?

- **Real time operations support with EFO model**
  - EFO model is run with each new issuance of the HEFS forecast
  - Multiple scenarios: Real Time EFO (1), Virtual Operations (2)
  - Results will be provided on CW3E website
- **Real Time EFO**
  - EFO model is always initialized to current observed storage and release.
  - Dual Objective EFO (DUO-514) w/ 505' buffer pool
    - Formulates releases based on risk of exceeding airport and spillway crest.
- **Virtual Operations**
  - Simulates storage and release outcomes for 2 FVA alternatives.
  - DUO-514 w/ 508' buffer pool
  - Baseline – Operations according to current water control diagram.

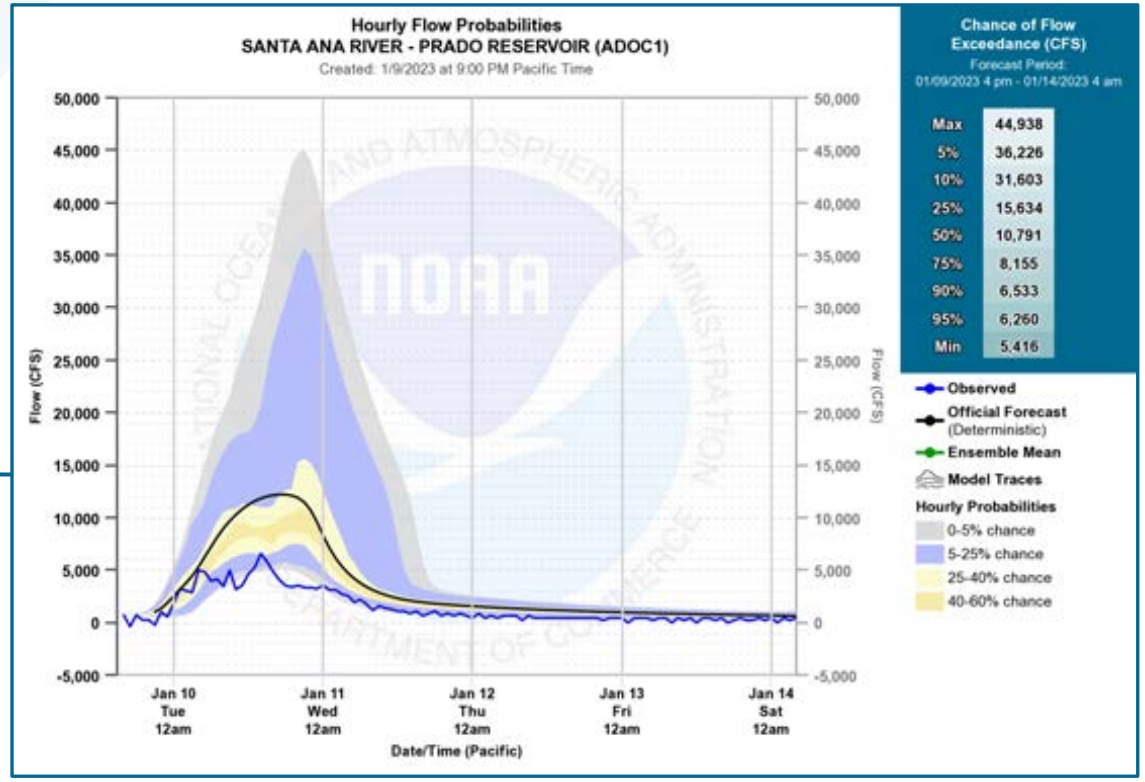




January 10 AR Event



CNRFC HEFS Forecast 1-day before event



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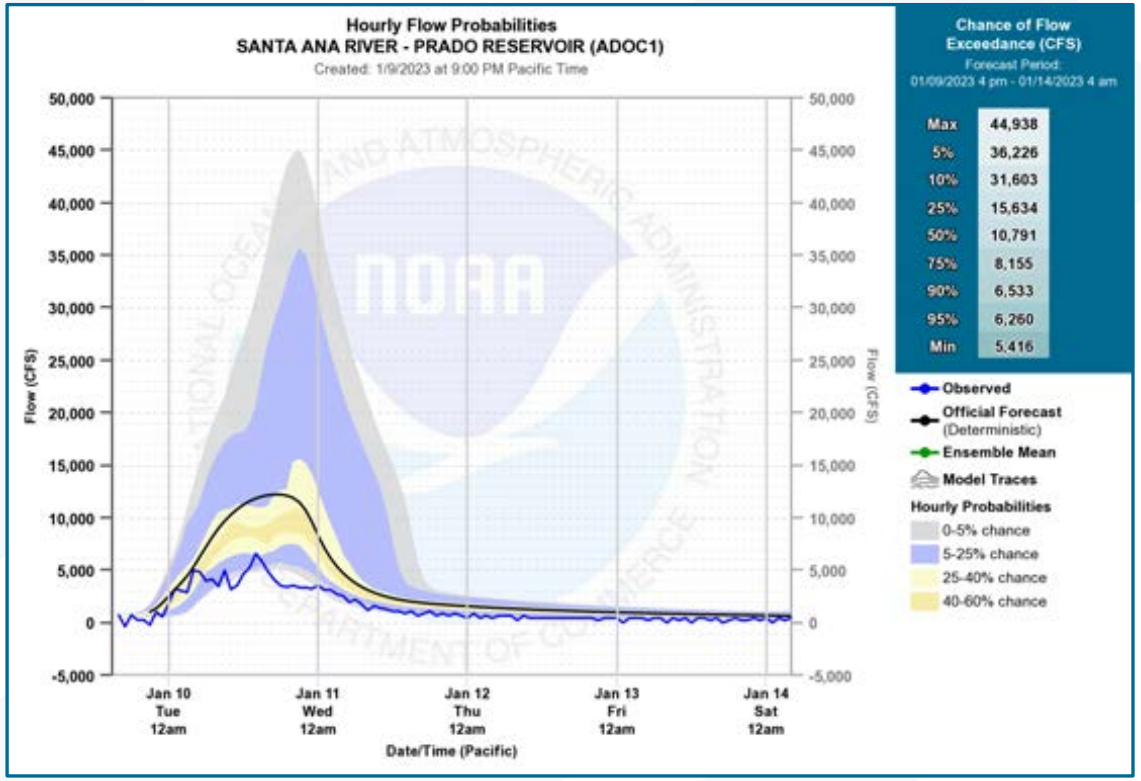
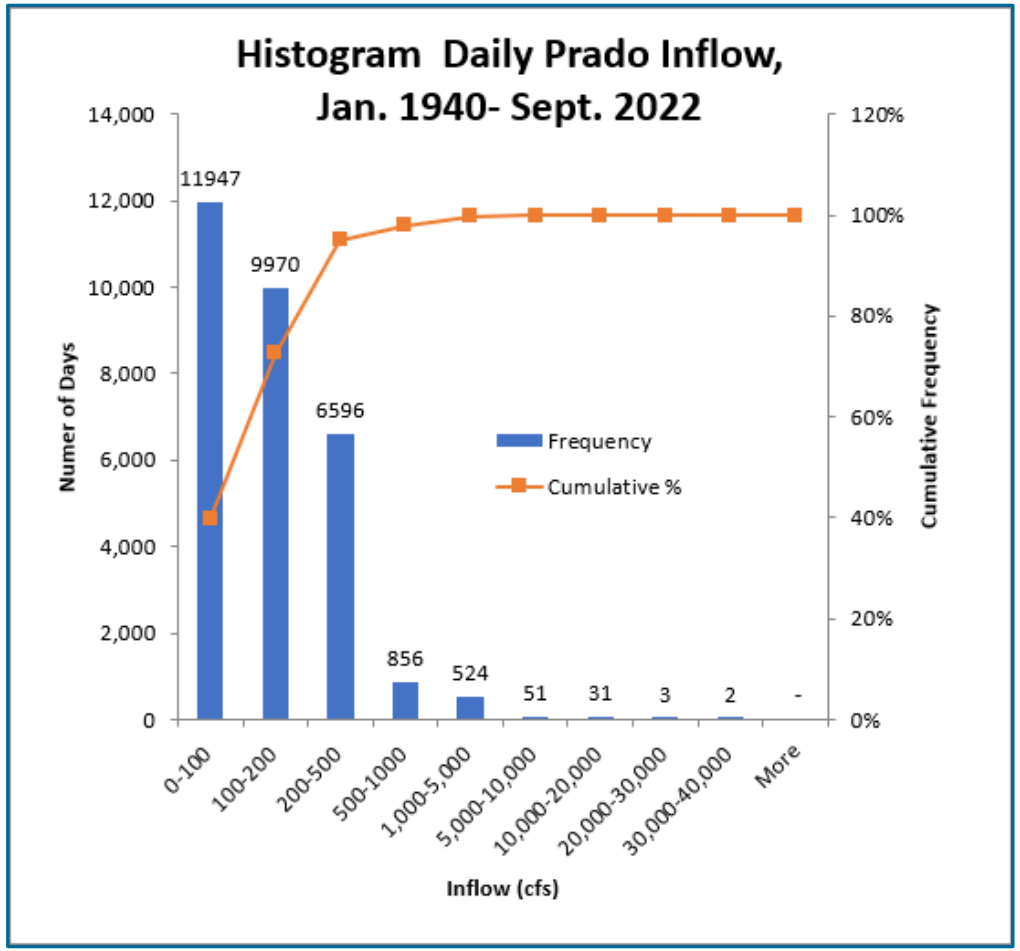
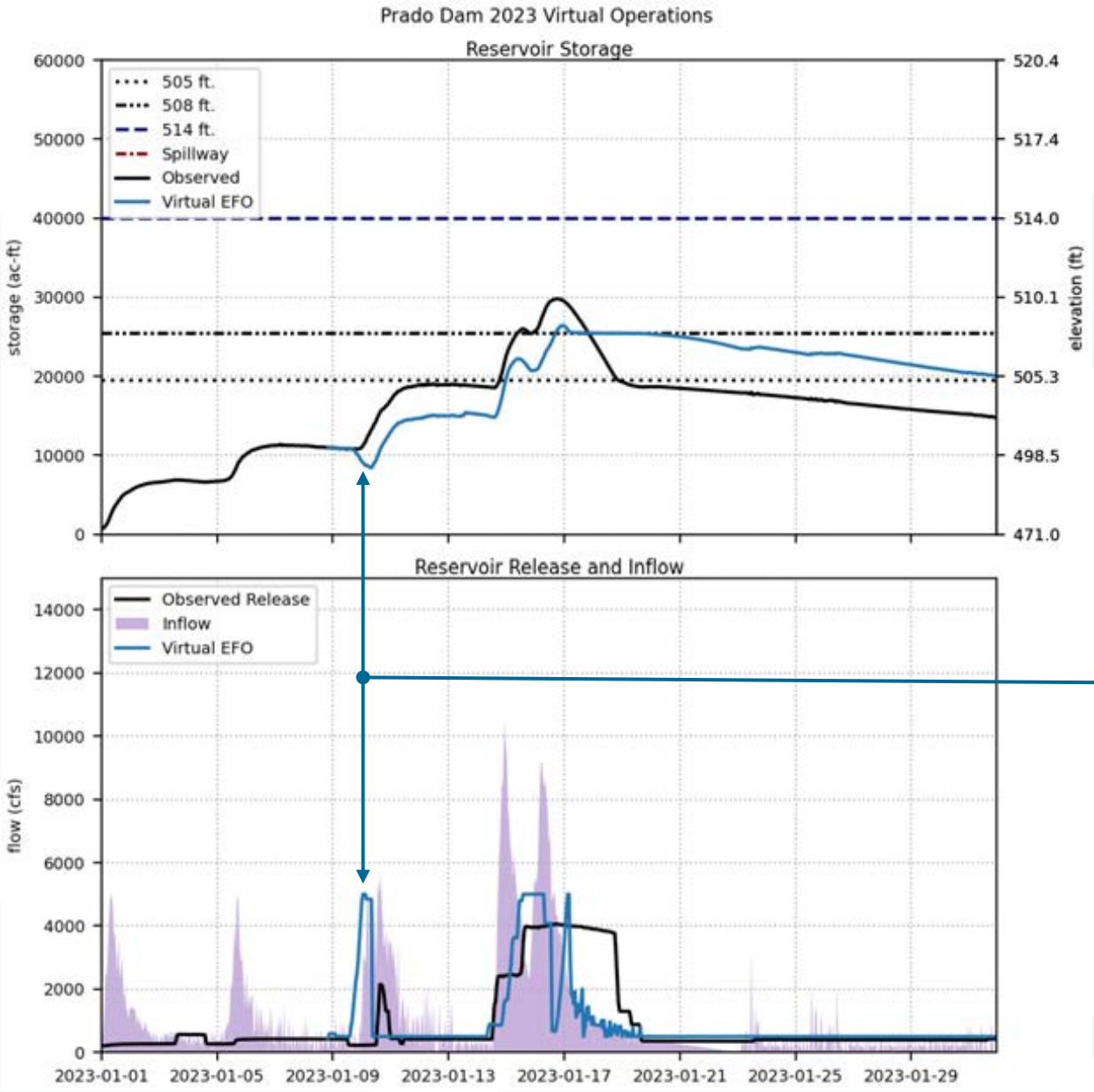
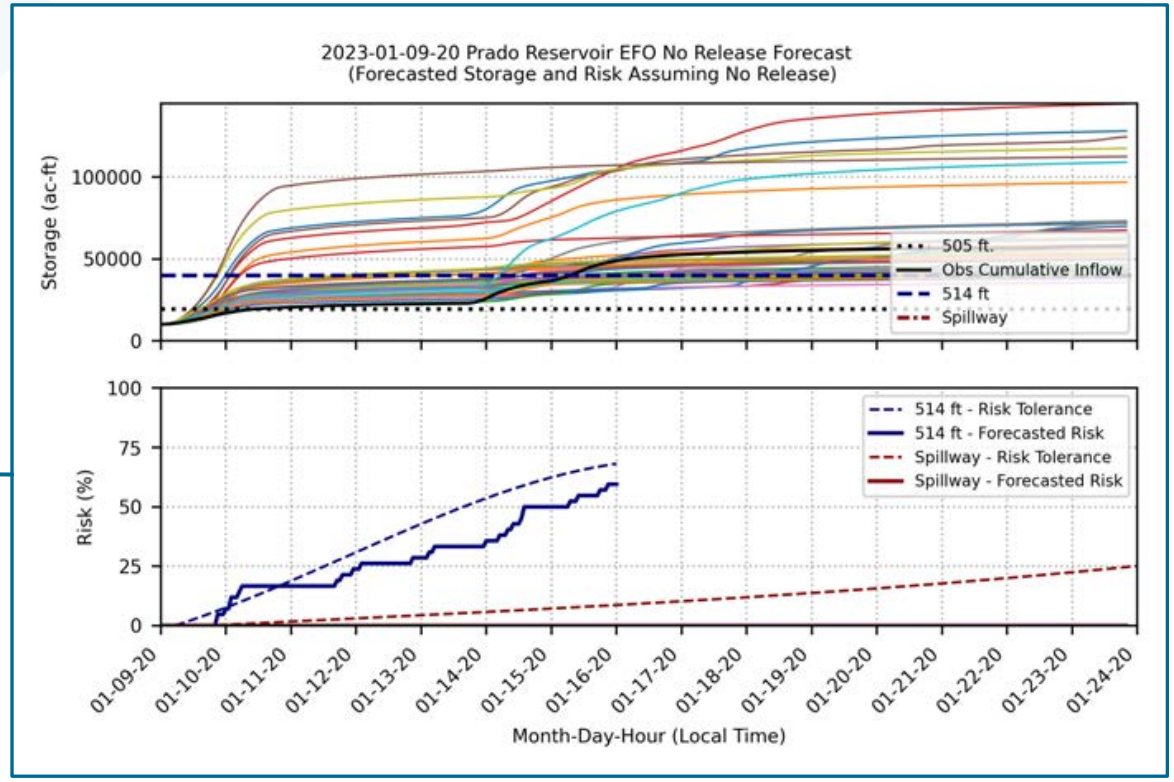




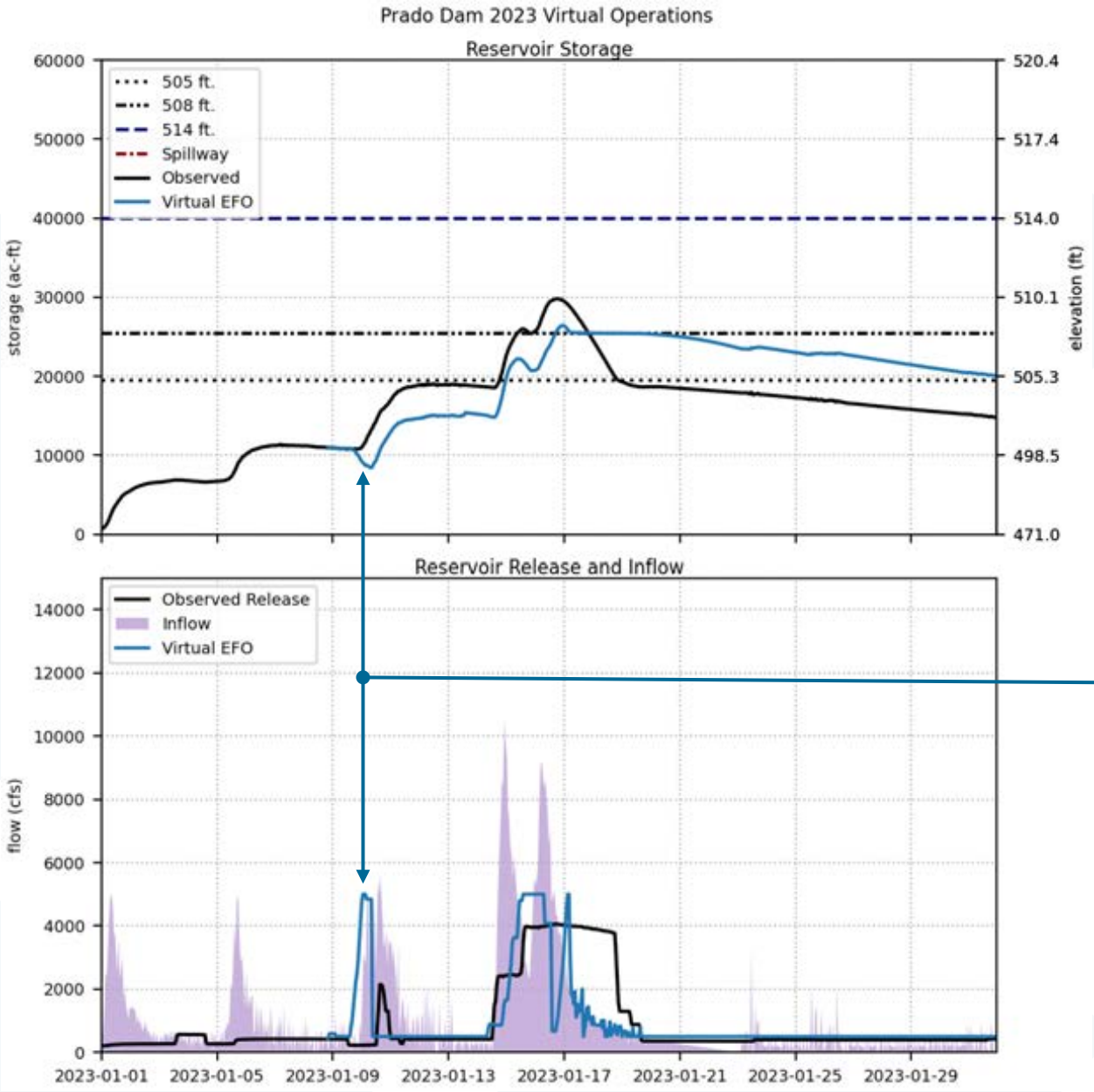
January 10 AR Event



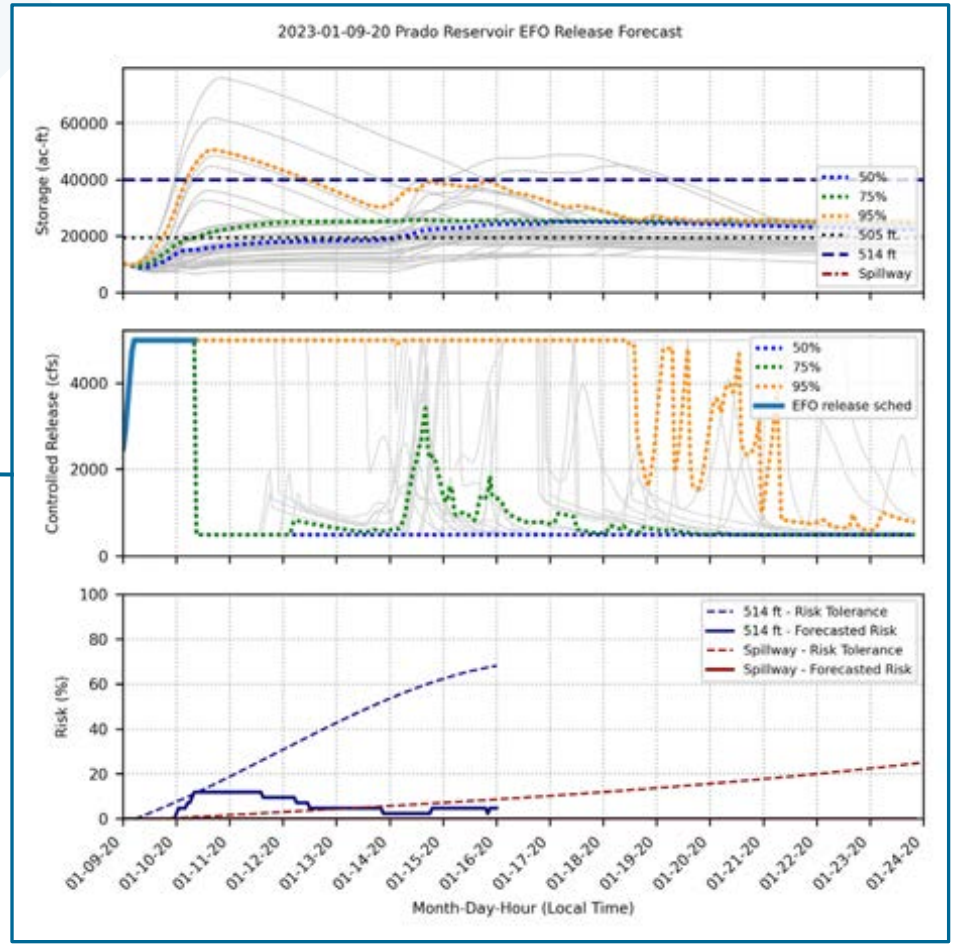
No Release Forecast 1-day before event



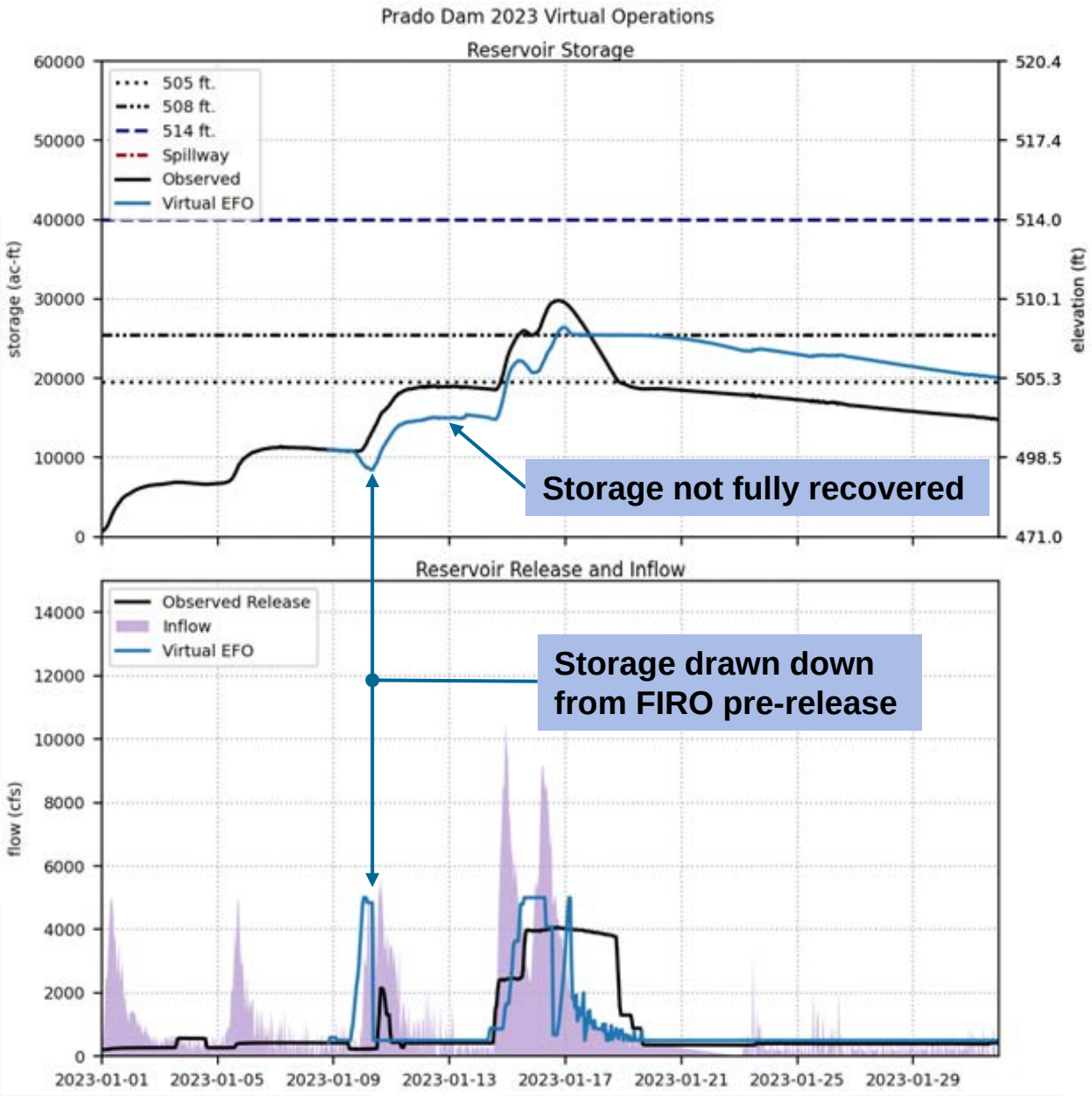
January 10 AR Event



Post Release Forecast 1-day before event

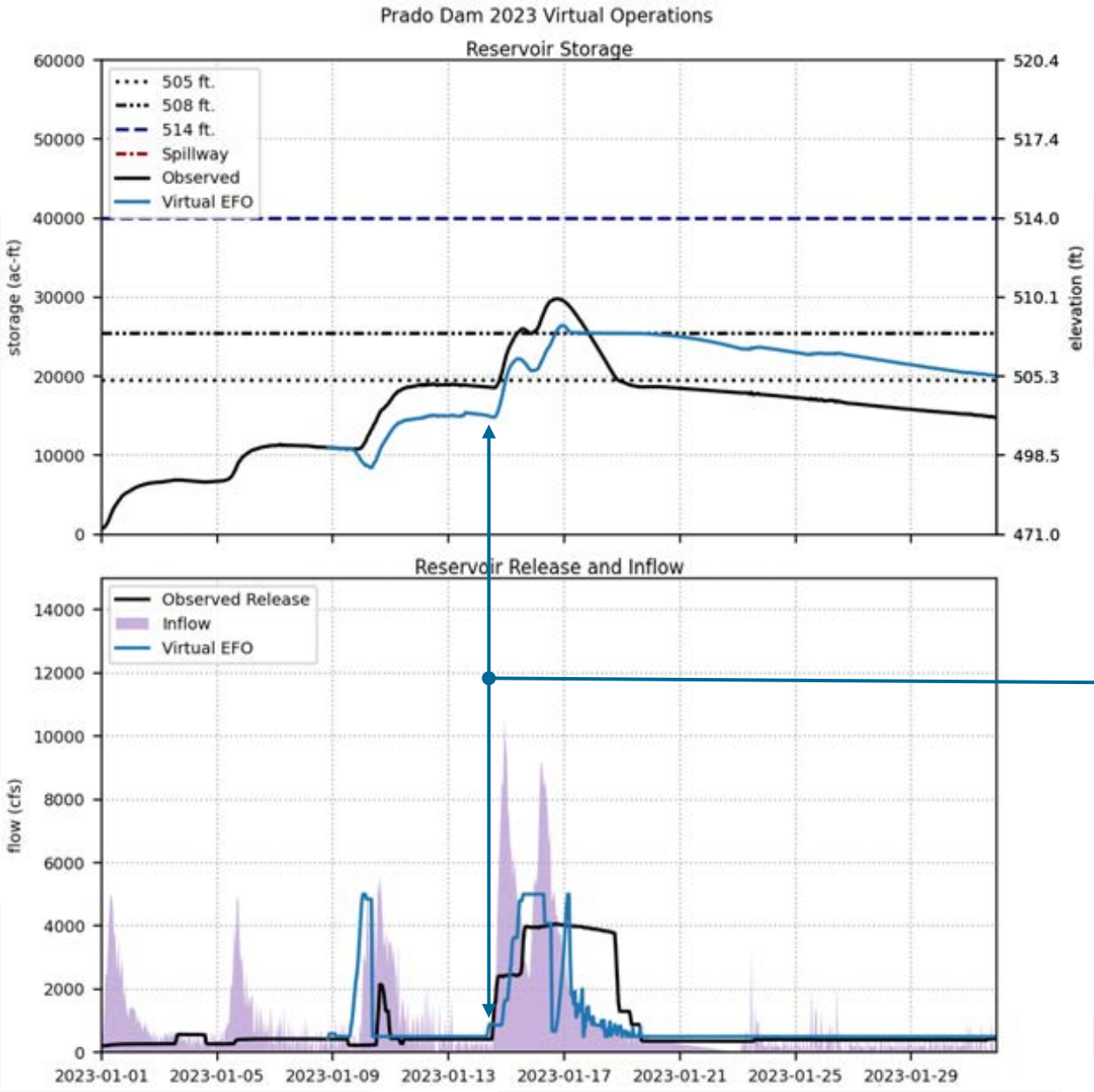


January 10 AR Event

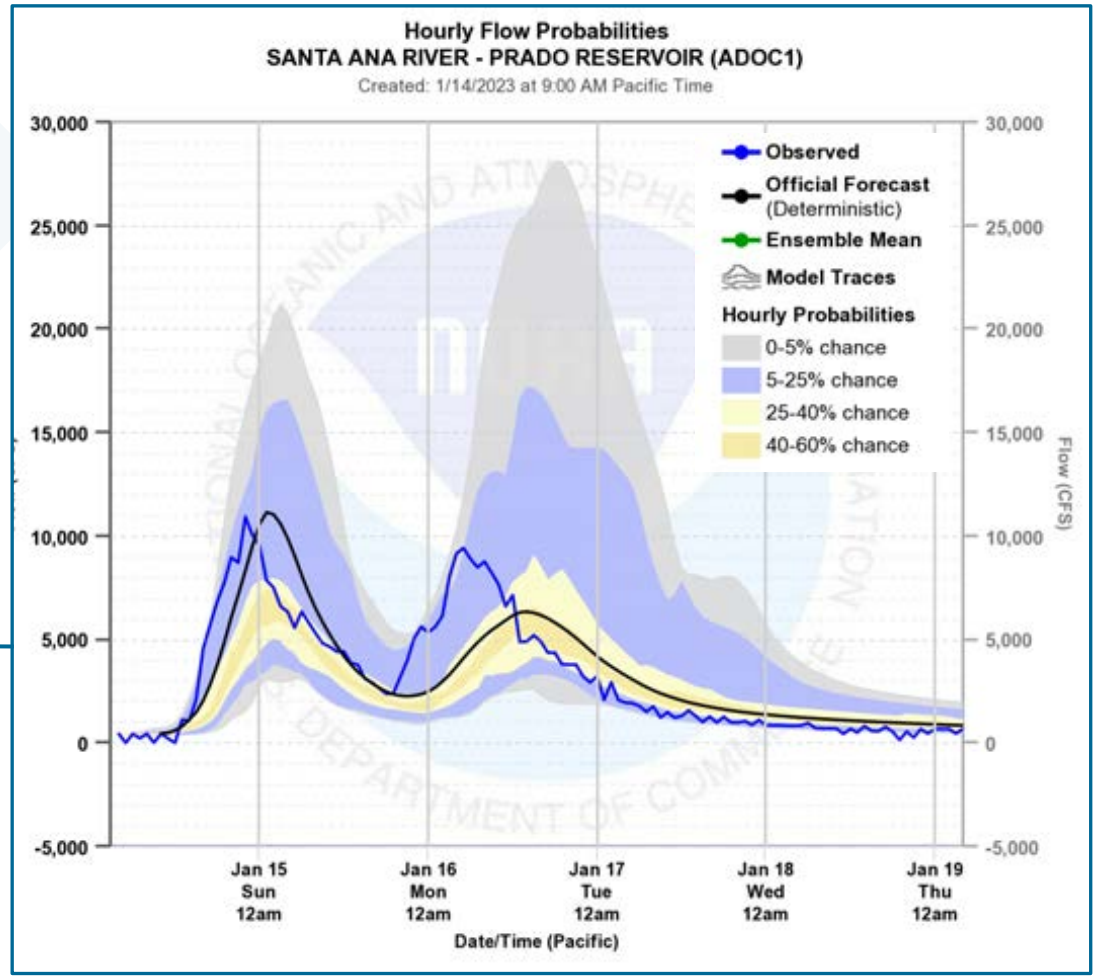


- **Water supply impacts from FIRO**
  - Too much water pre-released from over forecast.
  - ~5,000 cfs release for 10-hours
  - Virtual EFO ~4,000 ac-ft below observed.

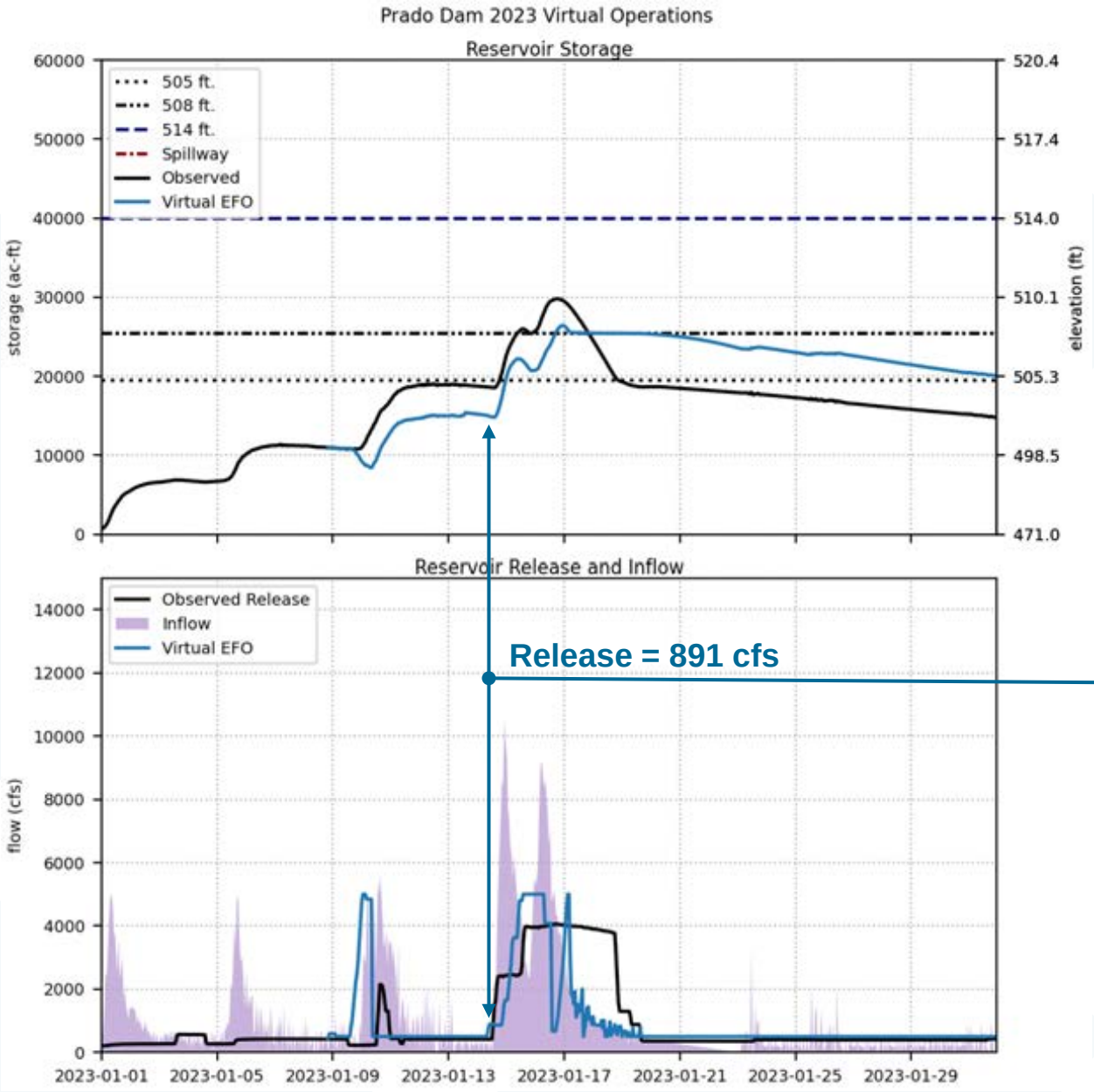
January 14 - 16 Events



CNRFC HEFS forecast before events

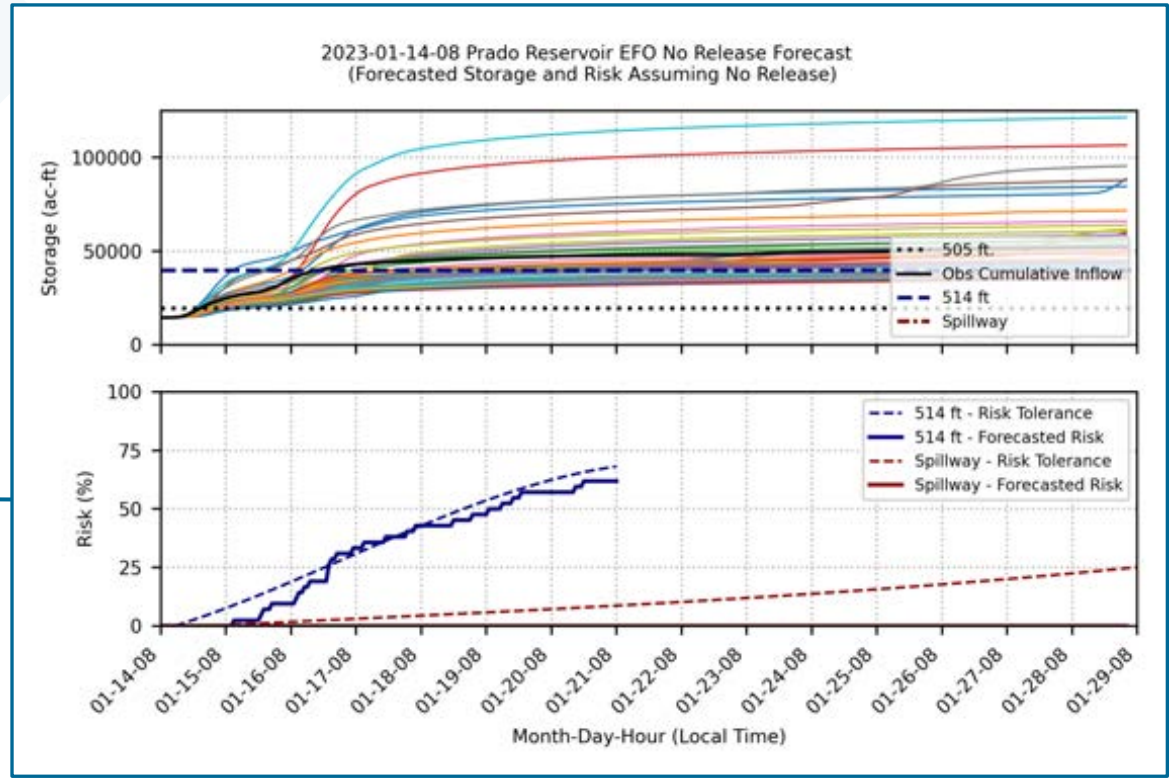


January 14 - 16 Events

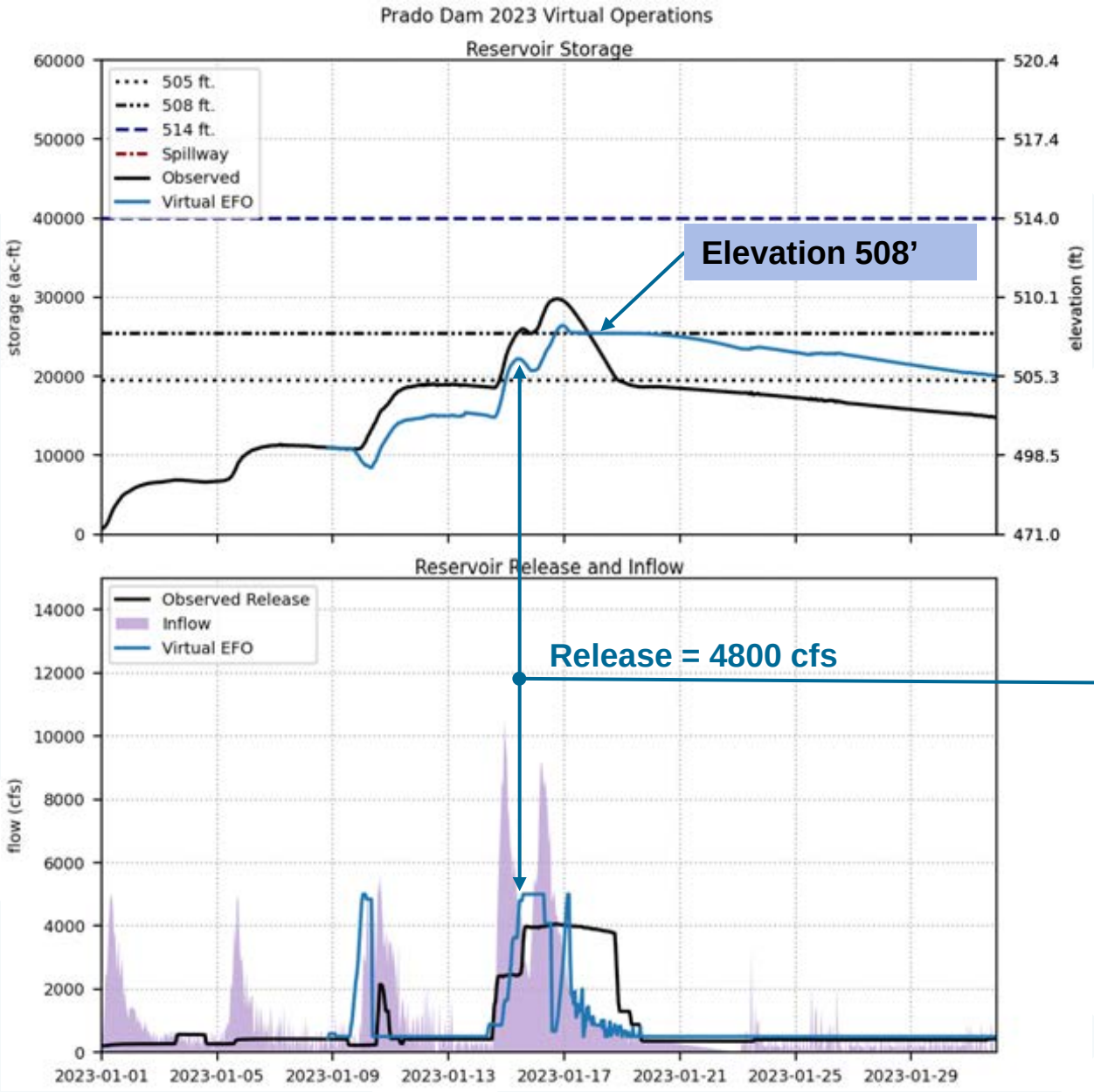


Release = 891 cfs

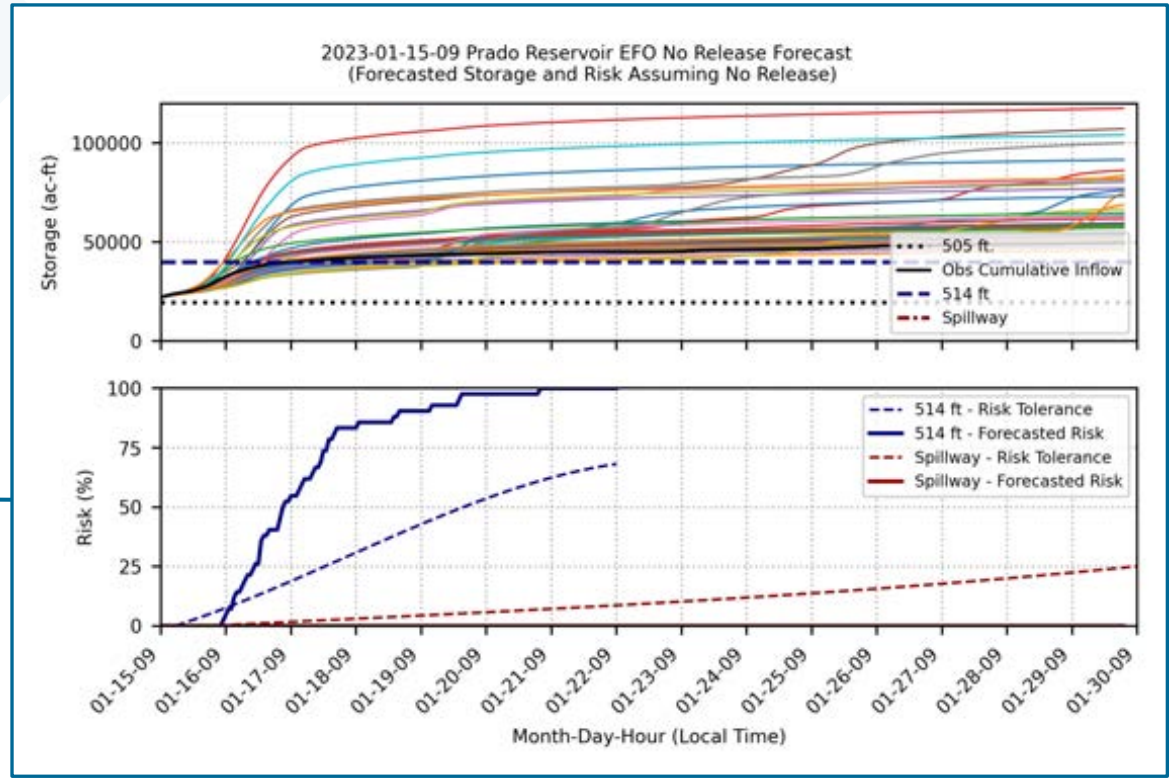
No Release Release Forecast <1-day before 1st event



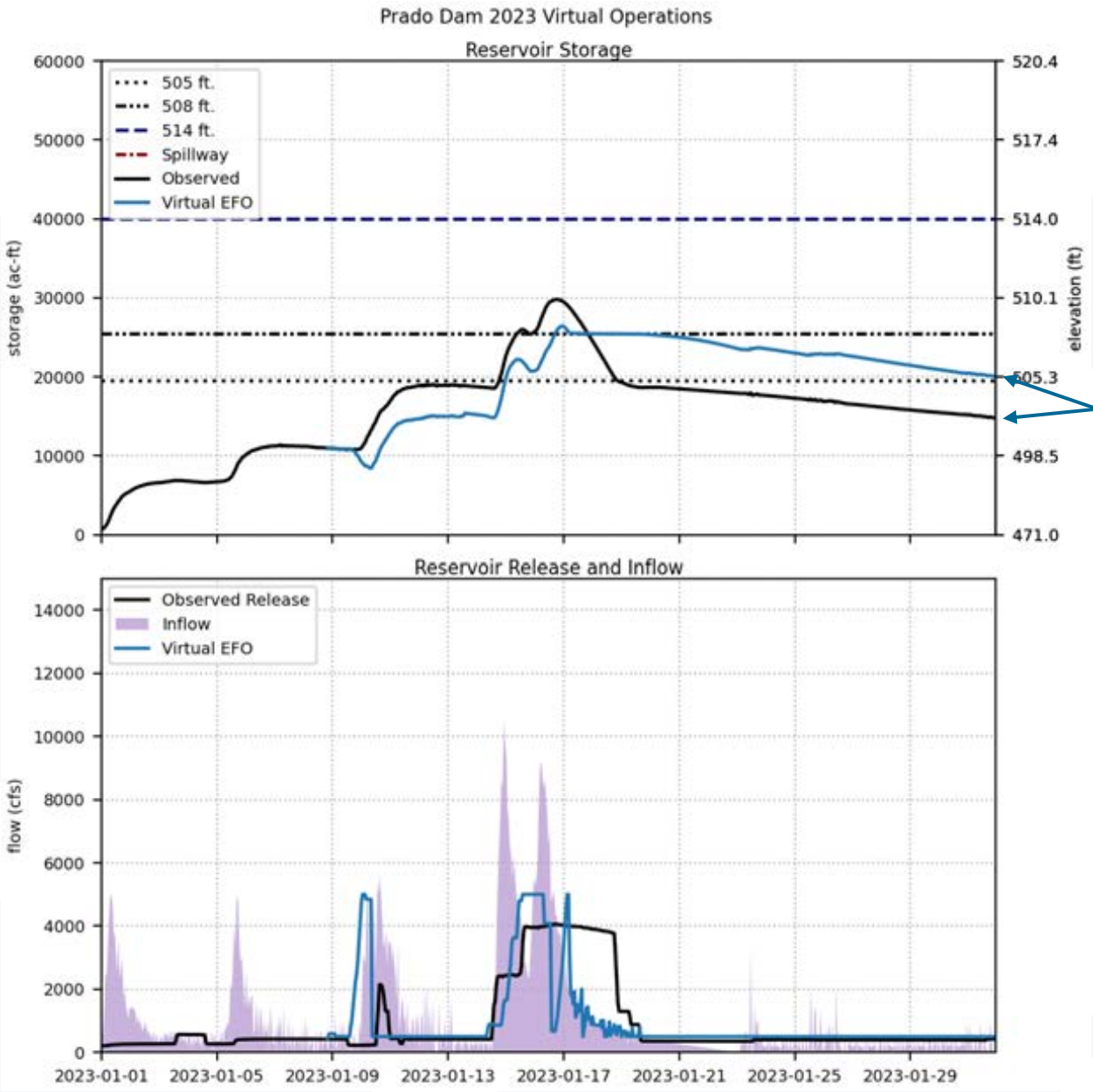
January 14 - 16 Events



No Release Release Forecast <1-day before 2nd event



January 14 - 16 Events

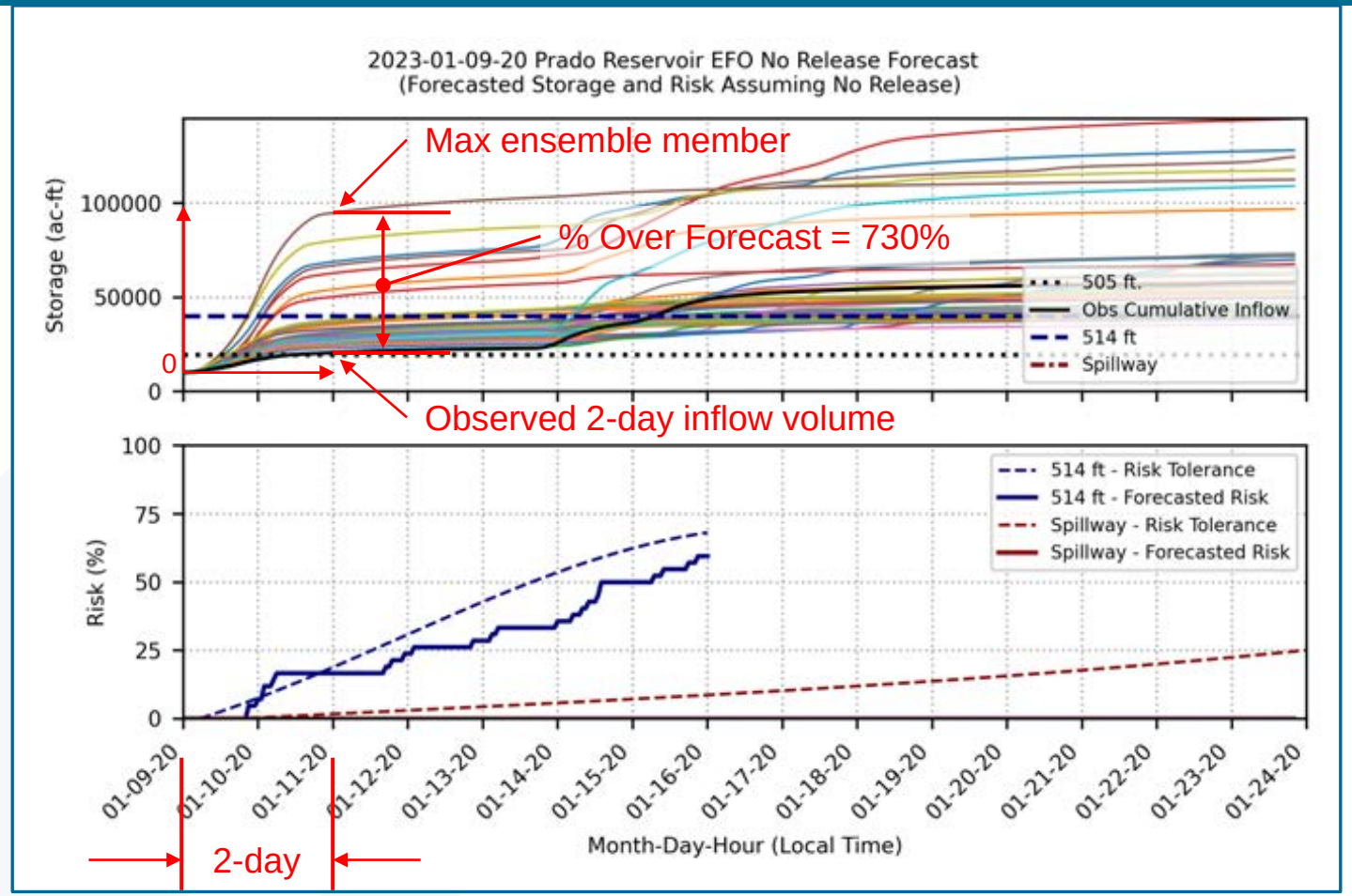


~5,300 ac-ft above observed

Presentation Overview

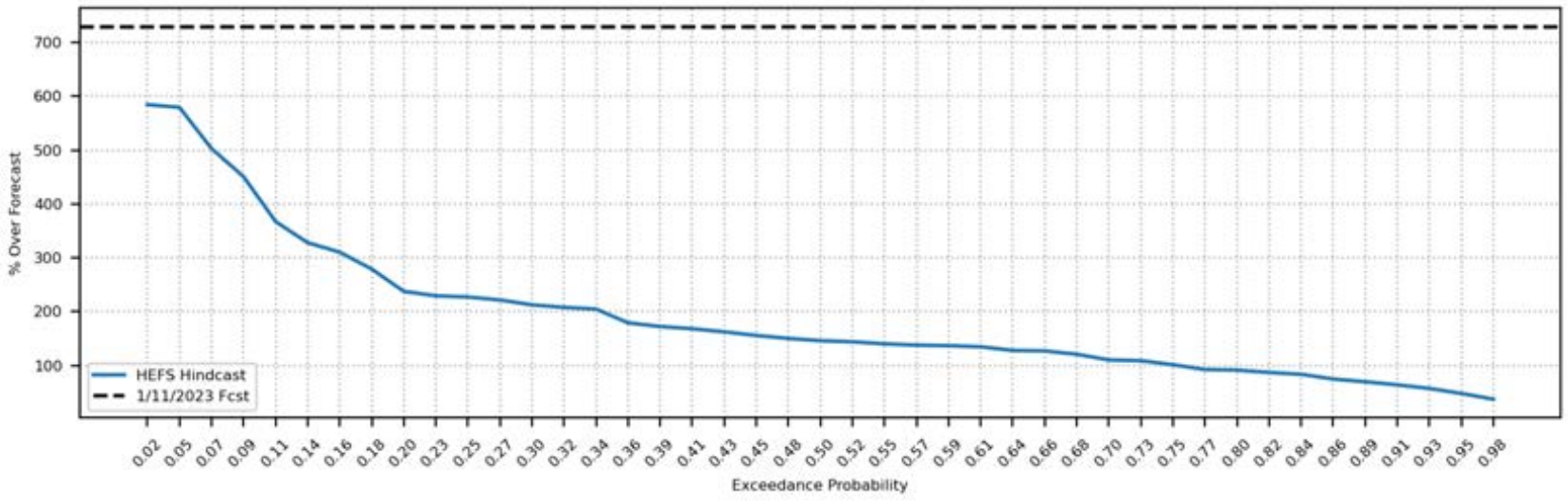
1. Evaluation of January EFO Virtual Operations
2. **Are the V12 hindcasts consistent with real time operations?**
3. Management challenges using HEFS forecasts for Prado and ways to address those challenges.

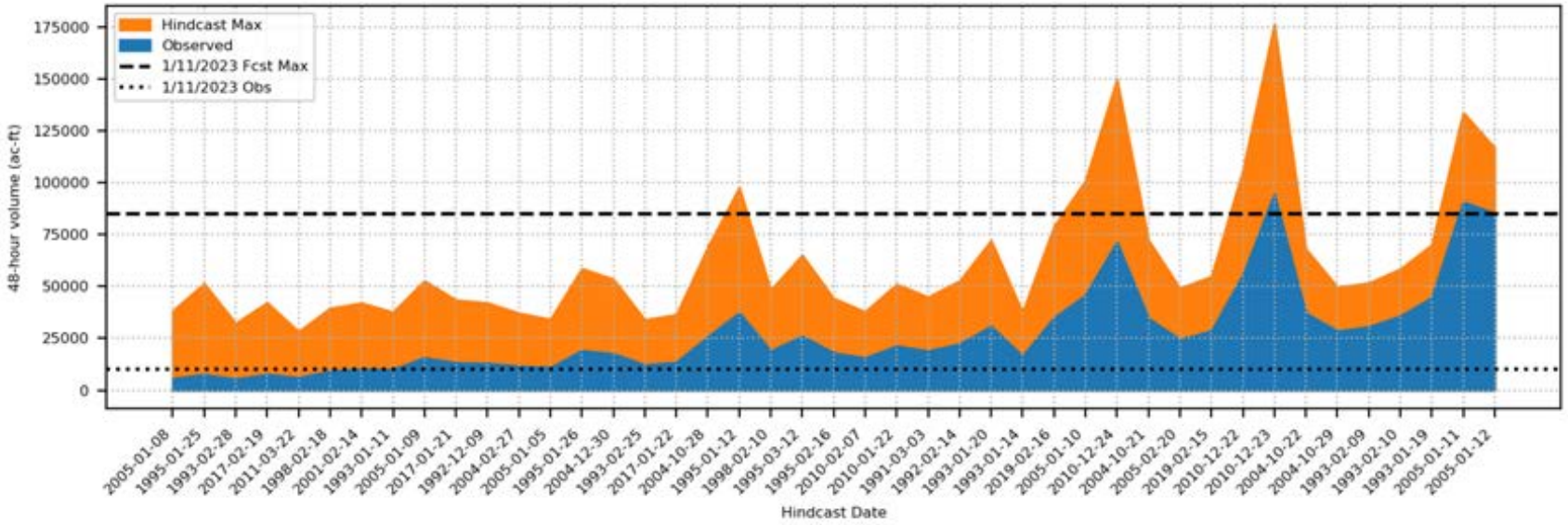
Do we see significant over forecasts in the v12 hindcast?



- **Analyze 2-day inflow volumes**
  - Hindcasted – 1st 2-days of lead
    - Operations could react to this due to low risk tolerance levels
  - Observed

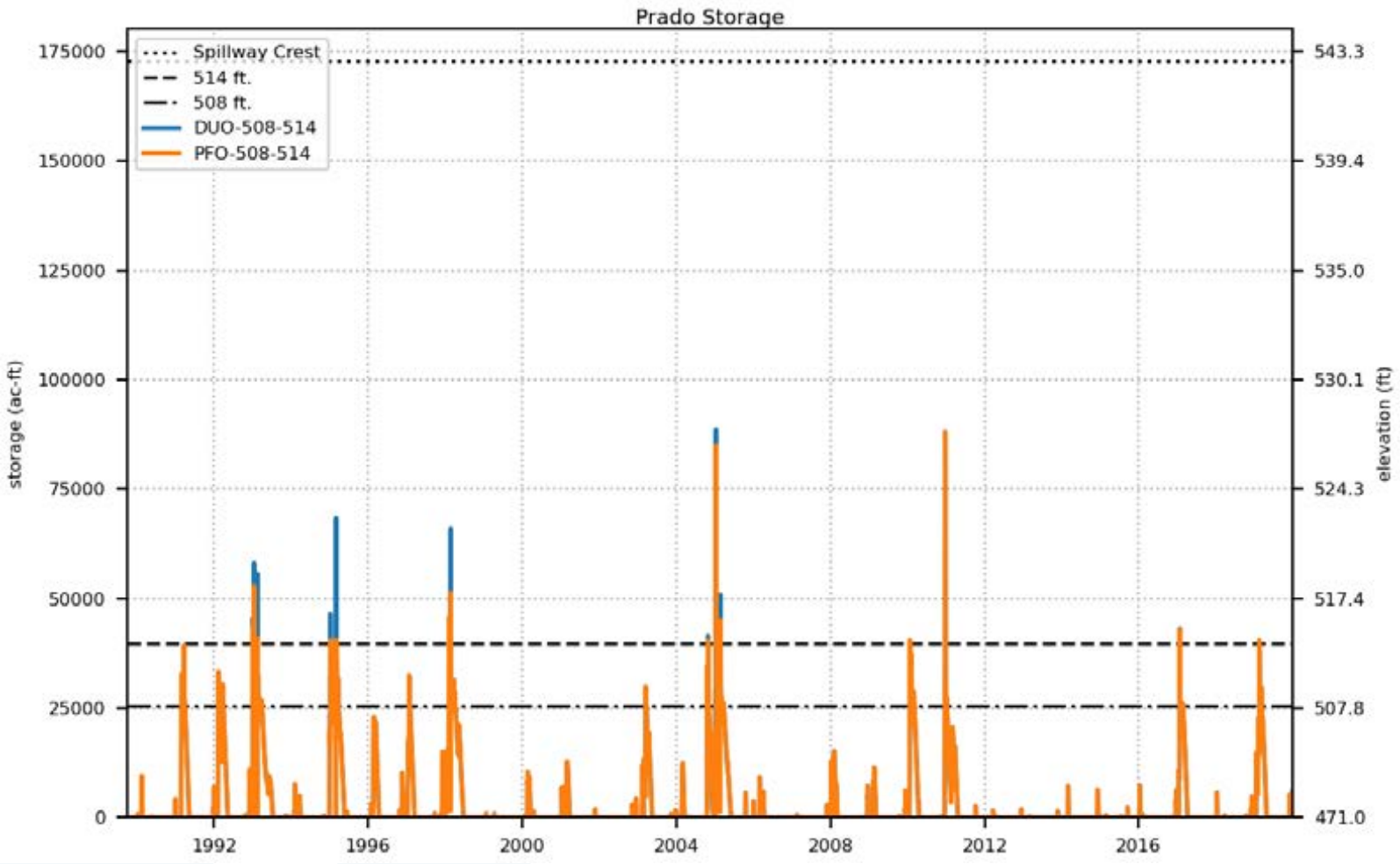
Do we see significant over forecasts in the v12 hindcast?





- **Results filtered for differences of hindcast and observed > 20,000 ac-ft**
  - 43 samples in figure

Do we see significant over releases in the EFO model simulations?

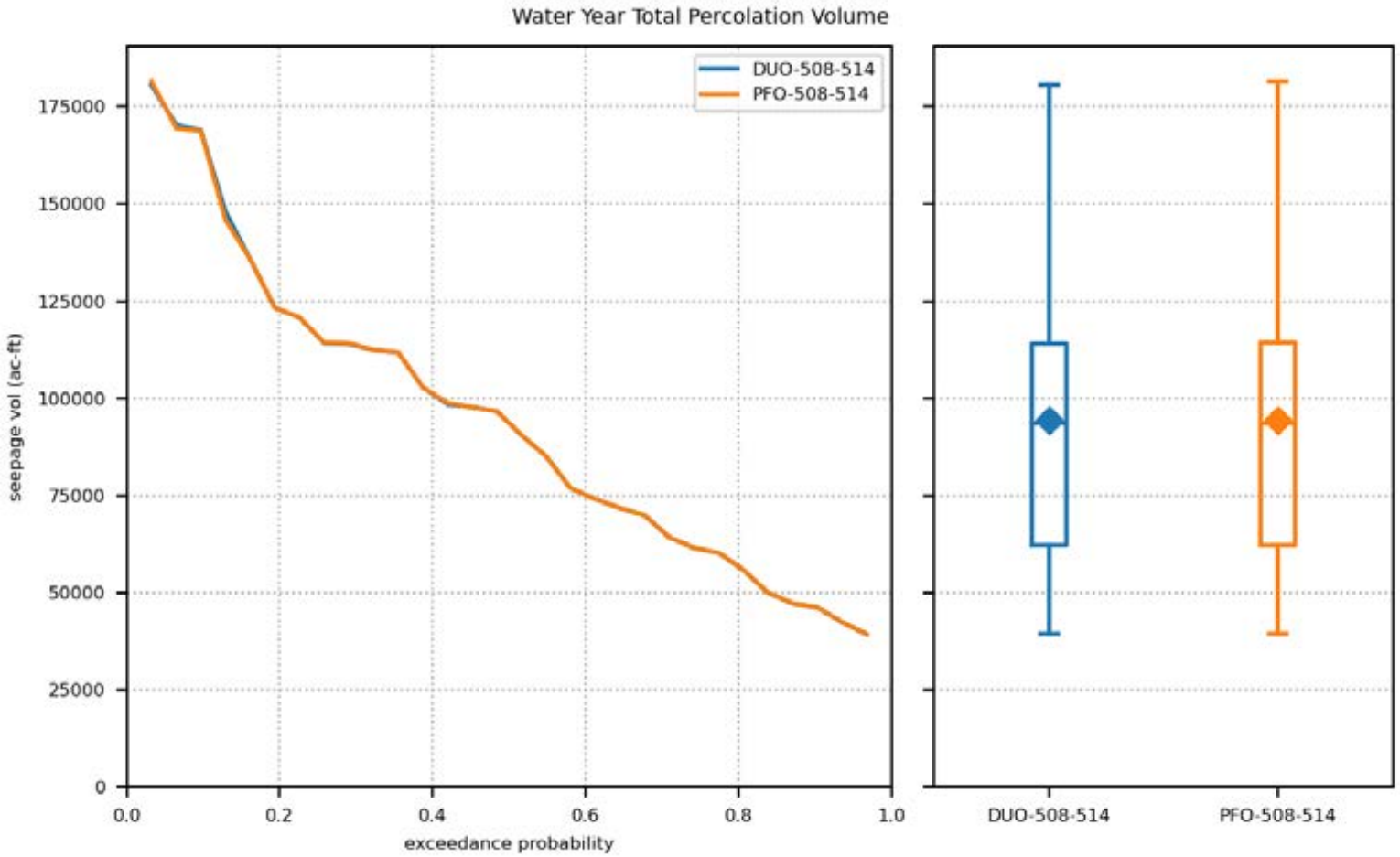


- **Period of record simulation WY 1990-2019**

  DUO-508-514: Uses V12 hindcasts

  PFO-508-514: Uses perfect information

Do we see significant over releases in the EFO model simulations?



- **Period of record simulation WY 1990-2019**

  DUO-508-514: Uses V12 hindcasts

  PFO-508-514: Uses perfect information

Presentation Overview

1. Evaluation of January EFO Virtual Operations
2. Are the V12 hindcasts consistent with real time operations?
3. **Management challenges using HEFS forecasts for Prado and ways to address those challenges.**

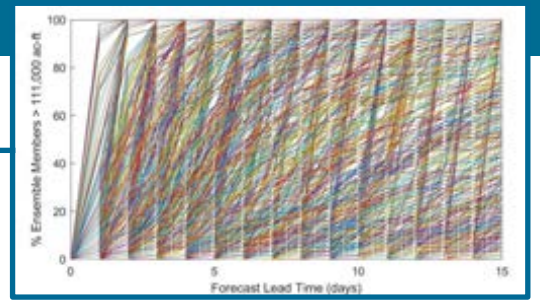
Management Challenges using HEFS Forecasts

- **Large over forecasts not shown in V12 Hindcast**
  - Analysis of 48-hour lead time volumes
  - Period of record simulations consistent w/ PFO
- **Large over forecasts have occurred twice in recent history.**
  - December 2021
  - January 2023
  - Indicates risk to water supply
- **Should be addressed in FVA analysis of operations alternatives.**
  - Simulation of 2021 & 2023 event.
- **Possible solutions for operations:**
  - Modify ensemble inflow forecasts
  - Adjust risk tolerance calibration to favor water supply
  - Modify EFO rule
  - Do nothing – accept risk to water supply.

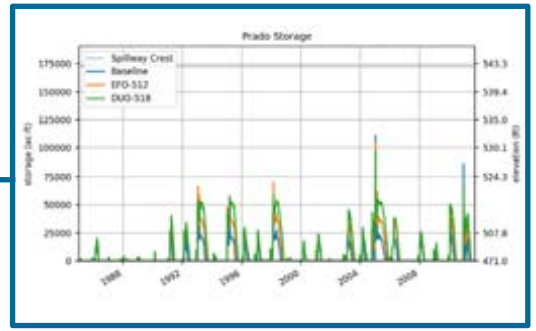
Calibration of EFO Risk Tolerance

- **Heavily dependent on HEFS hindcast to train curve.**
  - Limited period 1990-2019
  - Few extreme events
- **Objective function formulated based on FIRO objectives:**
  - Improve water supply
  - No increase in flood risk

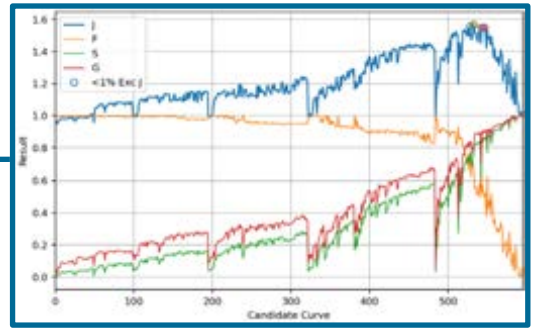
1. **Generate Candidate Tolerance Curves**



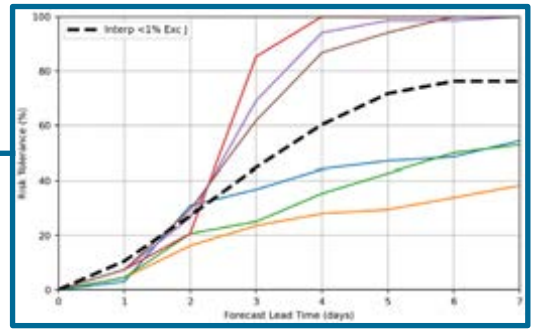
2. **Simulate Candidate Tolerance Curves**



3. **Evaluate Simulation Results for Each Curve**

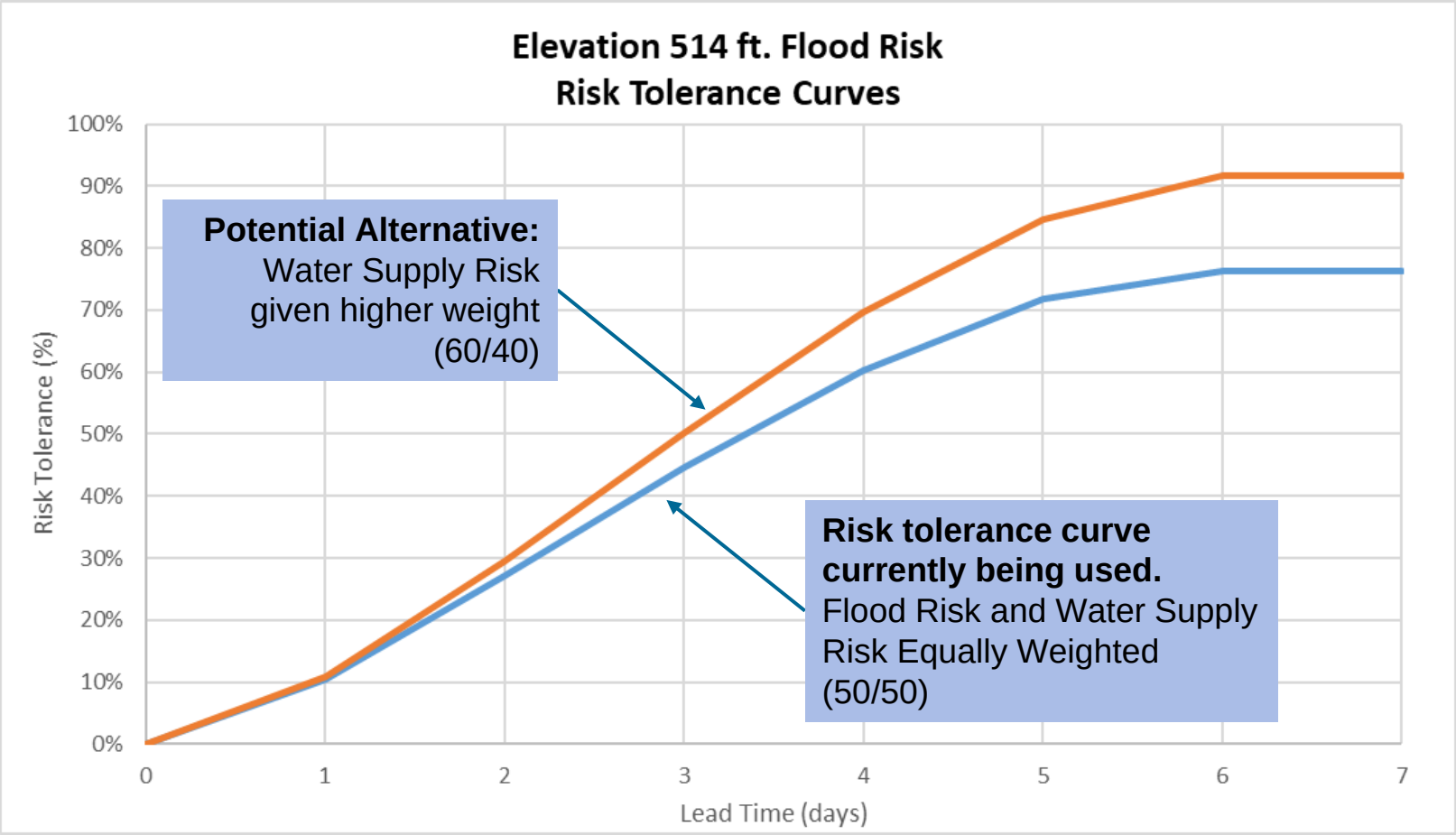


4. **Identify/ Enhance Tolerance Curve**



Modification of Objective Function

- **Objective function could be formulated differently:**
  - Slightly favored toward water supply.
  - Slight increase in risk of flooding above 514 ft.
  - Weighting could be informed by performance for 2021 and 2023 simulations.

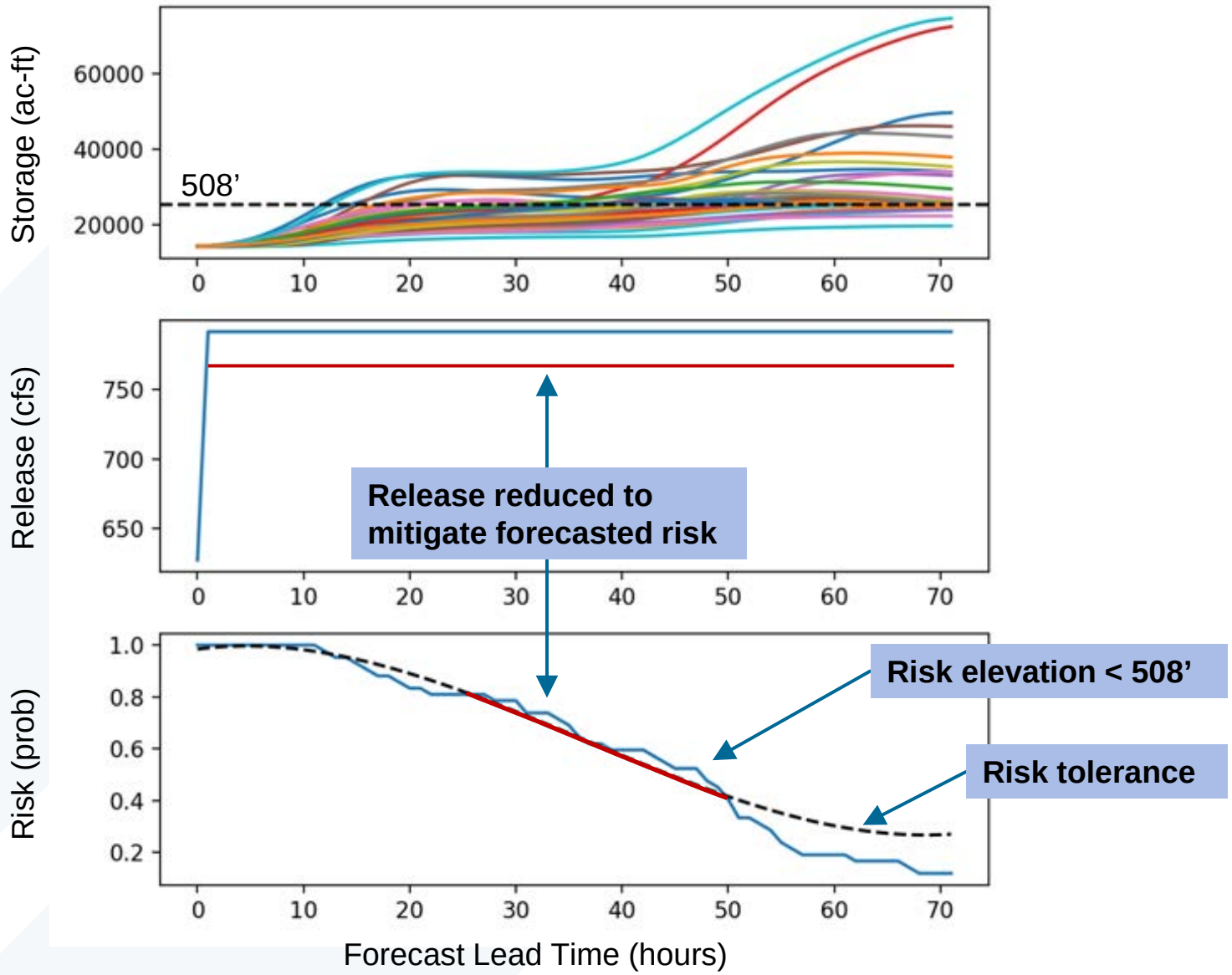


Reduce maximum release for FIRO pre-release

Reduce max release to limit impacts to water supply.

Reservoir Elevation (ft)	Maximum Release (cfs)	FIRO Pre-release for 514' (cfs)
> 470 & ≤ 490	600	600
> 490 & ≤ 505	5000	5000
> 505 & ≤ Top of Buffer	10000	5000
> Top of Buffer & ≤ 514	10000+	10000
> 514 & ≤ 520	15000	
> 520 & ≤ Spillway Crest	25000	
> Spillway Crest & ≤ 594.4	30000	

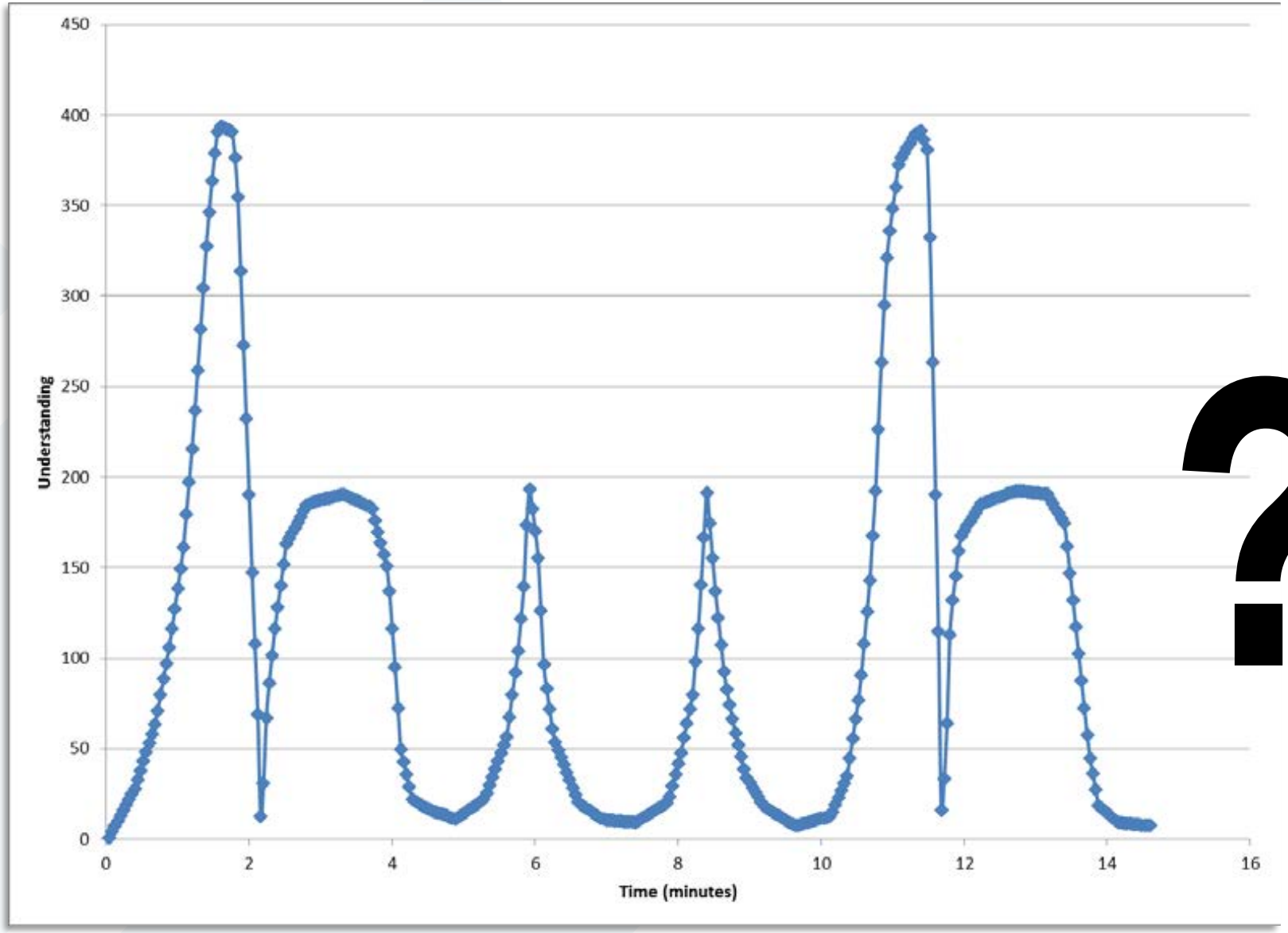
Mitigate forecasted risk of storage recovery



Conclusions

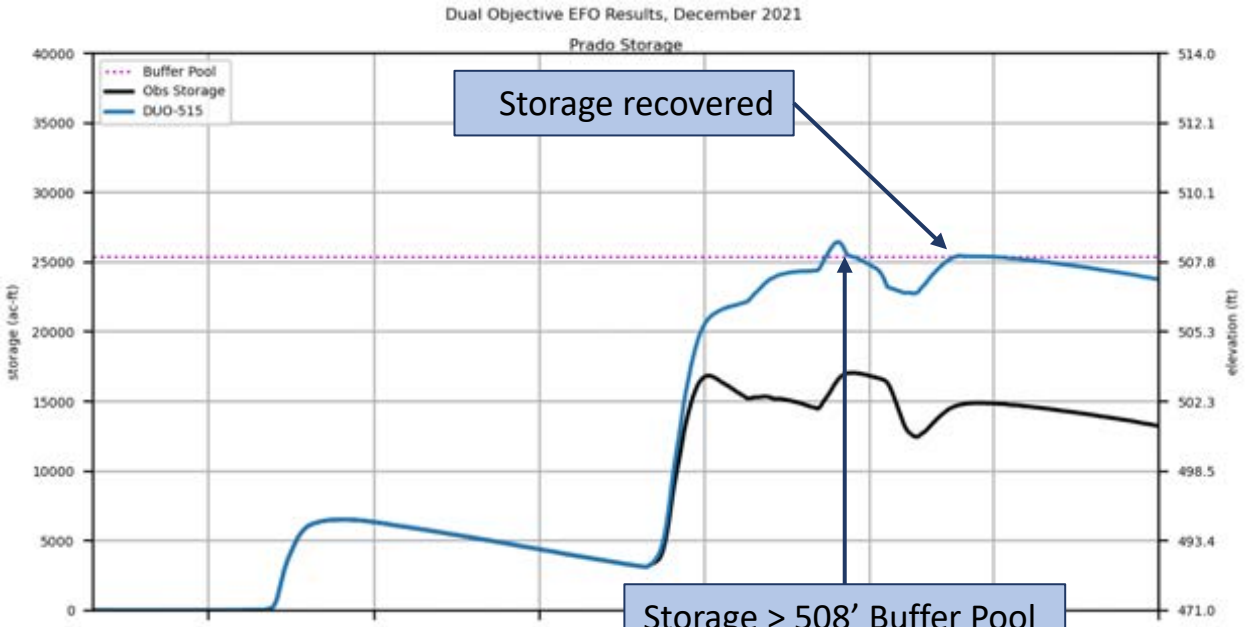
- EFO alternative does show a risk to water supply in simulations with actual HEFS forecasts (2021 & 2023).
- Risk to water supply is not seen in simulations using HEFS hindcast for period of record.
- Simulation of 2021 and 2023 events should be included in the engineering analysis of the FVA.
- EFO alternative should be modified to account for potential over forecasts.

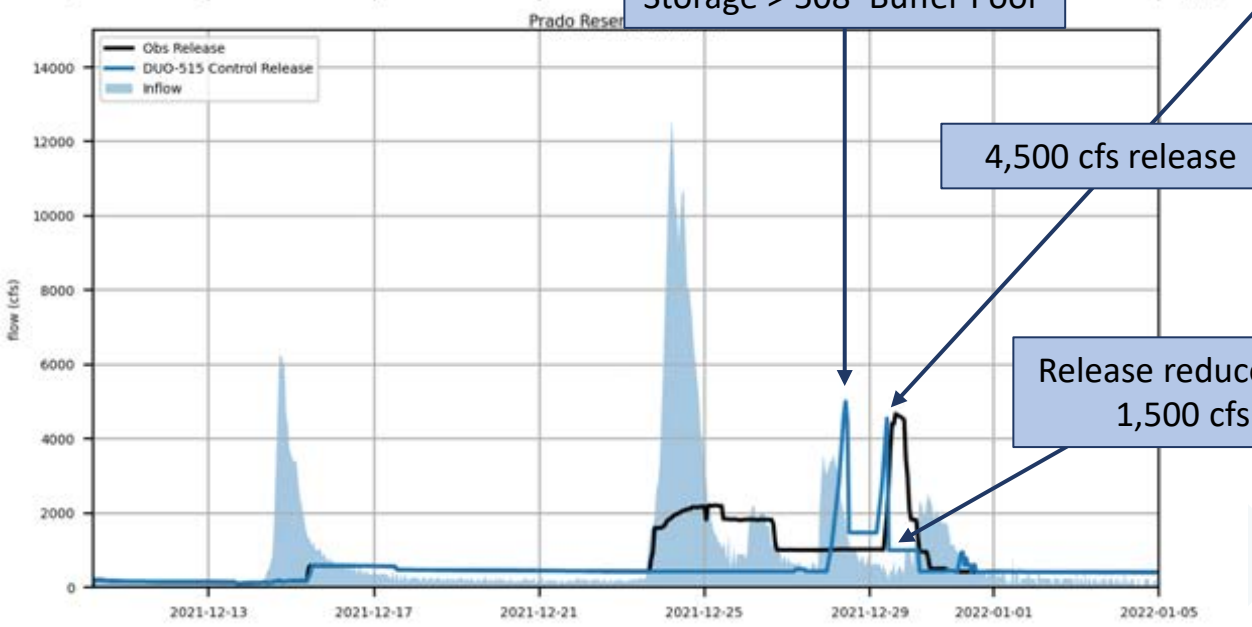
Questions?

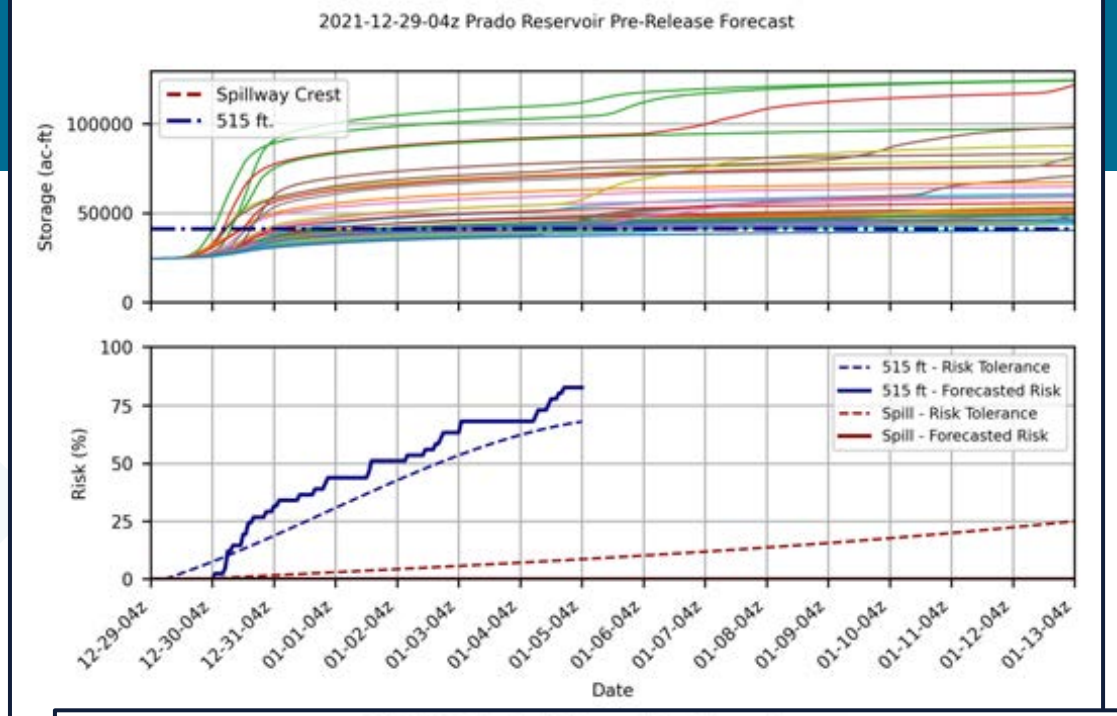

450
400
350
300
250
200
150
100
50
0
Understanding
0
2
4
6
8
10
12
14
16
Time (minutes)

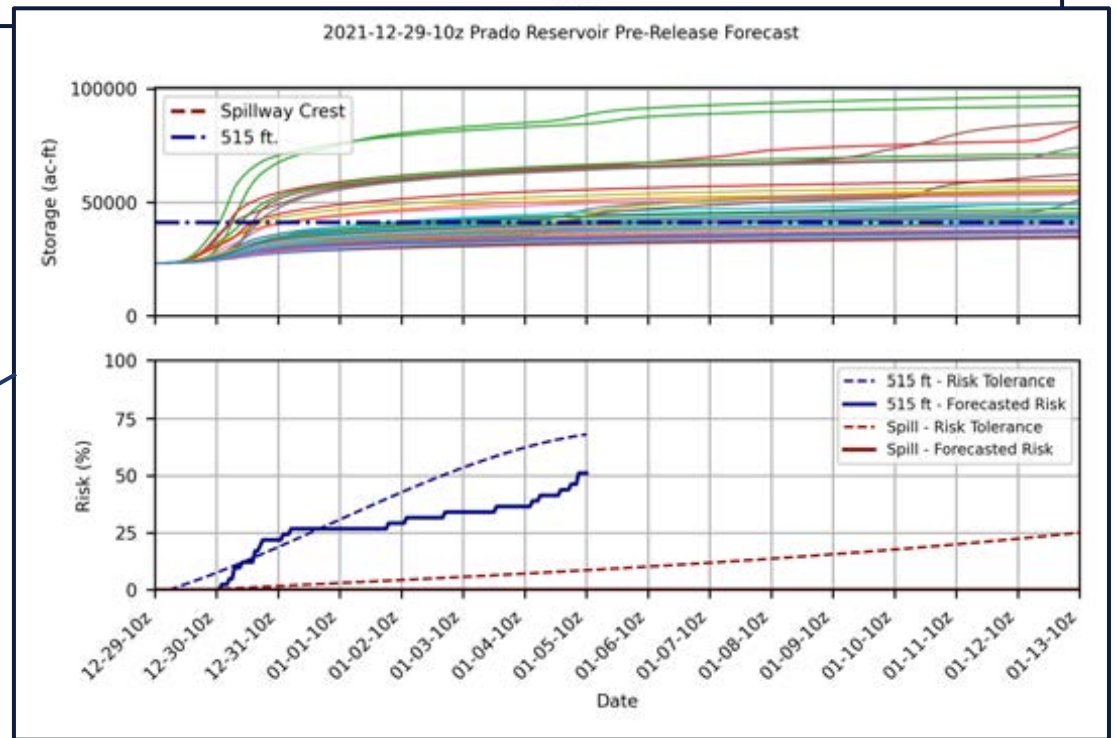
?

December 2021 Case Study

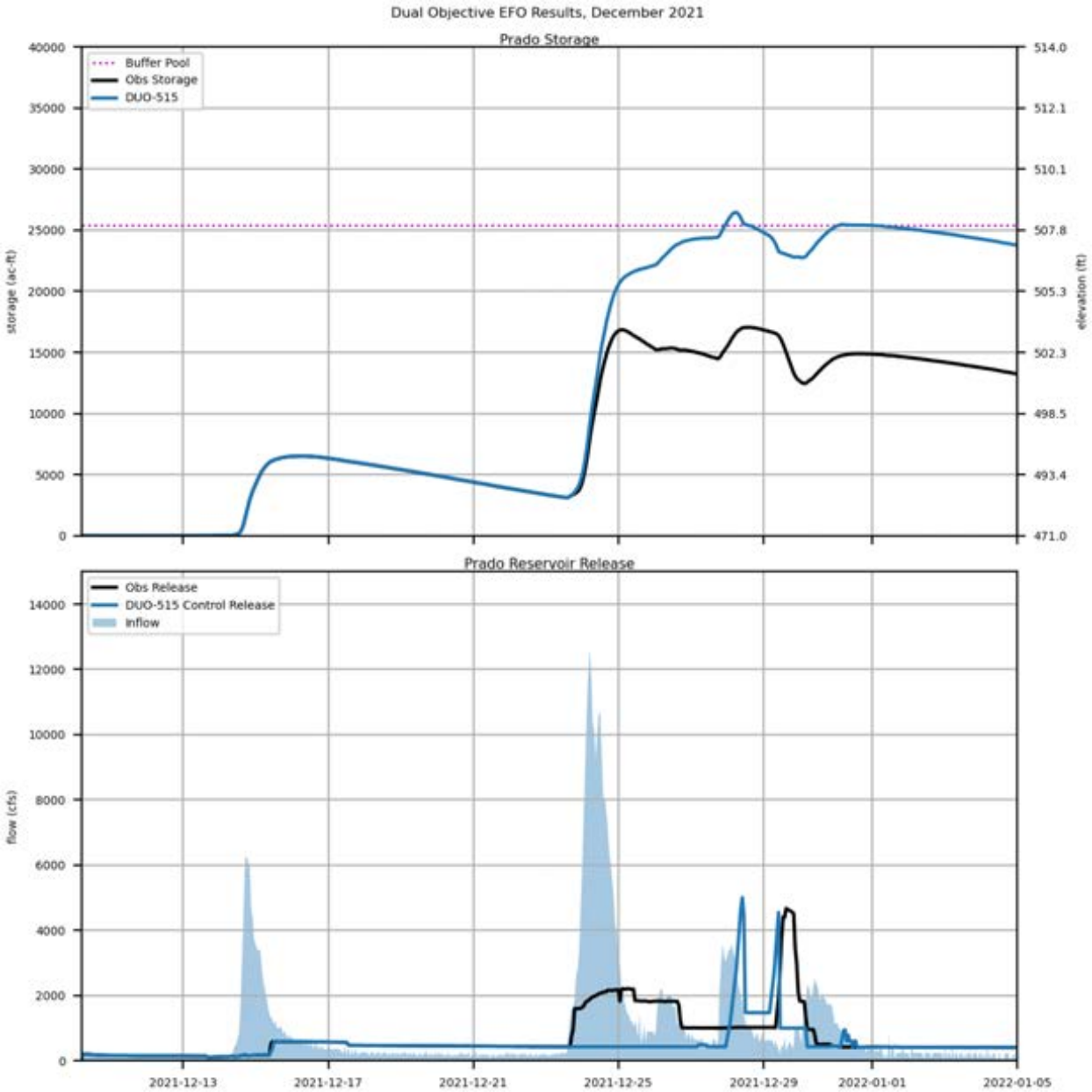








February 2019 Case Study – Findings



- **EFO managing to higher flood elevation than actual operations.**
  - ➢ EFO managing to minimize airport flooding.
  - ➢ Actual operations target peak was ~507’ .
- **EFO over released water in response to over forecast of December 31 event.**
  - ➢ Actual operations also showed similar challenges.
- **Case study limitation:**
  - ➢ Model simulation did not incorporate operational delays in making release changes.

CNRFC Precipitation Forecast Verification Study

- Comparisons between CNRFC observed precipitation with 3 forecast sources
  - CNRFC QPF
  - GEFSv12
  - WestWRF
- Looked at two periods:
  - 2003-2012
  - 2012-2019 - *what I will focus on*
- Generated verification metrics for various lead times
  - More focus on the 0-3 day precip totals
- Evaluated at the forecast group level and individual basin level

Verification Output

Statistical Metrics

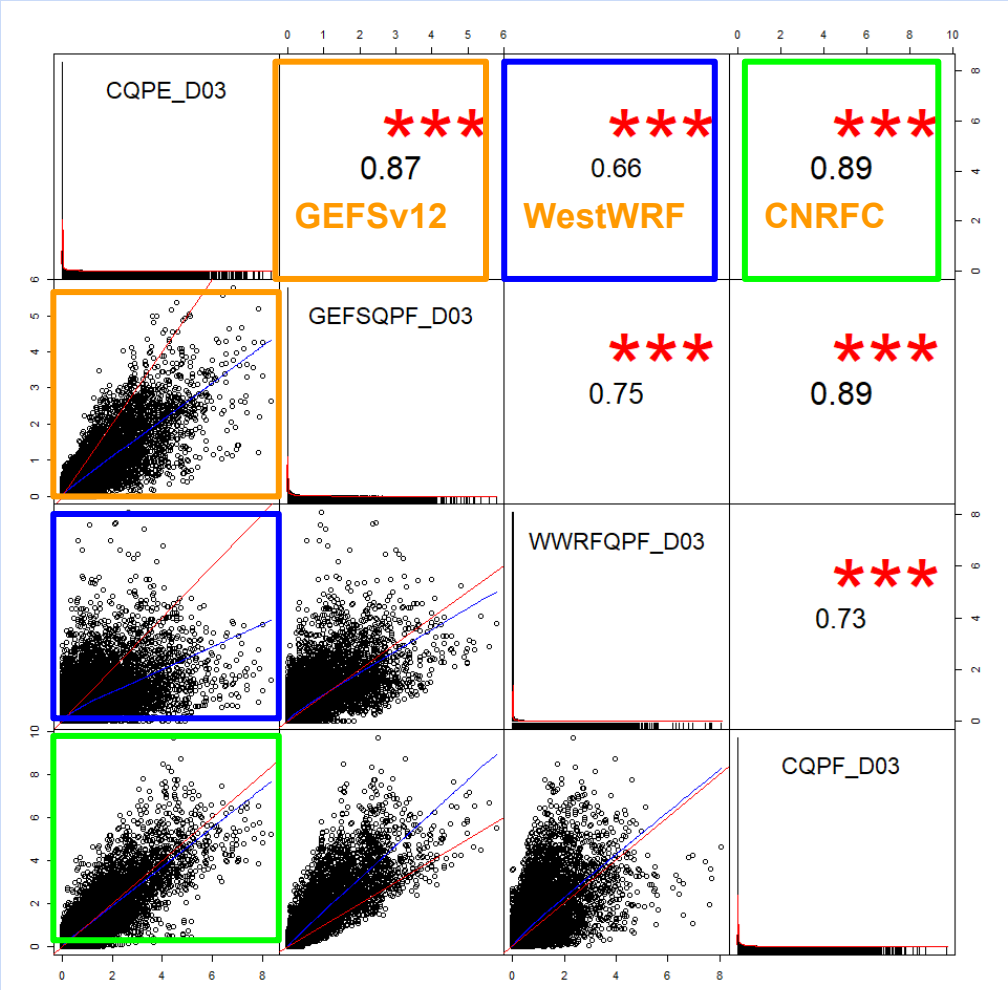
- Correlation
- Heidke Skill Score
- Root Mean Square Error
- Absolute Error

Plots/Data

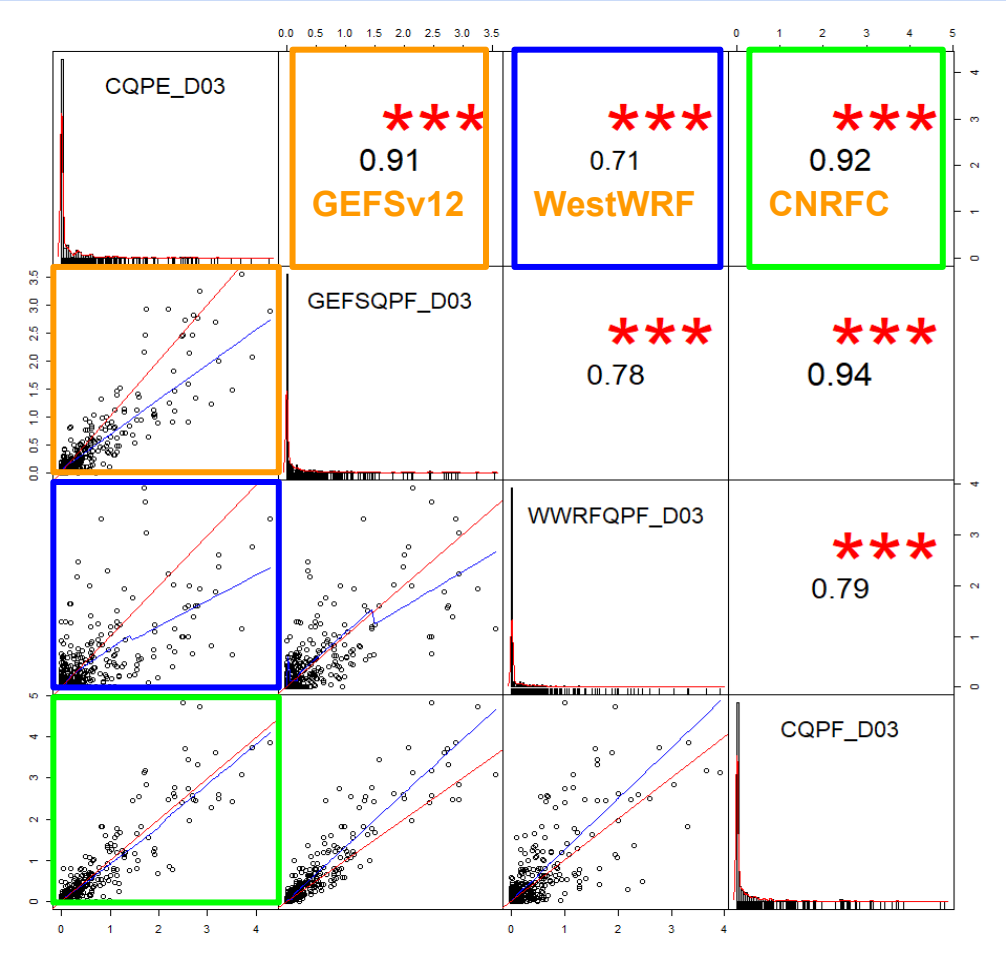
- Scatter Plots
- Heat Plots
- Time Series output in csv
- And more…

….and a 107 page report!

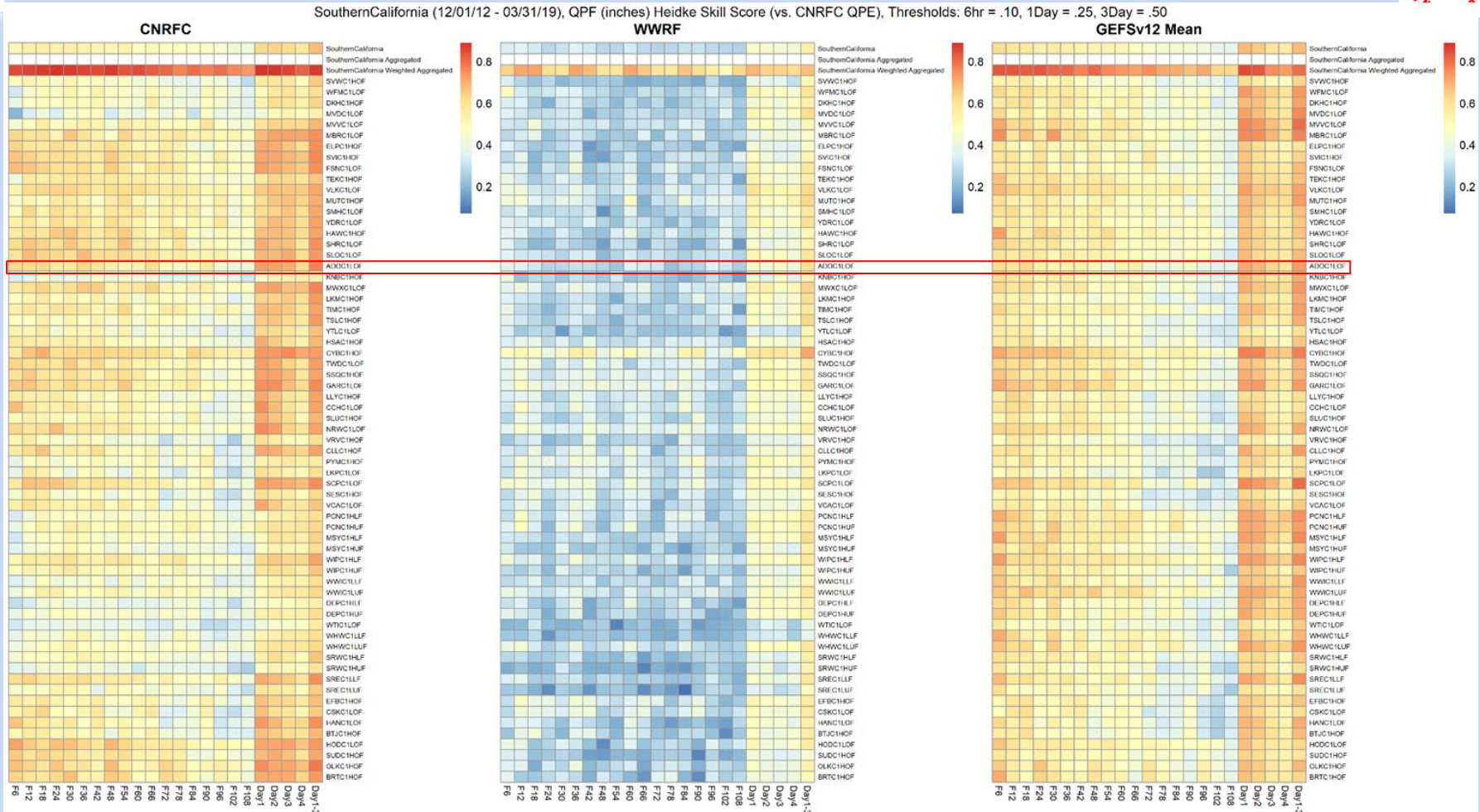
2012-2019 Correlations for Southern California Forecast Group (0-3 day)



2012-2019 0-3 Day Correlations for Prado (ADOC1 basin only)



Prado Heat Plot (2012-2019)



Conclusions

- CNRFC outperforms GEFSv12 for the 2012-2019 period
- CNRFC and GEFSv12 outperformed WestWRF
  - Part of that could be to the version of the WestWRF that was evaluated….
- WestWRF is negatively impacted by wet and dry biases at the basin scale, and some of this is smoothed out when aggregating to a larger watershed/forecast group scale.

CNRFC Prado Inflow Forecasts February 9-14, 2019

Prado Dam Current Operations

Interim Water Control Plan:

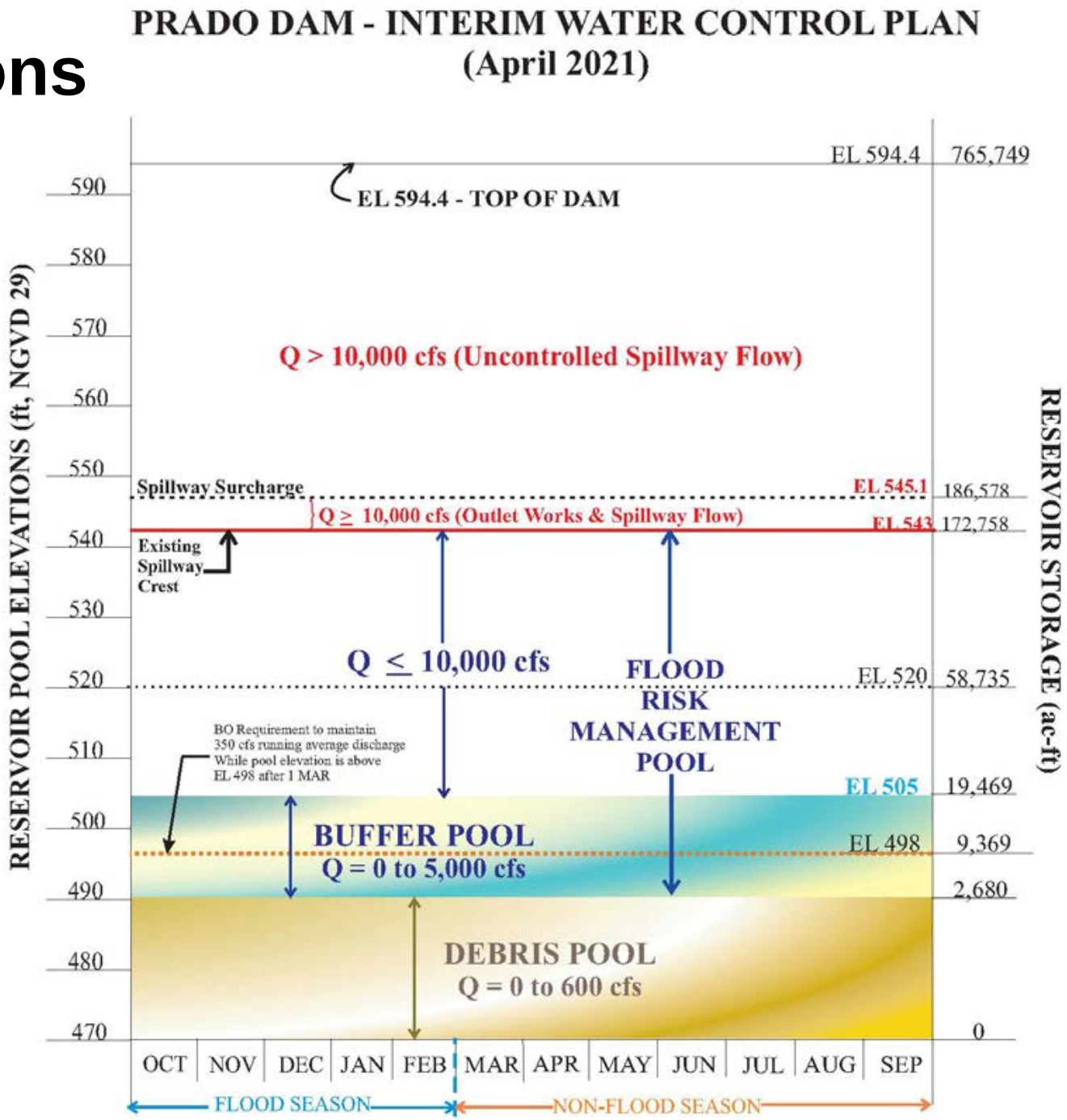
- Buffer Pool (aka Water Conservation Pool): 505 ft
- Spillway Crest: 543 ft.
- Total Capacity: 186.6 KAF

Release Schedules:

Elevation	Maximum Release (cfs)	
(feet NGVD 29)	Baseline	1988 GDM
>470 & ≤490	600	600
>490 & ≤505	5,000	5,000
>505 & ≤520	10,000	15,000
>520 & ≤594.4	10,000	30,000

Increasing Rate of Change:

	Increasing
Release	Rate of Change
(cfs)	(cfs/hr)
0	100
300	250
1000	400
2500	625
5000	625



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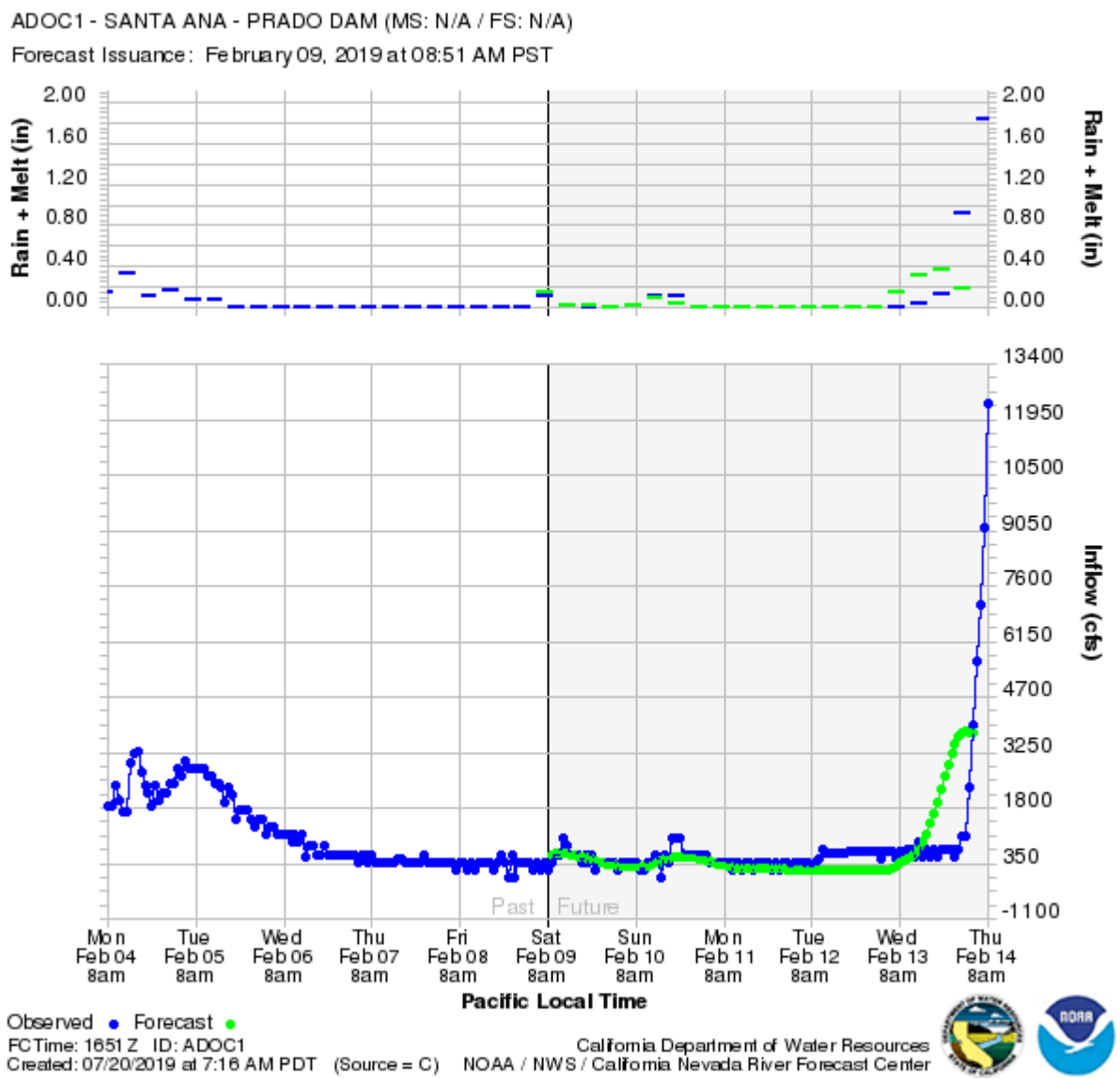

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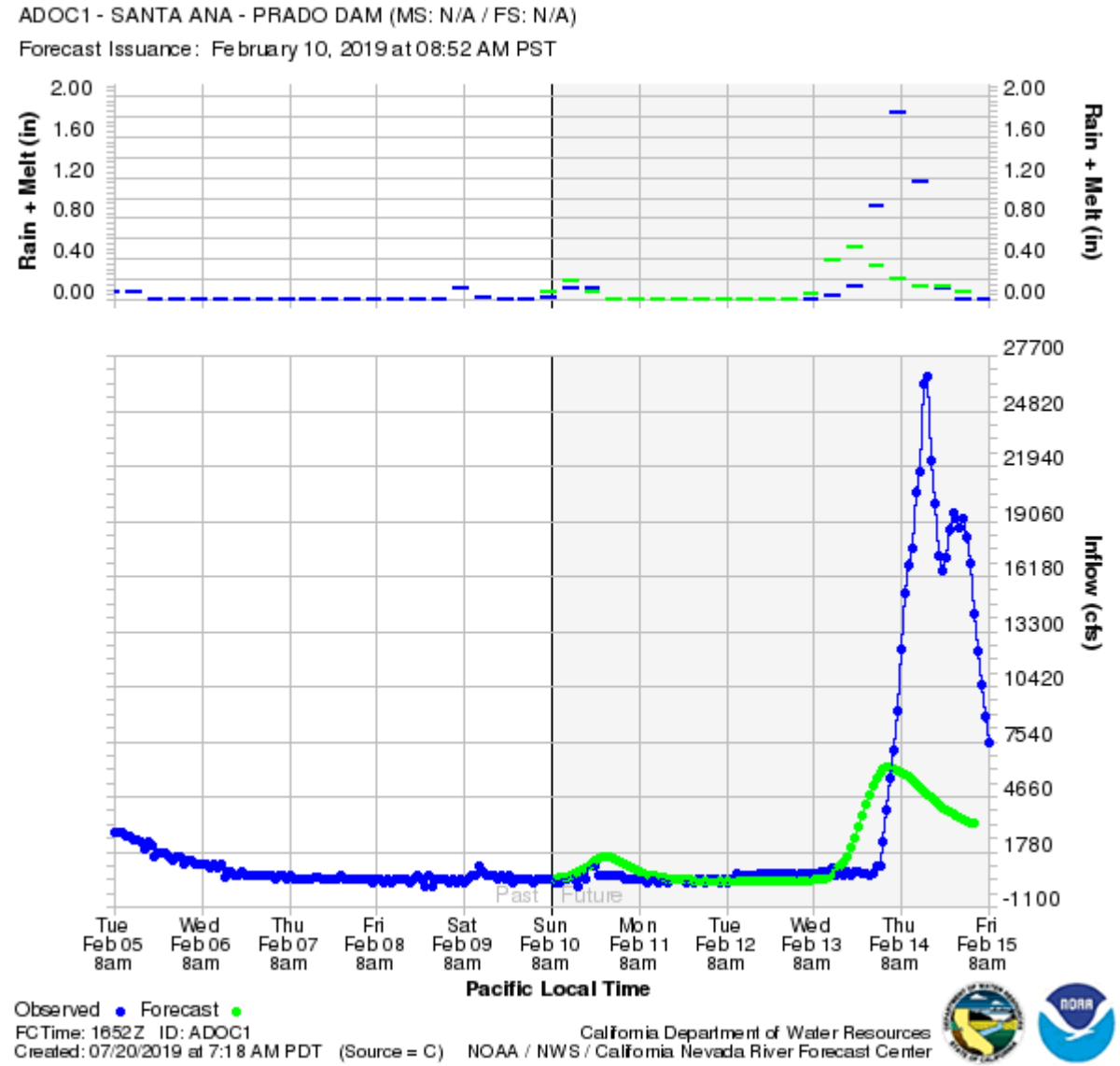

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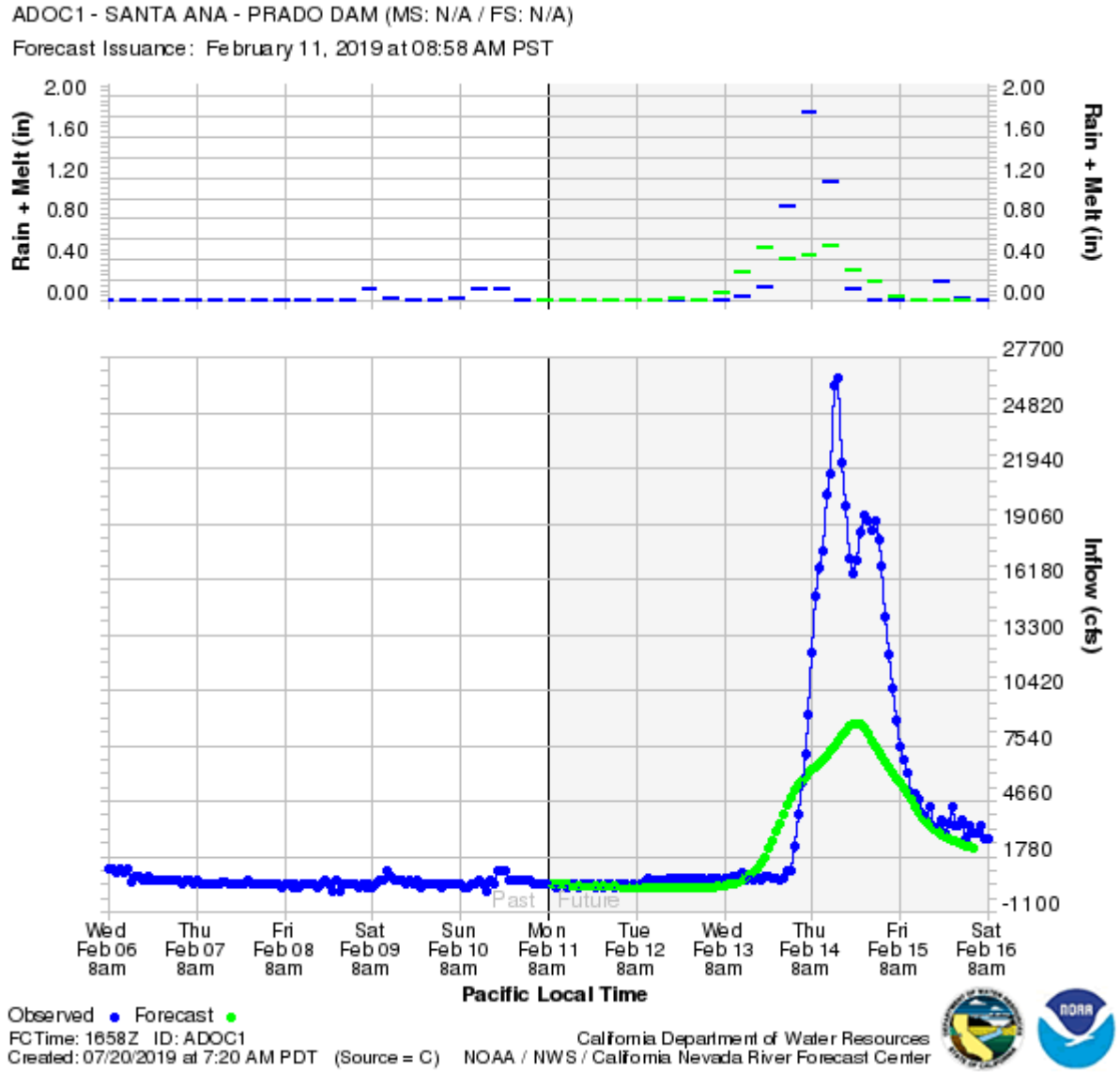

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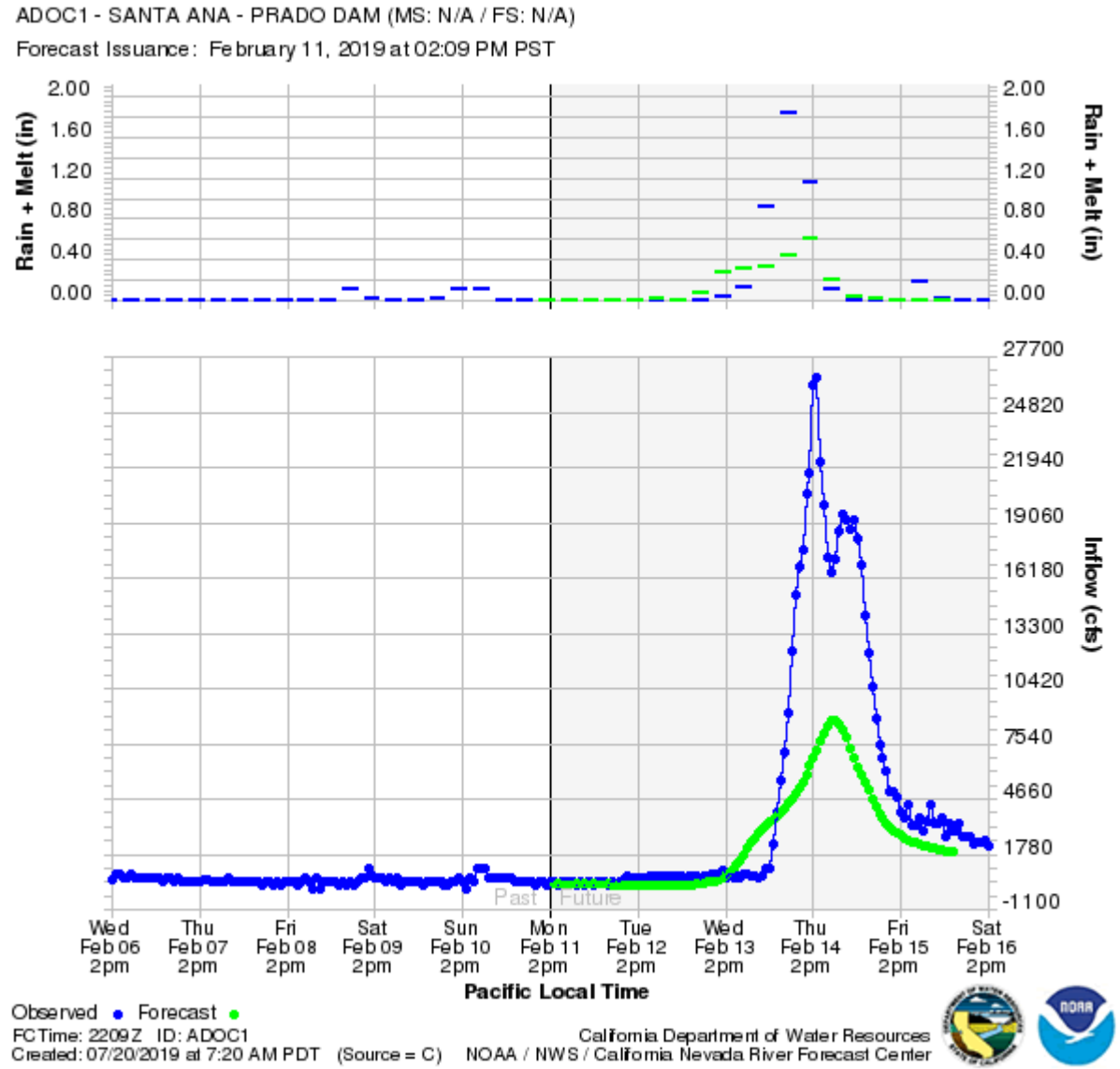

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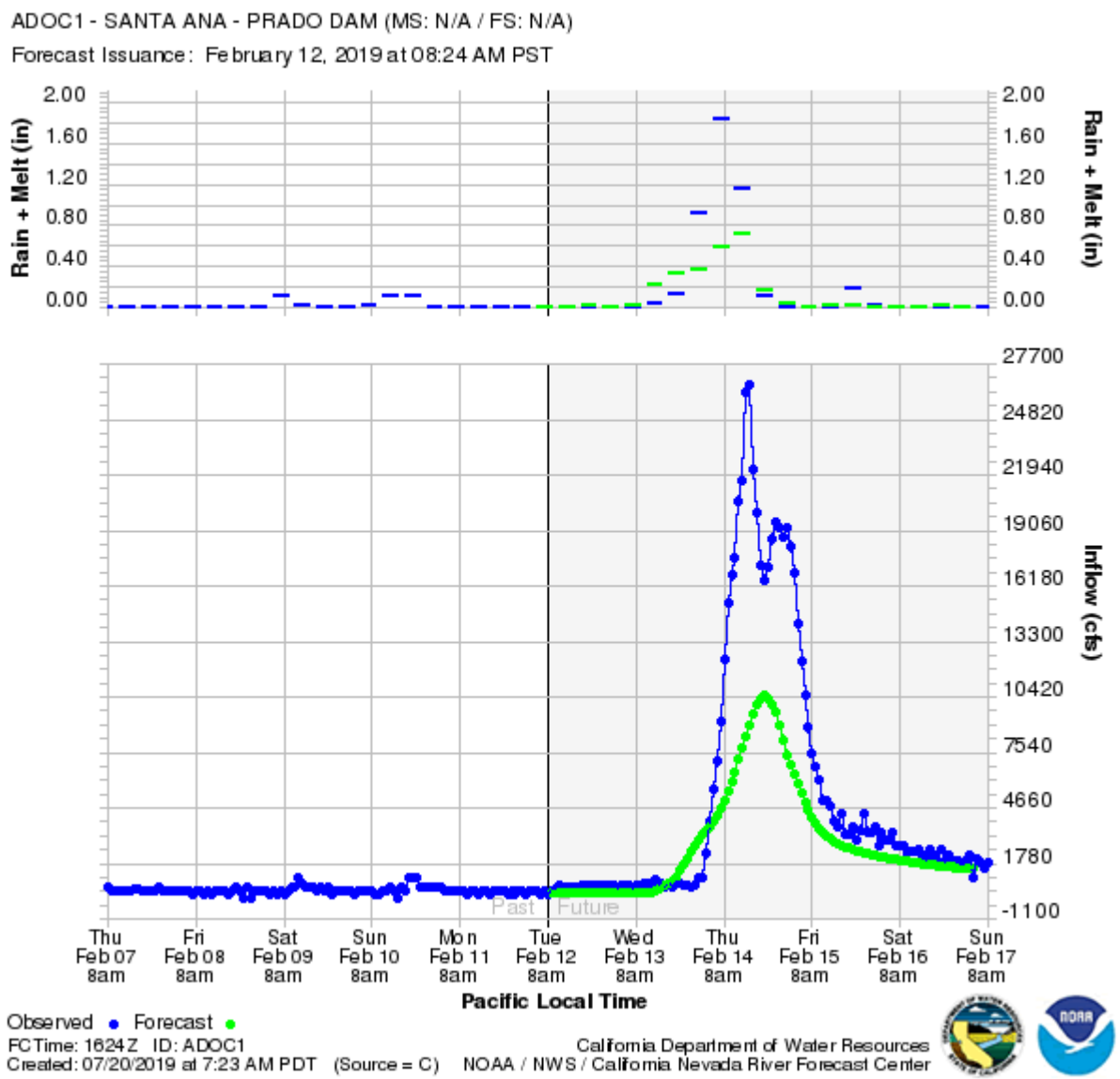

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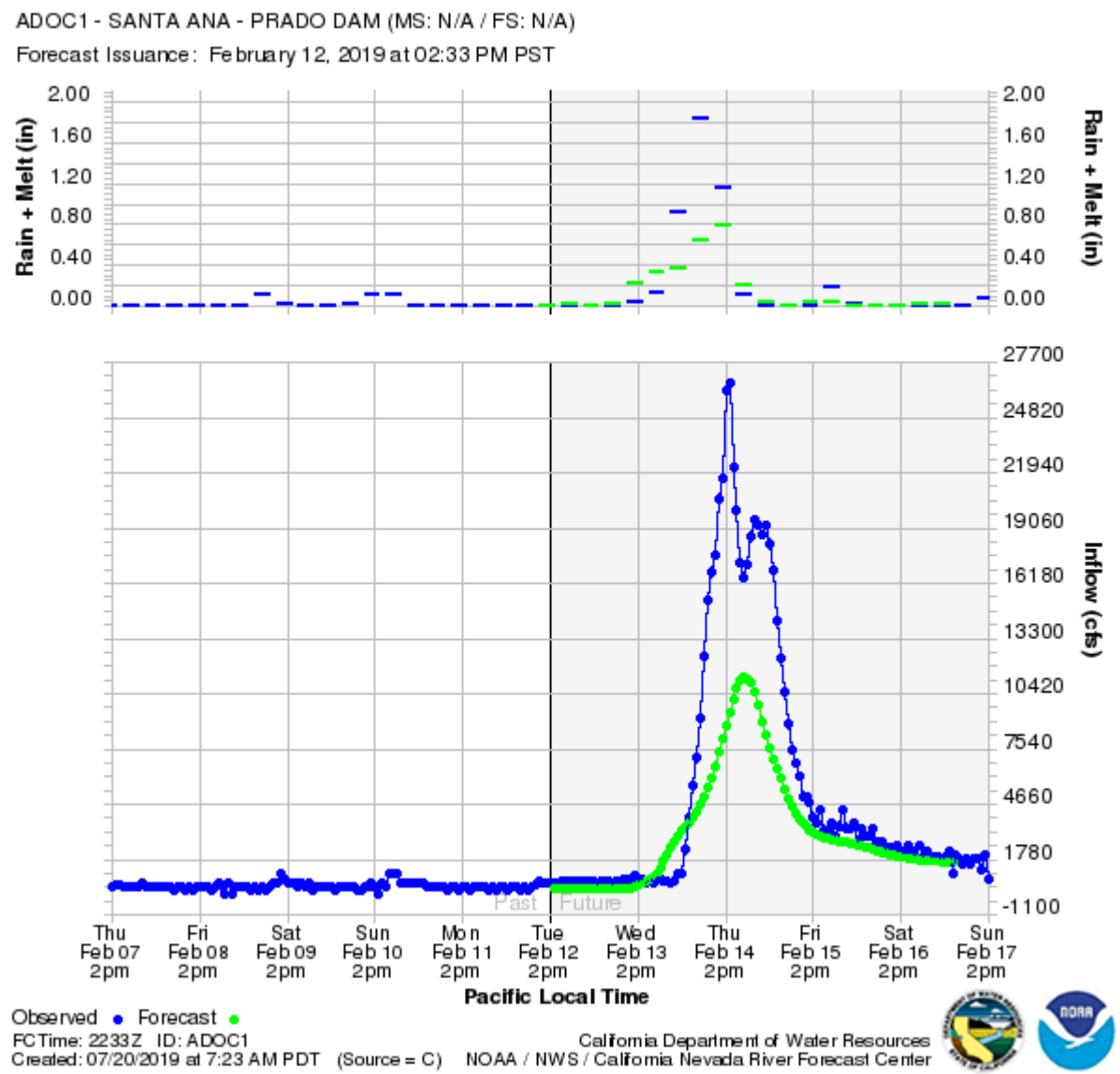

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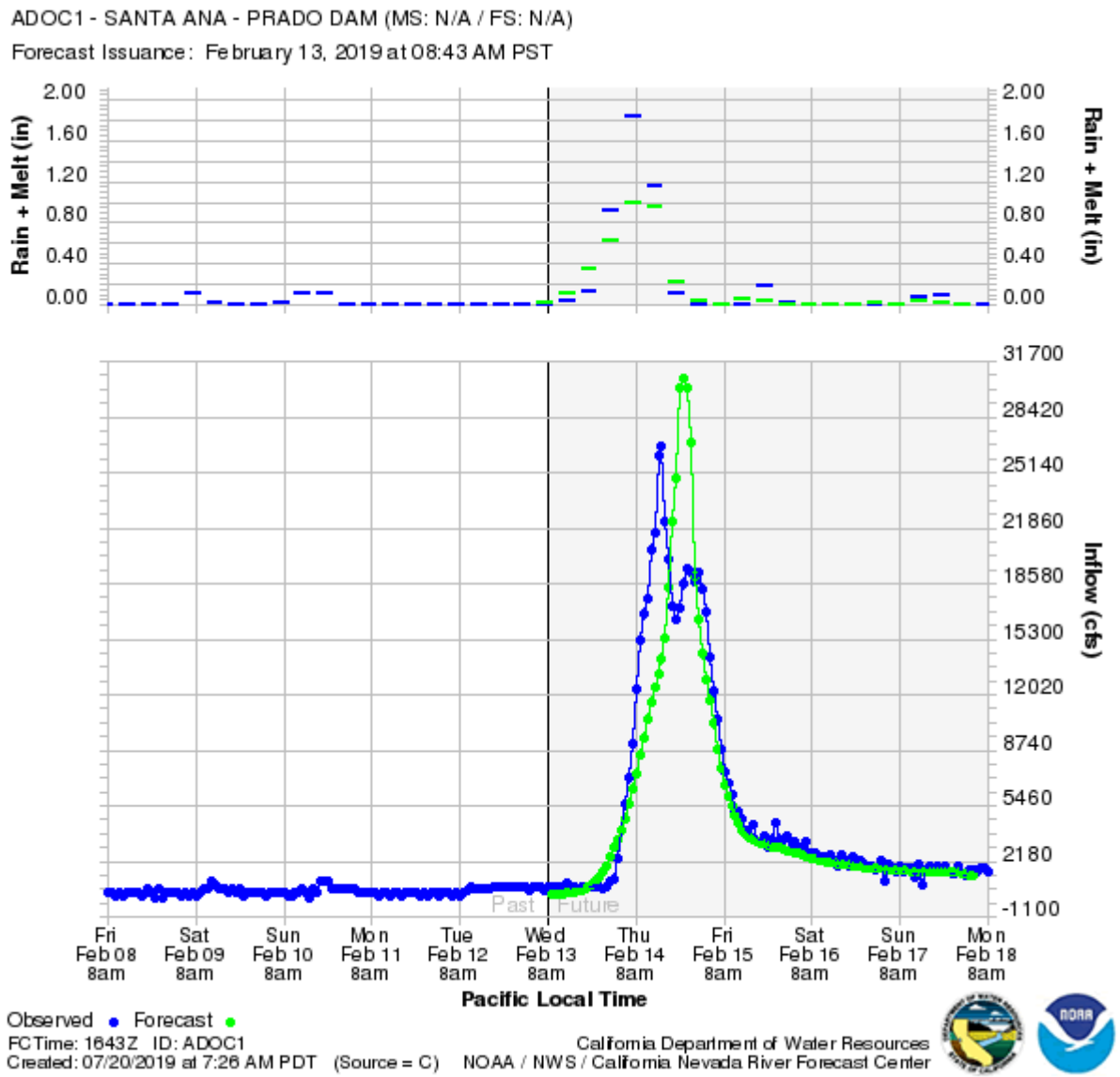

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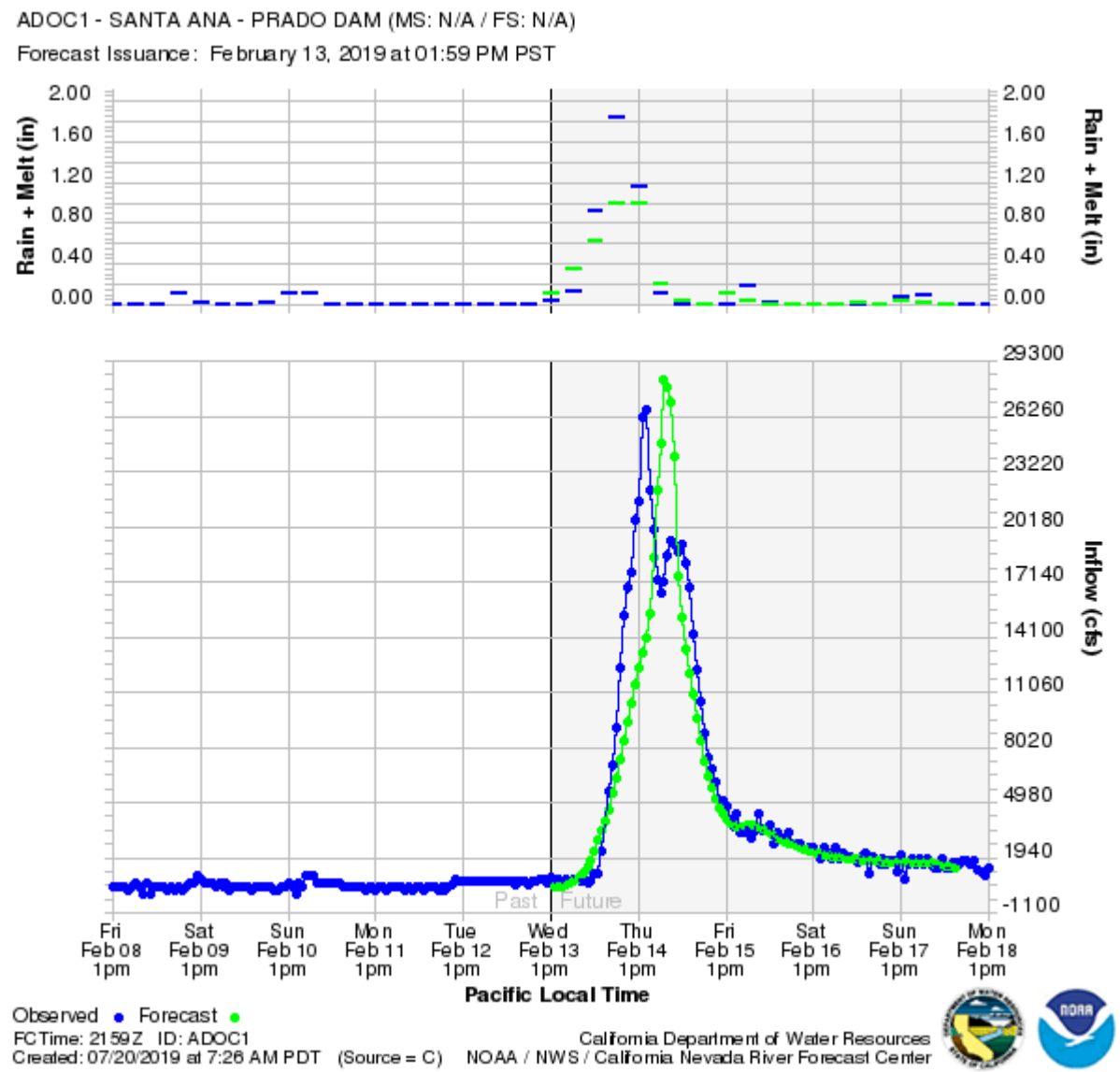

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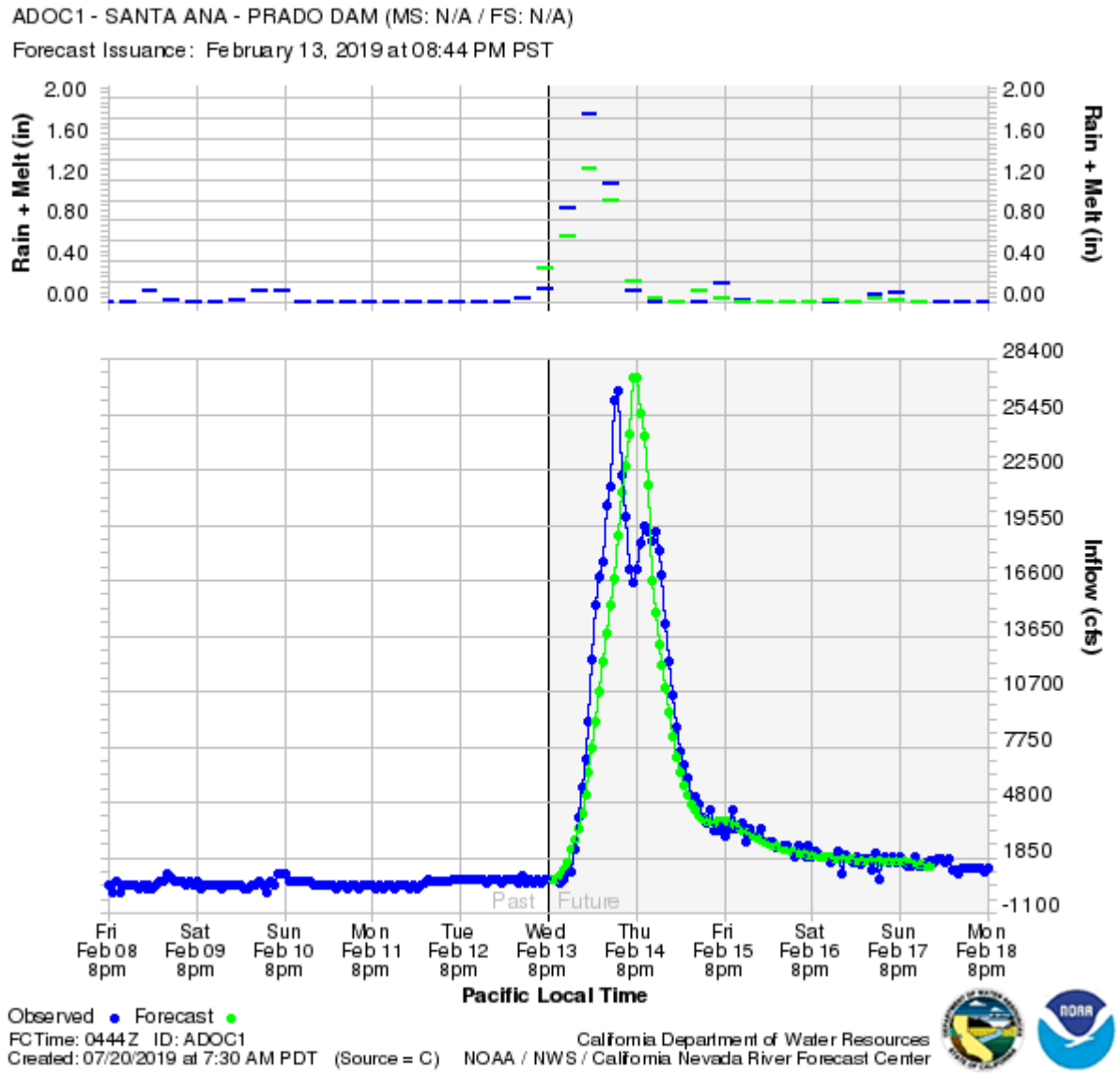

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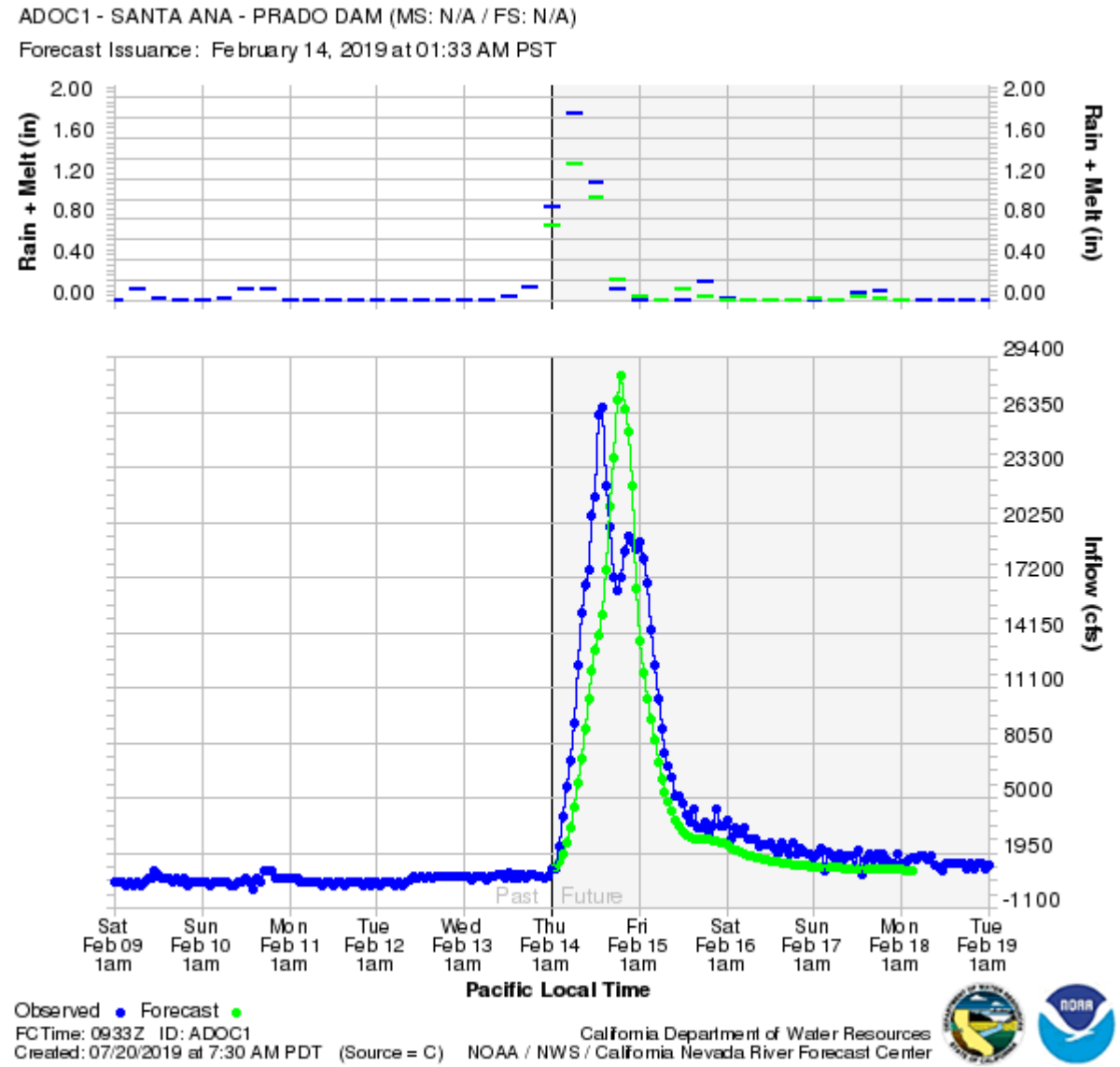

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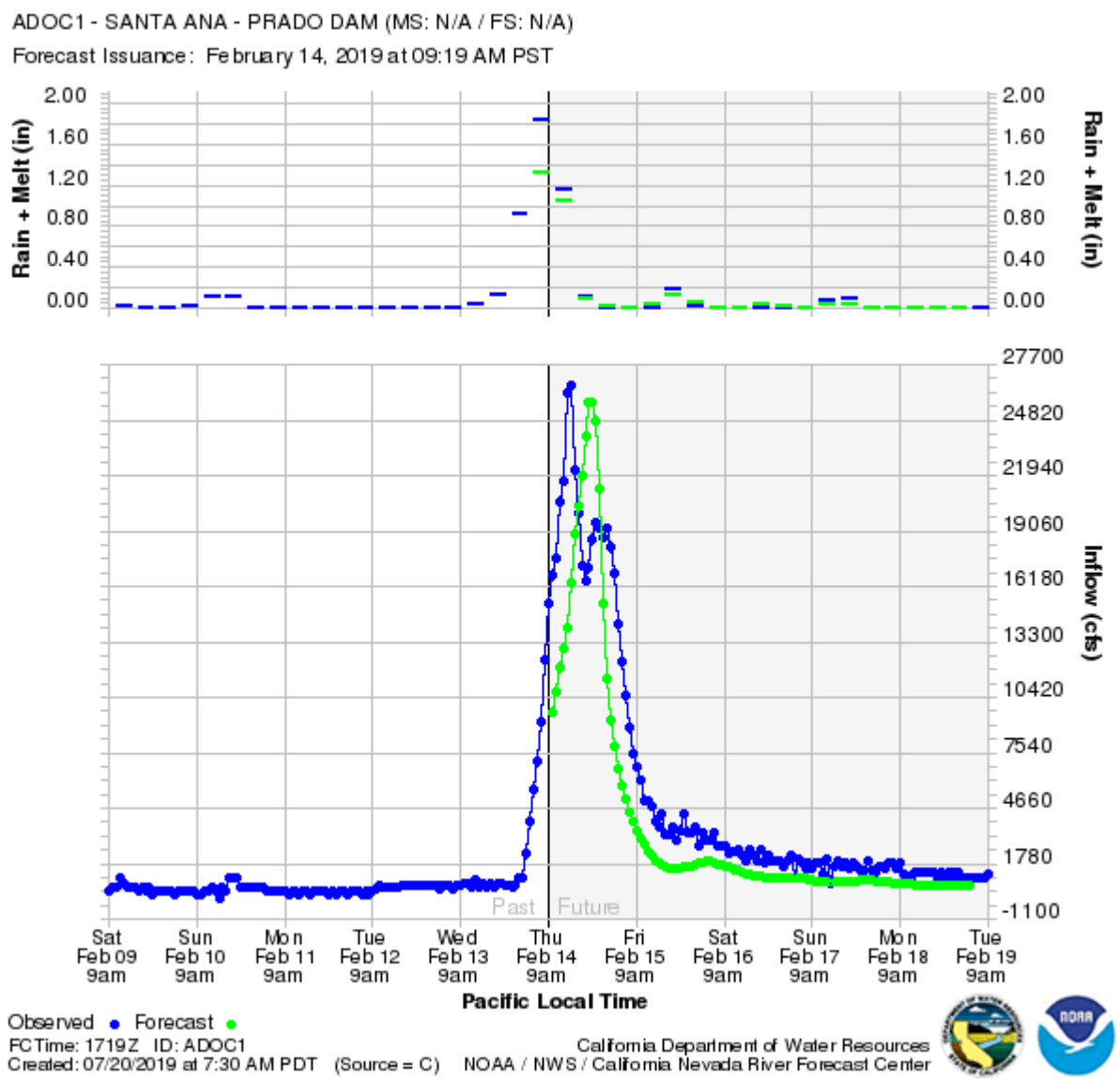

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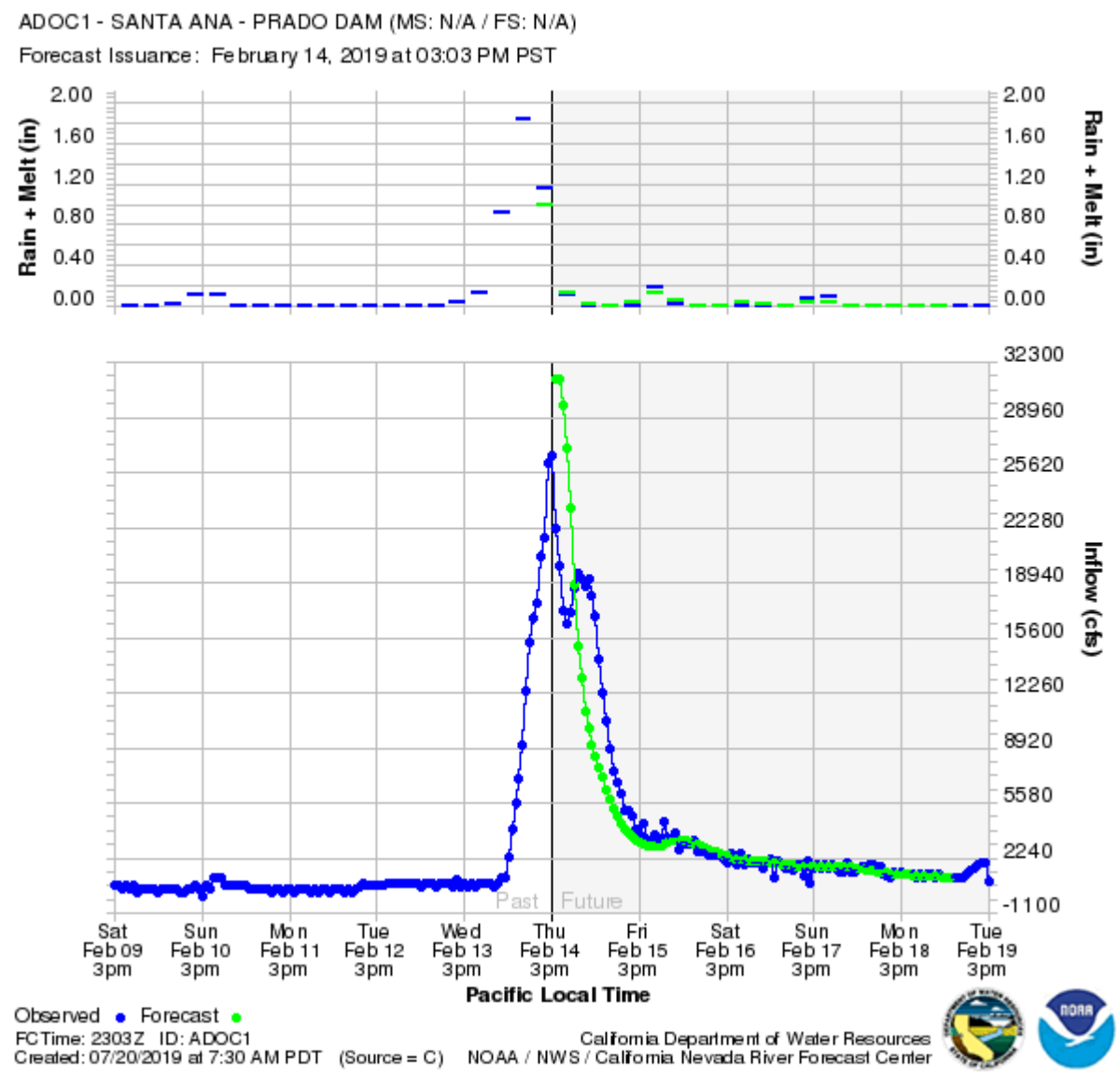

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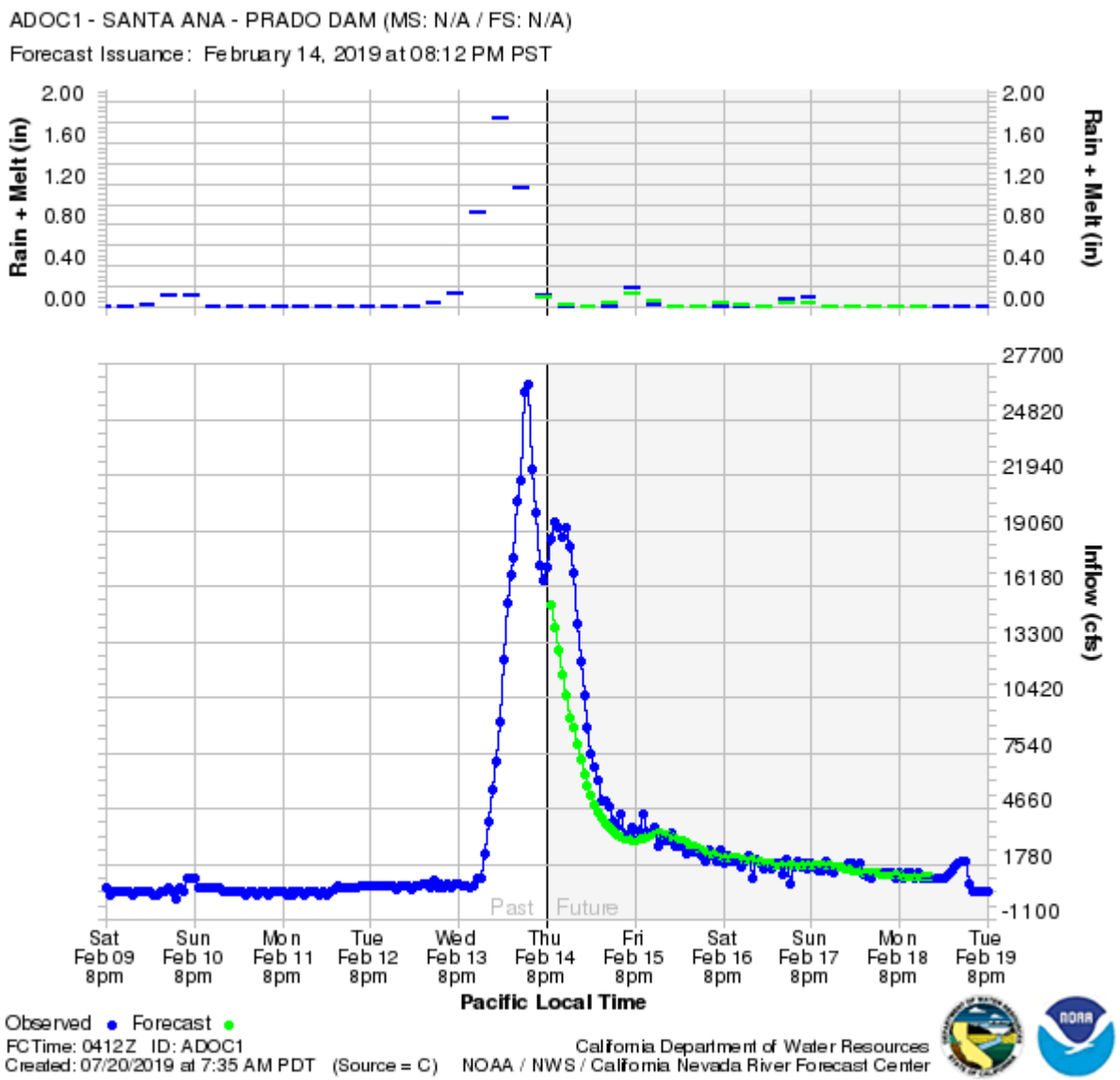

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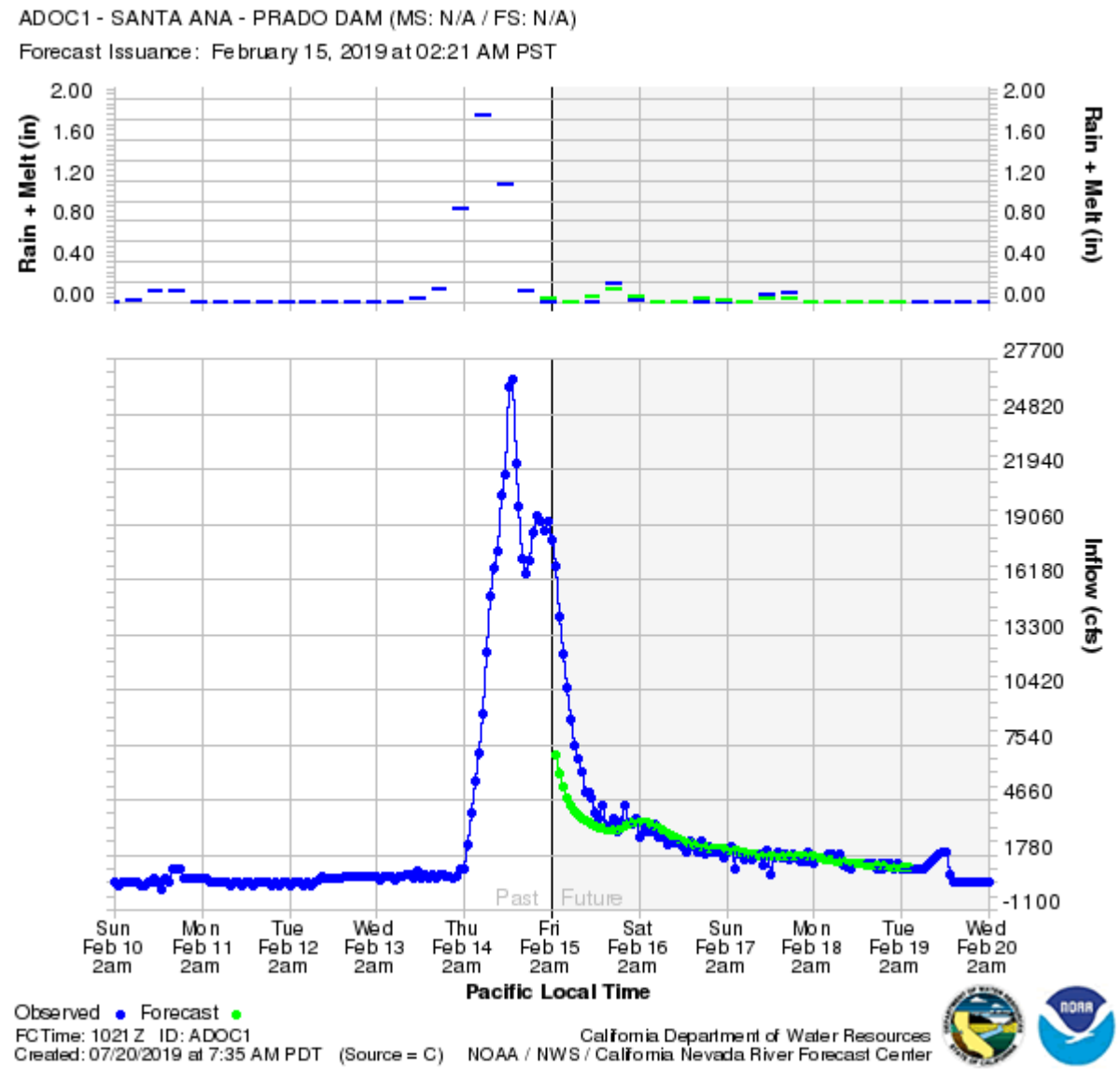
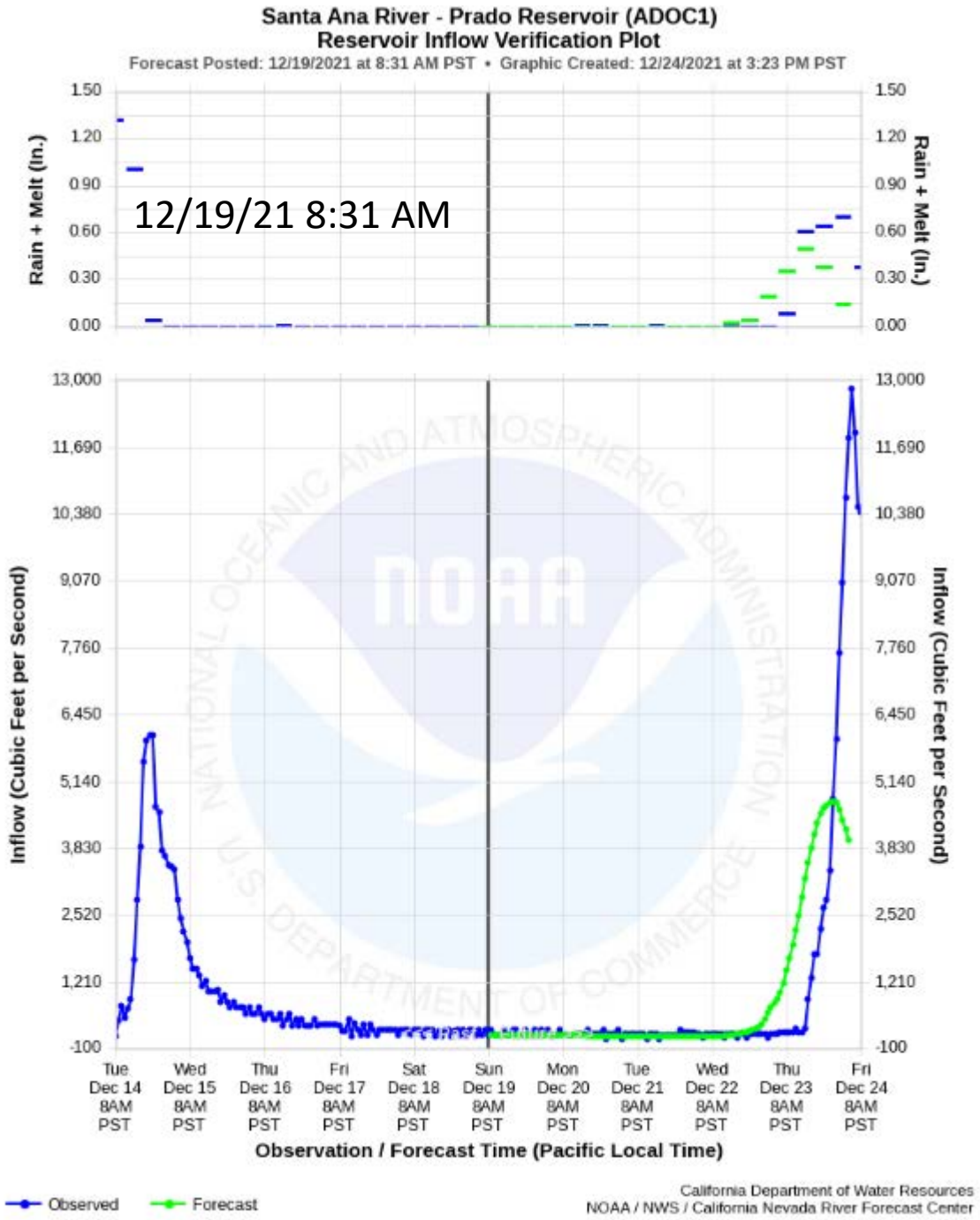
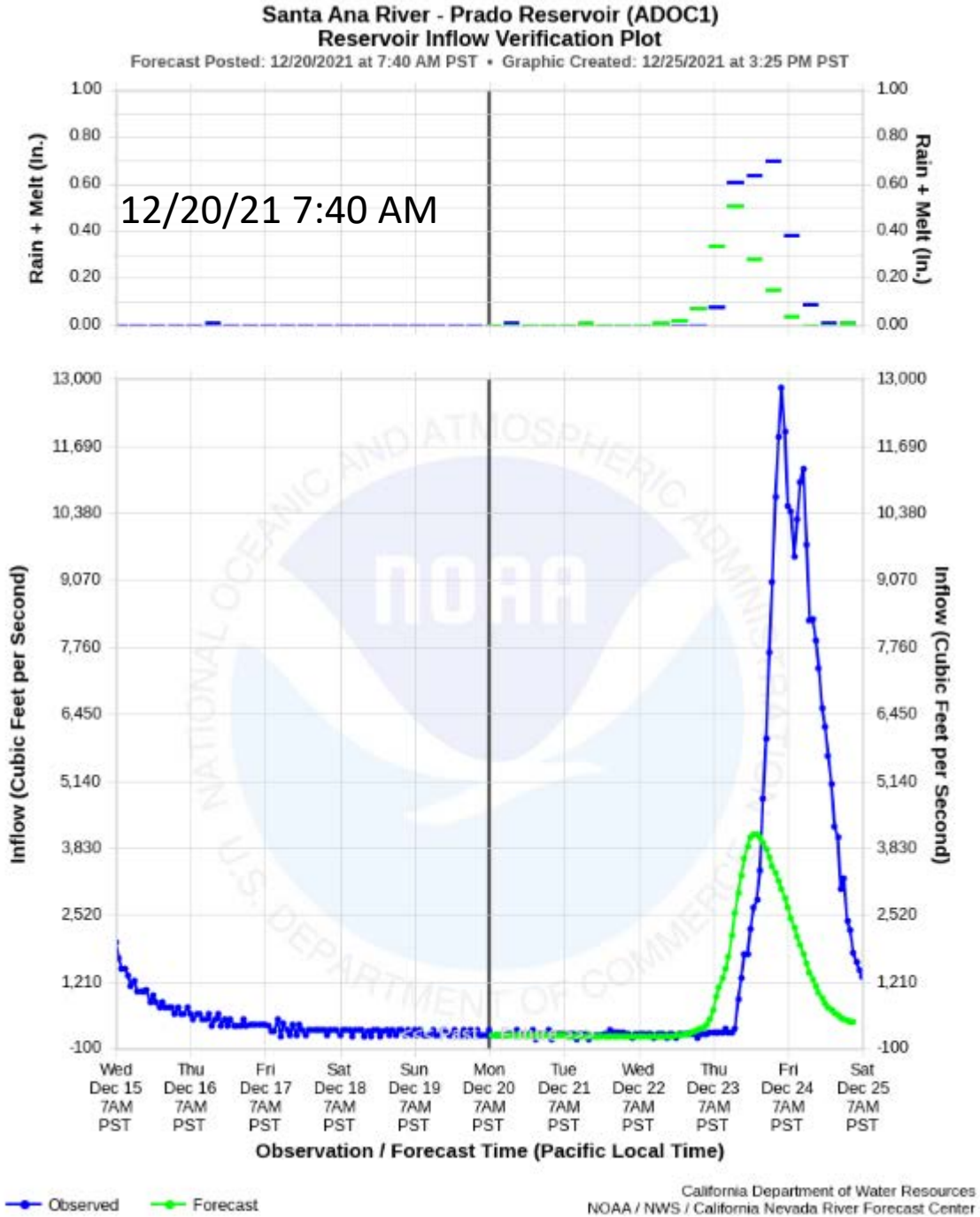
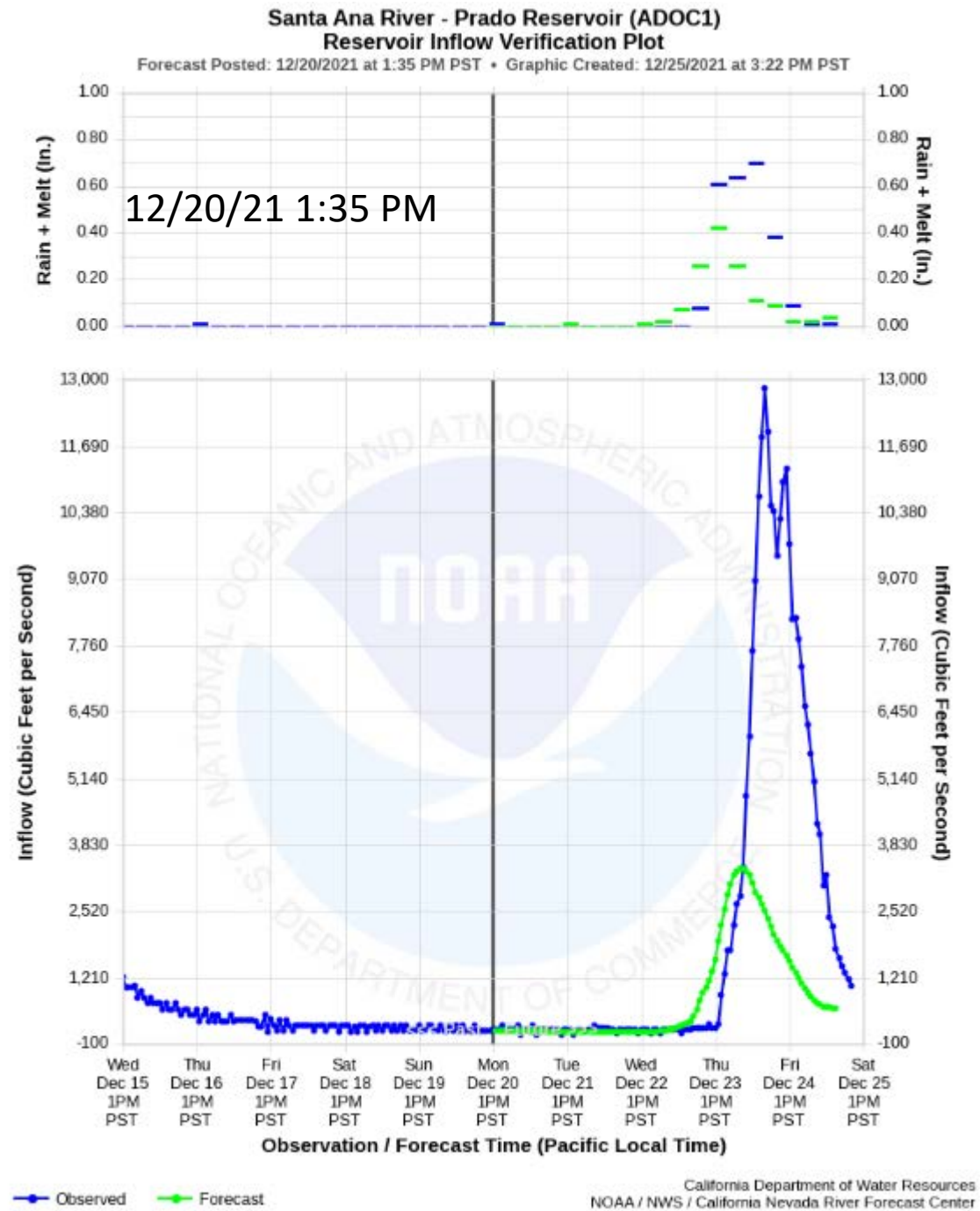


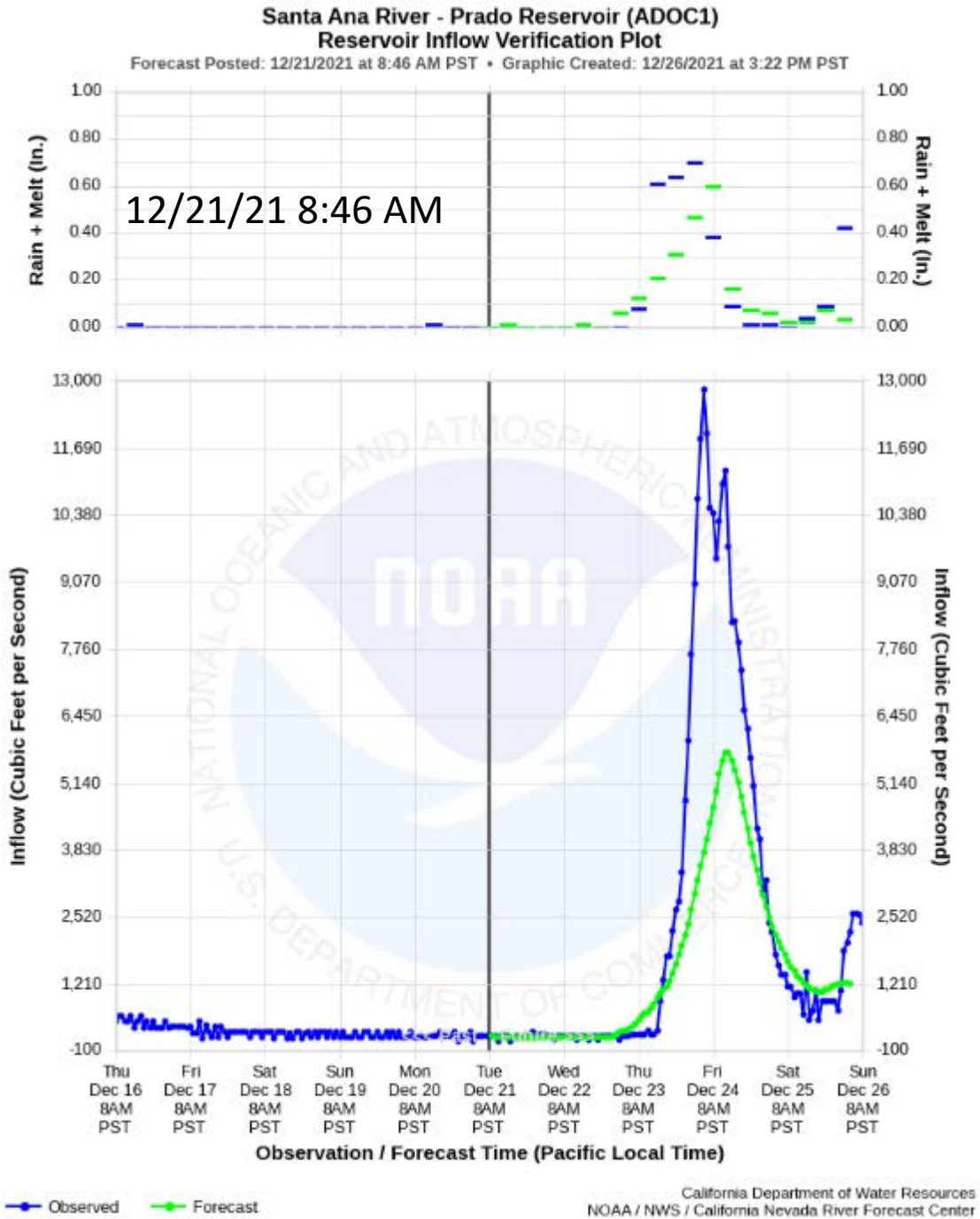
CNRFC Prado Inflow Forecasts December 19-24, 2021

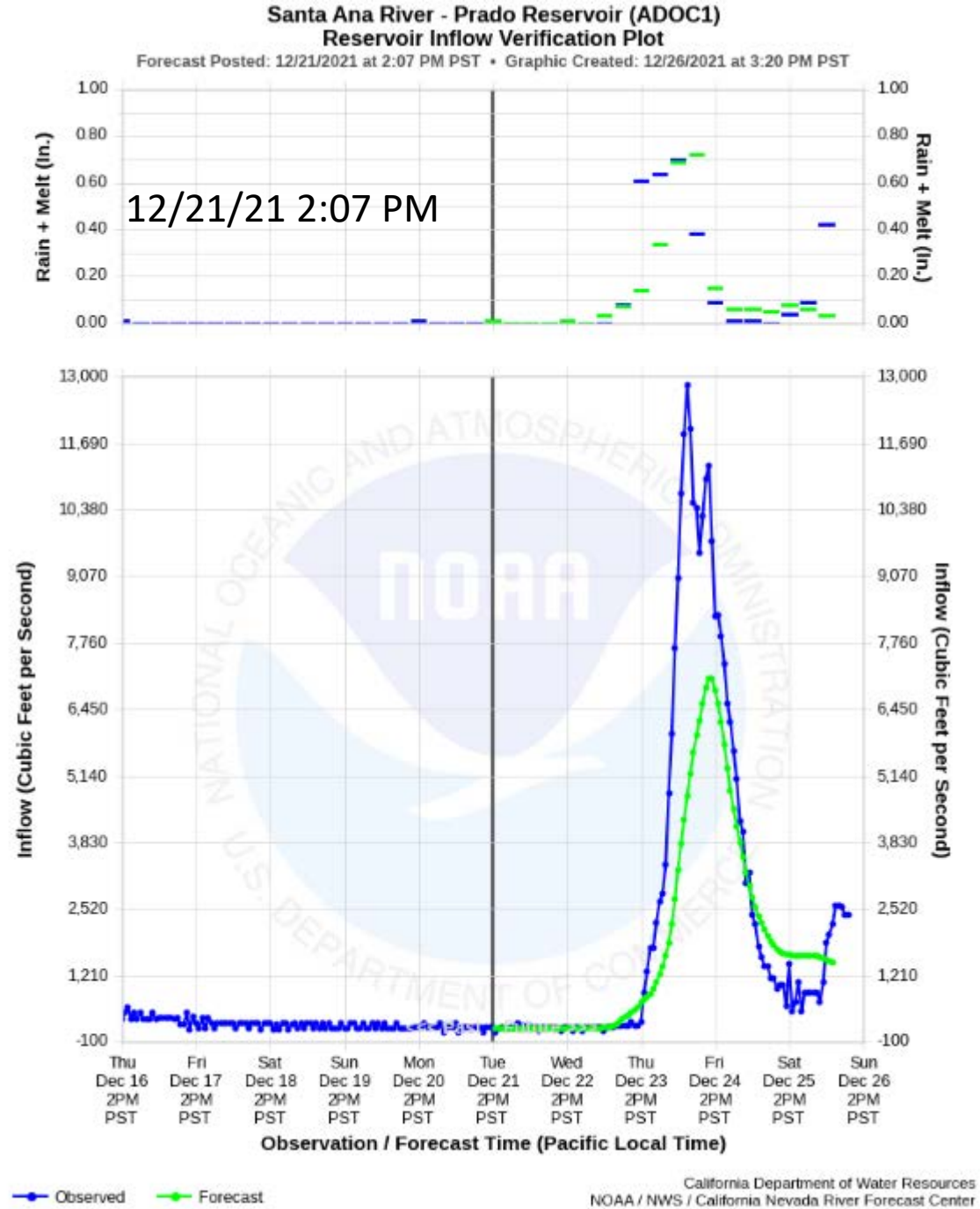


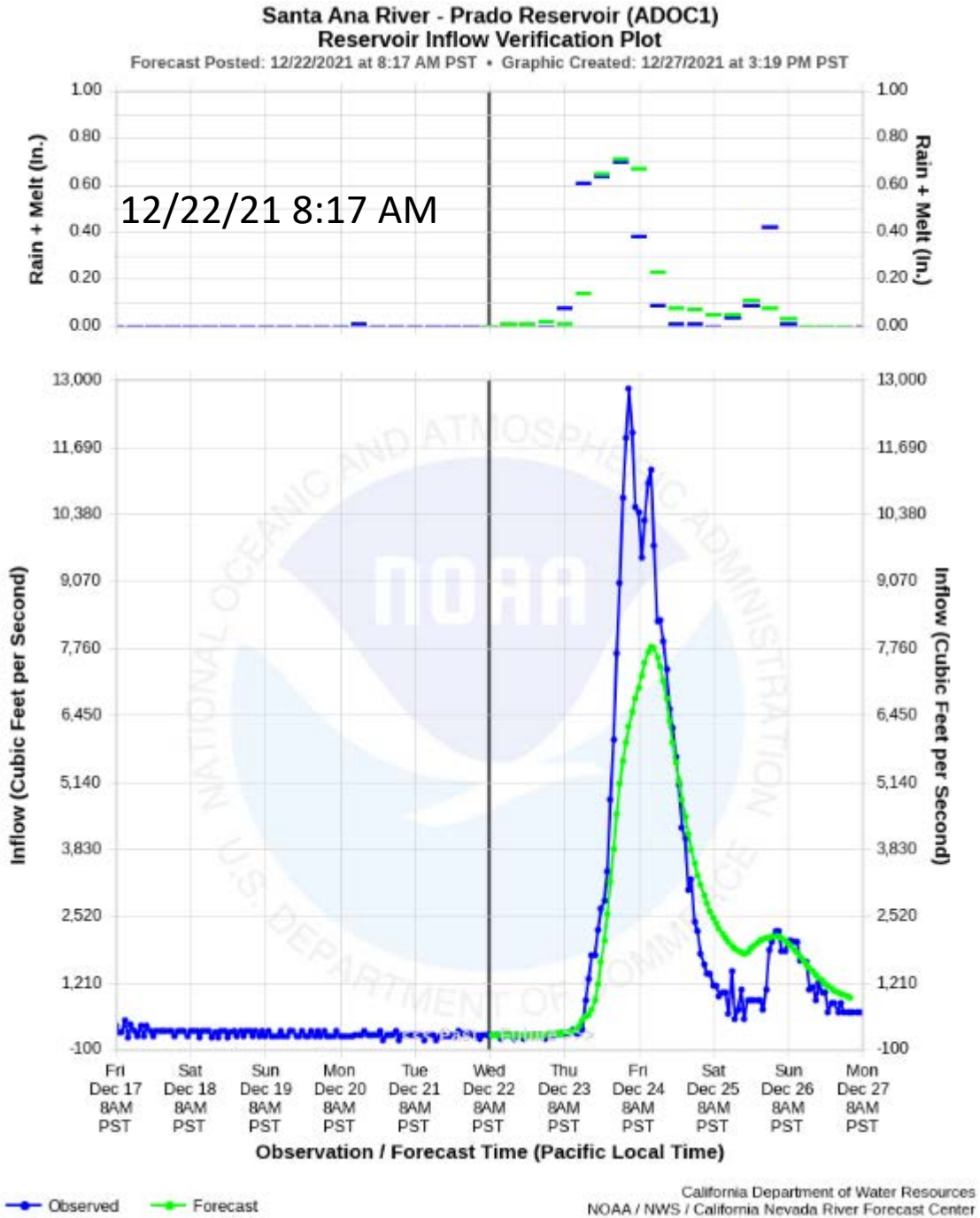
No Afternoon Forecast Available

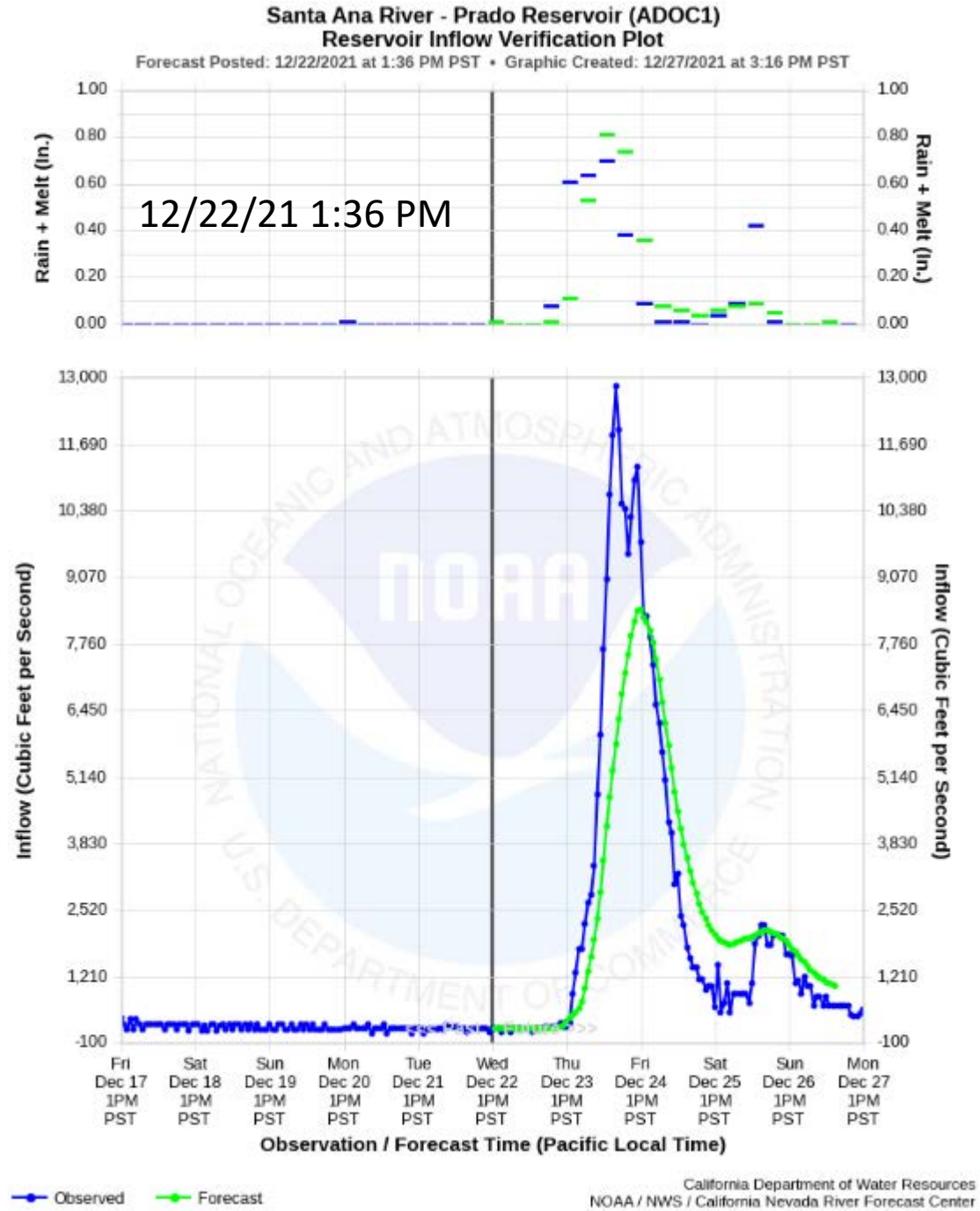

Santa Ana River - Prado Reservoir (ADOC1)
Reservoir Inflow Verification Plot
Forecast Posted: 12/20/2021 at 7:40 AM PST • Graphic Created: 12/25/2021 at 3:25 PM PST
12/20/21 7:40 AM
Rain + Melt (In.)
Inflow (Cubic Feet per Second)
Observation / Forecast Time (Pacific Local Time)
Observed
Forecast
California Department of Water Resources
NOAA / NWS / California Nevada River Forecast Center

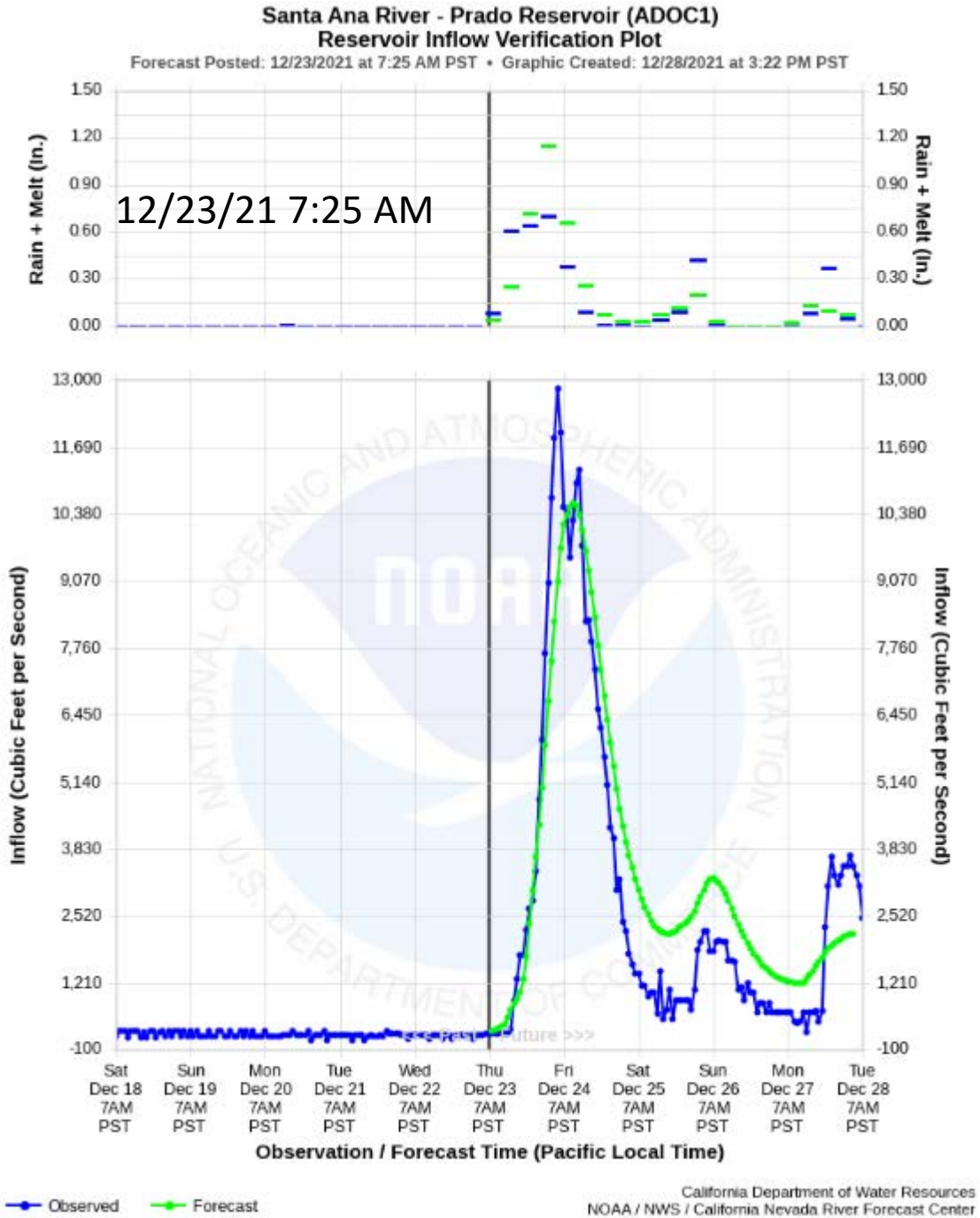

Santa Ana River - Prado Reservoir (ADOC1)
Reservoir Inflow Verification Plot
Forecast Posted: 12/20/2021 at 1:35 PM PST • Graphic Created: 12/25/2021 at 3:22 PM PST
12/20/21 1:35 PM
Rain + Melt (In.)
Inflow (Cubic Feet per Second)
Observation / Forecast Time (Pacific Local Time)
Observed
Forecast
California Department of Water Resources
NOAA / NWS / California Nevada River Forecast Center

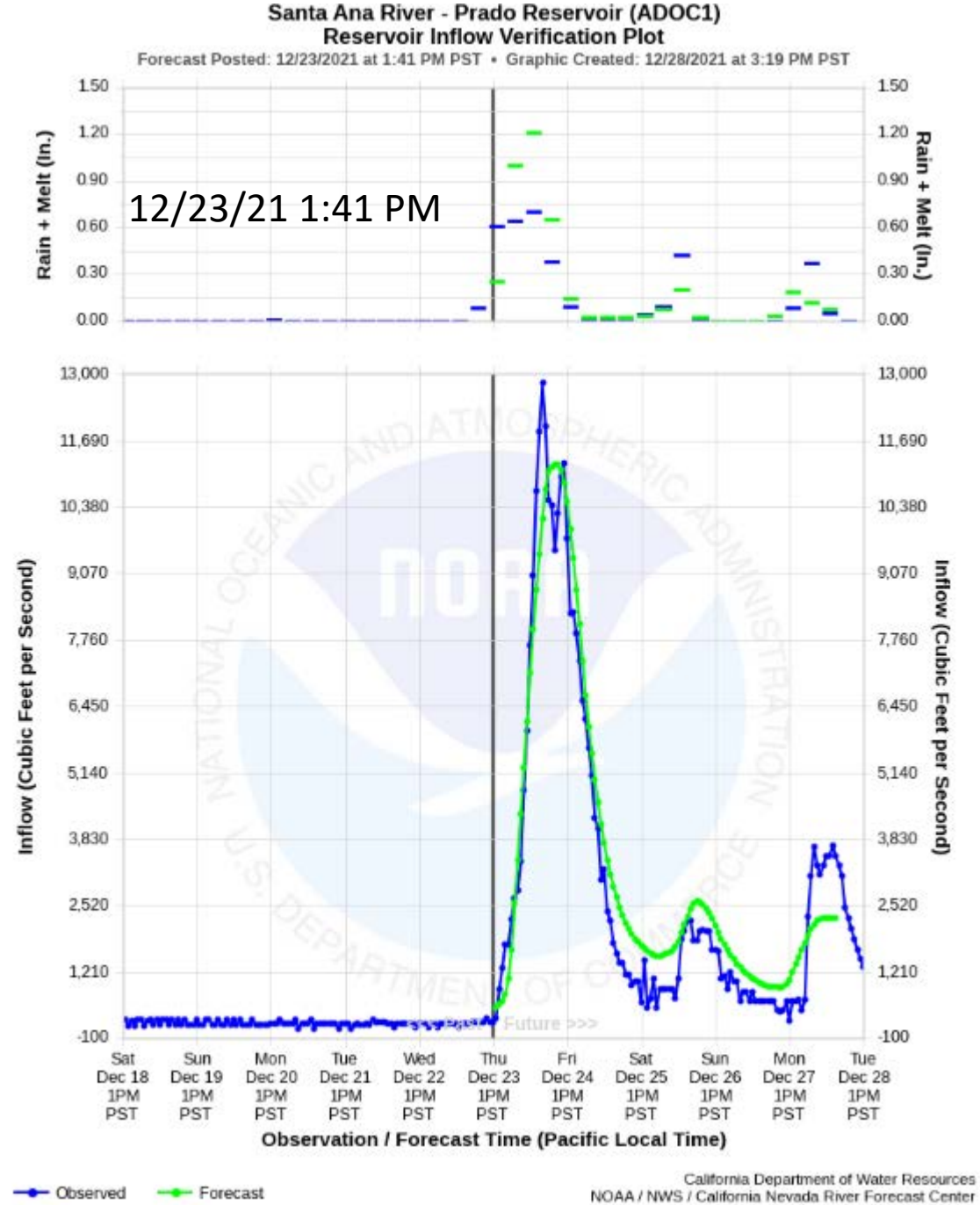

Santa Ana River - Prado Reservoir (ADOC1)
Reservoir Inflow Verification Plot
Forecast Posted: 12/21/2021 at 8:46 AM PST • Graphic Created: 12/26/2021 at 3:22 PM PST
12/21/21 8:46 AM
Rain + Melt (in.)
Inflow (Cubic Feet per Second)
Observation / Forecast Time (Pacific Local Time)
Observed
Forecast
California Department of Water Resources
NOAA / NWS / California Nevada River Forecast Center


Santa Ana River - Prado Reservoir (ADOC1)
Reservoir Inflow Verification Plot
Forecast Posted: 12/21/2021 at 2:07 PM PST • Graphic Created: 12/26/2021 at 3:20 PM PST
12/21/21 2:07 PM
Rain + Melt (in.)
Inflow (Cubic Feet per Second)
Observation / Forecast Time (Pacific Local Time)
Observed
Forecast
California Department of Water Resources
NOAA / NWS / California Nevada River Forecast Center


Santa Ana River - Prado Reservoir (ADOC1)
Reservoir Inflow Verification Plot
Forecast Posted: 12/22/2021 at 8:17 AM PST • Graphic Created: 12/27/2021 at 3:19 PM PST
12/22/21 8:17 AM
Rain + Melt (In.)
Inflow (Cubic Feet per Second)
Observation / Forecast Time (Pacific Local Time)
Observed
Forecast
California Department of Water Resources
NOAA / NWS / California Nevada River Forecast Center


Santa Ana River - Prado Reservoir (ADOC1)
Reservoir Inflow Verification Plot
Forecast Posted: 12/22/2021 at 1:36 PM PST • Graphic Created: 12/27/2021 at 3:16 PM PST
12/22/21 1:36 PM
Rain + Melt (In.)
Inflow (Cubic Feet per Second)
Observation / Forecast Time (Pacific Local Time)
Observed
Forecast
California Department of Water Resources
NOAA / NWS / California Nevada River Forecast Center


Santa Ana River - Prado Reservoir (ADOC1)
Reservoir Inflow Verification Plot
Forecast Posted: 12/23/2021 at 7:25 AM PST • Graphic Created: 12/28/2021 at 3:22 PM PST
12/23/21 7:25 AM
Rain + Melt (in.)
Inflow (Cubic Feet per Second)
Observation / Forecast Time (Pacific Local Time)
Observed
Forecast
California Department of Water Resources
NOAA / NWS / California Nevada River Forecast Center


Santa Ana River - Prado Reservoir (ADOC1)
Reservoir Inflow Verification Plot
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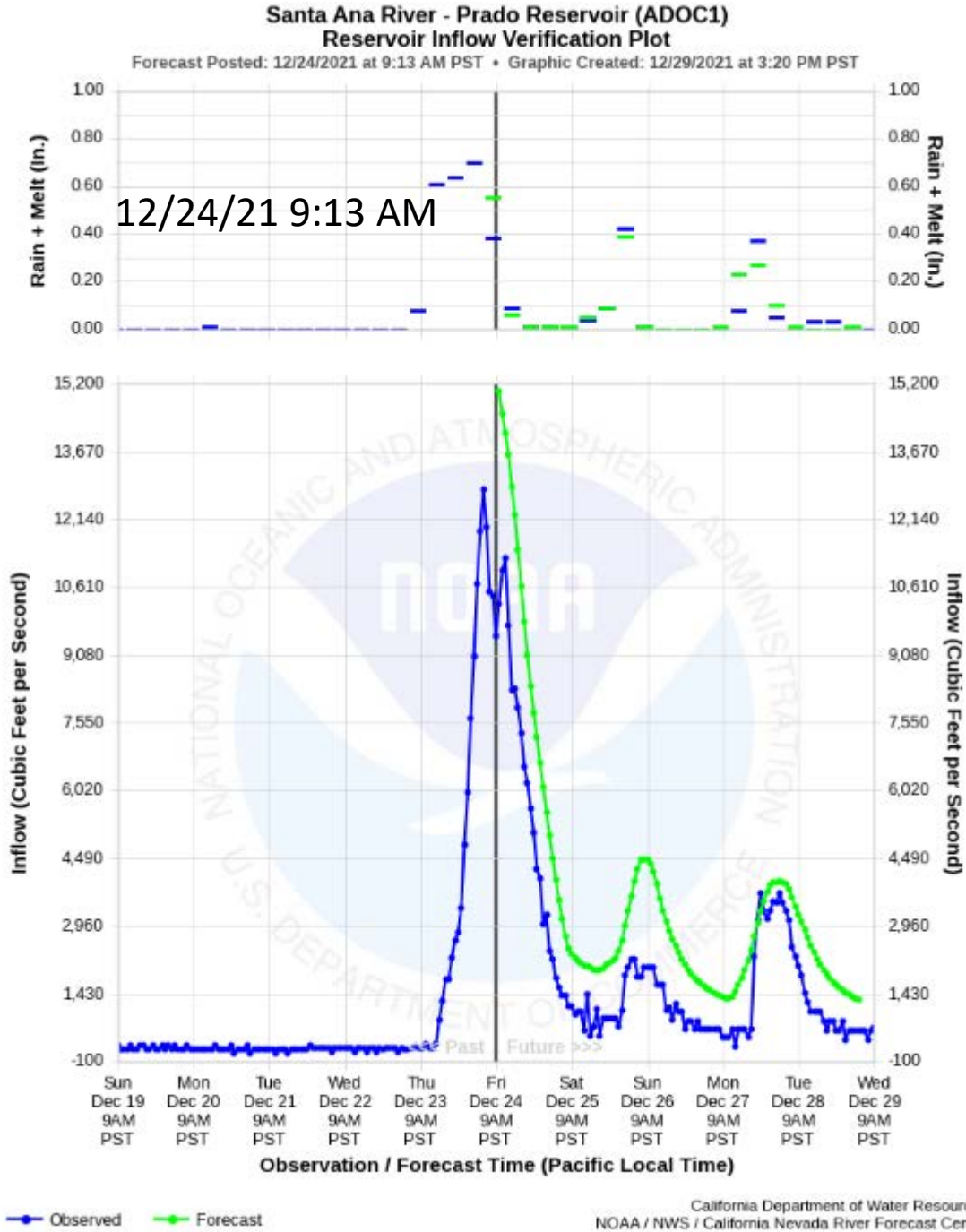
12/23/21 1:41 PM
Rain + Melt (in.)
Inflow (Cubic Feet per Second)
Observation / Forecast Time (Pacific Local Time)
Observed
Forecast
California Department of Water Resources
NOAA / NWS / California Nevada River Forecast Center


Santa Ana River - Prado Reservoir (ADOC1)
Reservoir Inflow Verification Plot
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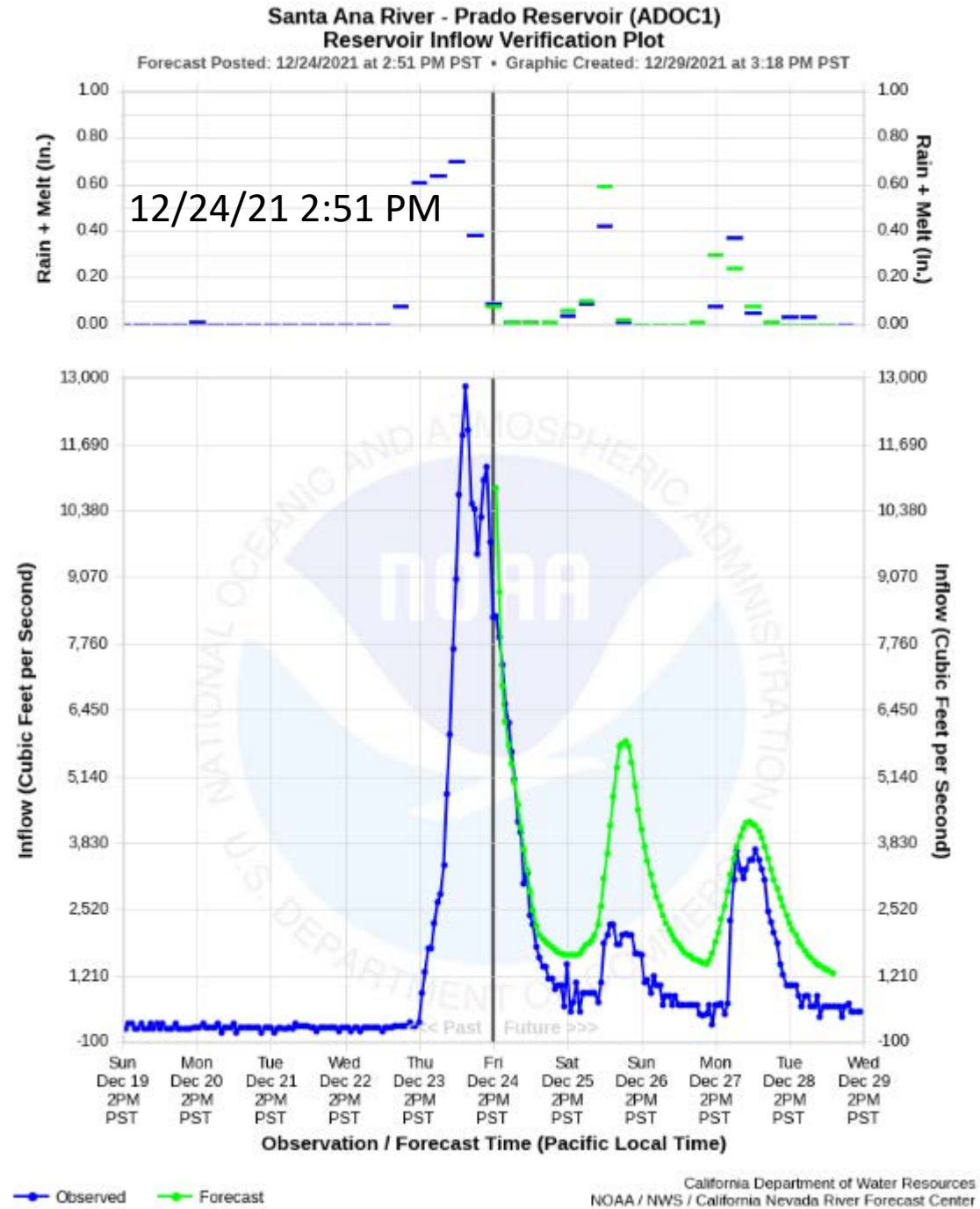
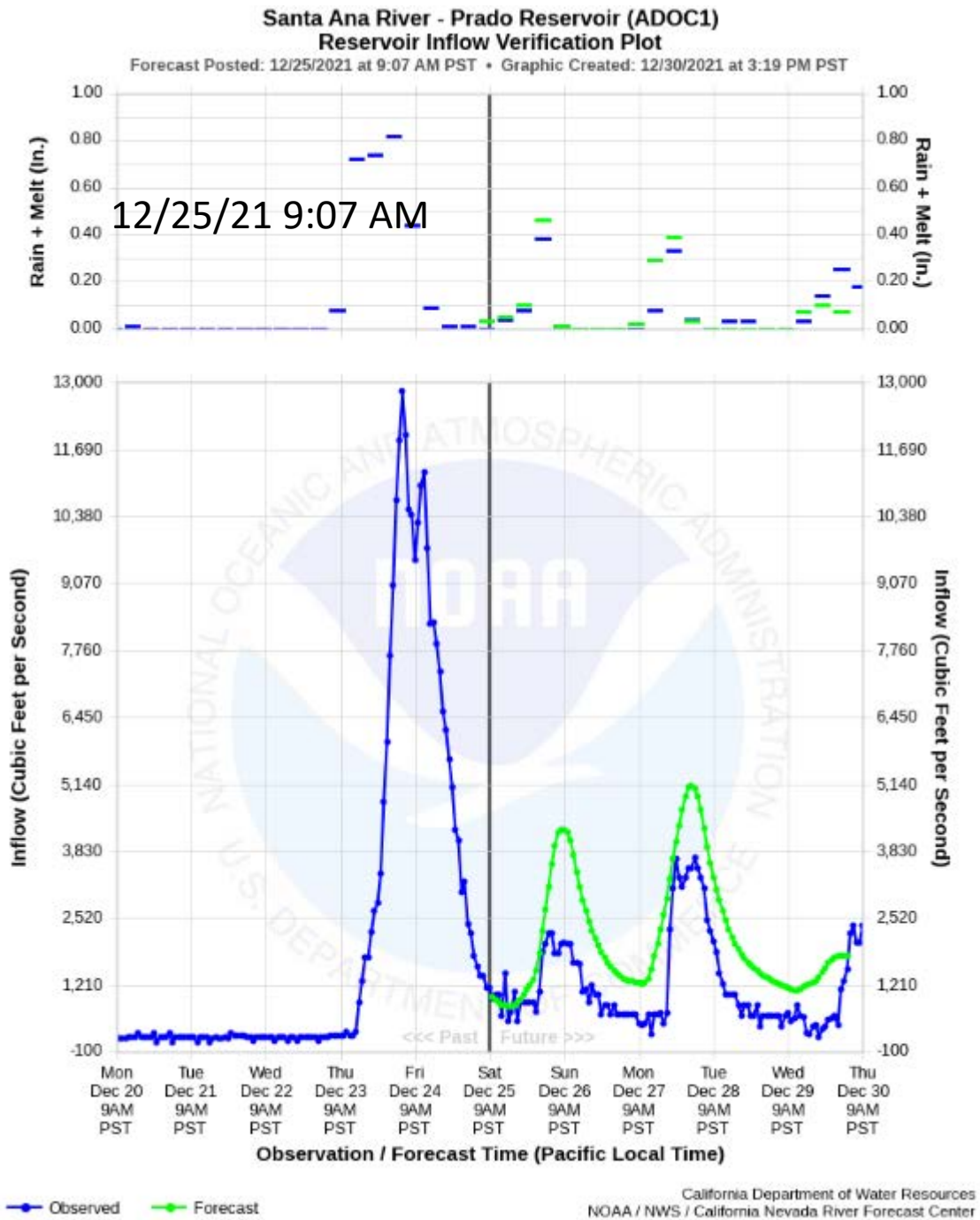
12/24/21 9:13 AM
Rain + Melt (in.)
Inflow (Cubic Feet per Second)
Observation / Forecast Time (Pacific Local Time)
Observed
Forecast
California Department of Water Resources
NOAA / NWS / California Nevada River Forecast Center


Santa Ana River - Prado Reservoir (ADOC1)
Reservoir Inflow Verification Plot
Forecast Posted: 12/24/2021 at 2:51 PM PST • Graphic Created: 12/29/2021 at 3:18 PM PST
12/24/21 2:51 PM
Rain + Melt (in.)
Inflow (Cubic Feet per Second)
Observation / Forecast Time (Pacific Local Time)
Observed
Forecast
California Department of Water Resources
NOAA / NWS / California Nevada River Forecast Center


Santa Ana River - Prado Reservoir (ADOC1)
Reservoir Inflow Verification Plot
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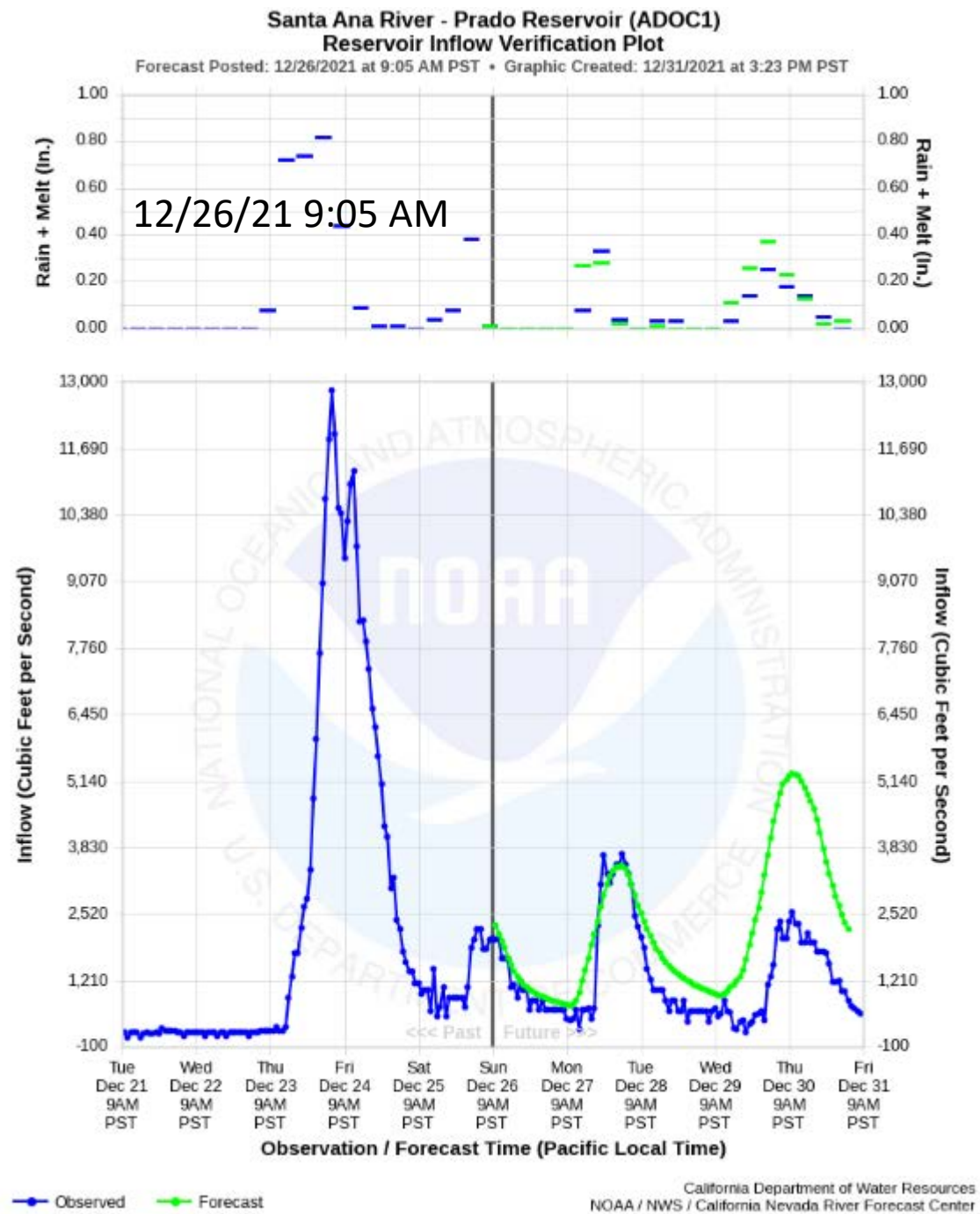
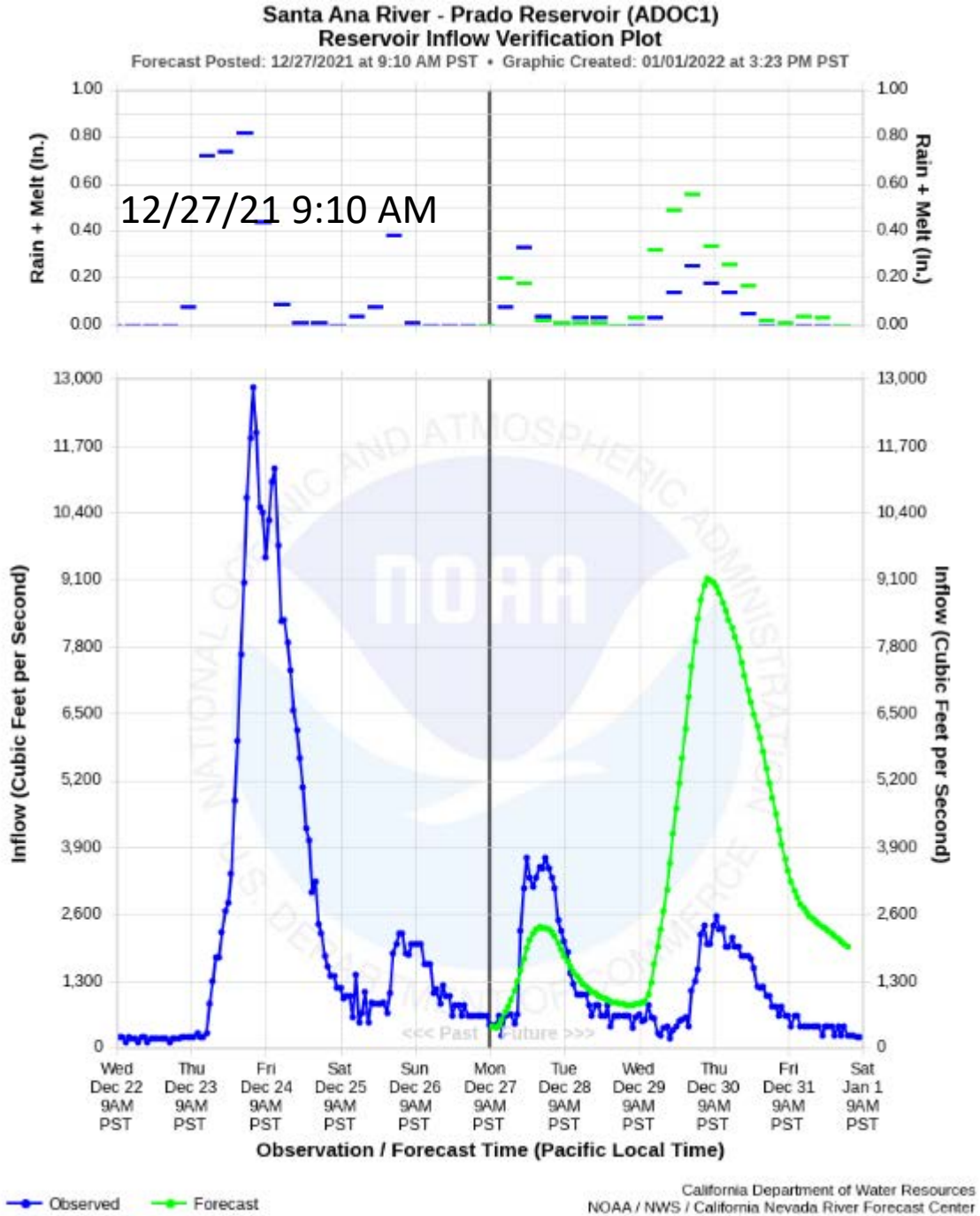
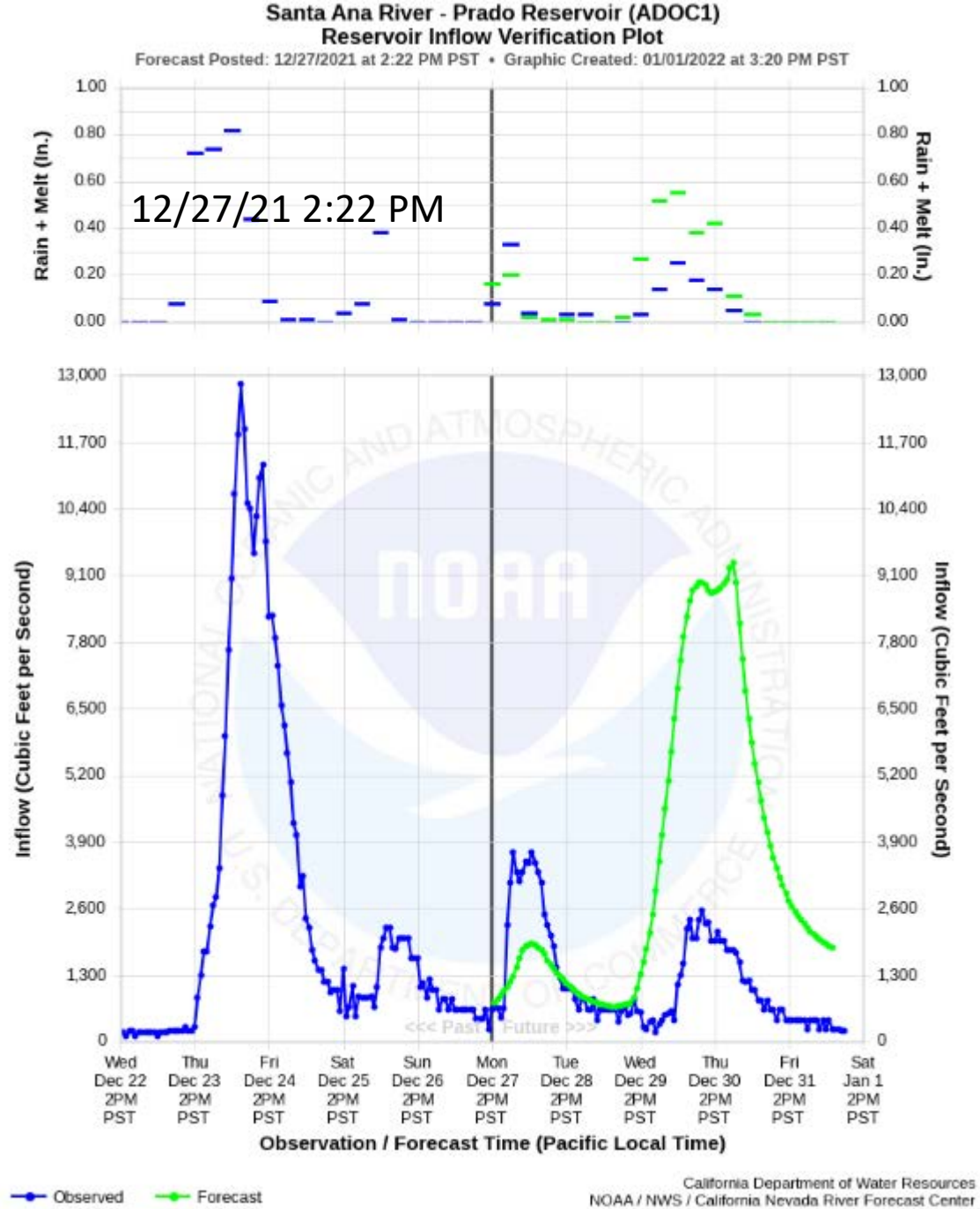
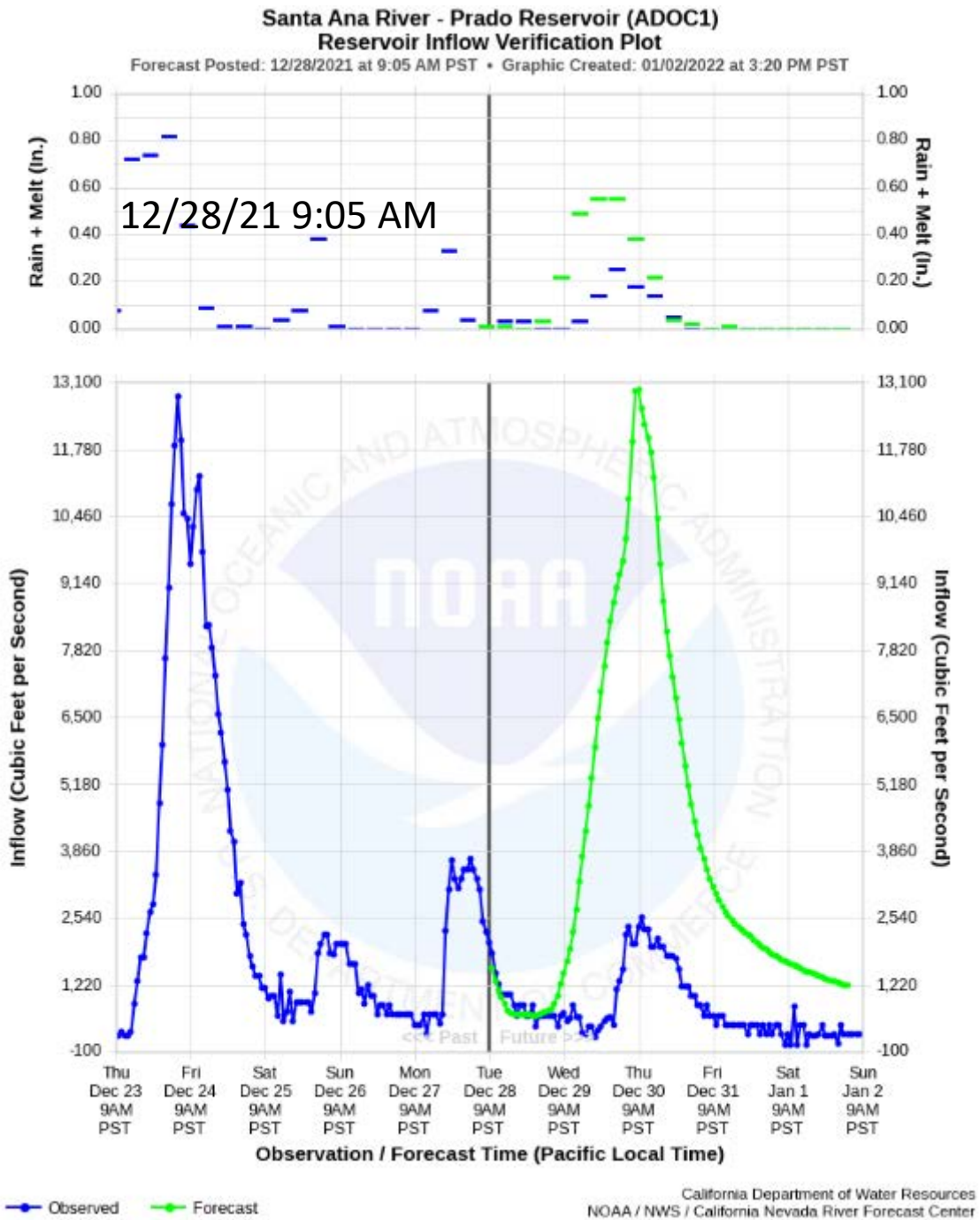
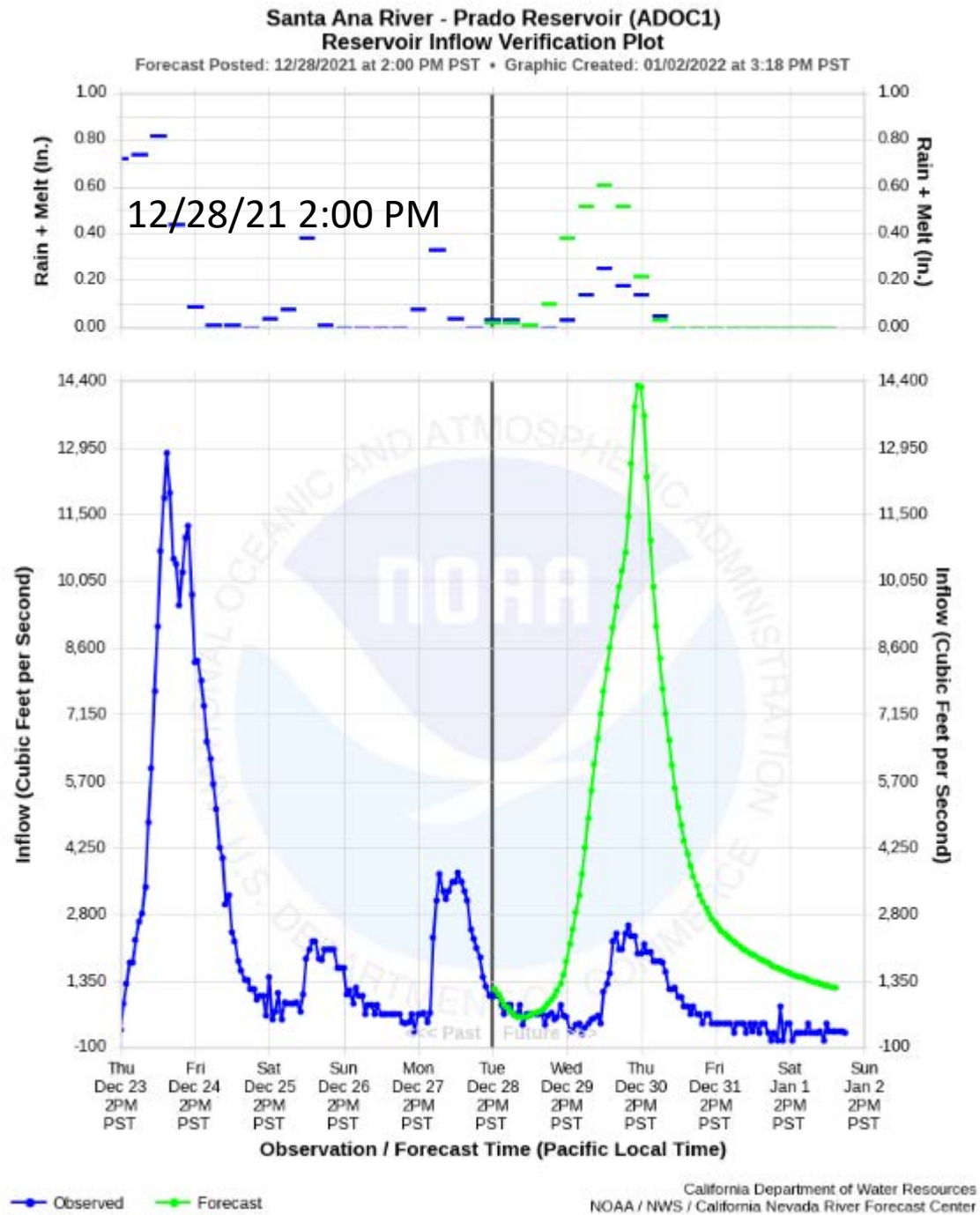
Rain + Melt (in.)
Inflow (Cubic Feet per Second)
<<< Past
Future >>>
Observation / Forecast Time (Pacific Local Time)
Observed
Forecast
California Department of Water Resources
NOAA / NWS / California Nevada River Forecast Center

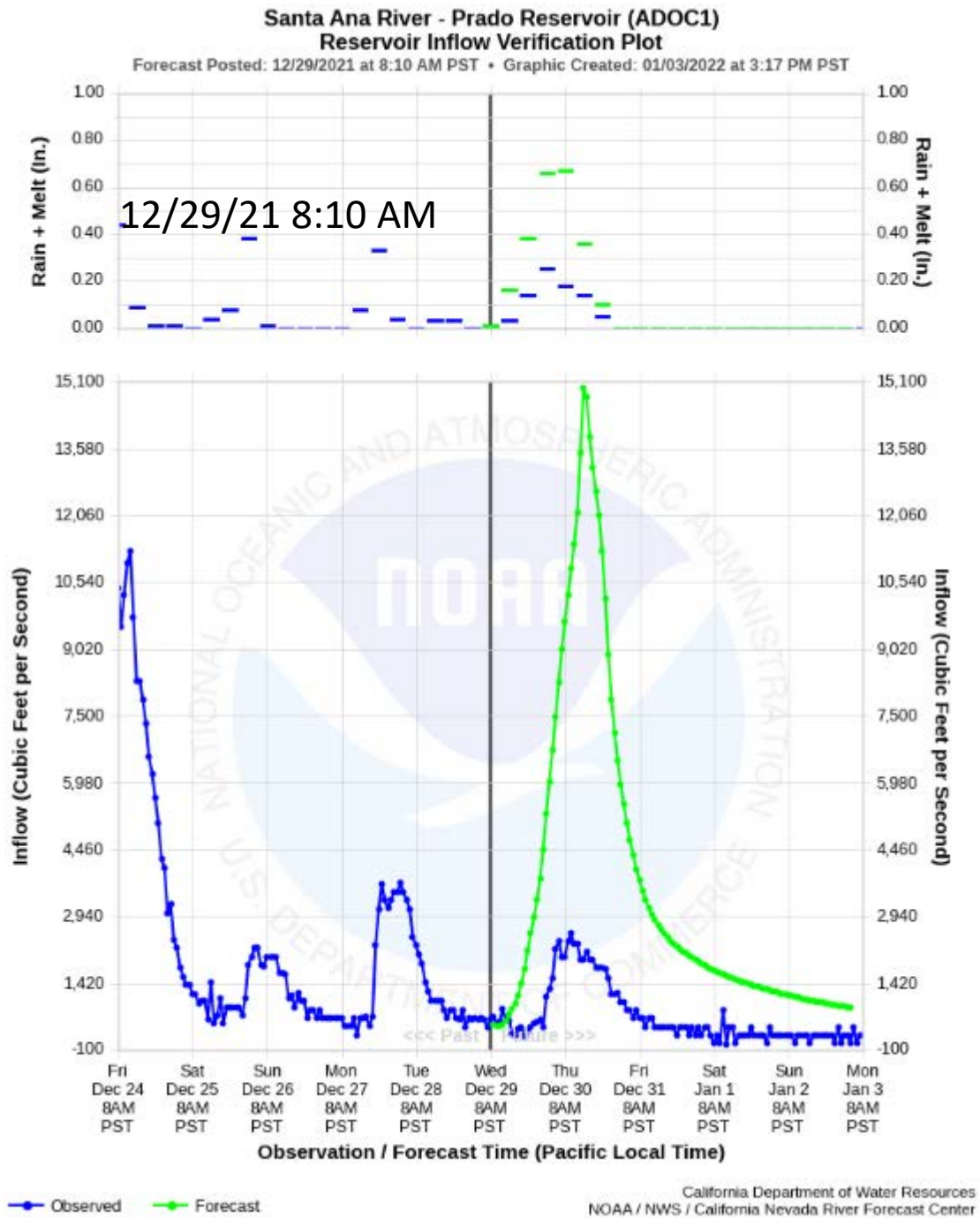

Santa Ana River - Prado Reservoir (ADOC1)
Reservoir Inflow Verification Plot
Forecast Posted: 12/26/2021 at 9:05 AM PST • Graphic Created: 12/31/2021 at 3:23 PM PST
12/26/21 9:05 AM
Rain + Melt (in.)
Inflow (Cubic Feet per Second)
<<< Past
Future >>>
Observation / Forecast Time (Pacific Local Time)
Observed
Forecast
California Department of Water Resources
NOAA / NWS / California Nevada River Forecast Center

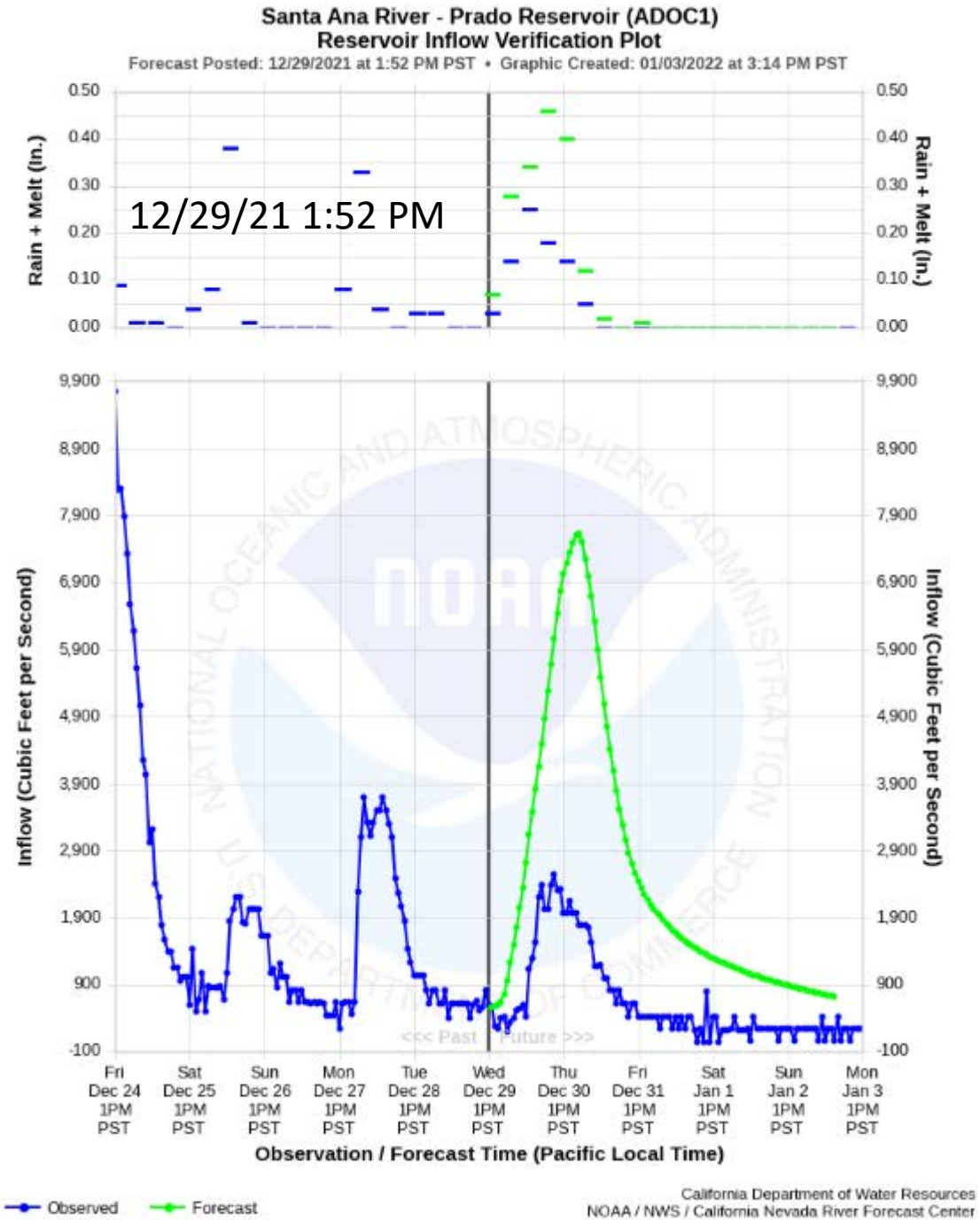

Santa Ana River - Prado Reservoir (ADOC1)
Reservoir Inflow Verification Plot
Forecast Posted: 12/27/2021 at 9:10 AM PST • Graphic Created: 01/01/2022 at 3:23 PM PST
12/27/21 9:10 AM
Rain + Melt (in.)
Inflow (Cubic Feet per Second)
<<< Past Future >>>
Observation / Forecast Time (Pacific Local Time)
Observed
Forecast
California Department of Water Resources
NOAA / NWS / California Nevada River Forecast Center

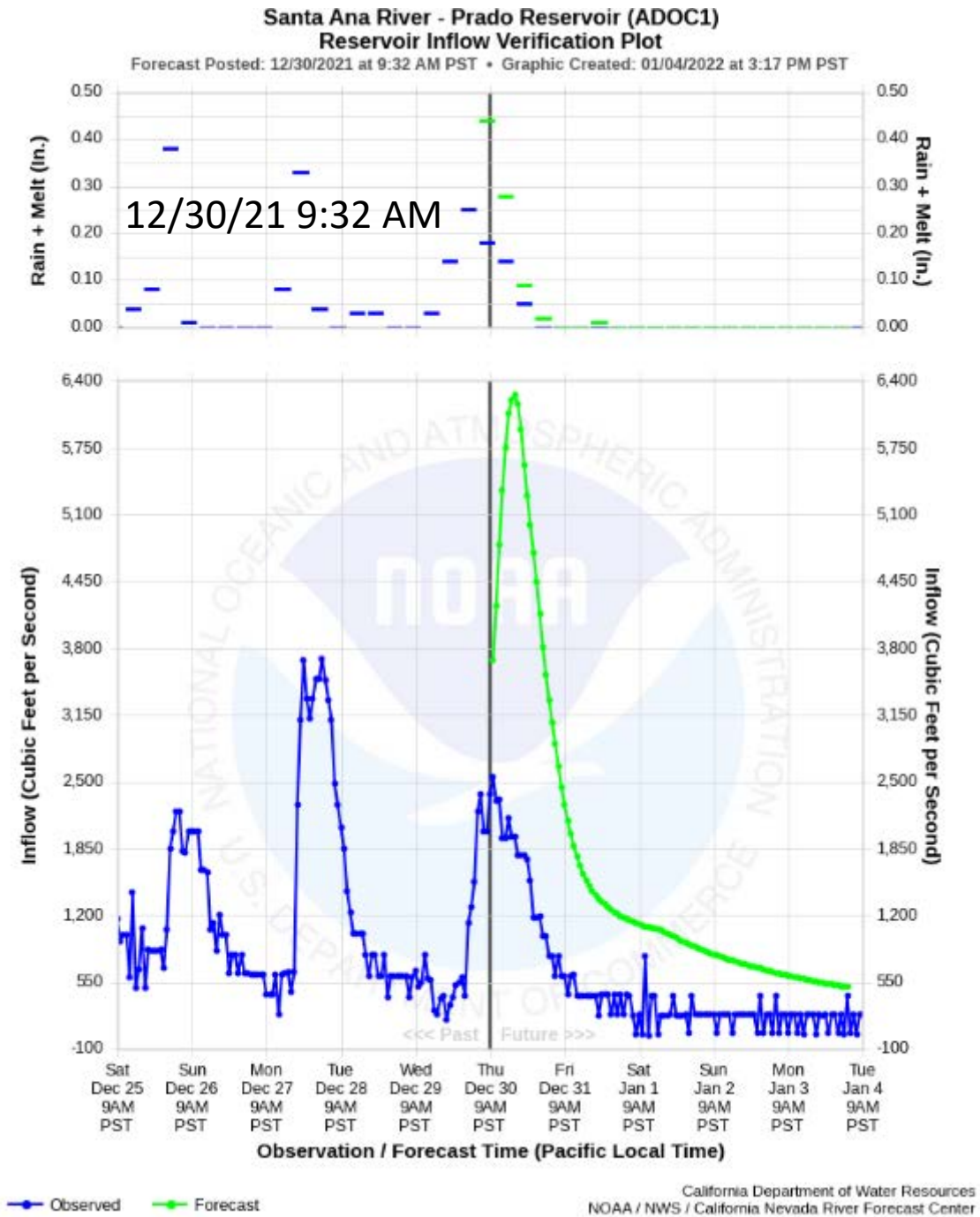

Santa Ana River - Prado Reservoir (ADOC1)
Reservoir Inflow Verification Plot
Forecast Posted: 12/27/2021 at 2:22 PM PST • Graphic Created: 01/01/2022 at 3:20 PM PST
12/27/21 2:22 PM
Rain + Melt (in.)
Inflow (Cubic Feet per Second)
<<< Past Future >>>
Observation / Forecast Time (Pacific Local Time)
Observed
Forecast
California Department of Water Resources
NOAA / NWS / California Nevada River Forecast Center

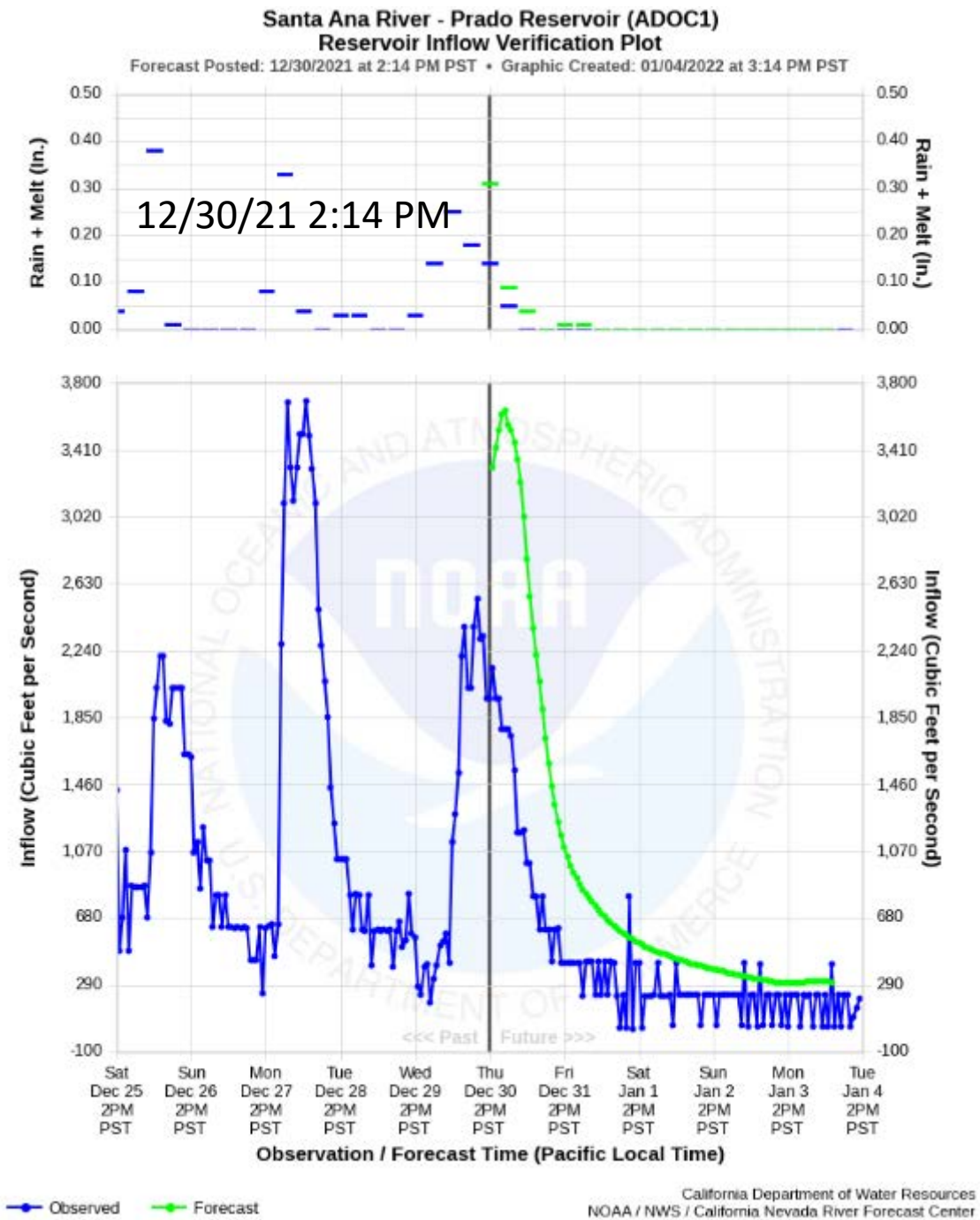

Santa Ana River - Prado Reservoir (ADOC1)
Reservoir Inflow Verification Plot
Forecast Posted: 12/28/2021 at 9:05 AM PST • Graphic Created: 01/02/2022 at 3:20 PM PST
12/28/21 9:05 AM
Rain + Melt (In.)
Inflow (Cubic Feet per Second)
Observation / Forecast Time (Pacific Local Time)
Observed
Forecast
California Department of Water Resources
NOAA / NWS / California Nevada River Forecast Center

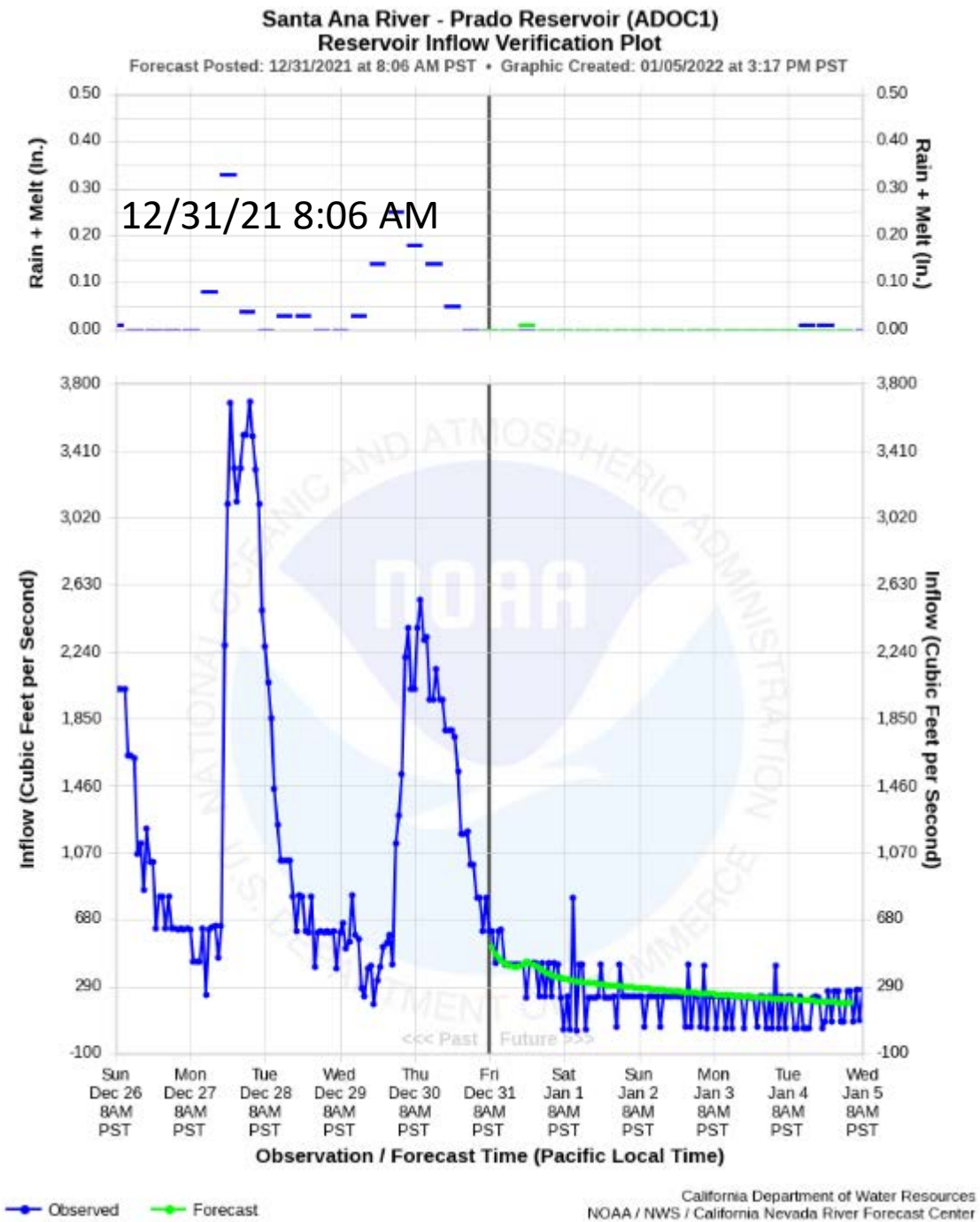

Santa Ana River - Prado Reservoir (ADOC1)
Reservoir Inflow Verification Plot
Forecast Posted: 12/28/2021 at 2:00 PM PST • Graphic Created: 01/02/2022 at 3:18 PM PST
12/28/21 2:00 PM
Rain + Melt (In.)
Inflow (Cubic Feet per Second)
Observation / Forecast Time (Pacific Local Time)
Observed
Forecast
California Department of Water Resources
NOAA / NWS / California Nevada River Forecast Center


Santa Ana River - Prado Reservoir (ADOC1)
Reservoir Inflow Verification Plot
Forecast Posted: 12/29/2021 at 8:10 AM PST • Graphic Created: 01/03/2022 at 3:17 PM PST
12/29/21 8:10 AM
Rain + Melt (in.)
Inflow (Cubic Feet per Second)
<<< Past Future >>>
Observation / Forecast Time (Pacific Local Time)
Observed
Forecast
California Department of Water Resources
NOAA / NWS / California Nevada River Forecast Center


Santa Ana River - Prado Reservoir (ADOC1)
Reservoir Inflow Verification Plot
Forecast Posted: 12/29/2021 at 1:52 PM PST • Graphic Created: 01/03/2022 at 3:14 PM PST
12/29/21 1:52 PM
Rain + Melt (in.)
Inflow (Cubic Feet per Second)
<<< Past Future >>>
Observation / Forecast Time (Pacific Local Time)
Observed
Forecast
California Department of Water Resources
NOAA / NWS / California Nevada River Forecast Center

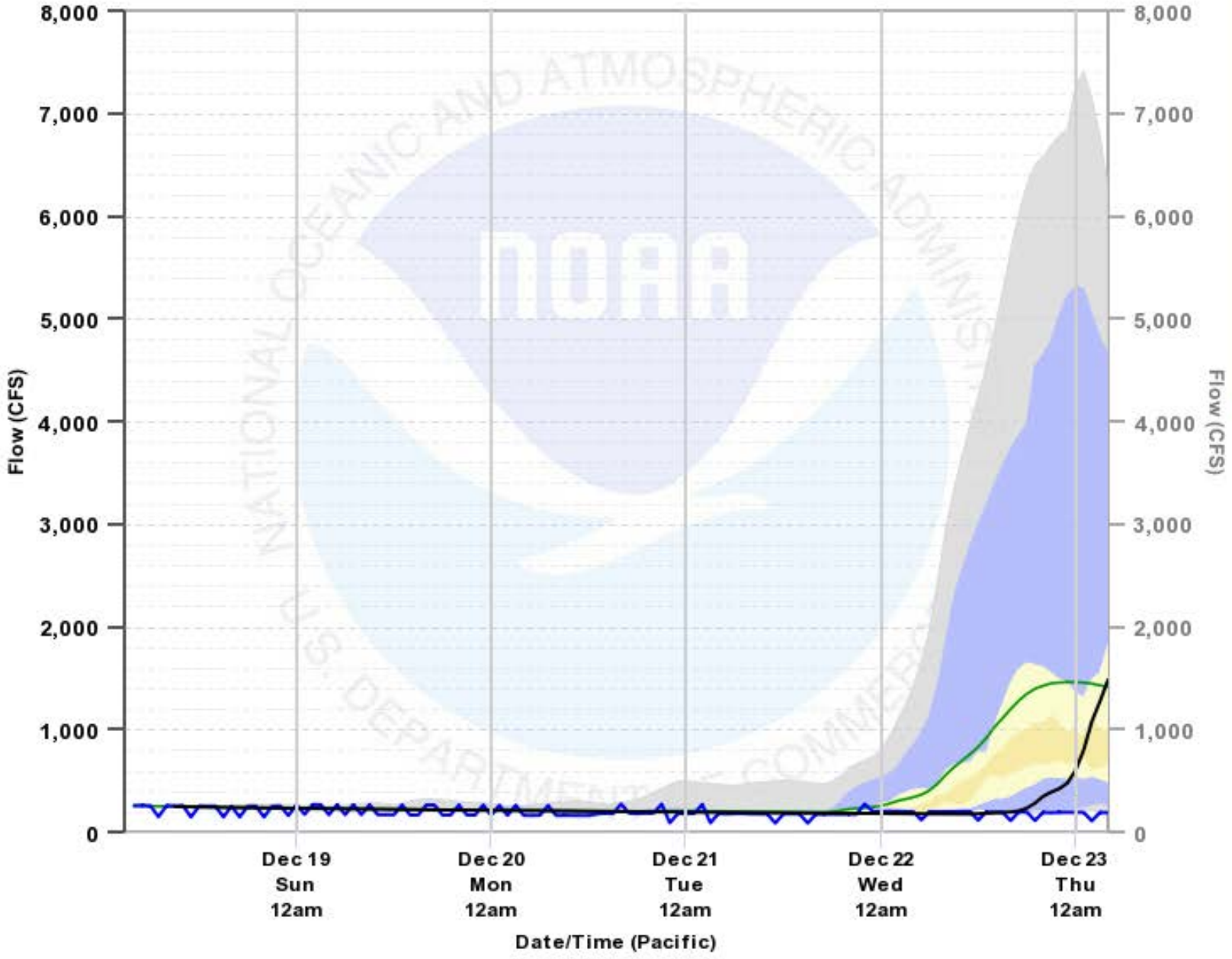

Santa Ana River - Prado Reservoir (ADOC1)
Reservoir Inflow Verification Plot
Forecast Posted: 12/30/2021 at 9:32 AM PST • Graphic Created: 01/04/2022 at 3:17 PM PST
12/30/21 9:32 AM
Rain + Melt (in.)
Inflow (Cubic Feet per Second)
<<< Past
Future >>>
Observation / Forecast Time (Pacific Local Time)
Observed
Forecast
California Department of Water Resources
NOAA / NWS / California Nevada River Forecast Center


Santa Ana River - Prado Reservoir (ADOC1)
Reservoir Inflow Verification Plot
Forecast Posted: 12/30/2021 at 2:14 PM PST • Graphic Created: 01/04/2022 at 3:14 PM PST
12/30/21 2:14 PM
Rain + Melt (in.)
Inflow (Cubic Feet per Second)
<<< Past
Future >>>
Observation / Forecast Time (Pacific Local Time)
Observed
Forecast
California Department of Water Resources
NOAA / NWS / California Nevada River Forecast Center


Santa Ana River - Prado Reservoir (ADOC1)
Reservoir Inflow Verification Plot
Forecast Posted: 12/31/2021 at 8:06 AM PST • Graphic Created: 01/05/2022 at 3:17 PM PST
12/31/21 8:06 AM
Rain + Melt (In.)
0.50
0.40
0.30
0.20
0.10
0.00
Inflow (Cubic Feet per Second)
3,800
3,410
3,020
2,630
2,240
1,850
1,460
1,070
680
290
-100
<<< Past
Future >>>
Sun Dec 26 8AM PST
Mon Dec 27 8AM PST
Tue Dec 28 8AM PST
Wed Dec 29 8AM PST
Thu Dec 30 8AM PST
Fri Dec 31 8AM PST
Sat Jan 1 8AM PST
Sun Jan 2 8AM PST
Mon Jan 3 8AM PST
Tue Jan 4 8AM PST
Wed Jan 5 8AM PST
Observation / Forecast Time (Pacific Local Time)
Observed
Forecast
California Department of Water Resources
NOAA / NWS / California Nevada River Forecast Center

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/18/2021 at 9:00 AM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/18/2021 4 am - 12/23/2021 4 am

Max	7,410
5%	5,320
10%	4,650
25%	2,244
50%	1,249
75%	840
90%	579
95%	363
Min	255

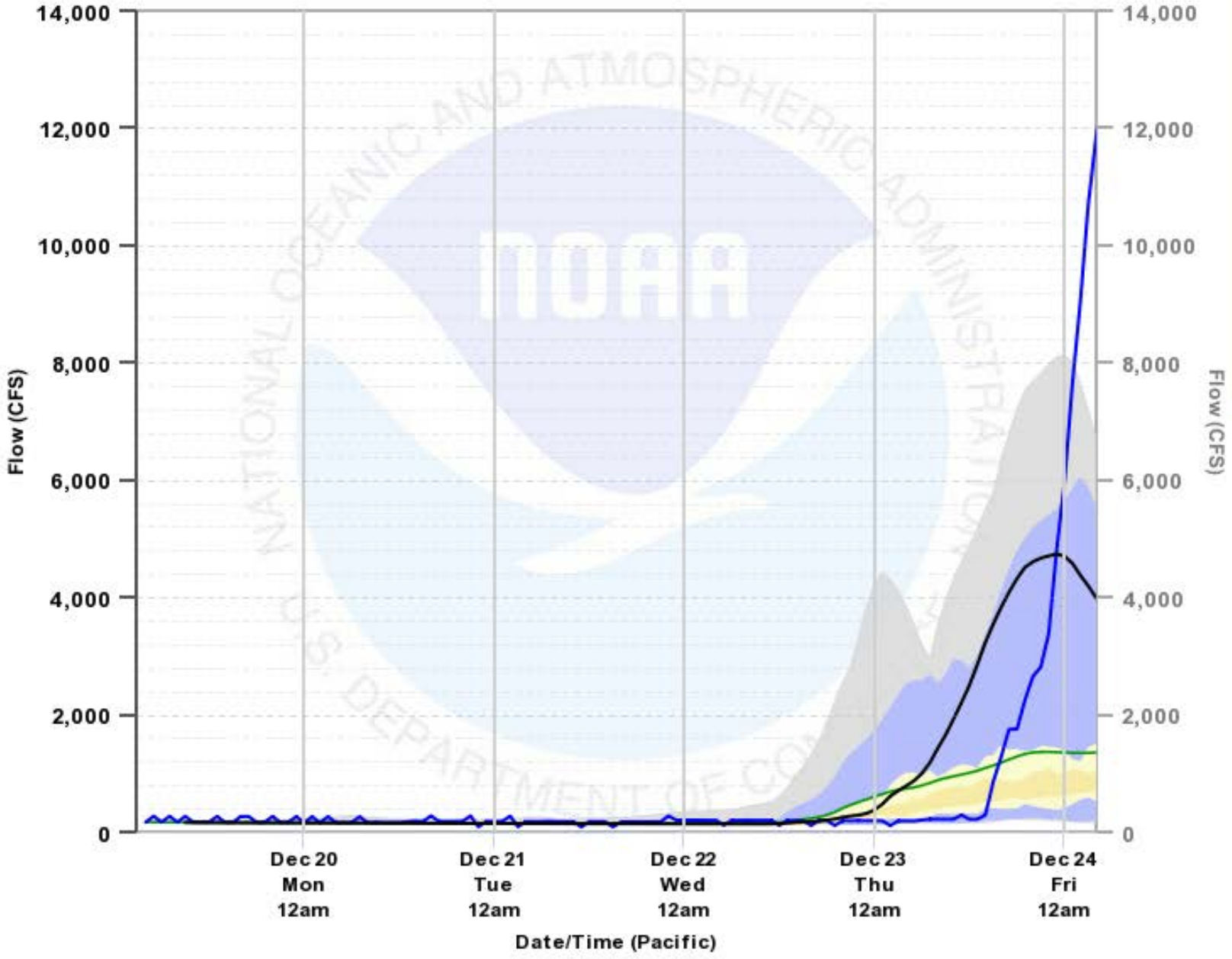
- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/19/2021 at 9:00 AM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/19/2021 4 am - 12/24/2021 4 am

Max	8,133
5%	6,573
10%	4,003
25%	2,129
50%	1,299
75%	749
90%	578
95%	455
Min	257

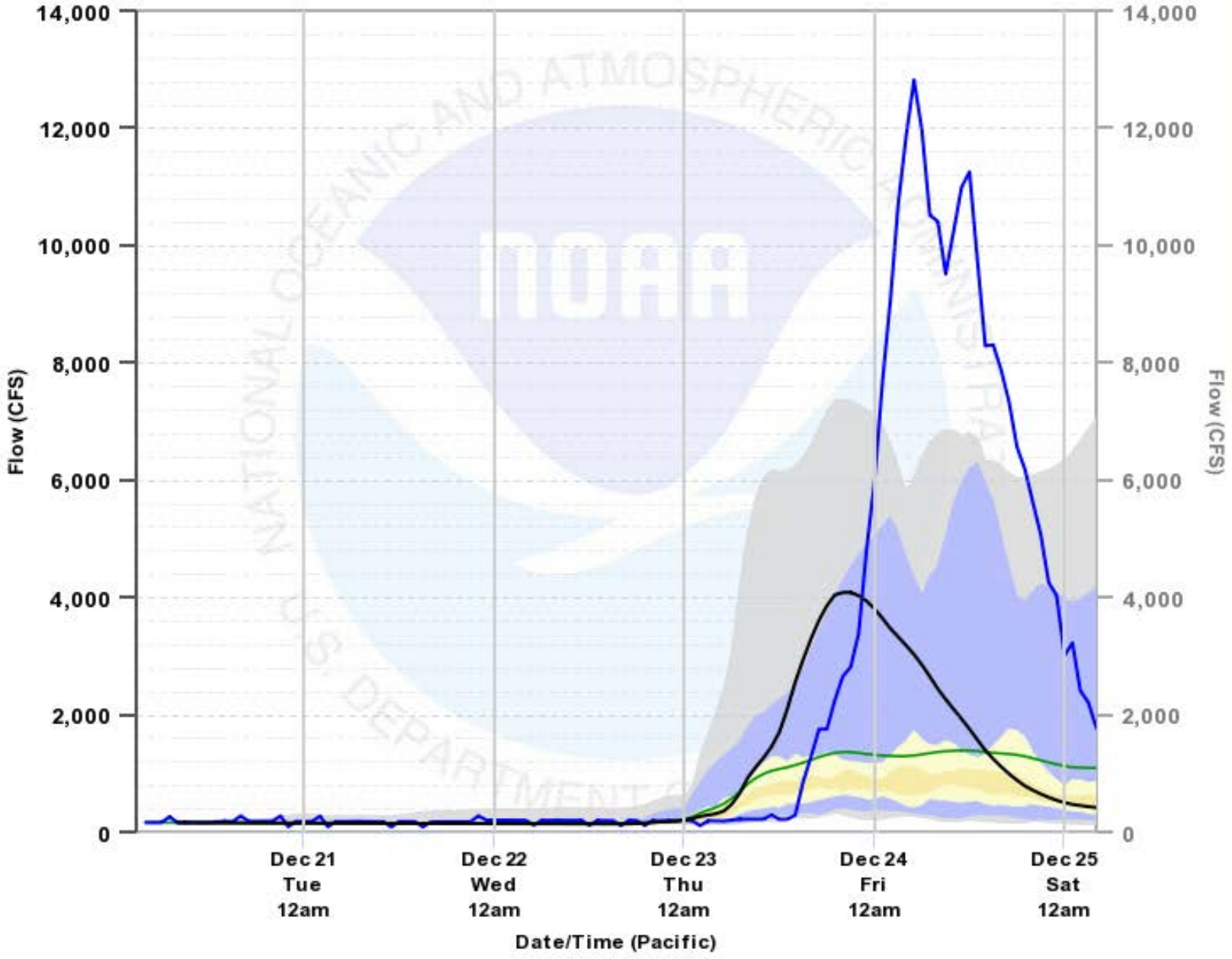
- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/20/2021 at 9:00 AM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/20/2021 4 am - 12/25/2021 4 am

Max	7,373
5%	6,997
10%	6,805
25%	2,409
50%	1,617
75%	932
90%	705
95%	596
Min	549

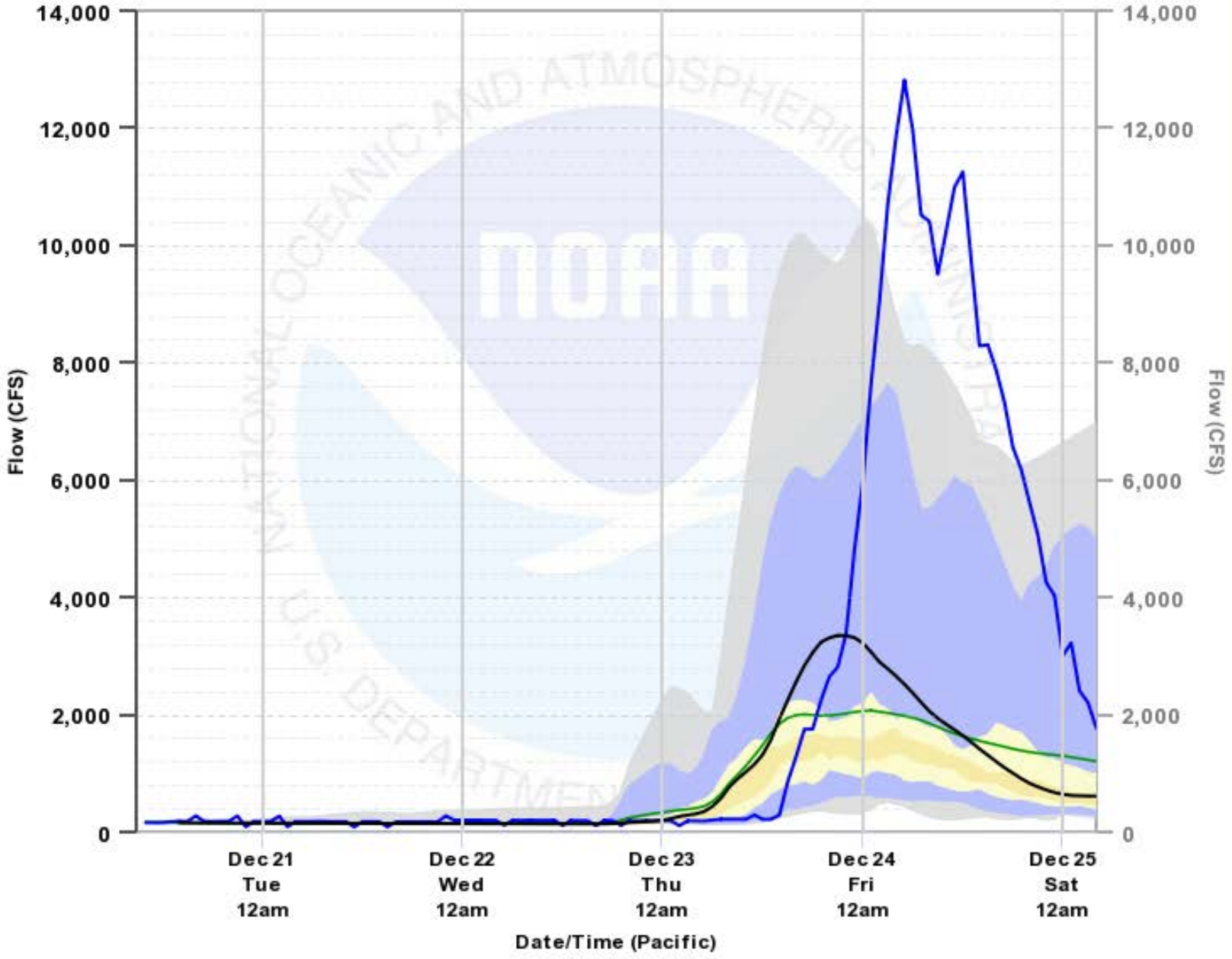
- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/20/2021 at 3:00 PM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/20/2021 10 am - 12/25/2021 4 am

Max	10,403
5%	8,318
10%	5,947
25%	3,132
50%	2,143
75%	1,537
90%	1,028
95%	891
Min	763

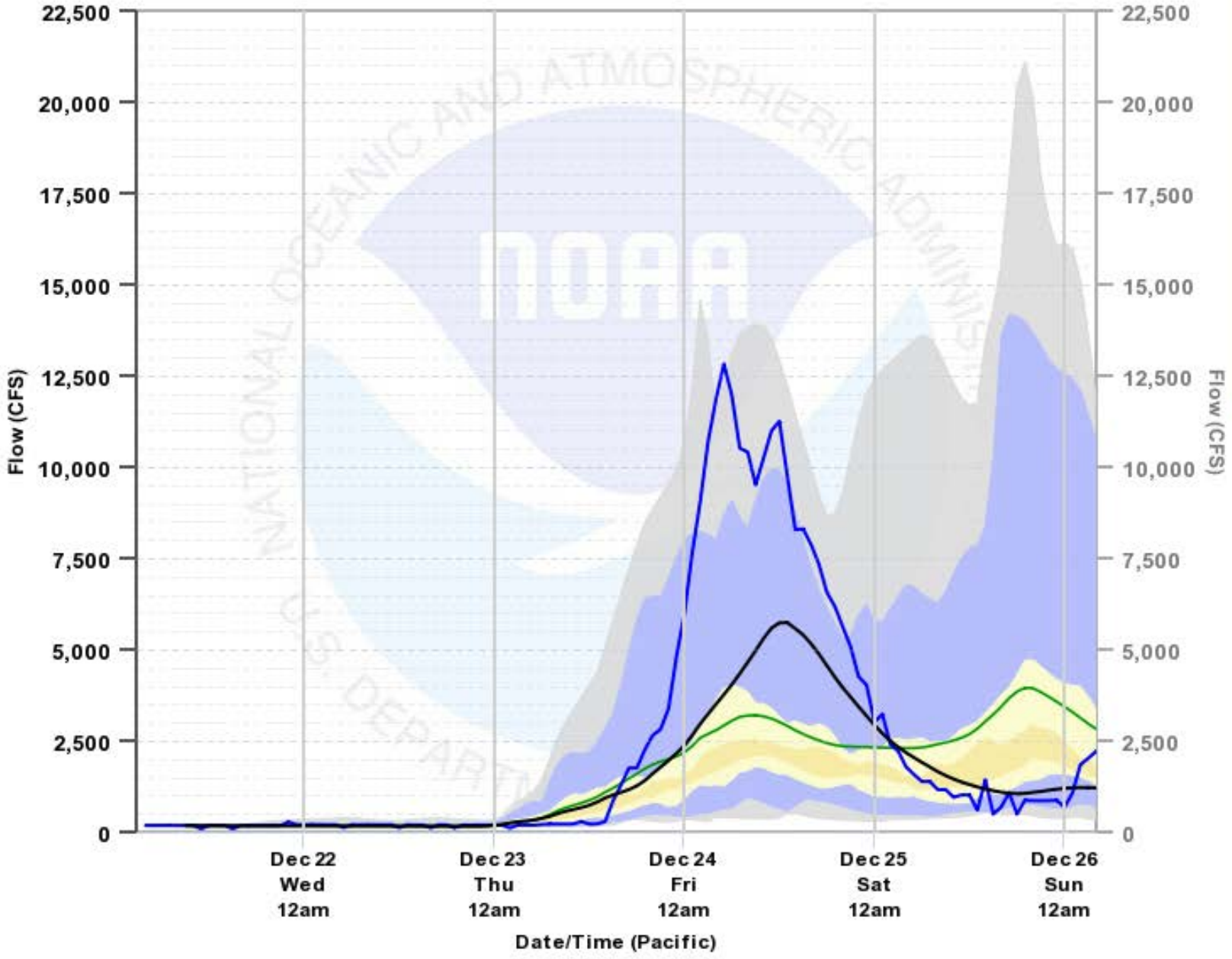
- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/21/2021 at 9:00 AM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/21/2021 4 am - 12/26/2021 4 am

Max	21,101
5%	16,151
10%	14,319
25%	6,232
50%	3,061
75%	2,424
90%	1,795
95%	1,604
Min	1,458

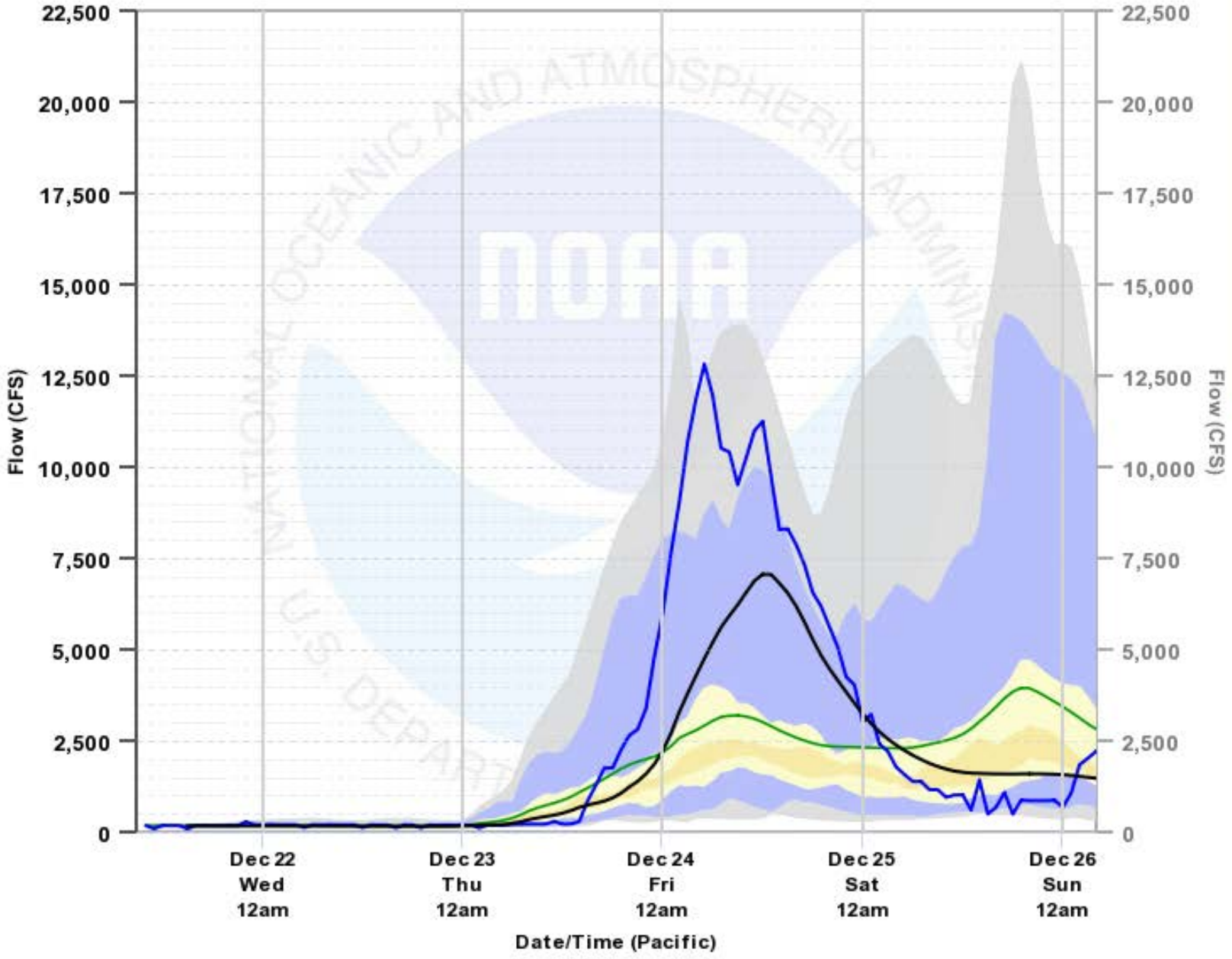
- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/21/2021 at 3:00 PM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/21/2021 10 am - 12/26/2021 4 am

Max	21,101
5%	16,146
10%	14,316
25%	6,199
50%	3,061
75%	2,423
90%	1,795
95%	1,602
Min	1,458

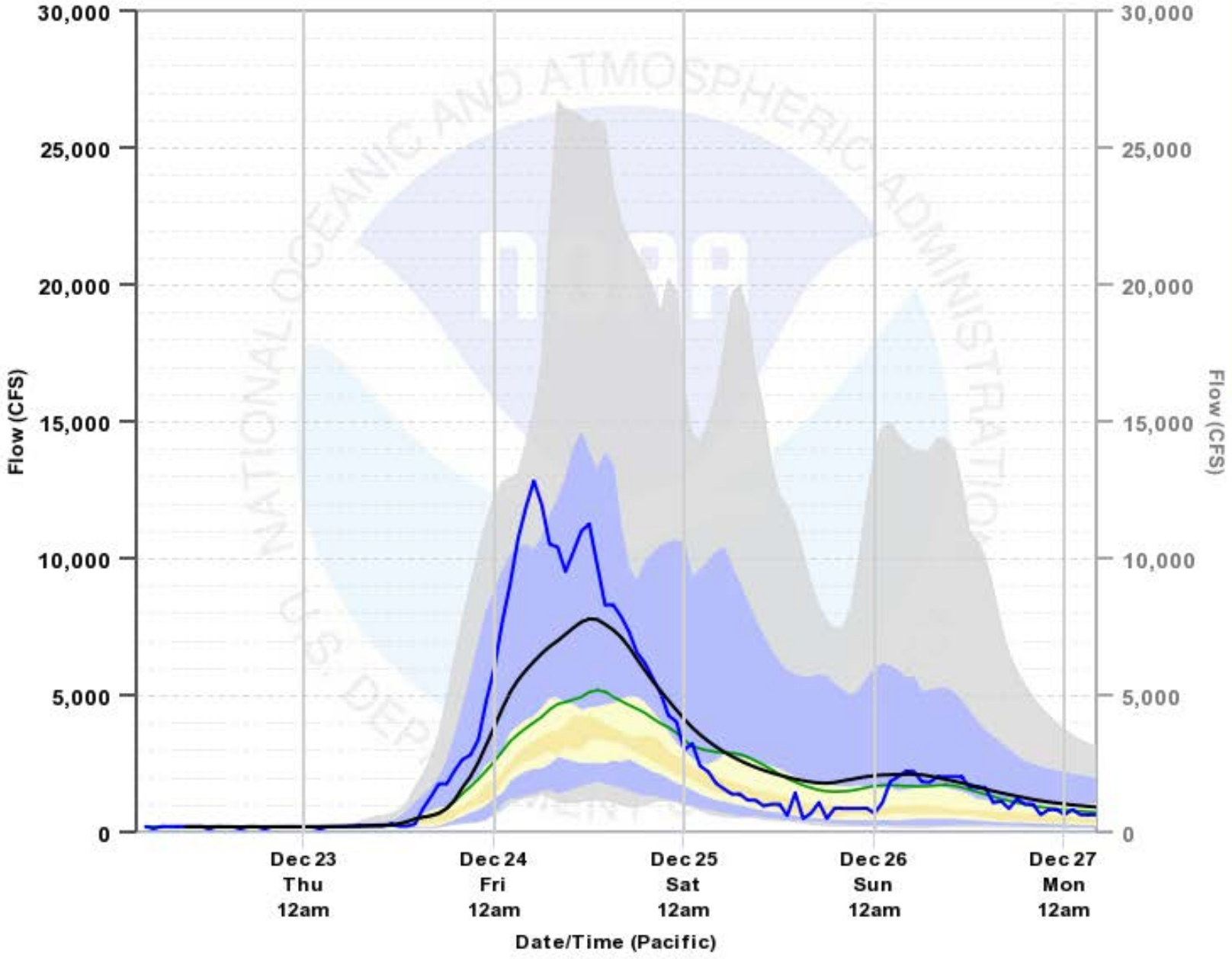
- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/22/2021 at 9:00 AM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/22/2021 4 am - 12/27/2021 4 am

Max	26,698
5%	15,538
10%	13,833
25%	6,133
50%	4,545
75%	3,057
90%	2,560
95%	2,349
Min	1,420

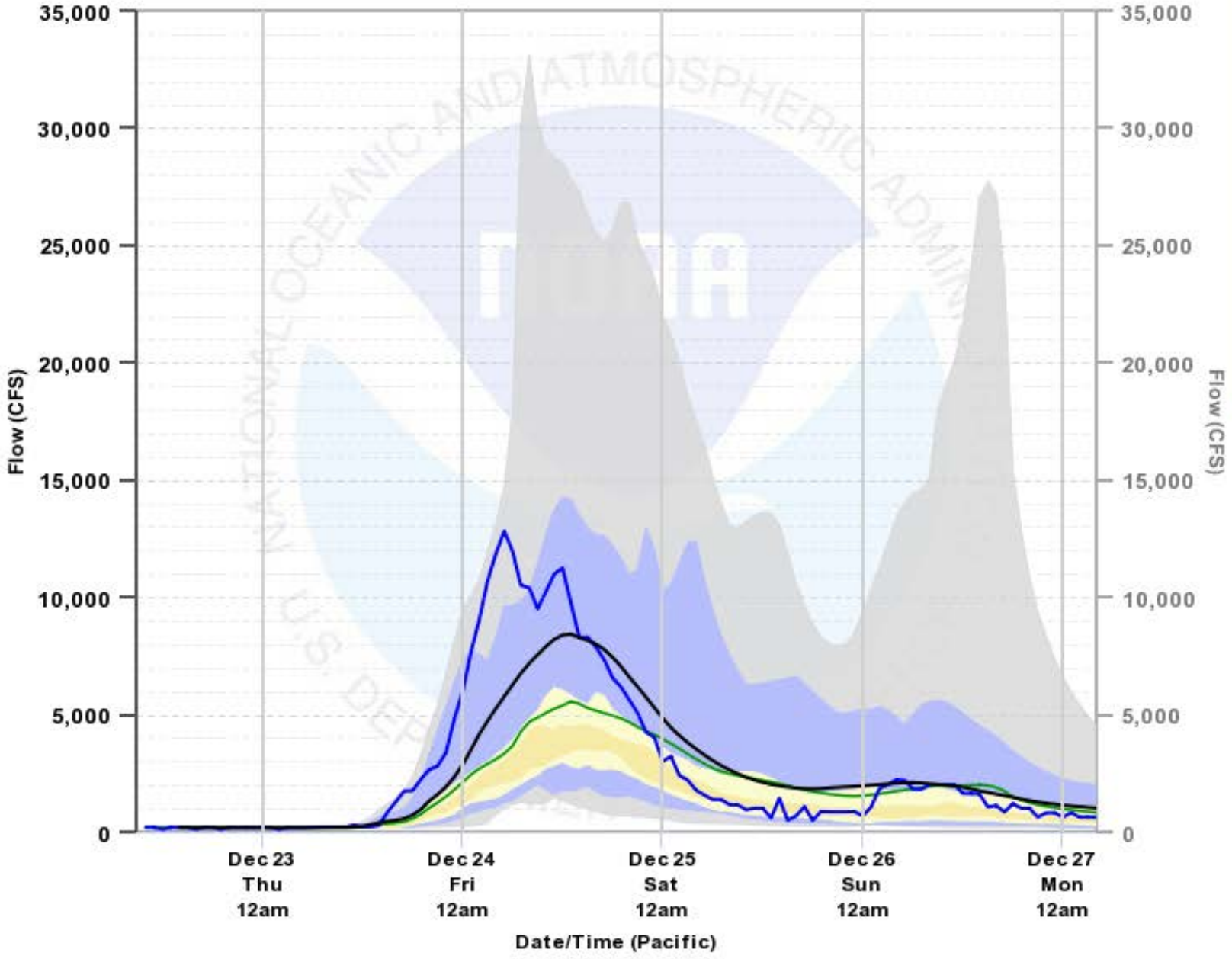
- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/22/2021 at 3:00 PM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/22/2021 10 am - 12/27/2021 4 am

Max	33,121
5%	27,358
10%	14,558
25%	6,865
50%	4,549
75%	3,324
90%	2,526
95%	2,204
Min	2,104

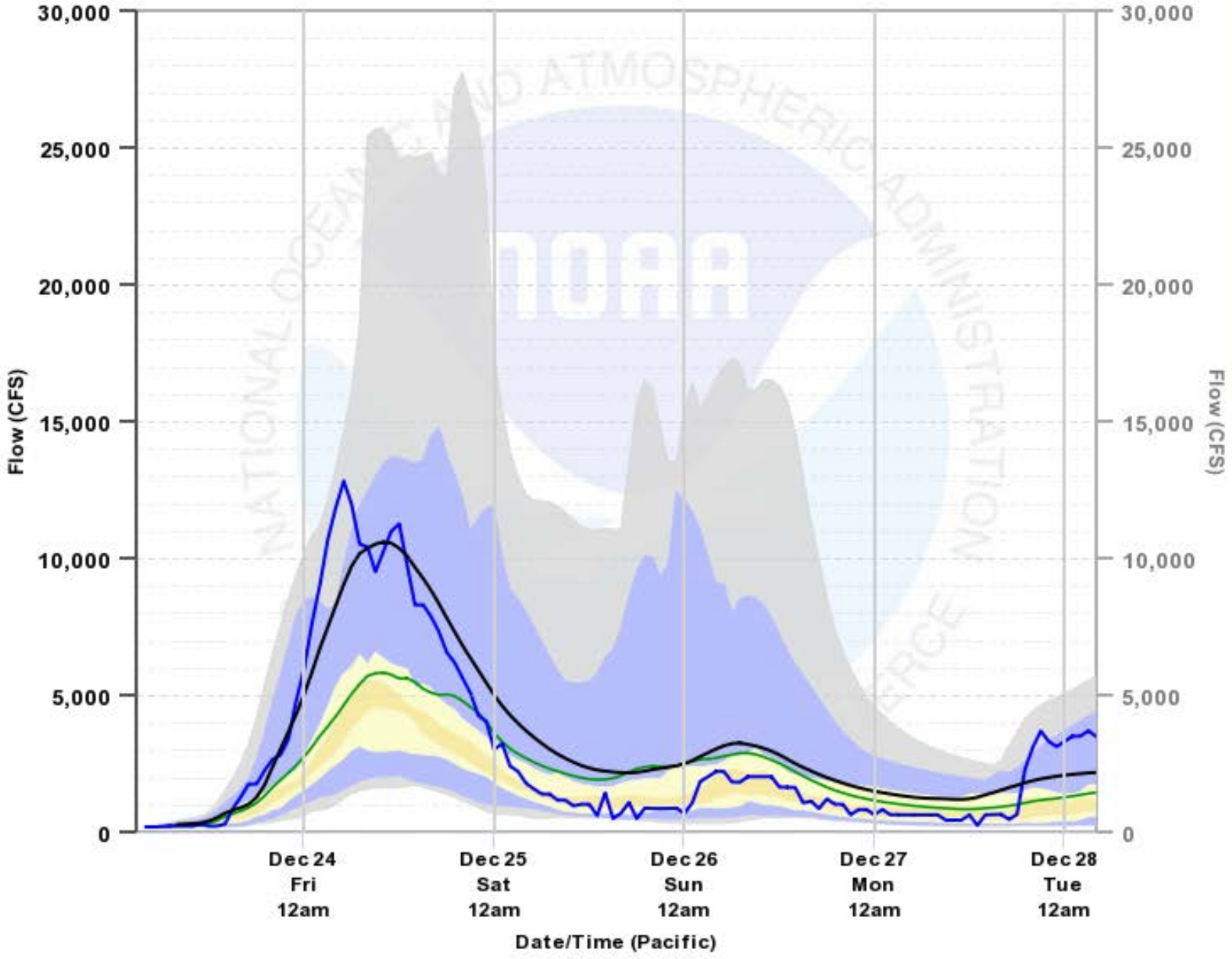
- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/23/2021 at 9:00 AM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/23/2021 4 am - 12/28/2021 4 am

Max	27,749
5%	23,847
10%	16,511
25%	8,582
50%	5,593
75%	3,345
90%	2,602
95%	2,210
Min	1,725

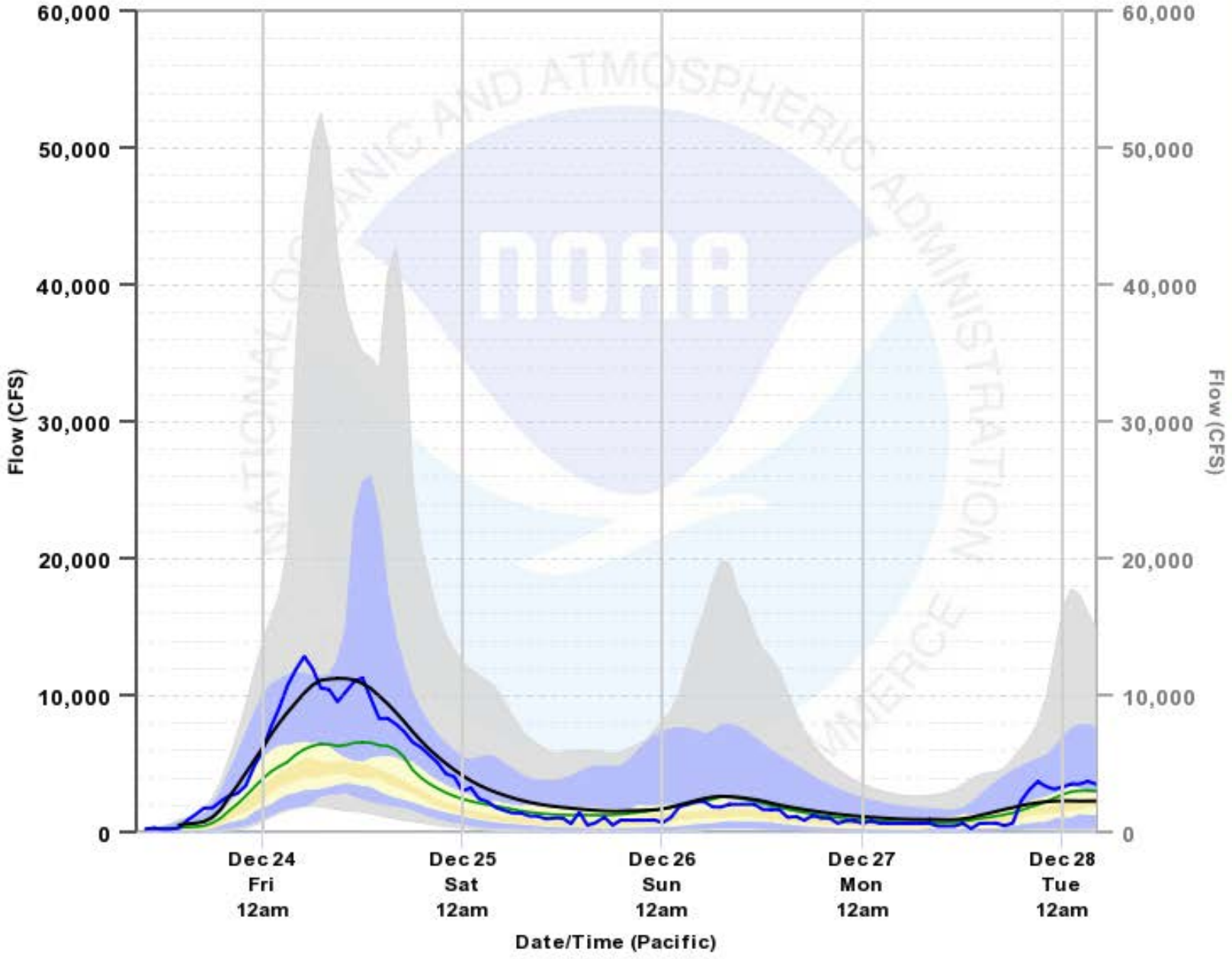
- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/23/2021 at 3:00 PM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/23/2021 10 am - 12/28/2021 4 am

Max	52,477
5%	26,004
10%	18,430
25%	9,129
50%	6,275
75%	4,357
90%	3,237
95%	3,121
Min	2,216

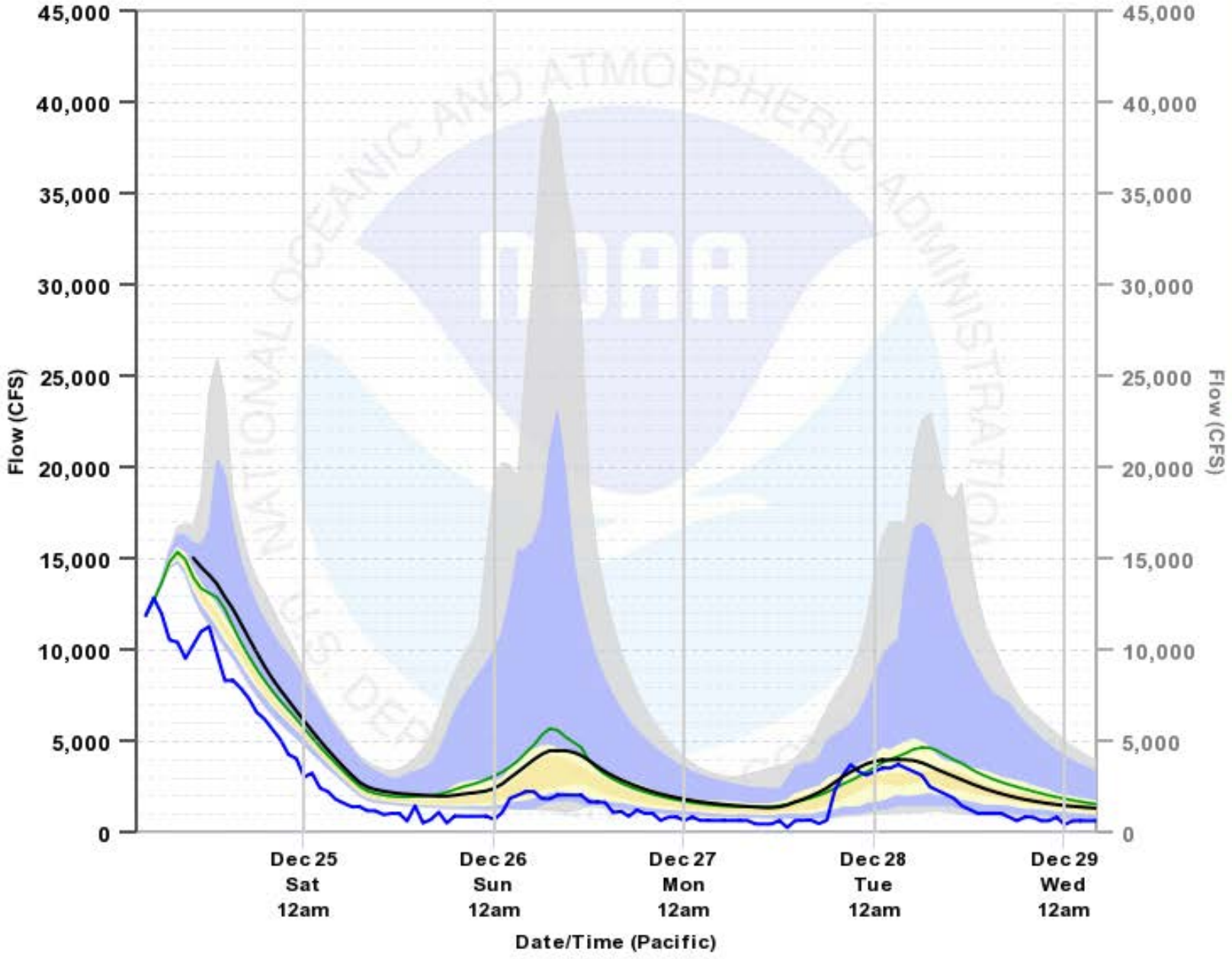
- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/24/2021 at 9:00 AM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/24/2021 4 am - 12/29/2021 4 am

Max	40,197
5%	25,958
10%	23,078
25%	17,395
50%	15,353
75%	15,068
90%	14,784
95%	14,748
Min	14,748

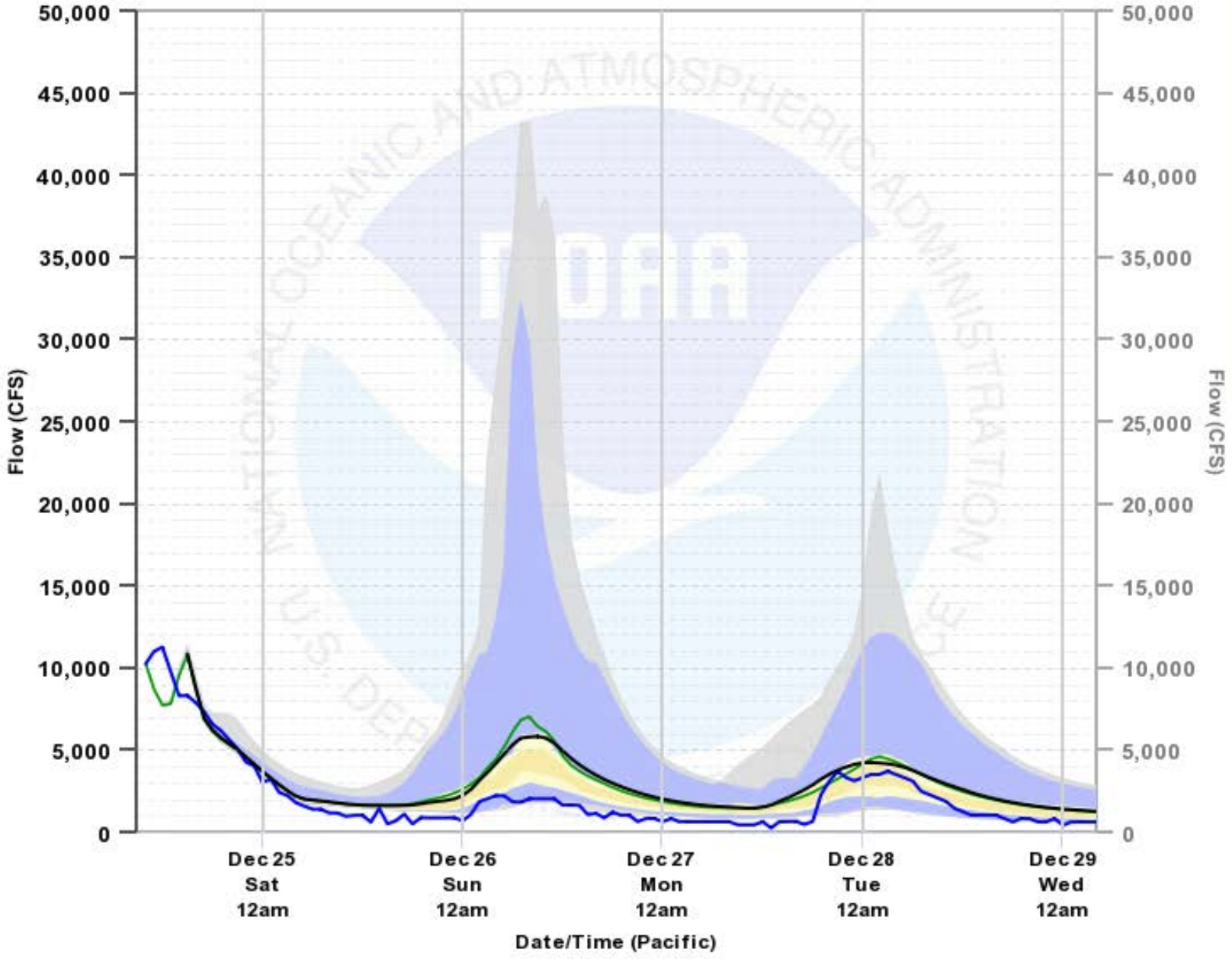
- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/24/2021 at 3:00 PM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/24/2021 10 am - 12/29/2021 4 am

Max	43,209
5%	32,224
10%	17,488
25%	11,042
50%	10,769
75%	10,681
90%	10,681
95%	10,681
Min	10,681

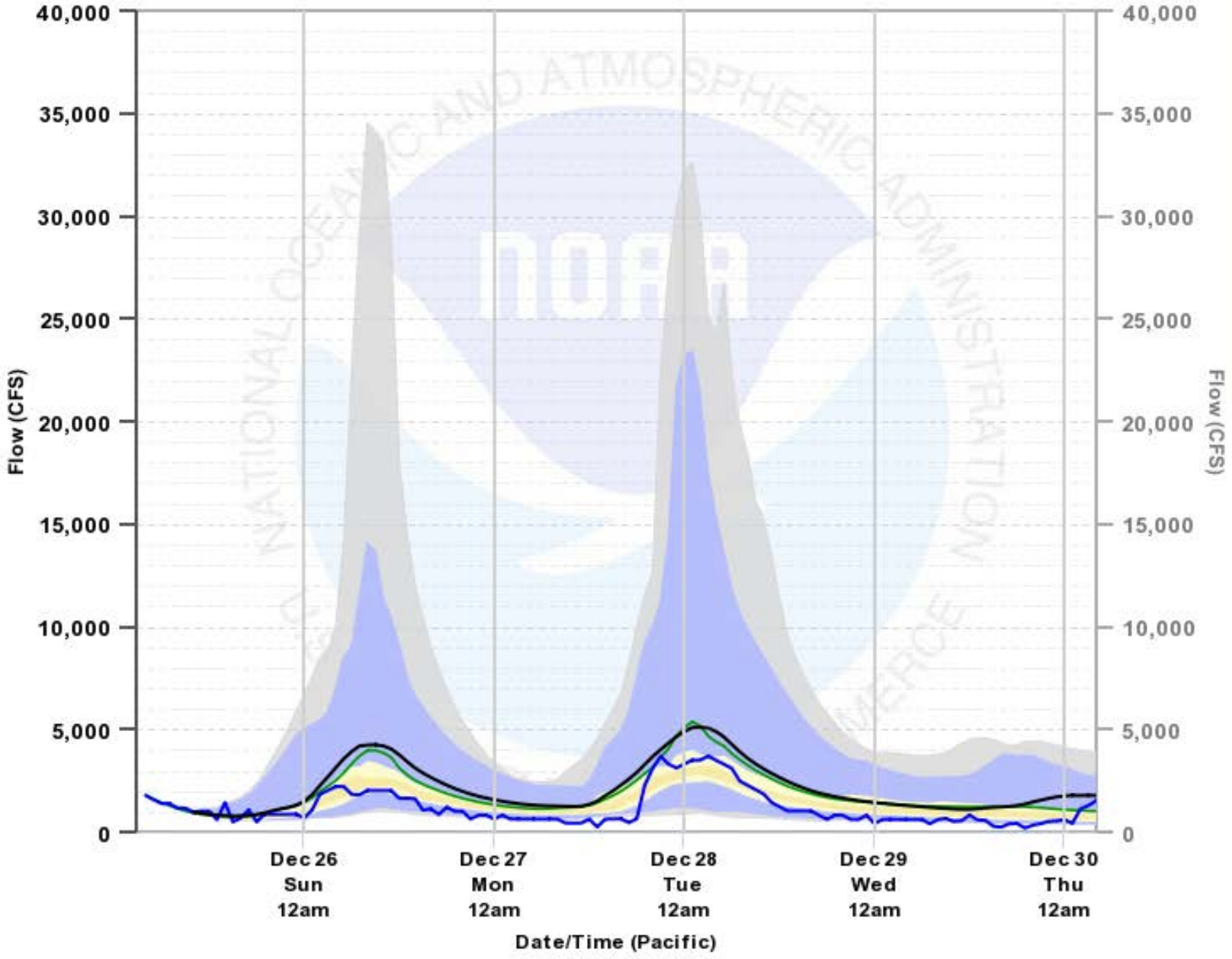
- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/25/2021 at 9:00 AM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/25/2021 4 am - 12/30/2021 4 am

Max	34,549
5%	31,342
10%	18,970
25%	5,654
50%	3,247
75%	2,760
90%	2,225
95%	1,984
Min	1,778

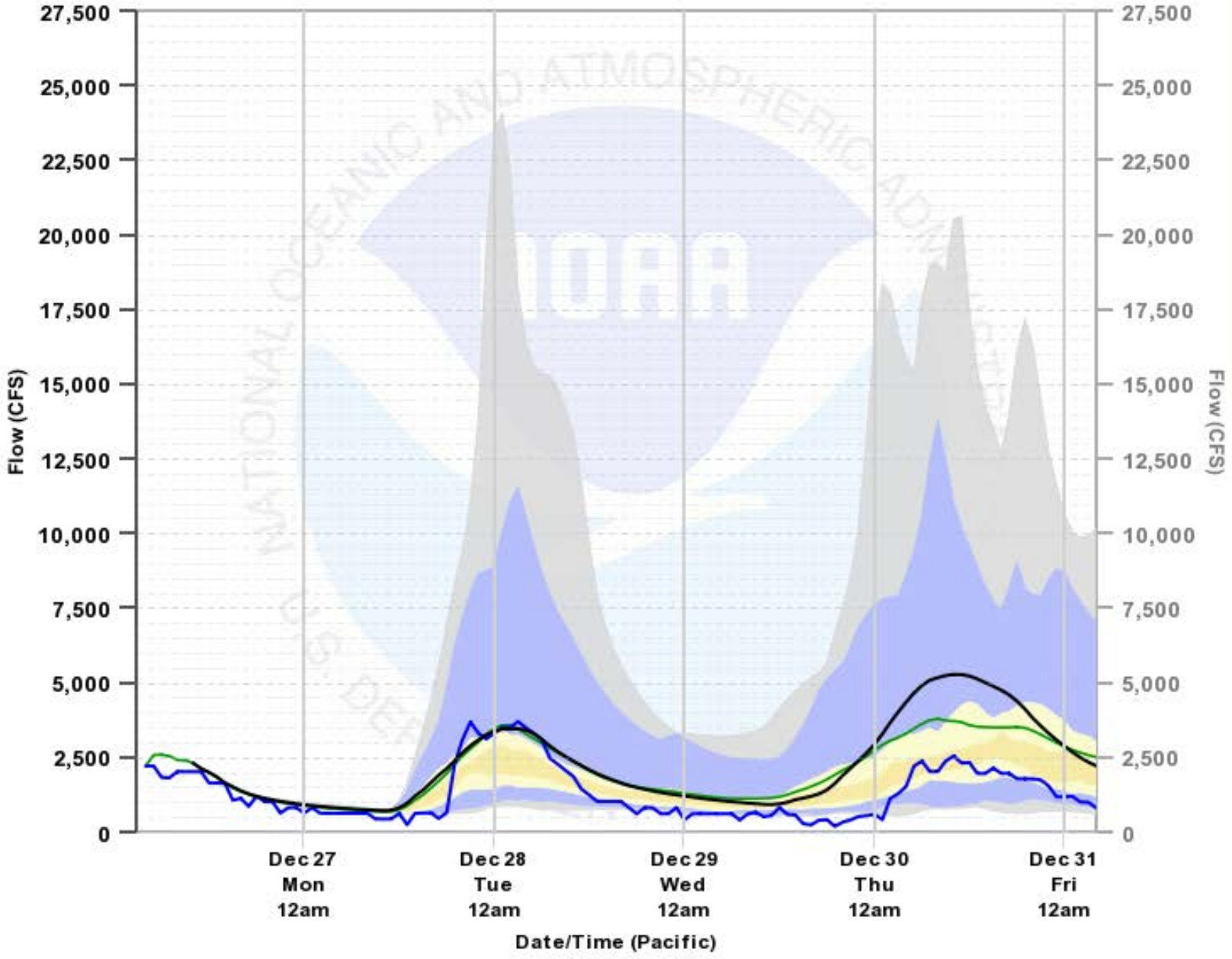
- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/26/2021 at 9:00 AM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/26/2021 4 am - 12/31/2021 4 am

Max	24,095
5%	17,192
10%	12,311
25%	7,864
50%	4,031
75%	2,912
90%	2,583
95%	2,583
Min	2,583

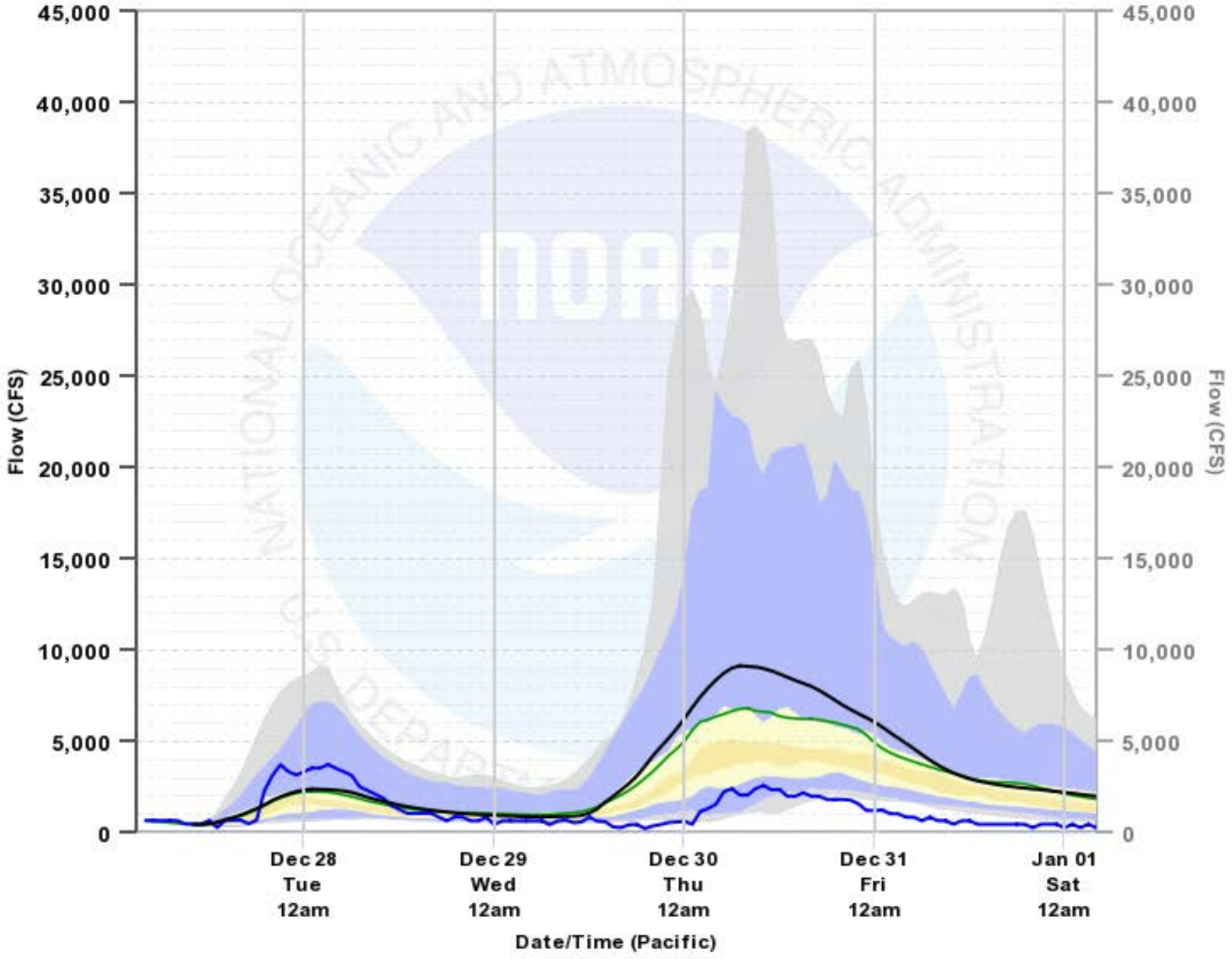
- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/27/2021 at 9:00 AM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/27/2021 4 am - 01/01/2022 4 am

Max	38,676
5%	27,576
10%	21,283
25%	9,132
50%	5,017
75%	4,110
90%	3,212
95%	3,000
Min	2,620

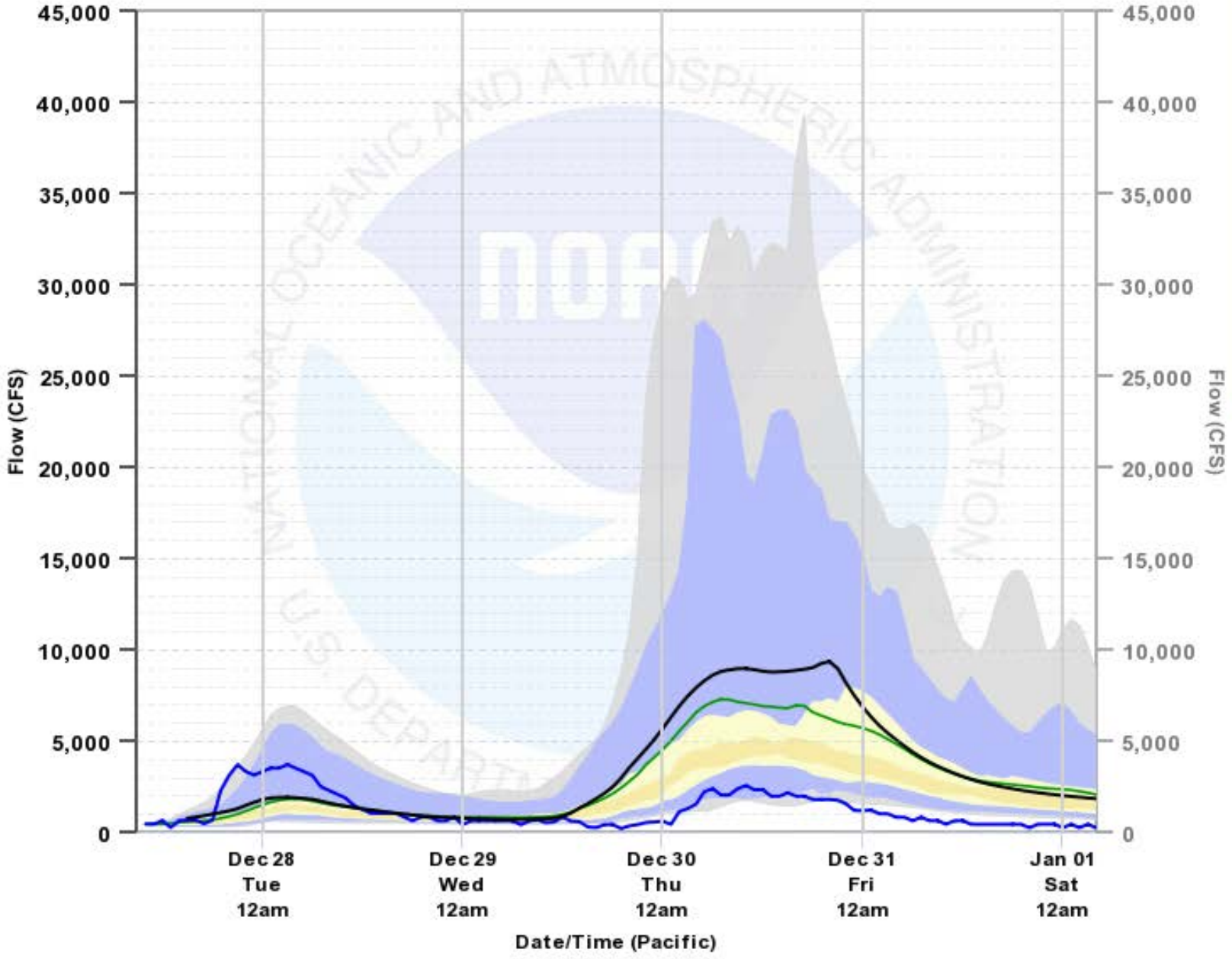
- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/27/2021 at 3:00 PM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/27/2021 10 am - 01/01/2022 4 am

Max	39,314
5%	33,263
10%	22,759
25%	11,863
50%	5,806
75%	4,674
90%	3,677
95%	3,149
Min	2,722

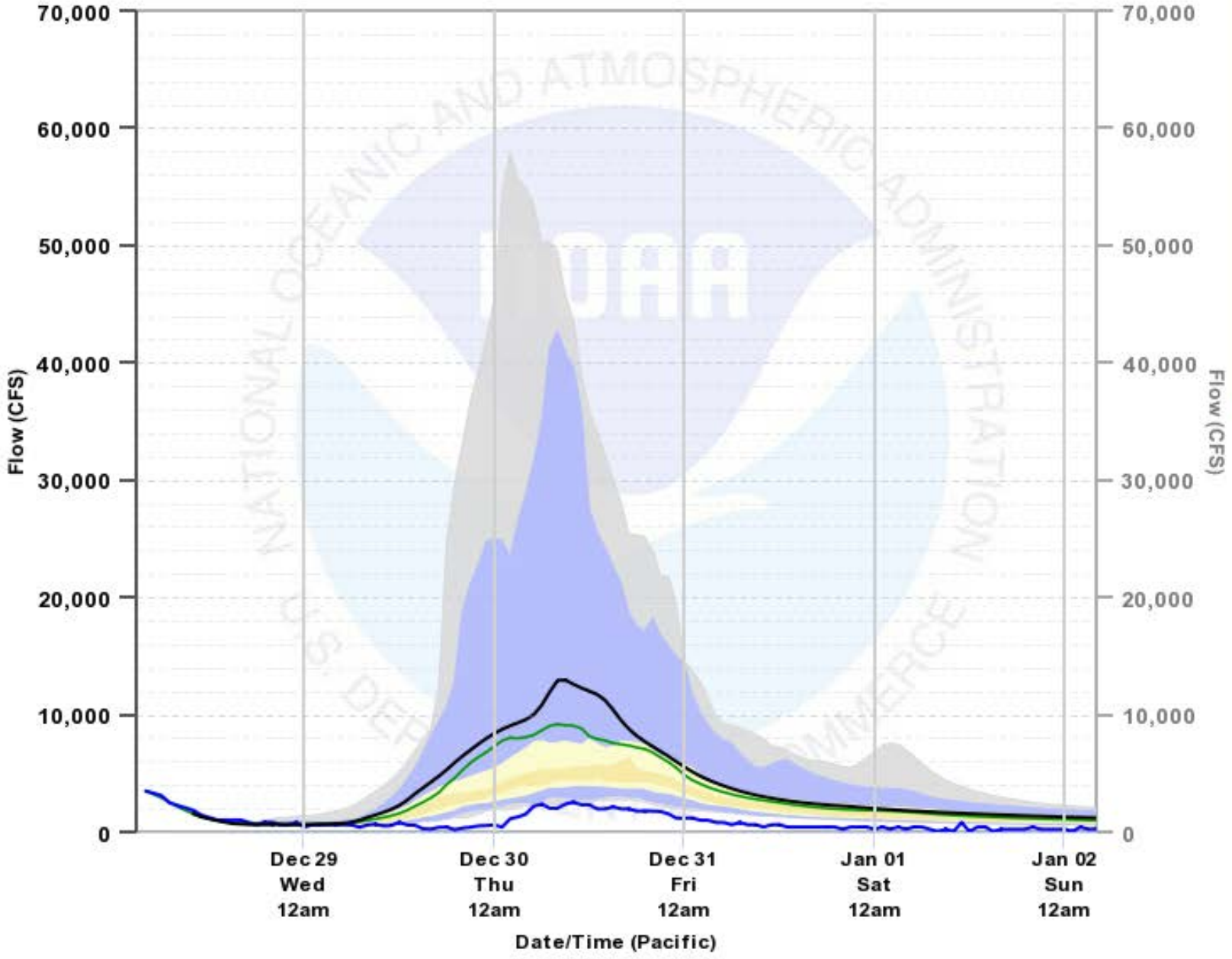
- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/28/2021 at 9:00 AM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/28/2021 4 am - 01/02/2022 4 am

Max	57,940
5%	42,729
10%	25,794
25%	14,202
50%	5,829
75%	4,448
90%	3,691
95%	3,490
Min	3,490

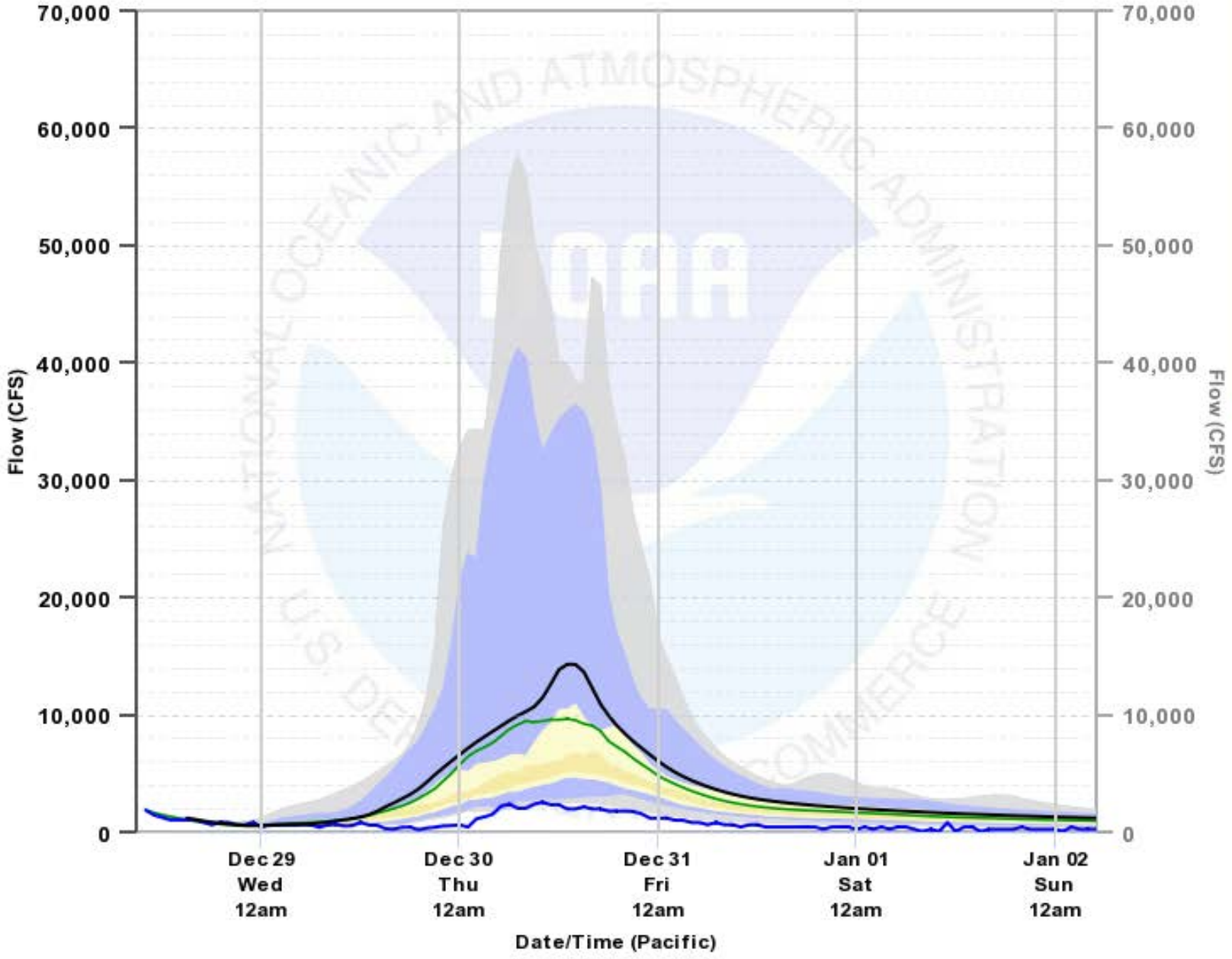
- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/28/2021 at 3:00 PM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/28/2021 10 am - 01/02/2022 5 am

Max	57,708
5%	42,634
10%	23,788
25%	14,834
50%	6,284
75%	4,846
90%	3,886
95%	3,612
Min	2,832

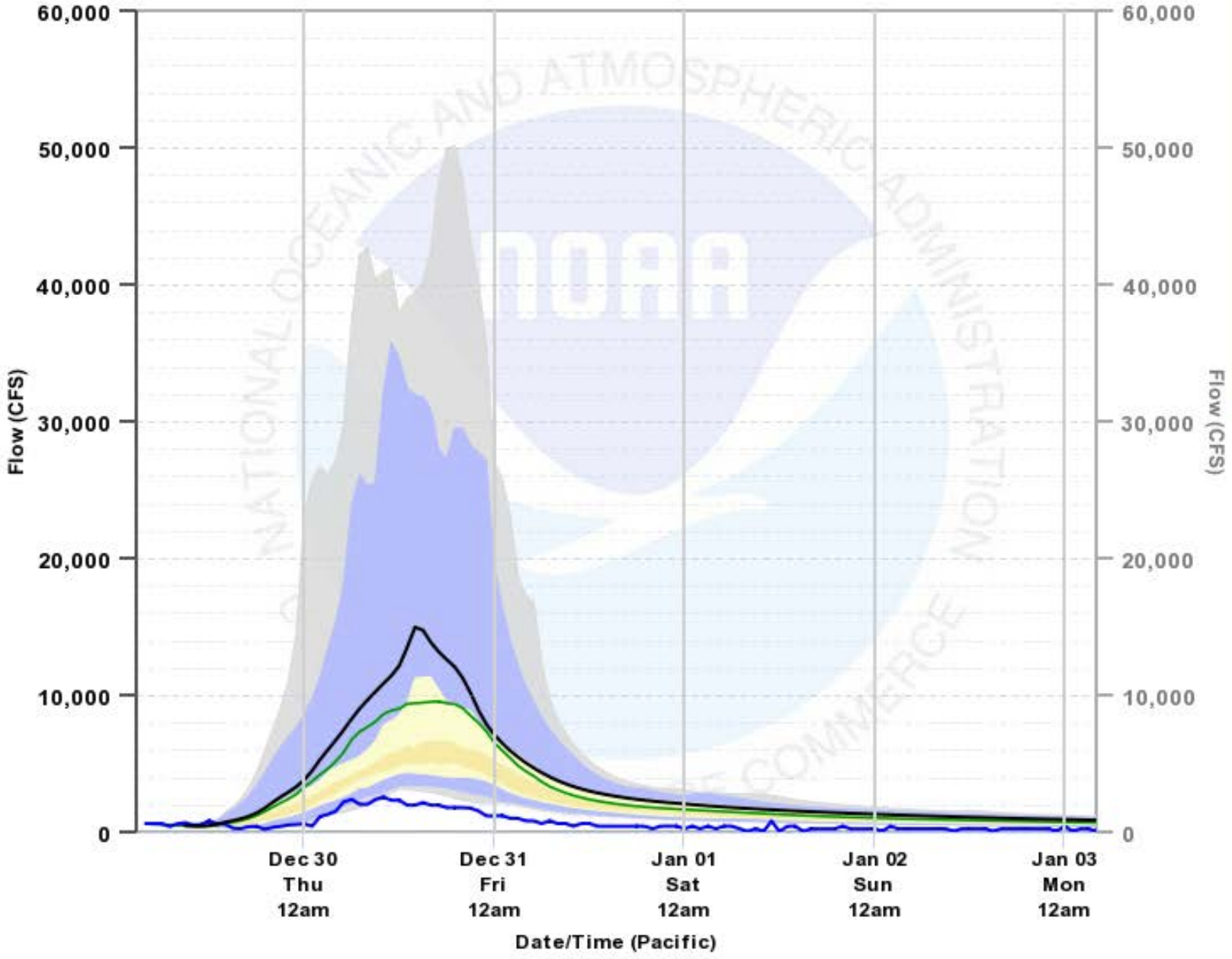
- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/29/2021 at 9:00 AM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/29/2021 4 am - 01/03/2022 4 am

Max	50,122
5%	41,157
10%	29,514
25%	14,324
50%	6,478
75%	4,796
90%	4,086
95%	3,588
Min	3,123

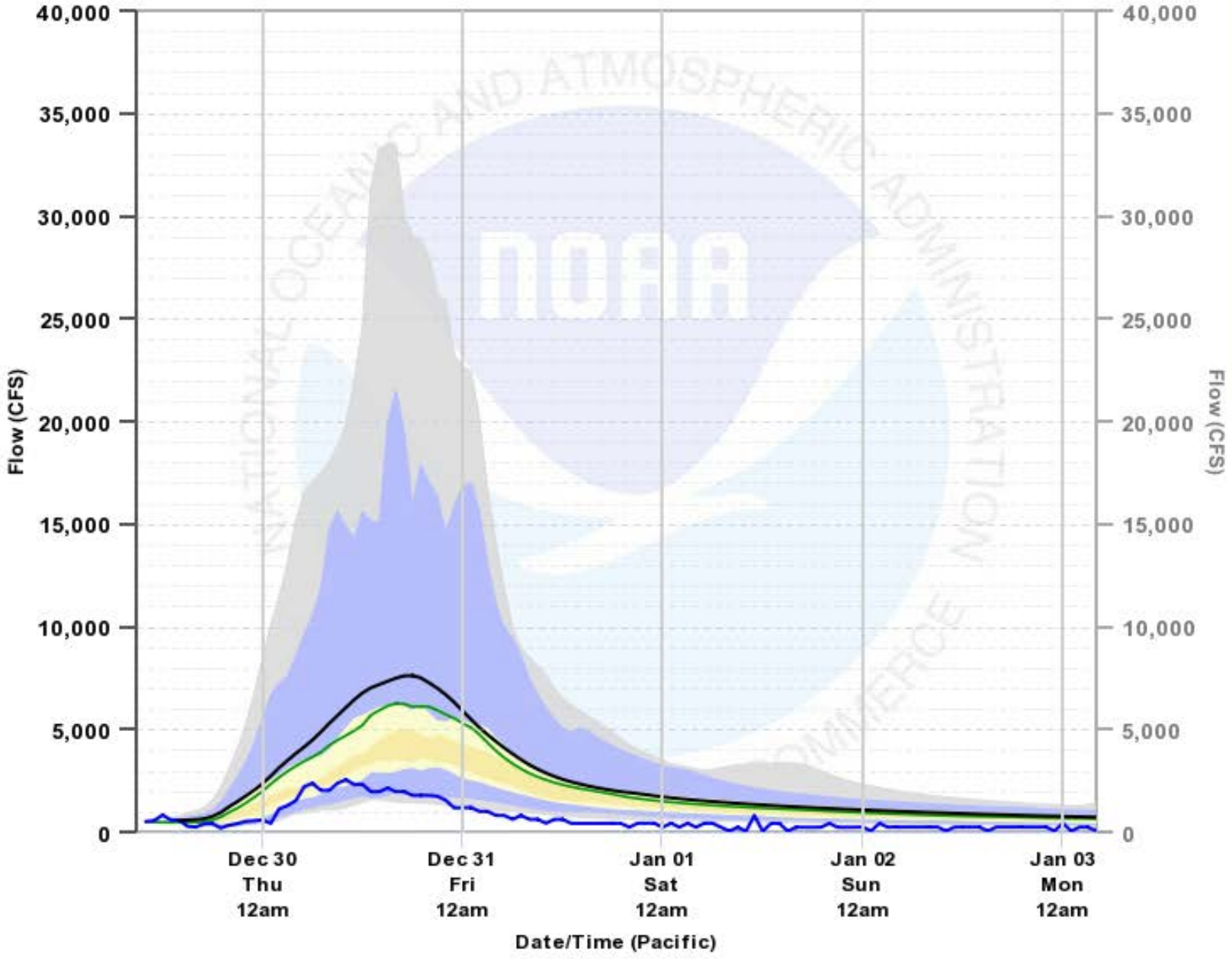
- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/29/2021 at 3:00 PM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/29/2021 10 am - 01/03/2022 4 am

Max	33,538
5%	22,677
10%	17,030
25%	7,933
50%	4,280
75%	3,451
90%	3,035
95%	2,339
Min	1,837

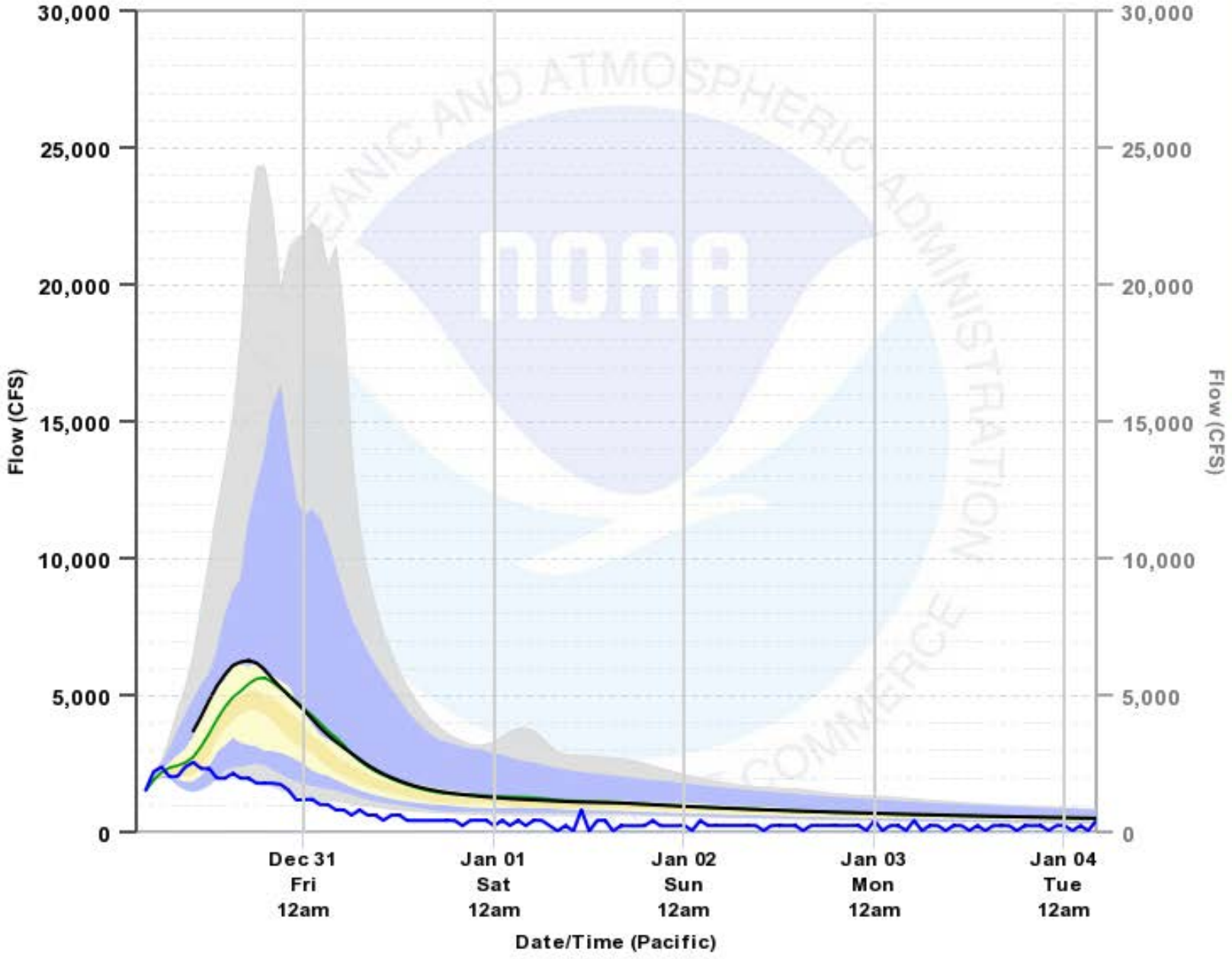
- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/30/2021 at 9:00 AM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/30/2021 4 am - 01/04/2022 4 am

Max	24,316
5%	19,852
10%	8,661
25%	6,450
50%	4,791
75%	3,497
90%	2,698
95%	2,623
Min	2,133

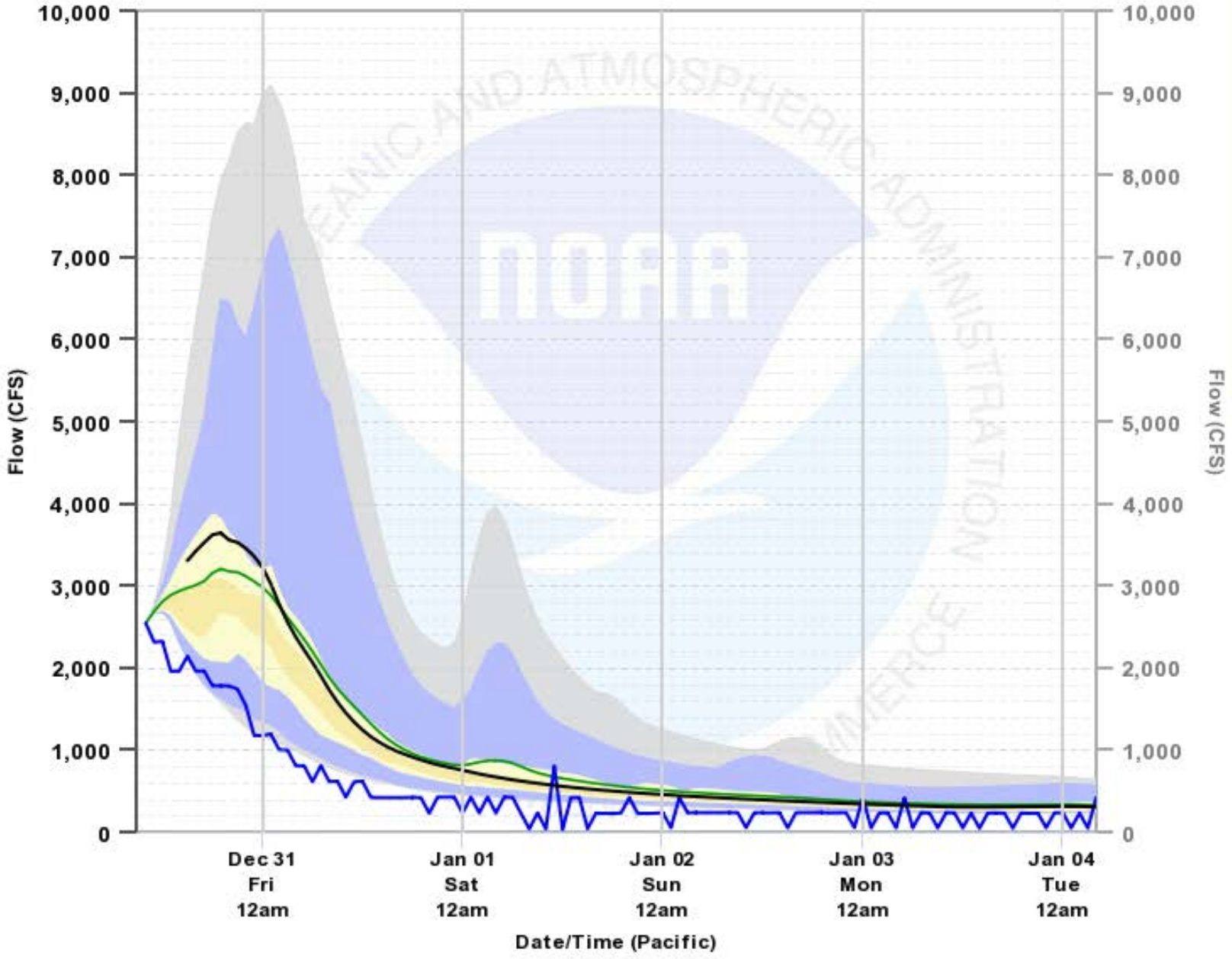
- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/30/2021 at 3:00 PM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/30/2021 10 am - 01/04/2022 4 am

Max	9,096
5%	7,463
10%	6,090
25%	3,914
50%	3,036
75%	2,713
90%	2,678
95%	2,674
Min	2,674

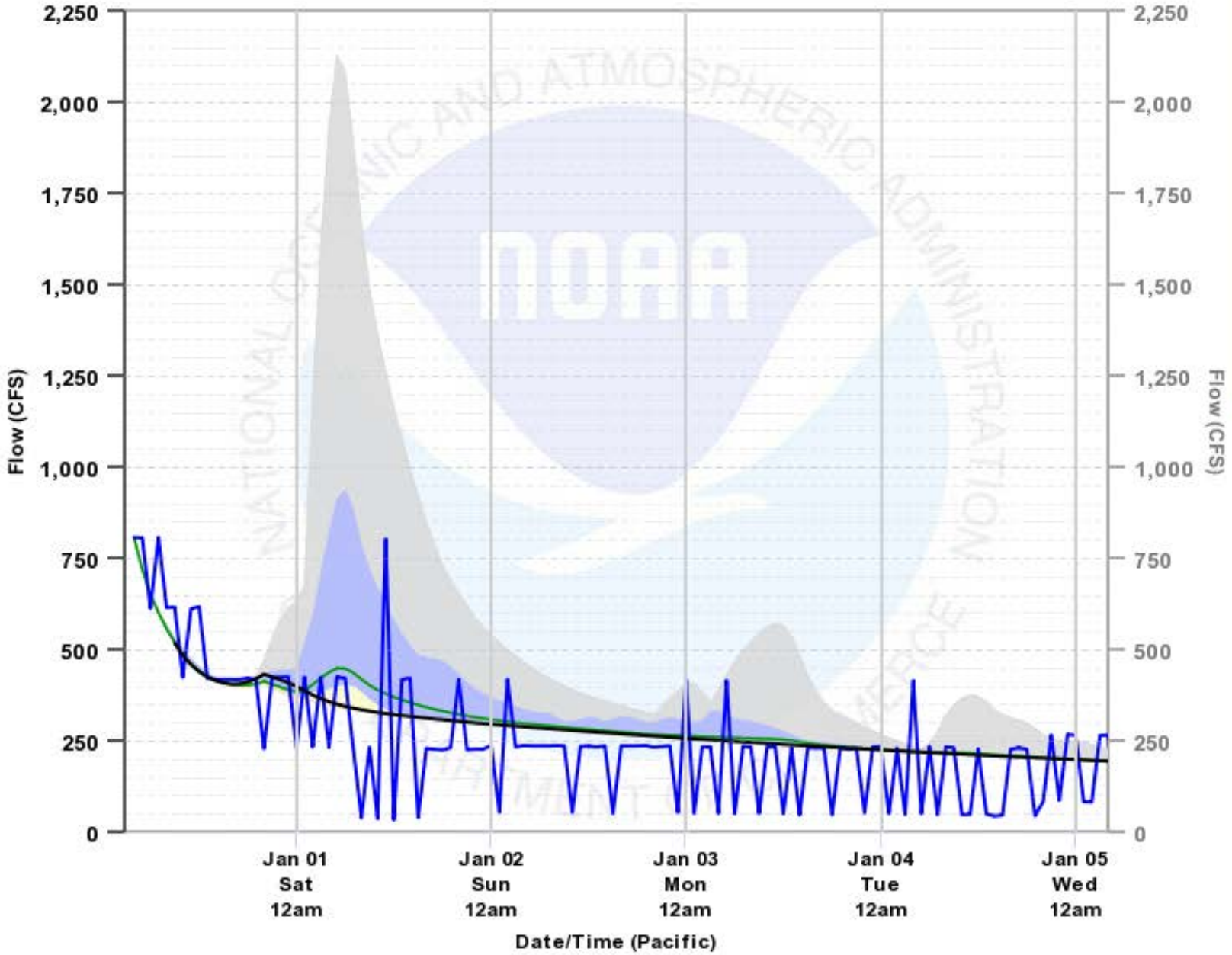
- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/31/2021 at 9:00 AM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/31/2021 4 am - 01/05/2022 4 am

Max	2,126
5%	936
10%	806
25%	806
50%	806
75%	806
90%	806
95%	806
Min	806

- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces

Hourly Probabilities

- 0-5% chance
- 5-25% chance
- 25-40% chance
- 40-60% chance

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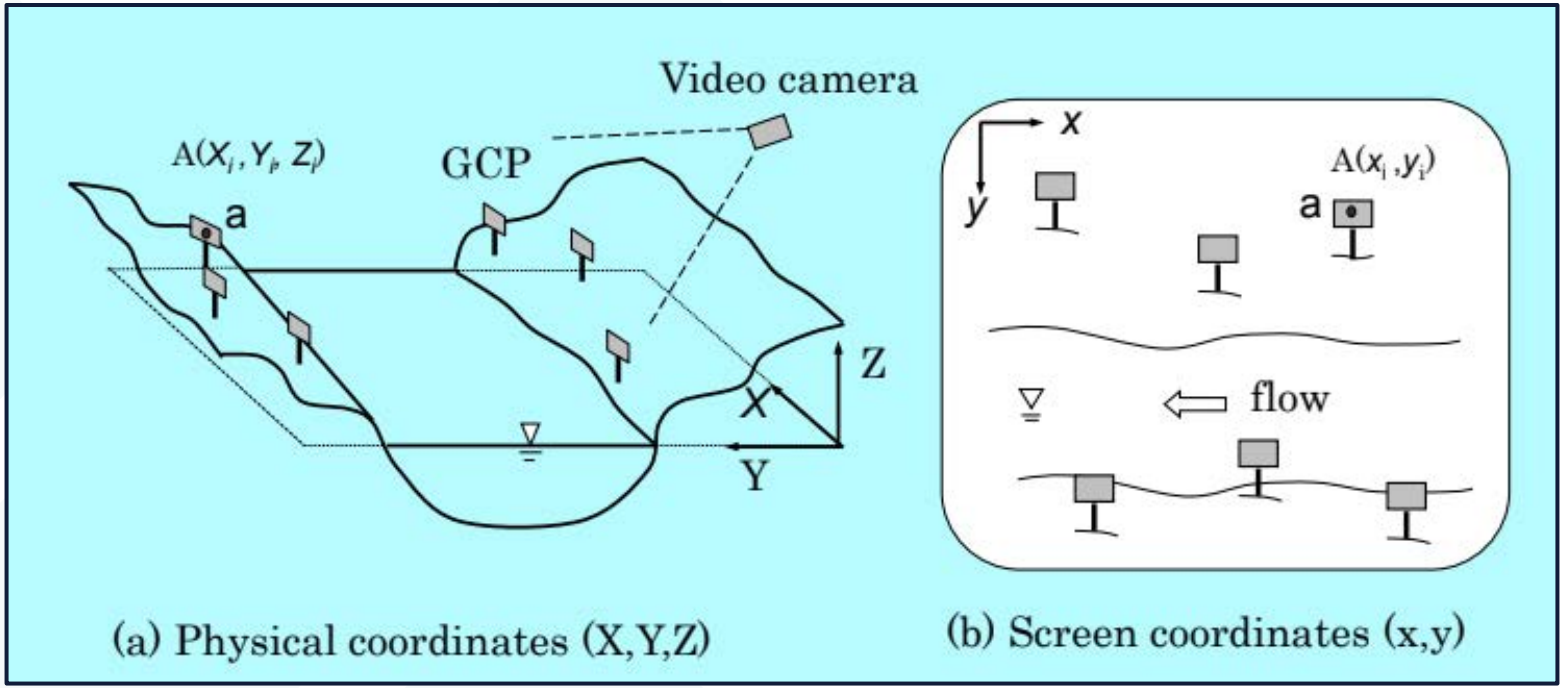
Space Time Image Velocimetry at USGS Prado Gage House

Garrett McGurk (UCSD/SIO/CW3E)

UC San Diego
SCRIPPS INSTITUTION OF OCEANOGRAPHY

Space Time Image Velocimetry (STIV)



Provided by: Xylem

STIV Example

Provided by: CVSG.IO

STIV at Prado Dam

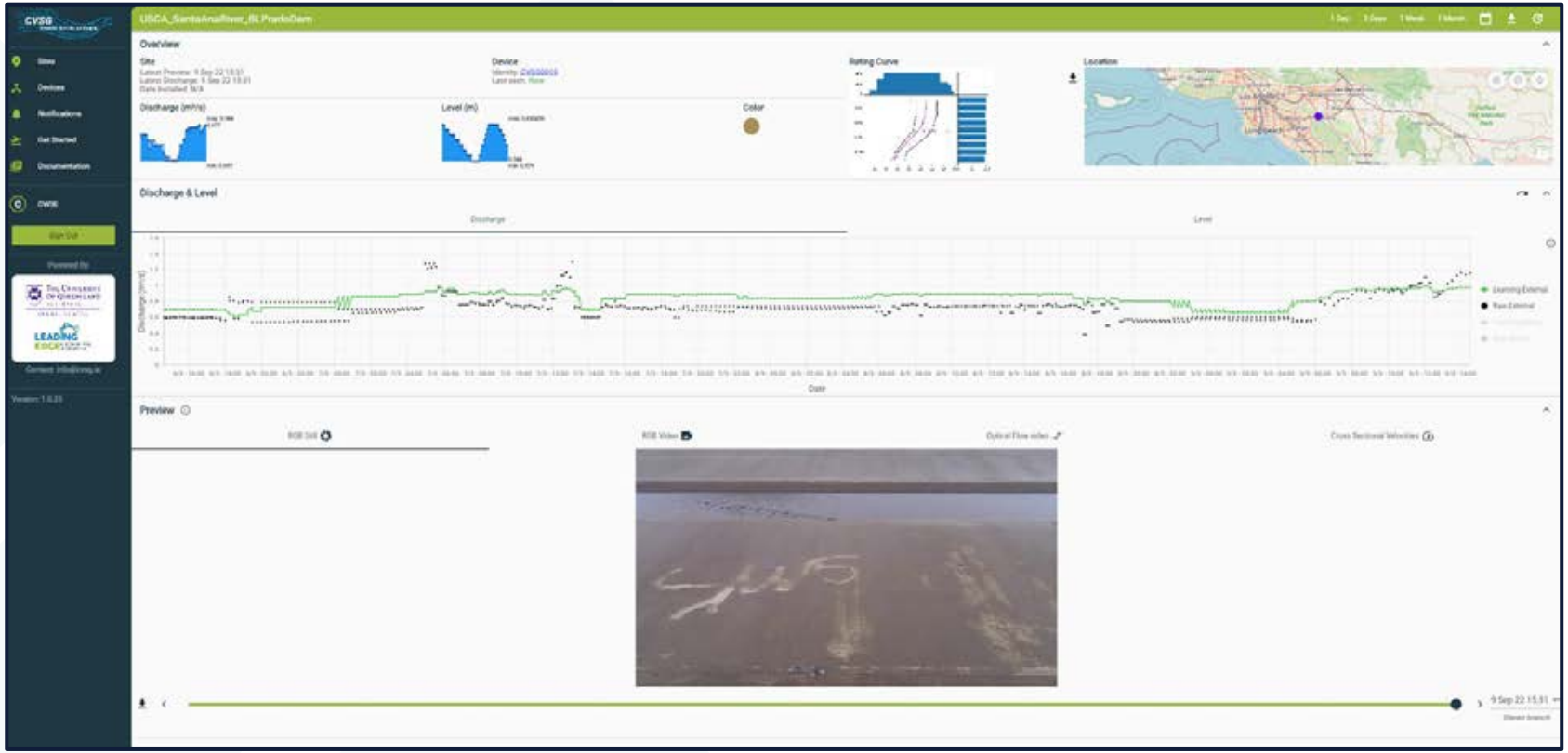
STIV Installation at Prado Gage House - 8/22/2022

Provided by: G. McGurk

STIV - Installation Details

Provided by: G. McGurk

Computer Vision Stream Gage (CVSG) Dashboard

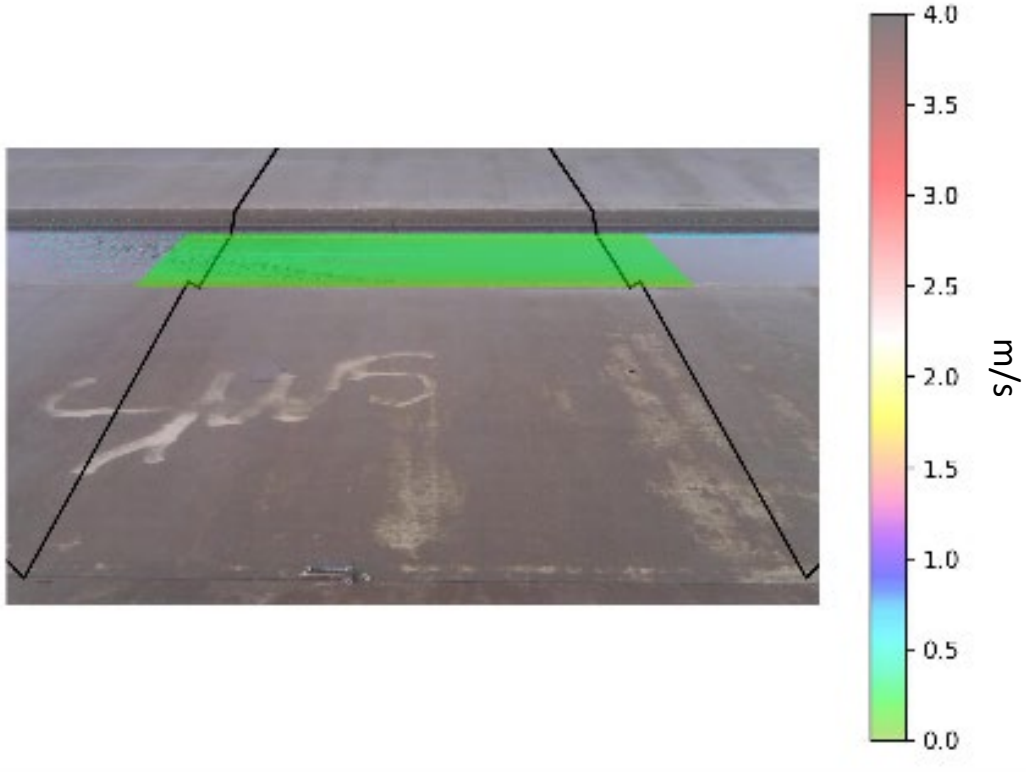


Provided by: CVSG.IO

Optical Flow Example

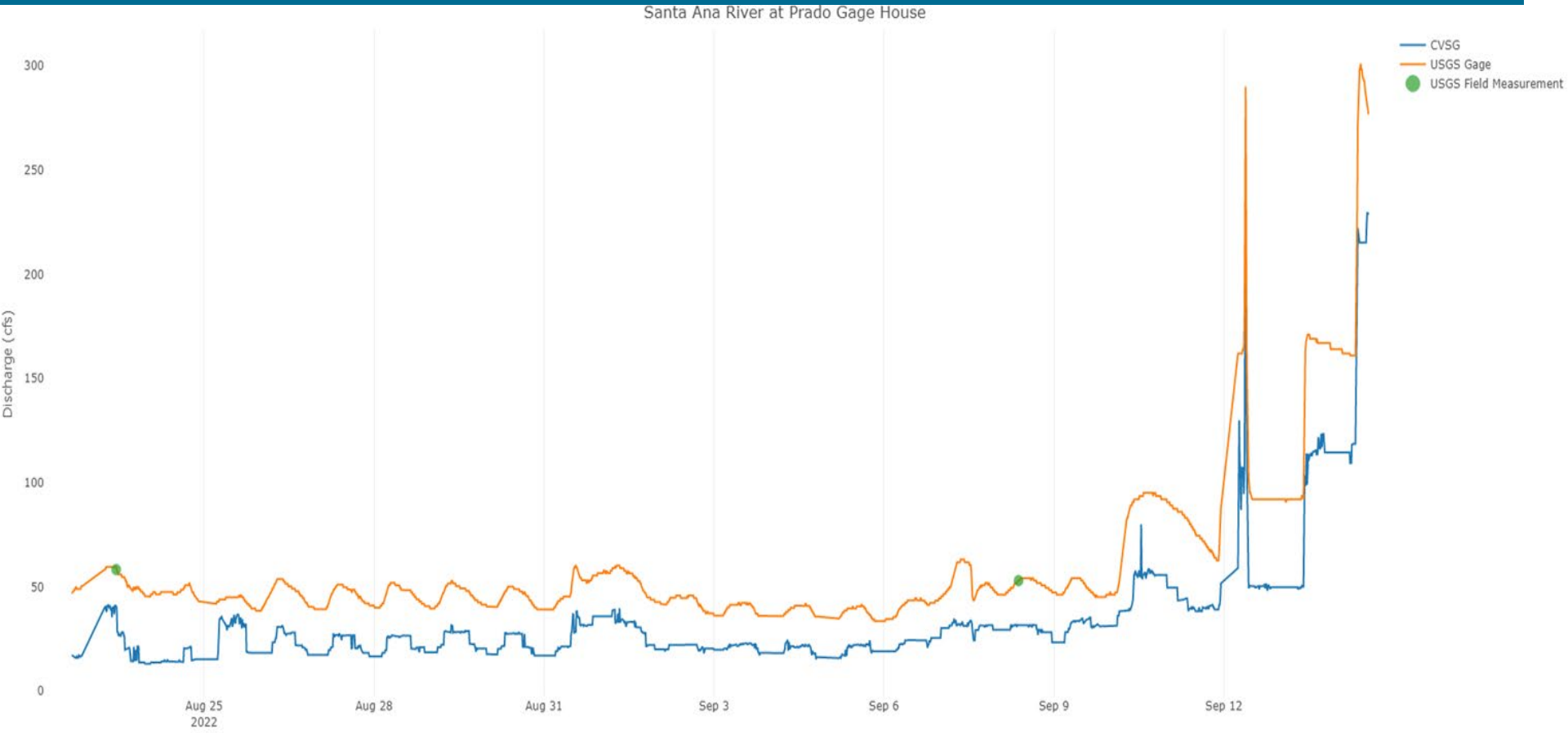
Provided by: CVSG.IO

Cross Sectional Velocities from STIV



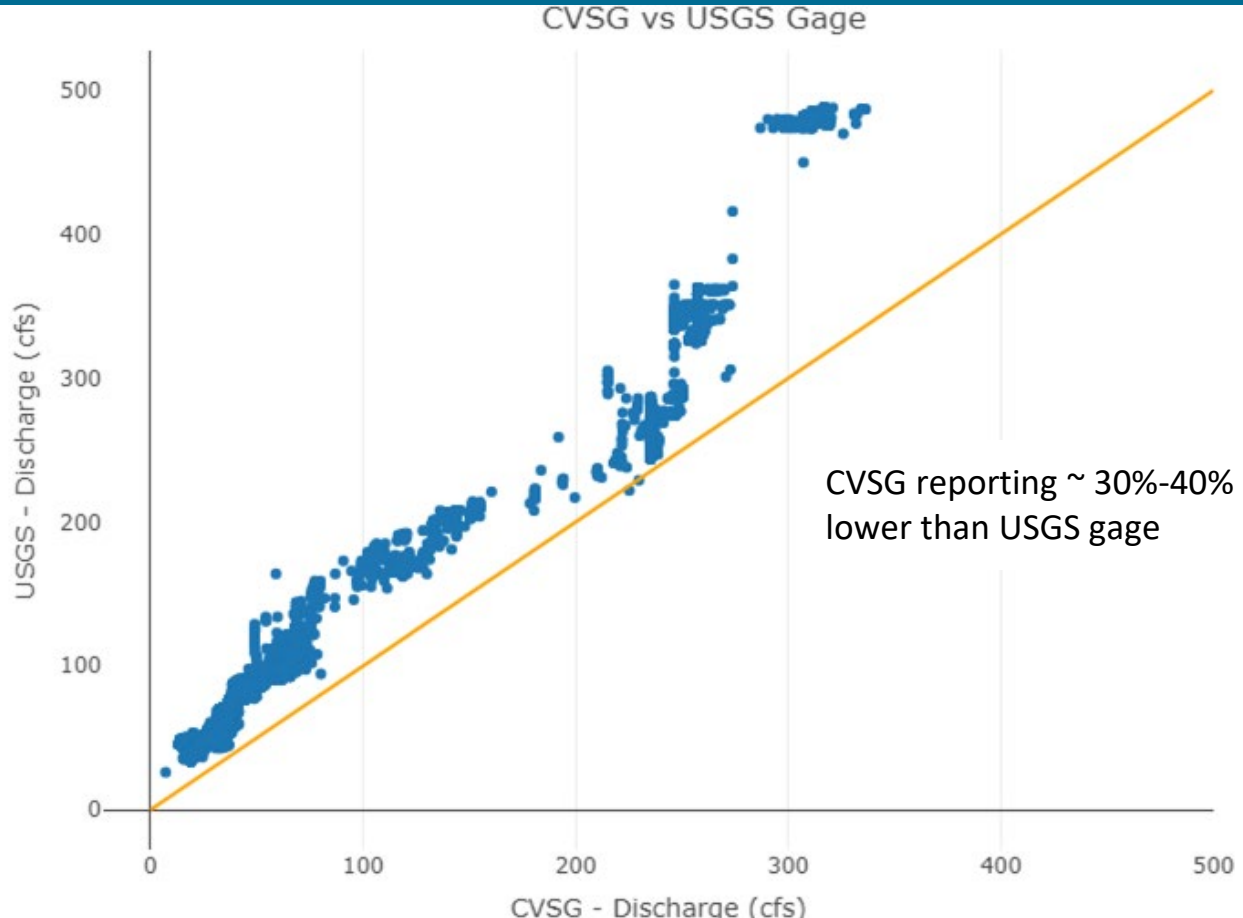
Provided by: CVSG.IO

Preliminary Comparison to USGS Gage



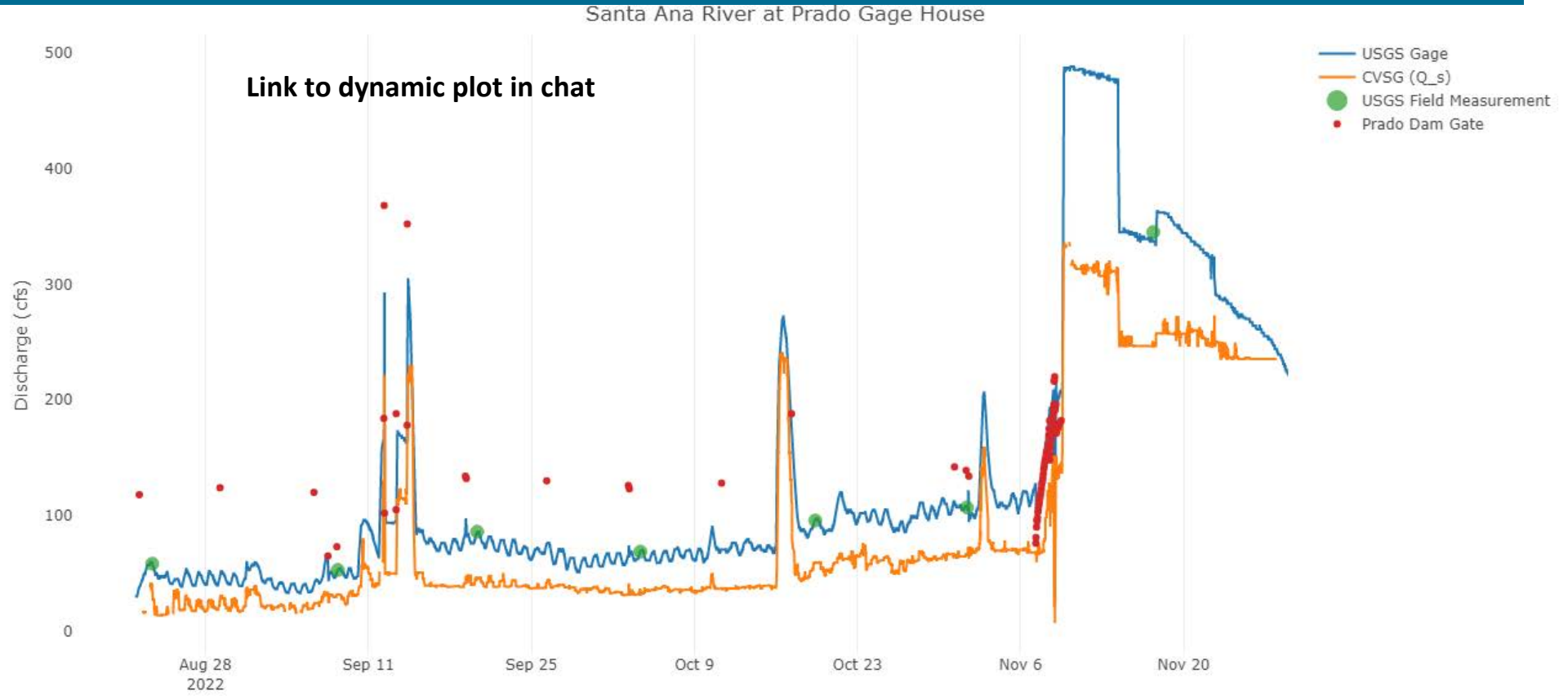
Prado Dam Flow Monitoring Update

USGS Prado vs CVSG 1:1

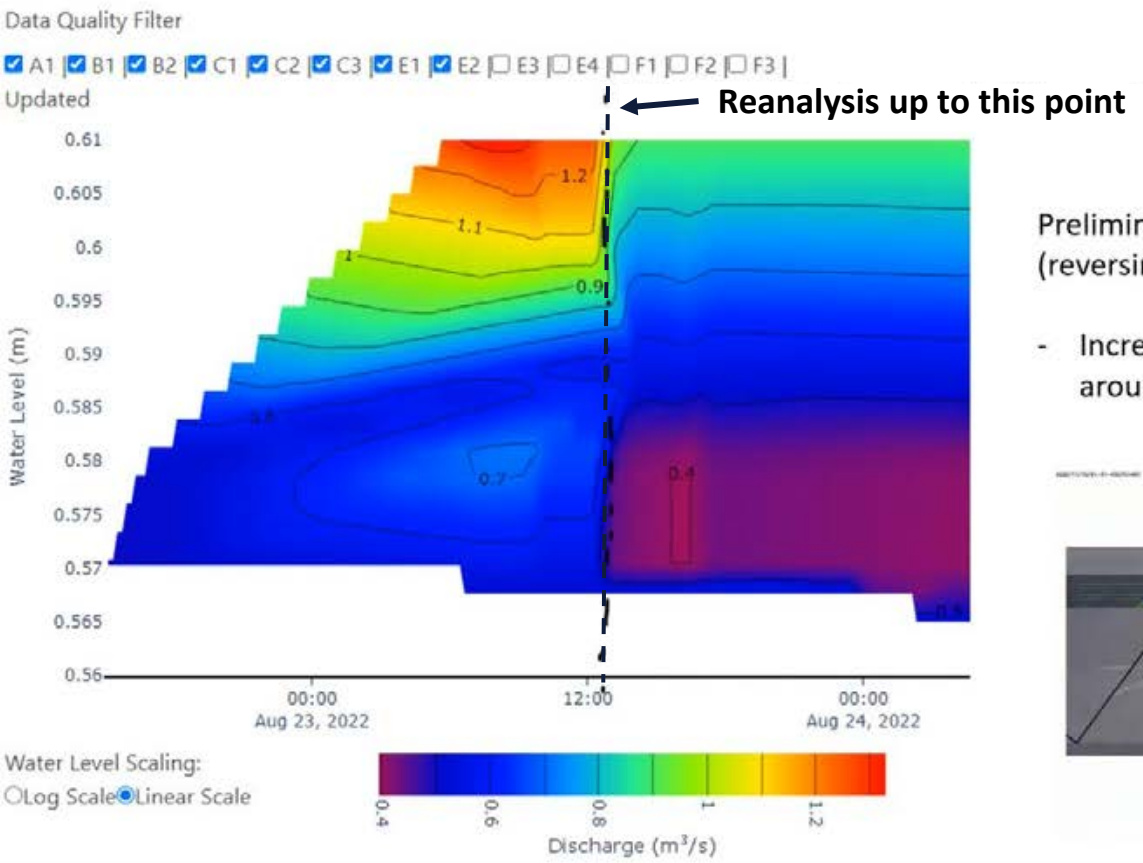


CVSG reporting ~ 30%-40% lower than USGS gage

Full Period of Record

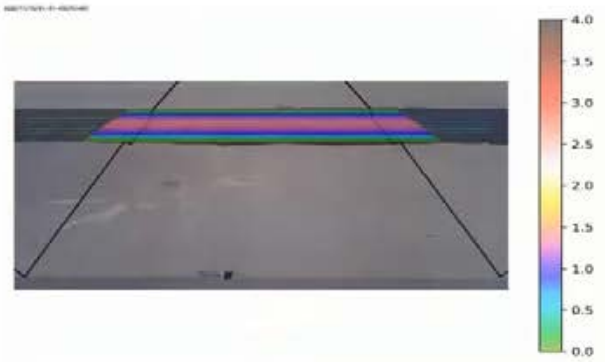


CVSG Reanalysis

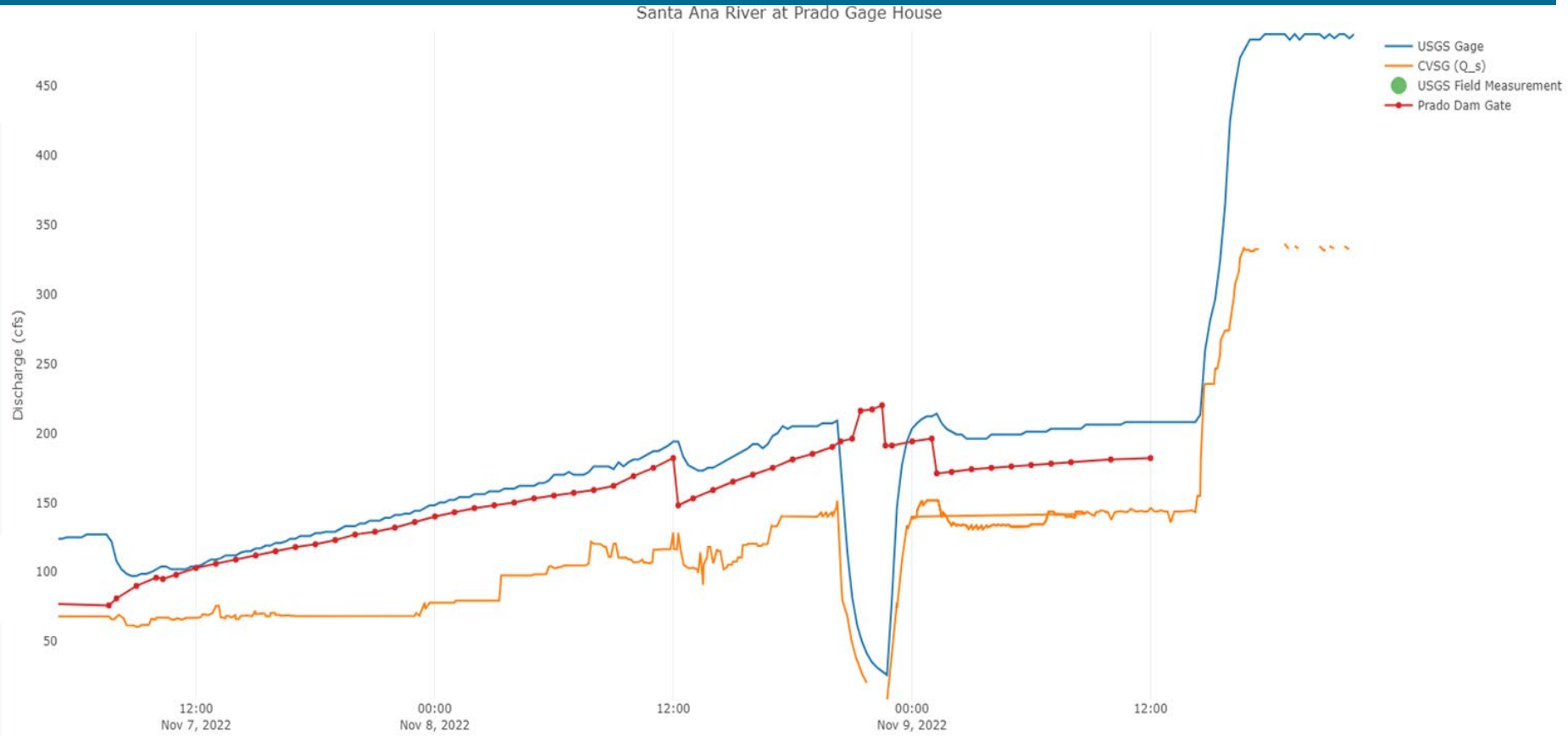


Preliminary reanalysis results
(reversing horizontal lens distortion factor)

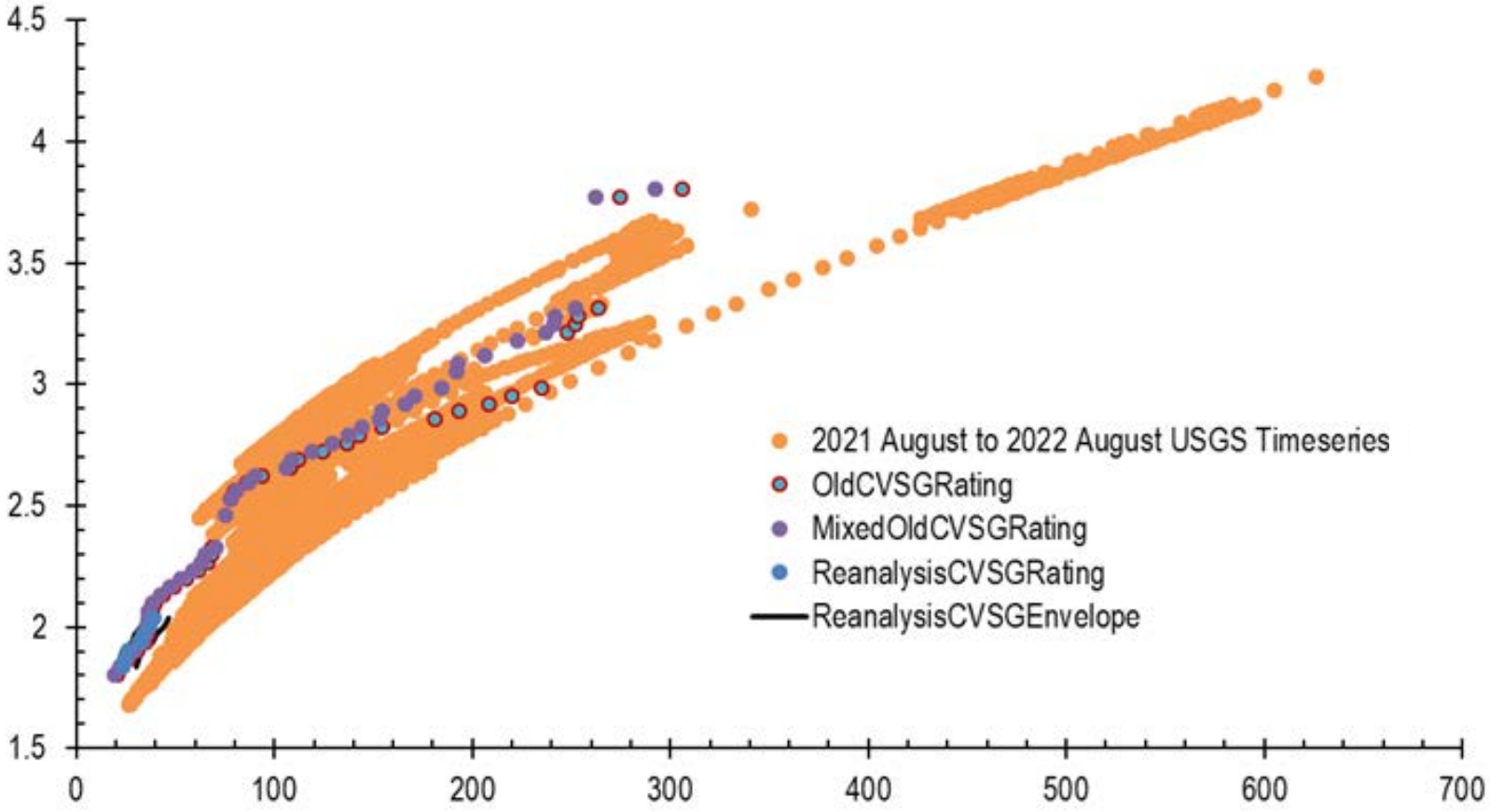
- Increasing previously estimated flows by around 30%



November 7th, 2022 Event



CVSG Reanalysis Rating



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Questions?

UC San Diego | SCRIPPS INSTITUTION OF OCEANOGRAPHY

Provided by: G. McGurk

Santa Ana River below Prado Dam (upstream)

Provided by: G. McGurk

STIV Installation continued

Provided by: G. McGurk

STIV Installation continued

Provided by: A. Lopez

Importance of Ensemble Forecasts in Decision Making

Rob Hartman

Prado FVA DST Workshop #3

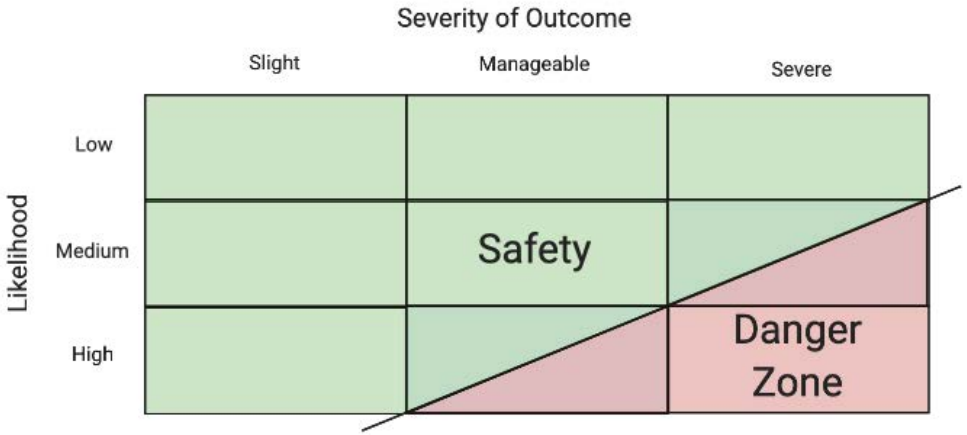
November 2, 2022

Outline

- Ensemble forecast basics
  - Why bother?, Uses, Sources of uncertainty, Operational generation, Interpretation
- Fundamentals of uncertainty, probability, and risk
- Examples and applications of risk mitigation using ensembles
  - Simple emergency management application
  - Prado water management application

Why is it important to characterize uncertainty?

- All deterministic forecasts are wrong
  - Some a little
  - Some a lot!
- Forecast users need to manage their *risk*
  - Risk = Probability x Consequence
  - If the probability is unknown, the risk can't be accurately assessed



Uncertainty, Probability, and Risk

- Uncertainty?
  - Vague
  - Most definitions tend to be circular (“lack of being certain”)

- Probability?
  - More quantifiable
  - Likelihood mathematics

- Risk?
  - Notion of Consequences (positive and/or negative)
  - Probability x Consequence

Examples of Risk

- Purchase a Lottery Ticket
  - Probability (odds) of winning the big jackpot ~300 million to 1
    - That's 1/300,000,000 or 0.00000000333 or 0.000000333%!!!
    - That's almost zero… but not quite! Only zero if you don't buy at ticket!
  - But the consequence of purchasing a $2 ticket is very low
  - How about the consequence of purchasing 10,000 tickets?
    - Improved probability to 10,000/300,000,000 or 1/30,000 or 0.0333%
- Take a commercial airplane flight
  - Probability of a deadly crash (1 in 29.4 million)
  - Consequence extremely high
  - Risk is low
  - What if the probability was 1 in 100? Would you go?

How might we estimate hydrologic forecast uncertainty?

- Error propagation
  - Kalman Filter
  - Error structure and estimates of contributing sources modeled
  - Possible but difficult
  - Hard for users to visualize, understand, and trust
- Ensembles*
  - Create a series of outcomes that accurately describe the probability of the future observation
  - Substantial challenges but possible
  - Easier for users to visualize, understand, and trust

*Error propagation has been explored; ensembles have emerged as the preferred pathway.

Uses of Hydrologic Ensemble Forecasts

Short-range (hours-days)

- Watch and warning program
- Local emergency management activities
- Reservoir and flood control

Medium-range (days to weeks)

- Reservoir management
- Local emergency management preparedness
- Snowmelt runoff management

Long-range (weeks to months)

- Water supply and drought mitigation
- Reservoir management

FIRO!

Sources of Uncertainty in Hydrologic Forecasts

MODEL STATES
snow
soil moisture
basin routing

OBSERVATIONS
precipitation
air temperature
streamflow

MODELING SYSTEM
simplifications
temporal issues
scale issues

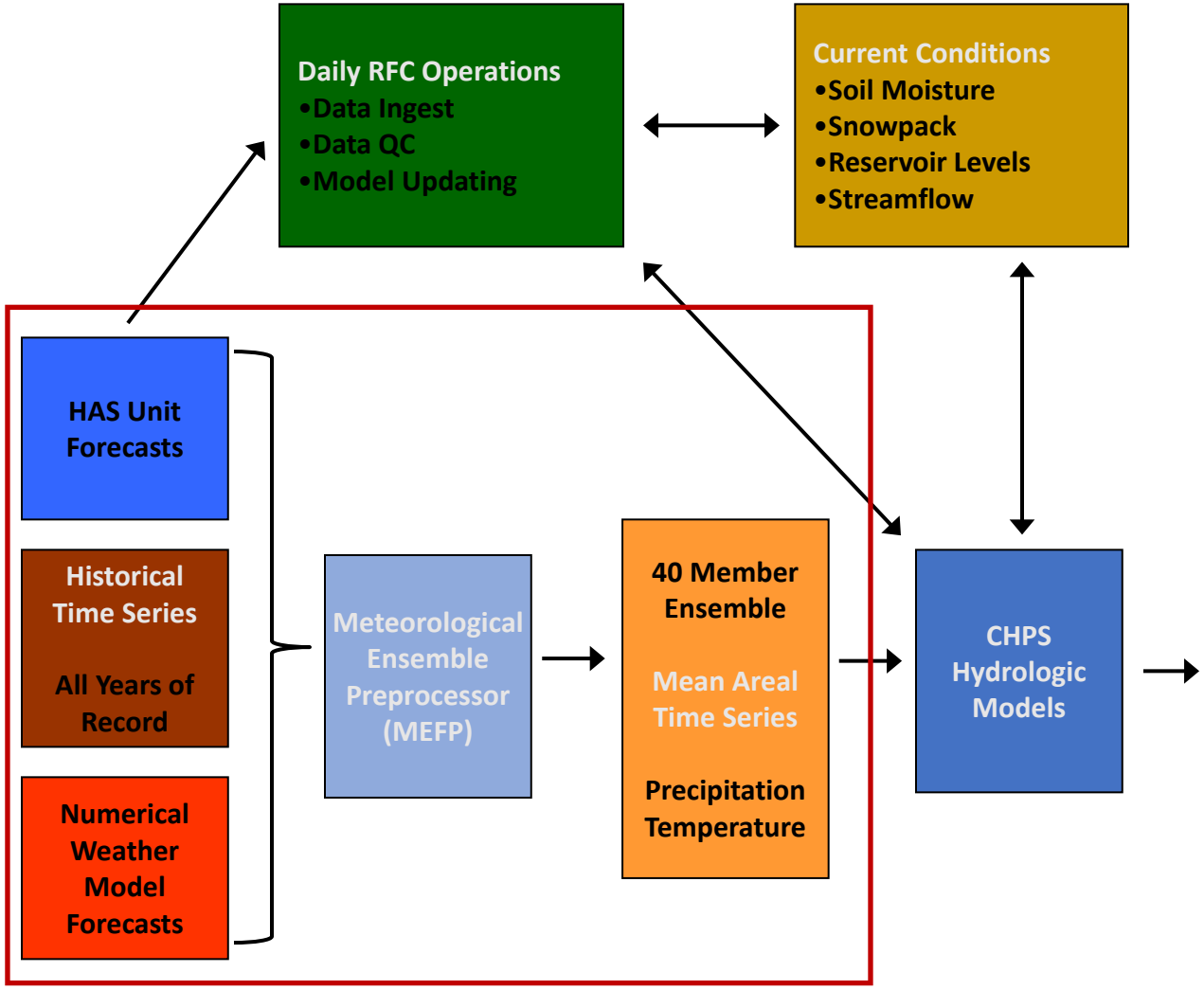
Total Uncertainty

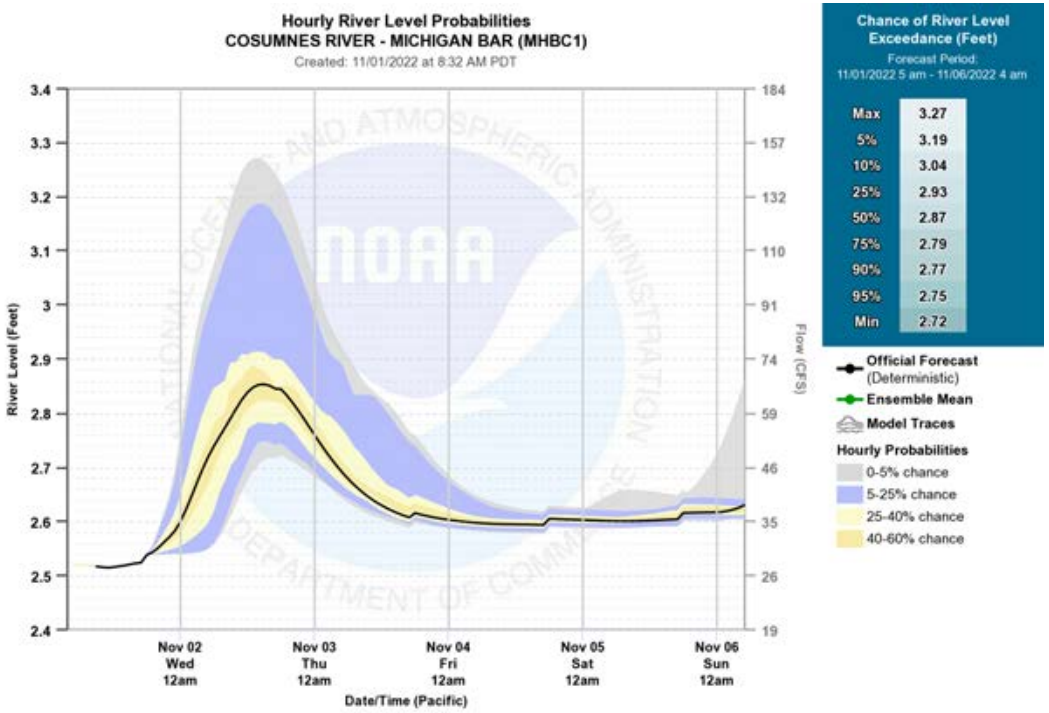
MODEL PARMS
snow
soil moisture
basin routing

HUMAN INPUT
education
training
experience
mental state

FORECASTS
precipitation
air temperature
reservoir regulation

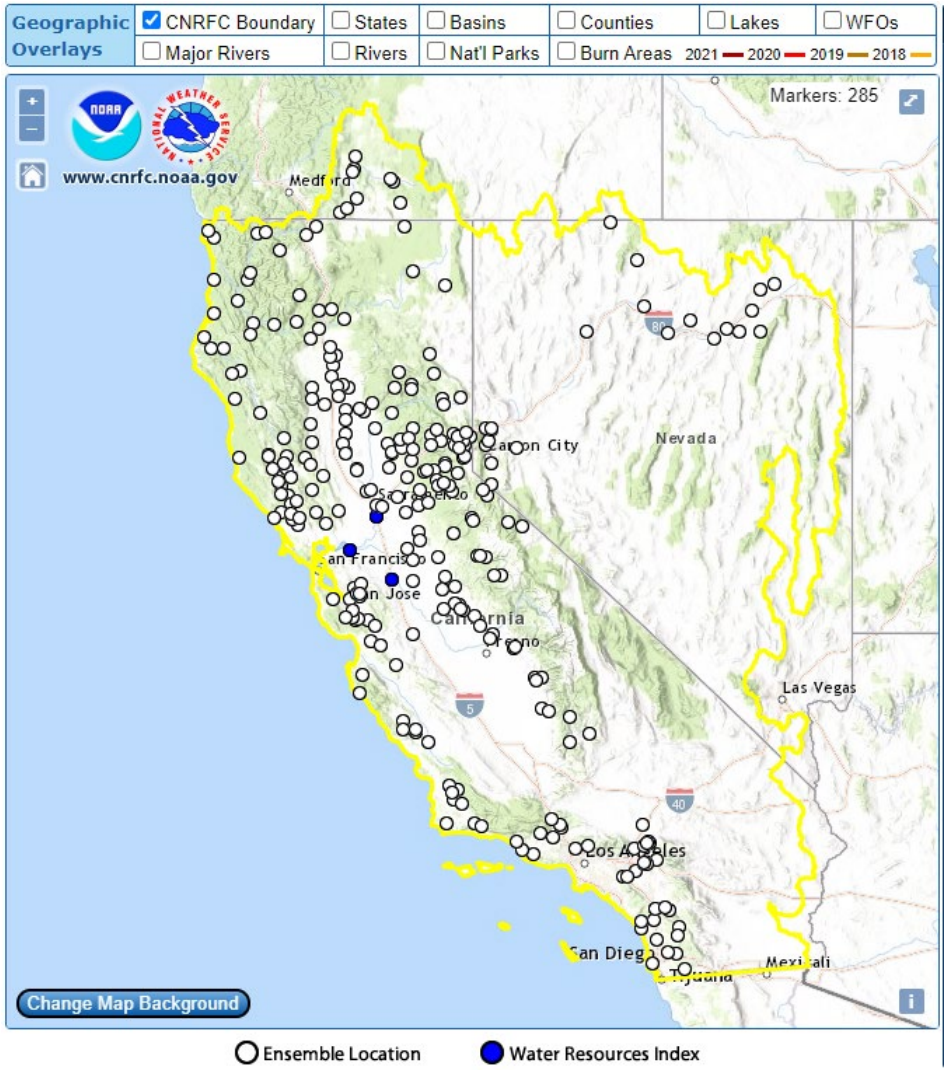
Ensemble Streamflow Prediction Process





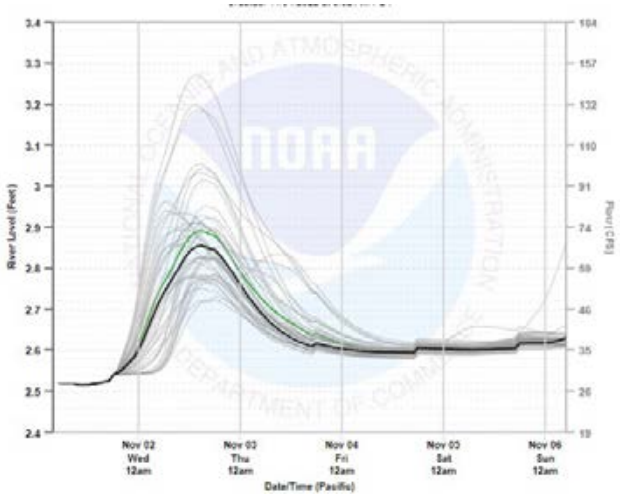
CNRFC Hydrologic Ensemble Forecasts (HEFS)

www.cnrfc.noaa.gov



- Most river forecast locations
- 15-day regulated
  - Updated up to 4x/day
- 365-day unregulated
  - Updated daily
- Multiple graphics and .csv
- 30+ year hindcasts can be generated by request

Interpretation of Ensemble Forecasts



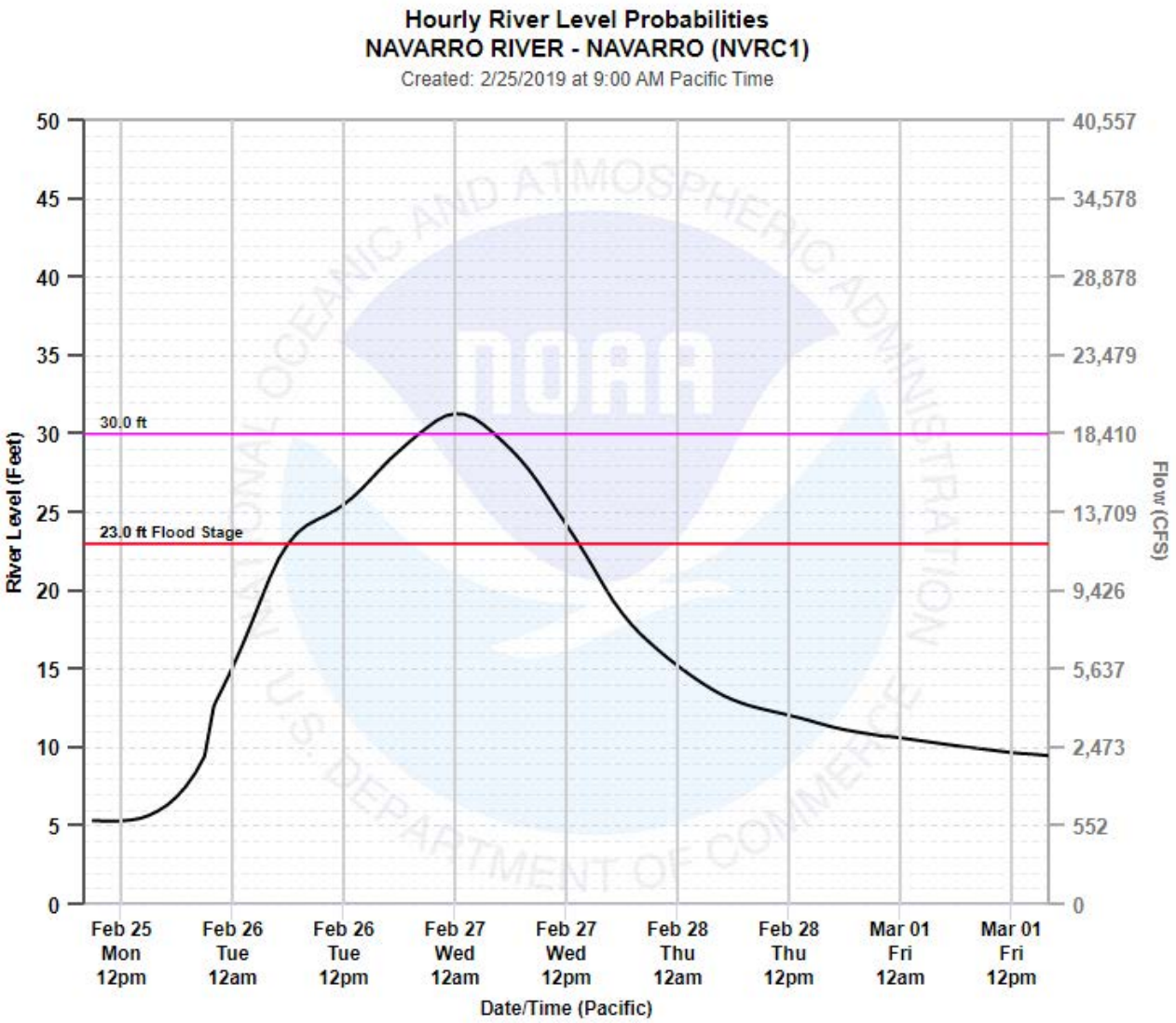
- Individual ensemble members are “equally likely”
- Probability of a variety of outcomes can be estimated
  - Peak flow
  - Low flow
  - Volumes of any duration anywhere within the forecast time domain
    - 3-day inflow, lead time 3-days
    - Total 10-day accumulated volume
- Normally an empirical distribution is assumed and applied
  - A theoretical distribution often works better in the tails of the distribution

General questions or observations before we jump into emergency services and water management examples?

Emergency Services Example

- You are responsible for initiating actions to mitigate the impacts of community flooding for the City Navarro on the Navarro River.
- You have an ensemble stage forecast from the NWS that covers the next 5 days.
- Your available options include:
  - Do nothing
  - Sandbag the levee to 30’ (takes 24 hours)
  - Evacuate at-risk residents. (takes 24 hours)
  - Sandbag and evacuate (takes 24 hours)

Deterministic Forecast

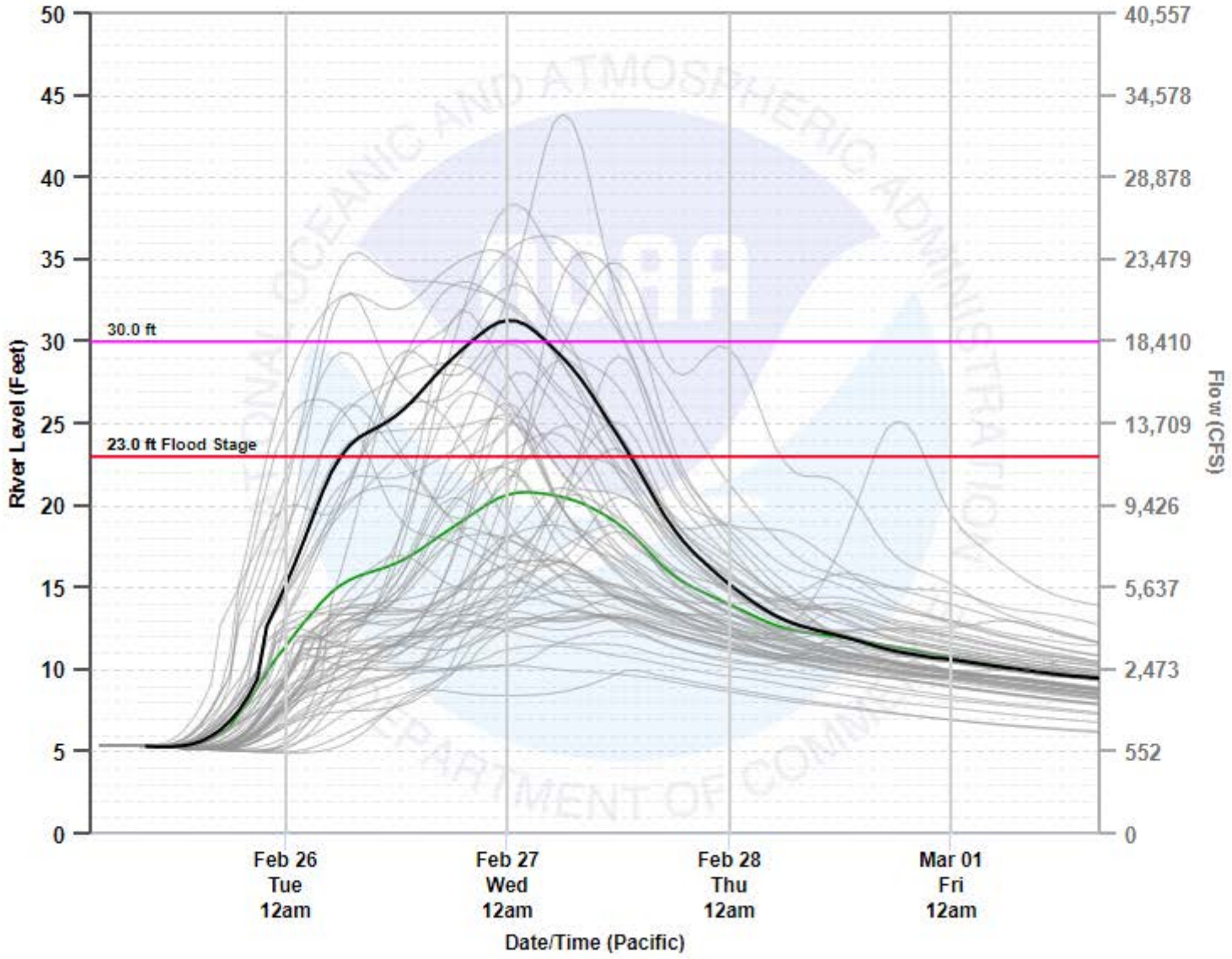


Actions & Consequences

	Peak Observed Stage		
Response	**< 23 ft**	**23ft to 30ft**	**> 30ft**
Do Nothing	$0	$10M	$50M + 10 fatals
Sandbag to 30ft	$250K	$250K	$50M + $250K + 10 fatals
Evacuate Residents	$50K	$50K + $10M	$50M +$50K
Sandbag and Evacuate	$300K	$300K	$300K + $50M

Hourly River Level Probabilities
NAVARRO RIVER - NAVARRO (NVRC1)

Created: 2/25/2019 at 9:00 AM Pacific Time



Chance of River Level Exceedance (Feet)

Forecast Period:
02/25/2019 4 am - 03/01/2019 4 pm

Max	43.83		
5%	36.42		
10%	35.42	30.0 ft	20%
25%	29.05		
50%	22.32	23.0 ft	47%
75%	15.36		
90%	13.19		
95%	11.41		
Min	9.93		

Custom Thresholds

Show: 5 Days 10 Days

Export Image

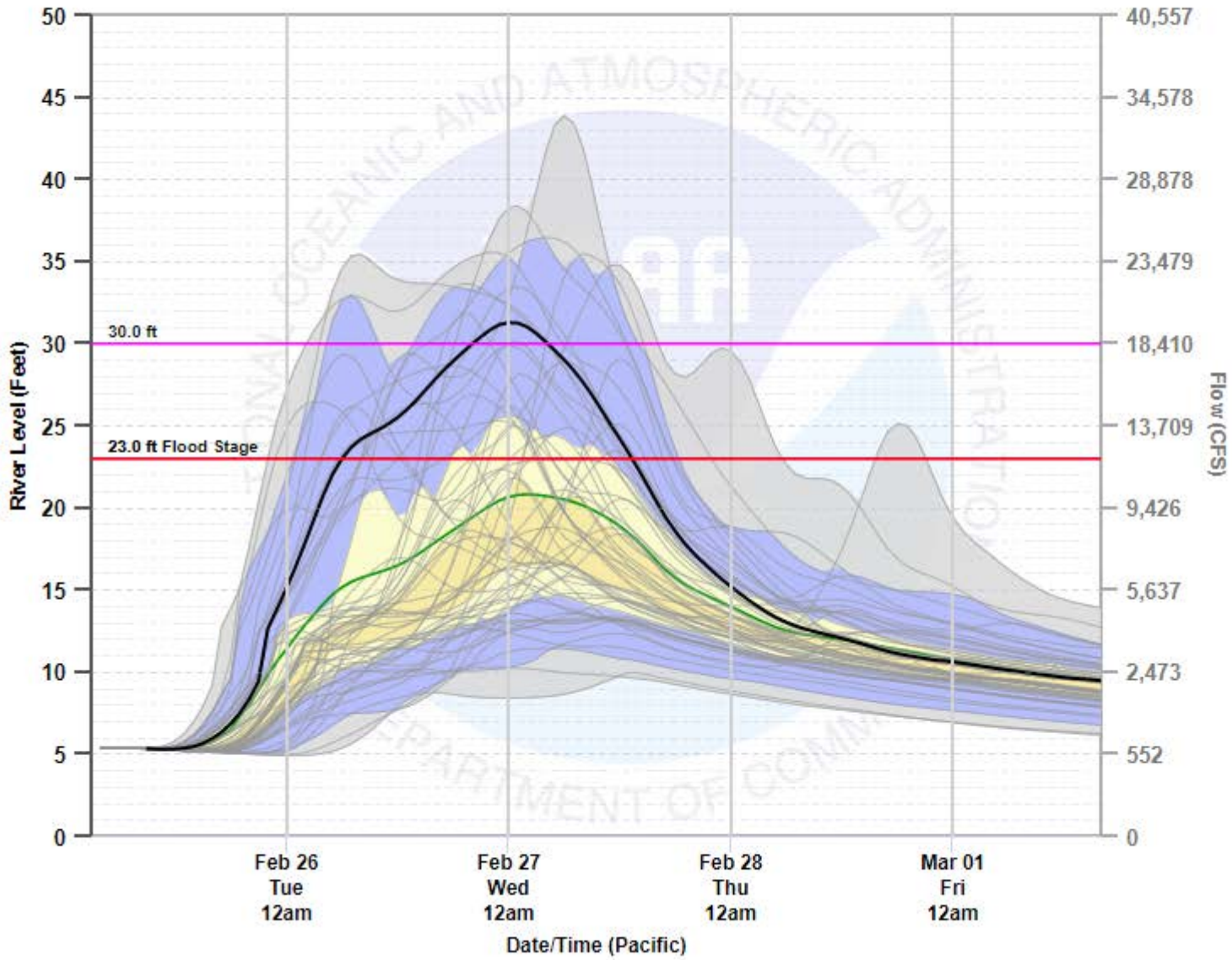
Export Chart Data (CSV)

Scale To Data

- [ ] Observed
- [x] Official Forecast (Deterministic)
- [x] Ensemble Mean
- [x] Model Traces
- [ ] Hourly Probabilities
  - 0-5% chance
  - 5-25% chance
  - 25-40% chance
  - 40-60% chance

Hourly River Level Probabilities
NAVARRO RIVER - NAVARRO (NVRC1)

Created: 2/25/2019 at 9:00 AM Pacific Time



Chance of River Level Exceedance (Feet)

Forecast Period:
02/25/2019 4 am - 03/01/2019 4 pm

Max	43.83	
5%	36.42	
10%	35.42	30.0 ft 20%
25%	29.05	
50%	22.32	23.0 ft 47%
75%	15.36	
90%	13.19	
95%	11.41	
Min	9.93	

Custom Thresholds

Show: 5 Days 10 Days

Export Image

Export Chart Data (CSV)

Scale To Data

- [ ] Observed
- [x] Official Forecast (Deterministic)
- [x] Ensemble Mean
- [x] Model Traces
- [x] Hourly Probabilities
  - 0-5% chance
  - 5-25% chance
  - 25-40% chance
  - 40-60% chance

Emergency Services Example

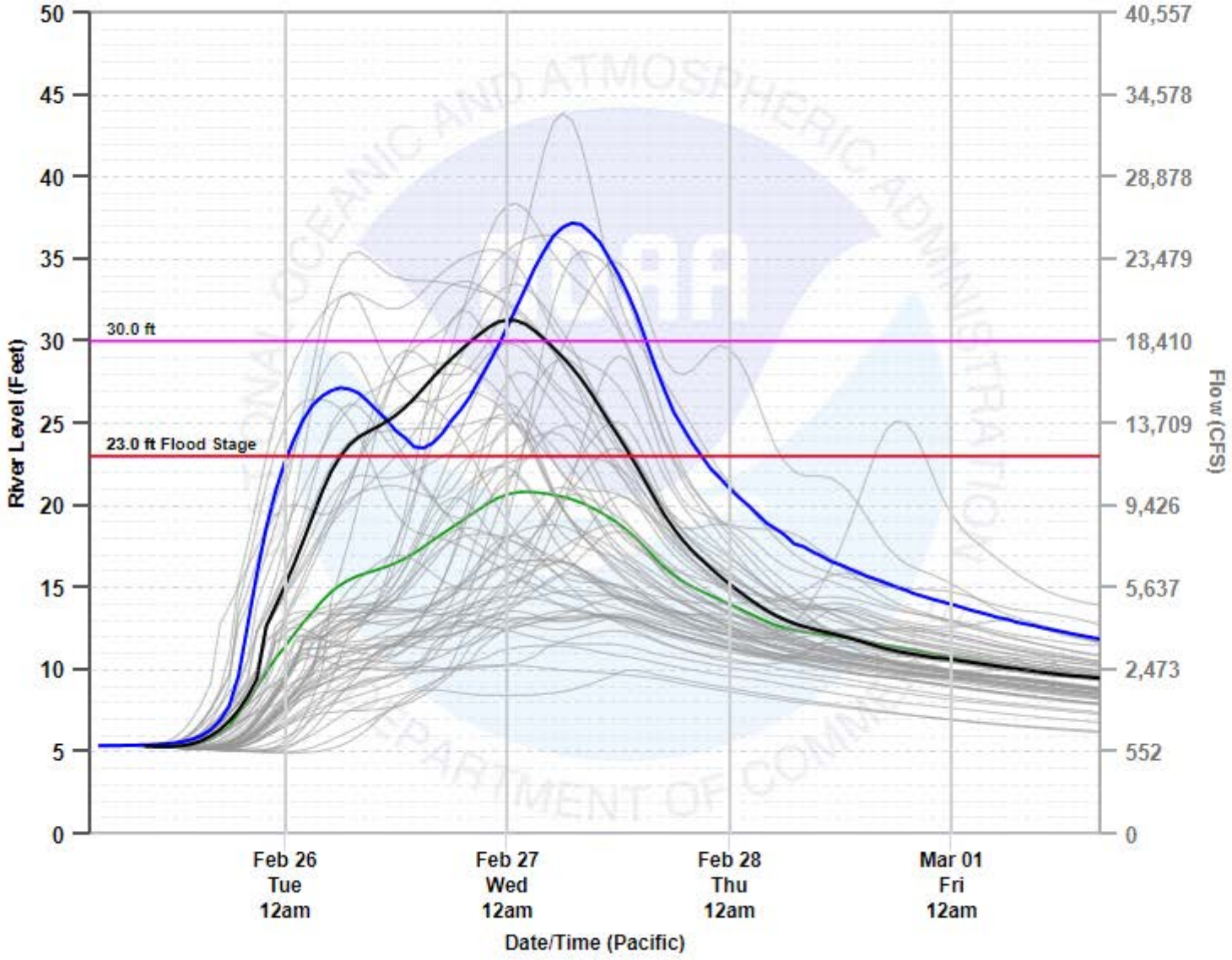
Actions & Consequences w/Probabilities

	Peak Observed Stage			Total Cost
Response	**< 23 ft**	**23ft to 30ft**	**> 30ft**	
Do Nothing	$0	$10M	$50M + 10 fatals	$13.3M + 2 fatals
Sandbag to 30ft	$250K	$250K	$50M + $250K + 10 fatals	$10.3M + 2 fatals
Evacuate Residents	$50K	$50K + $10M	$50M +$50K	$13.3M
Sandbag and Evacuate	$300K	$300K	$300K + $50M	$10.3M
Probability	47%	33%	20%	

What action should you take?

Hourly River Level Probabilities
NAVARRO RIVER - NAVARRO (NVRC1)

Created: 2/25/2019 at 9:00 AM Pacific Time



Chance of River Level Exceedance (Feet)

Forecast Period:
02/25/2019 4 am - 03/01/2019 4 pm

Max	43.83		
5%	36.42		
10%	35.42	30.0 ft	20%
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50%	22.32	23.0 ft	47%
75%	15.36		
90%	13.19		
95%	11.41		
Min	9.93		

Custom Thresholds

Show: 5 Days 10 Days

Export Image

Export Chart Data (CSV)

Scale To Data

- [x] Observed
- [x] Official Forecast (Deterministic)
- [x] Ensemble Mean
- [x] Model Traces
- [ ] Hourly Probabilities
  - 0-5% chance
  - 5-25% chance
  - 25-40% chance
  - 40-60% chance

Discussion and Questions

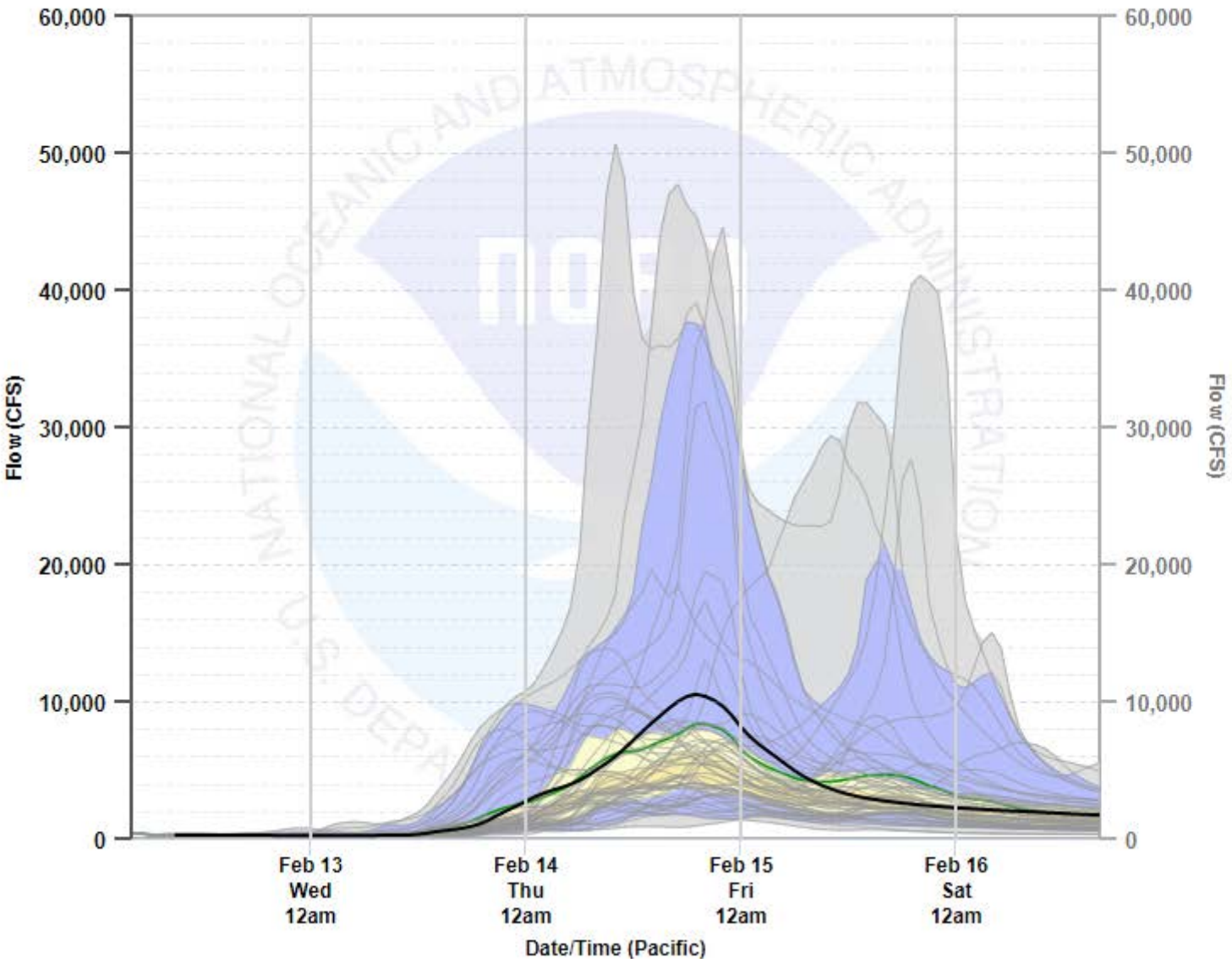
Water Management Examples

- Prado Dam – February 2019 (case study #1)
  - Under forecast
- Prado Dam – December 2021 (case study #2)
  - Significant Over forecast

- How do the ensembles help us mitigate the impacts of relying on the deterministic forecast?

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 2/12/2019 at 9:00 AM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
02/12/2019 4 am - 02/16/2019 4 pm

Max	50,606
5%	44,550
10%	31,835
25%	12,926
50%	7,011
75%	3,908
90%	3,073
95%	2,439
Min	1,931

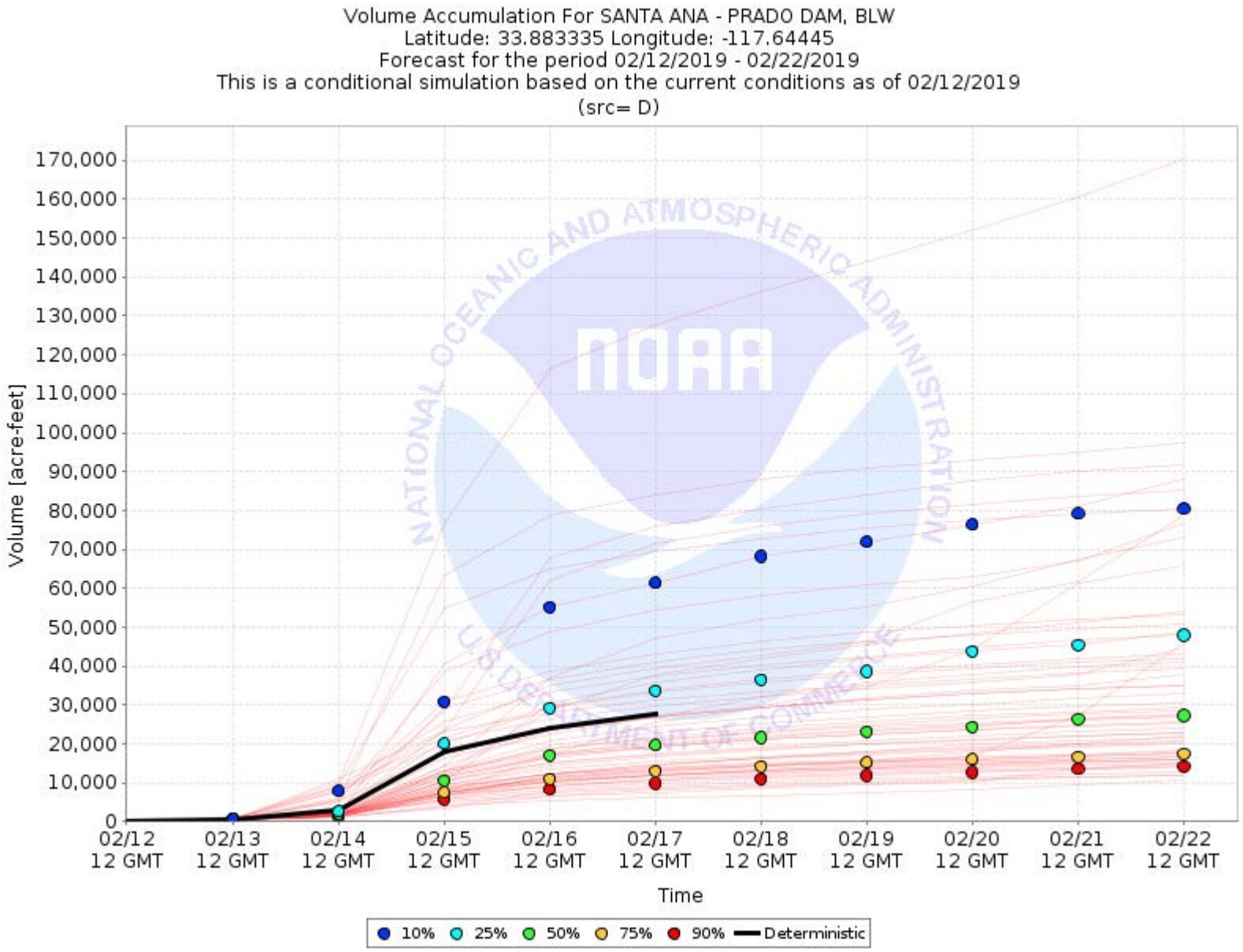
Custom Thresholds

Show: 5 Days 10 Days

Export Image

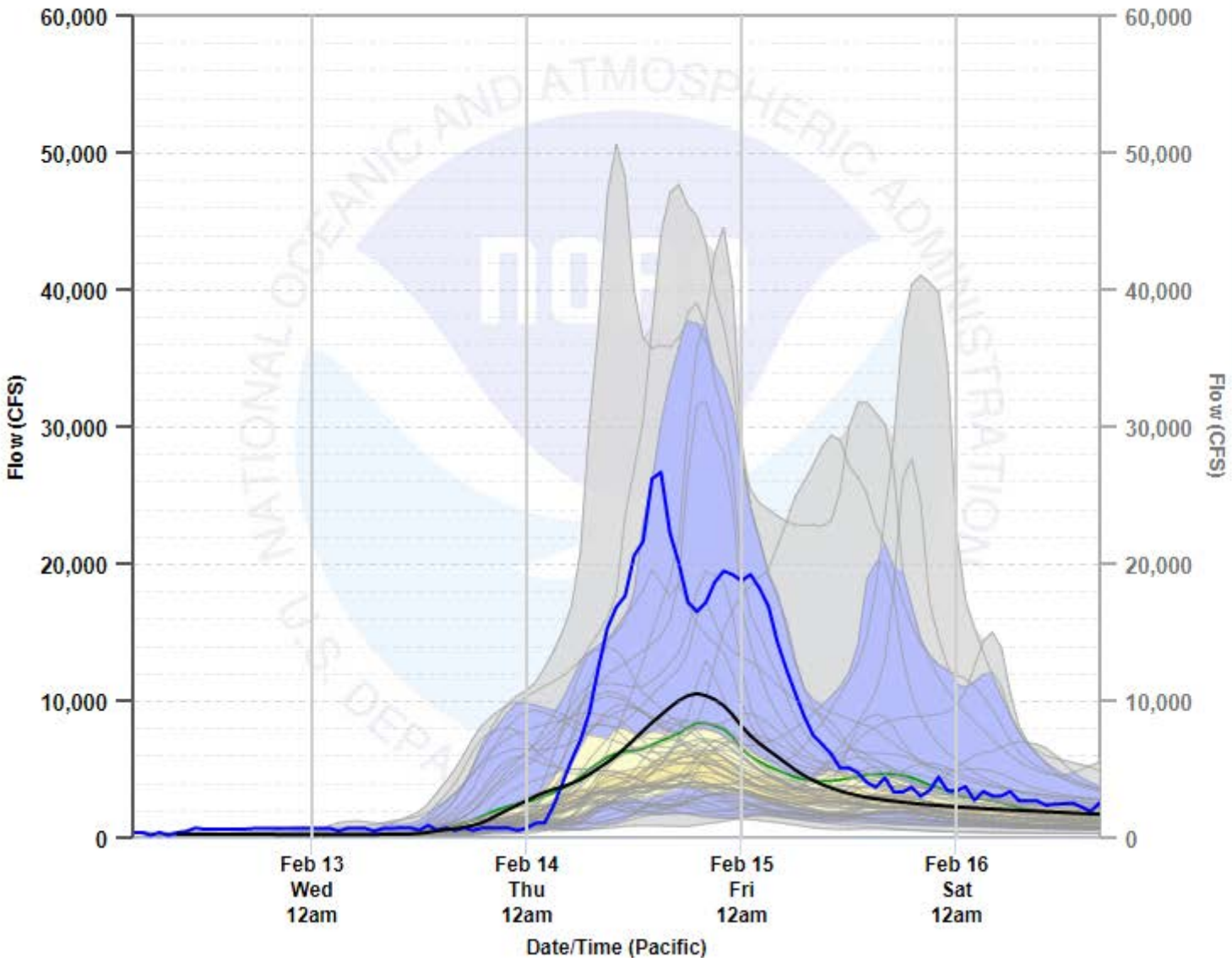
Export Chart Data (CSV)

- [ ] Observed
- [x] Official Forecast (Deterministic)
- [x] Ensemble Mean
- [x] Model Traces
- [x] Hourly Probabilities
  - 0-5% chance
  - 5-25% chance
  - 25-40% chance
  - 40-60% chance


Volume Accumulation For SANTA ANA - PRADO DAM, BLW
Latitude: 33.883335 Longitude: -117.64445
Forecast for the period 02/12/2019 - 02/22/2019
This is a conditional simulation based on the current conditions as of 02/12/2019
(src= D)
Volume [acre-feet]
170,000
160,000
150,000
140,000
130,000
120,000
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
02/12 12 GMT
02/13 12 GMT
02/14 12 GMT
02/15 12 GMT
02/16 12 GMT
02/17 12 GMT
02/18 12 GMT
02/19 12 GMT
02/20 12 GMT
02/21 12 GMT
02/22 12 GMT
Time
10%
25%
50%
75%
90%
Deterministic

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 2/12/2019 at 9:00 AM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
02/12/2019 4 am - 02/16/2019 4 pm

Max	50,606
5%	44,550
10%	31,835
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75%	3,908
90%	3,073
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Min	1,931

Custom Thresholds

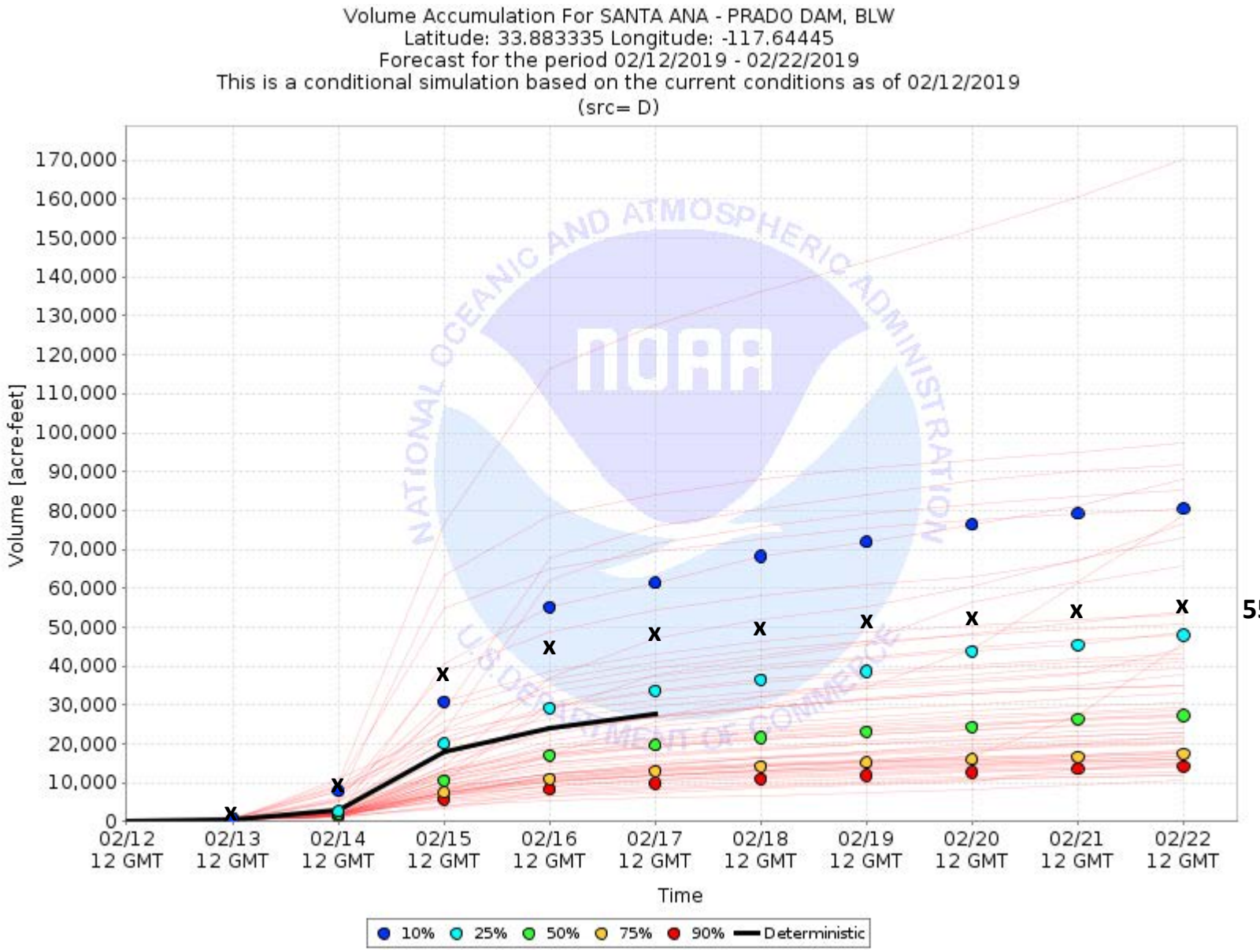
Show: 5 Days 10 Days

Export Image

Export Chart Data (CSV)

- Observed
- Official Forecast (Deterministic)
- Ensemble Mean
- Model Traces
- Hourly Probabilities
  - 0-5% chance
  - 5-25% chance
  - 25-40% chance
  - 40-60% chance

x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(src= D)
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160,000
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100,000
90,000
80,000
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10,000
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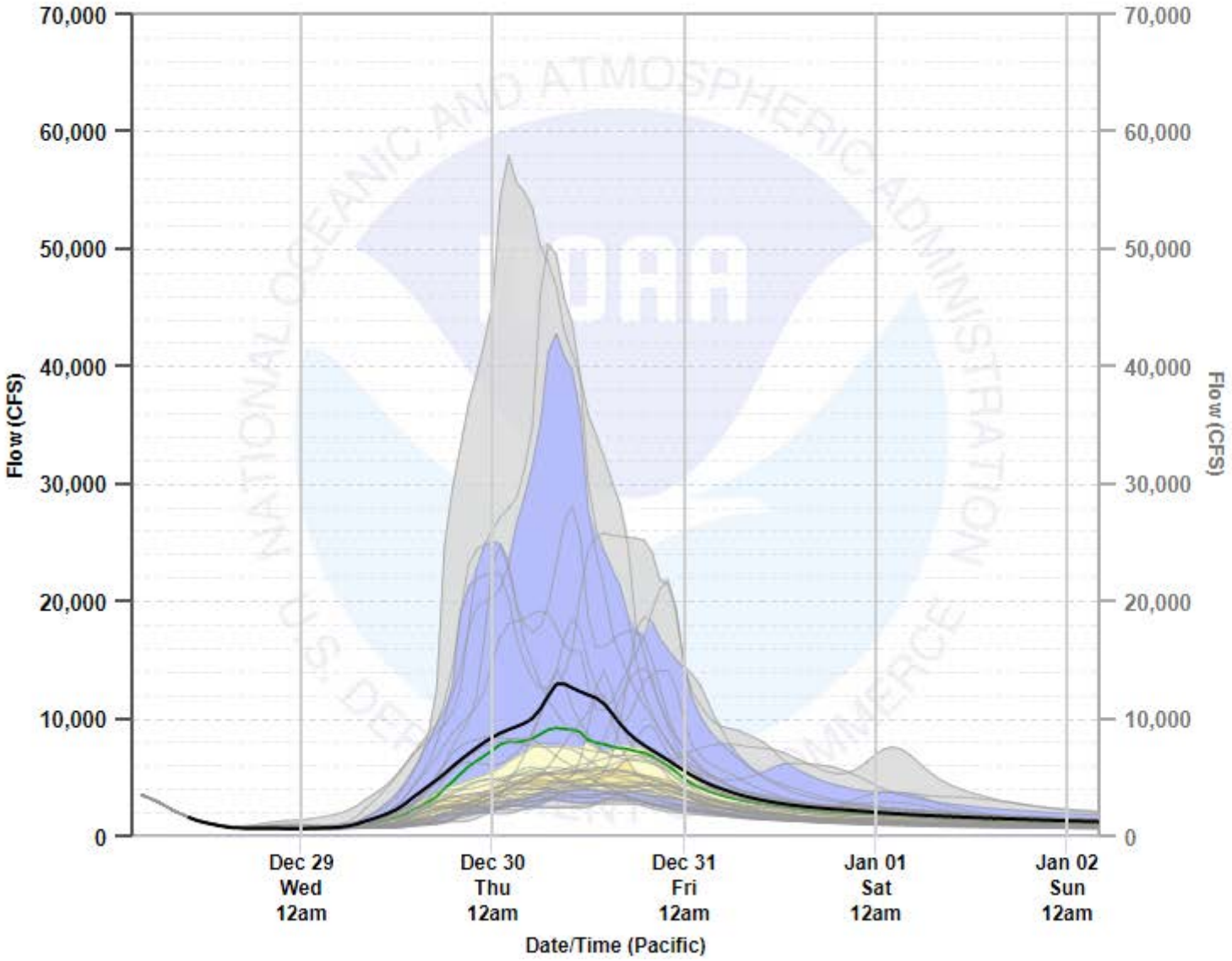
02/12 12 GMT
02/13 12 GMT
02/14 12 GMT
02/15 12 GMT
02/16 12 GMT
02/17 12 GMT
02/18 12 GMT
02/19 12 GMT
02/20 12 GMT
02/21 12 GMT
02/22 12 GMT
Time
10%
25%
50%
75%
90%
Deterministic

55,000 acft

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/28/2021 at 9:00 AM Pacific Time



Chance of Flow Exceedance (CFS)

Forecast Period:
12/28/2021 4 am - 01/02/2022 4 am

Max	57,940
5%	42,729
10%	25,794
25%	14,202
50%	5,829
75%	4,448
90%	3,691
95%	3,490
Min	3,490

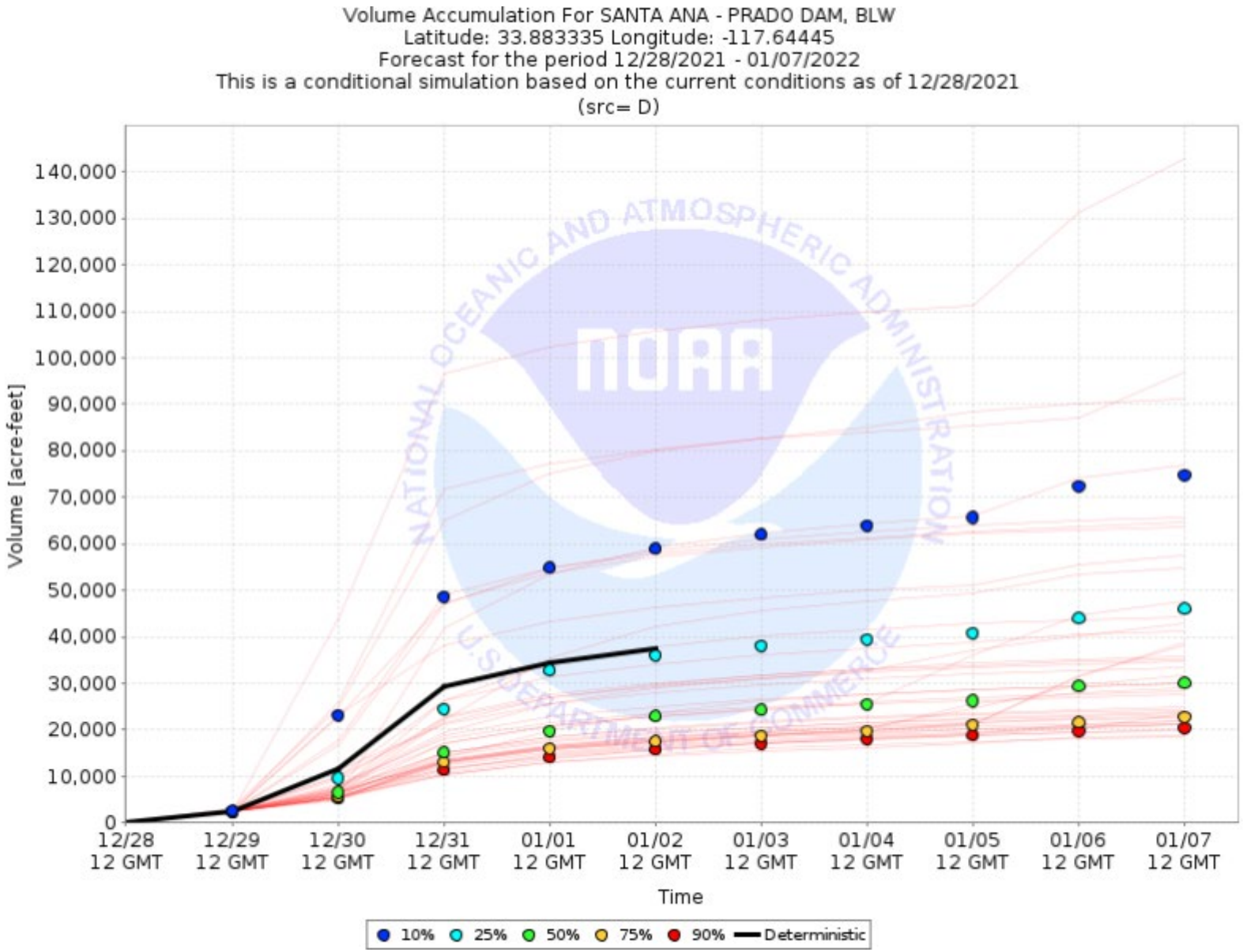
Custom Thresholds

Show: 5 Days 10 Days

Export Image

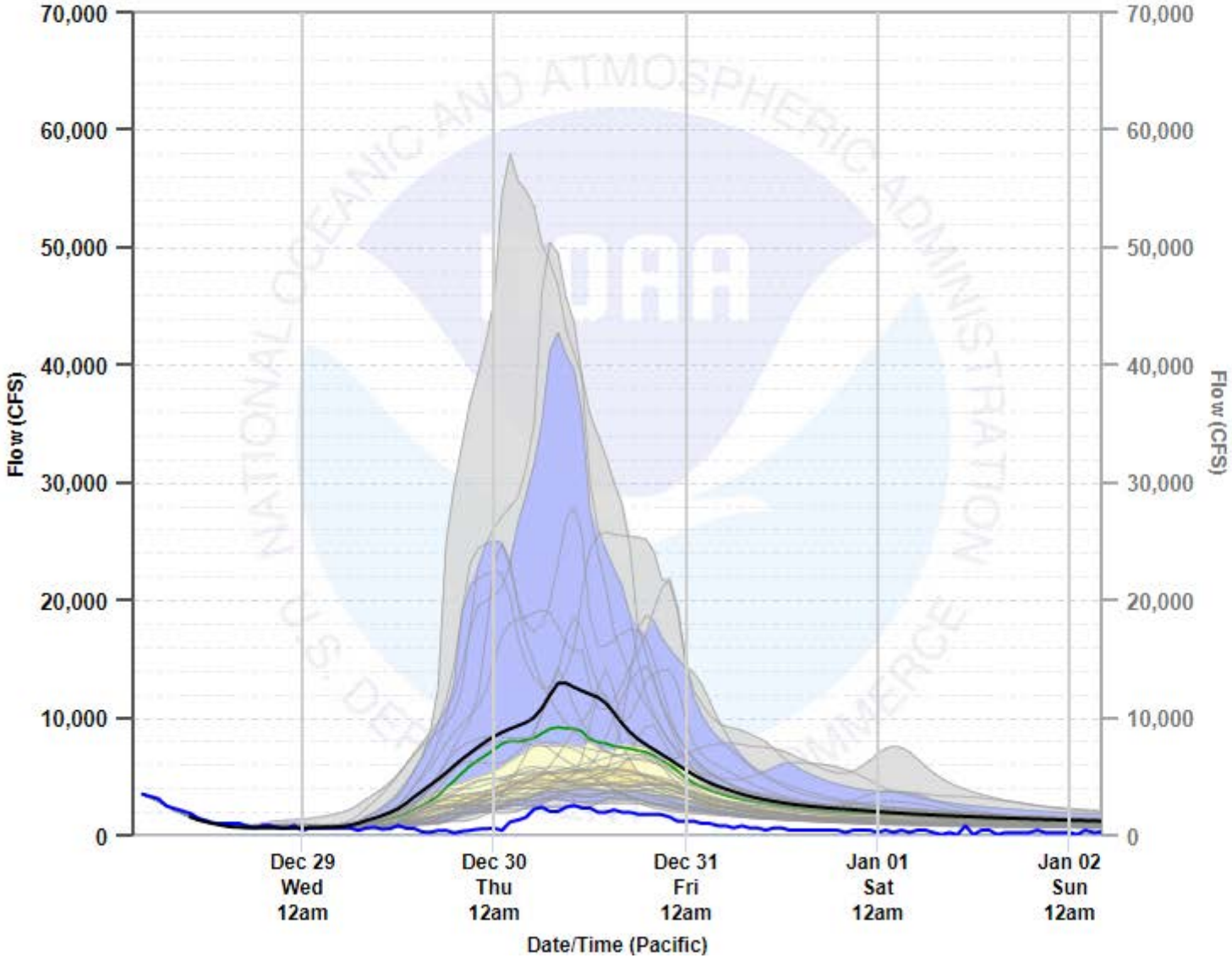
Export Chart Data (CSV)

- [ ] Observed
- [x] Official Forecast (Deterministic)
- [x] Ensemble Mean
- [x] Model Traces
- [x] Hourly Probabilities
  - 0-5% chance
  - 5-25% chance
  - 25-40% chance
  - 40-60% chance


Volume Accumulation For SANTA ANA - PRADO DAM, BLW
Latitude: 33.883335 Longitude: -117.64445
Forecast for the period 12/28/2021 - 01/07/2022
This is a conditional simulation based on the current conditions as of 12/28/2021
(src= D)
Volume [acre-feet]
140,000
130,000
120,000
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
12/28 12 GMT
12/29 12 GMT
12/30 12 GMT
12/31 12 GMT
01/01 12 GMT
01/02 12 GMT
01/03 12 GMT
01/04 12 GMT
01/05 12 GMT
01/06 12 GMT
01/07 12 GMT
Time
10%
25%
50%
75%
90%
Deterministic

Hourly Flow Probabilities
SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Created: 12/28/2021 at 9:00 AM Pacific Time



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Max	57,940
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Custom Thresholds

Show: 5 Days 10 Days

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- [x] Official Forecast (Deterministic)
- [x] Ensemble Mean
- [x] Model Traces
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  - 0-5% chance
  - 5-25% chance
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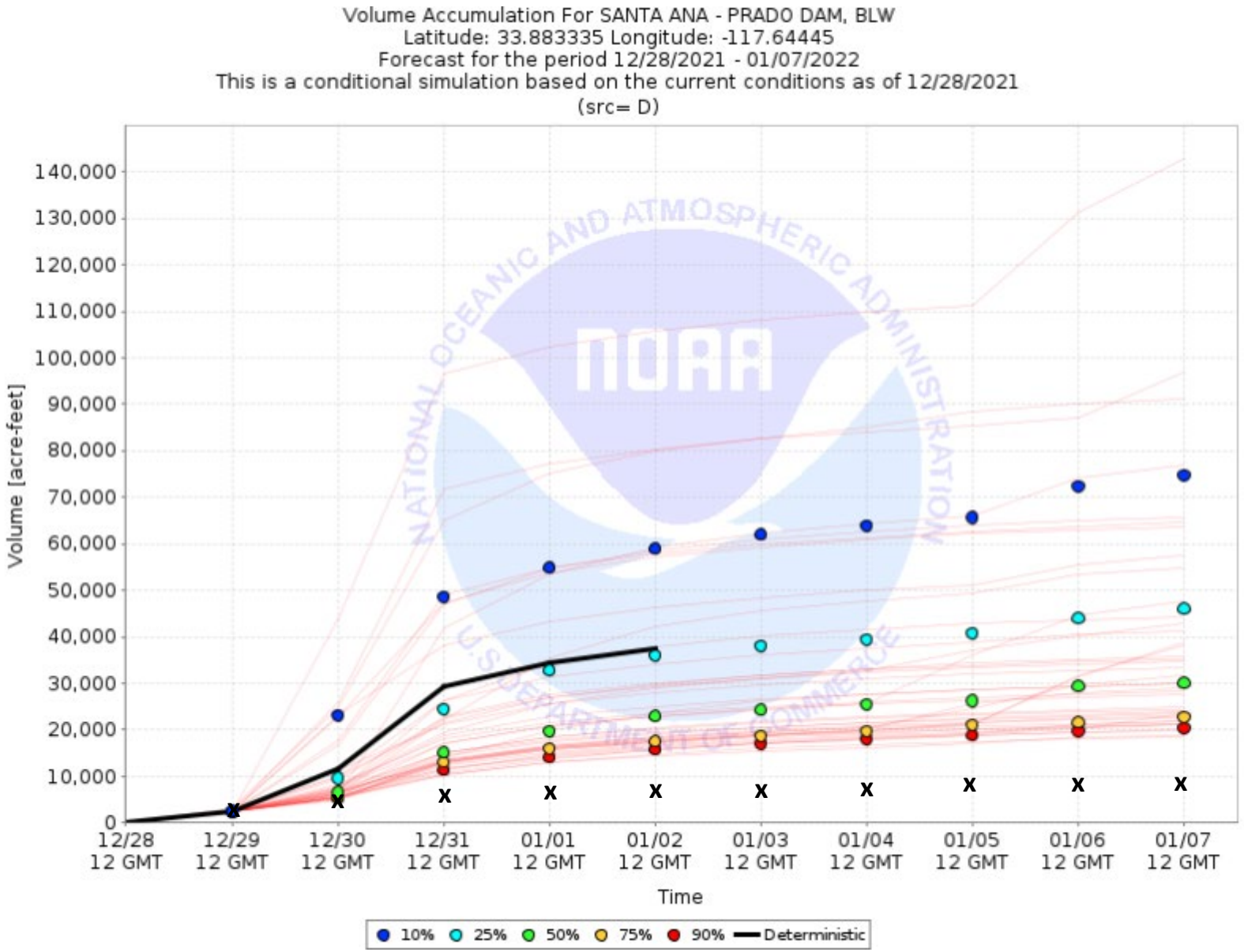

Volume Accumulation For SANTA ANA - PRADO DAM, BLW
Latitude: 33.883335 Longitude: -117.64445
Forecast for the period 12/28/2021 - 01/07/2022
This is a conditional simulation based on the current conditions as of 12/28/2021
(src= D)
Volume [acre-feet]
140,000
130,000
120,000
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
12/28 12 GMT
12/29 12 GMT
12/30 12 GMT
12/31 12 GMT
01/01 12 GMT
01/02 12 GMT
01/03 12 GMT
01/04 12 GMT
01/05 12 GMT
01/06 12 GMT
01/07 12 GMT
Time
10%
25%
50%
75%
90%
Deterministic

9,300 acft

Things to Consider for Reservoir Operations…

- Are the ensemble forecasts reliable?
  - Review verification studies
  - Is there something about *this storm* that makes it more/less predictable?
    - Ensemble spread is based on average predictability
    - Call the RFC and ask about <u>their</u> level of confidence
- Really need a modeling framework to properly assess the risk
  - Spreadsheet tool (ensemble enabled)
  - Ensemble Forecast Operations model (EFO)
  - Another variant

Things to Consider for Reservoir Operations…

- Evaluate your risks and benefits
  - Cost of taking the wrong action
    - Damages and losses
    - Lost opportunity
  - Benefit of taking the right action

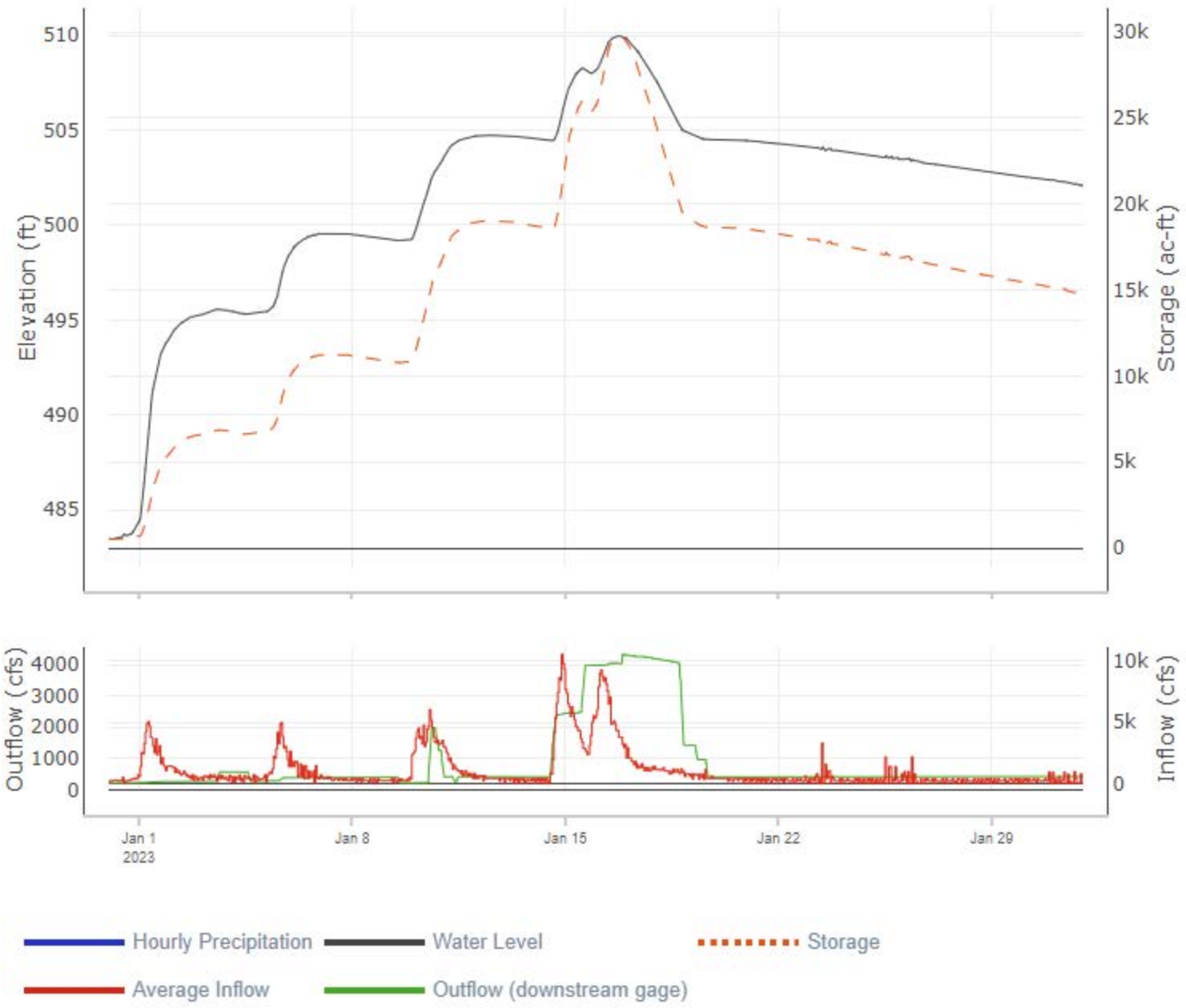
Balance

- Understand lead time requirements
  - Don’t take actions before (or after) you need to.
- Practice with simulated events to build confidence

Discussion and Questions

Thank you!

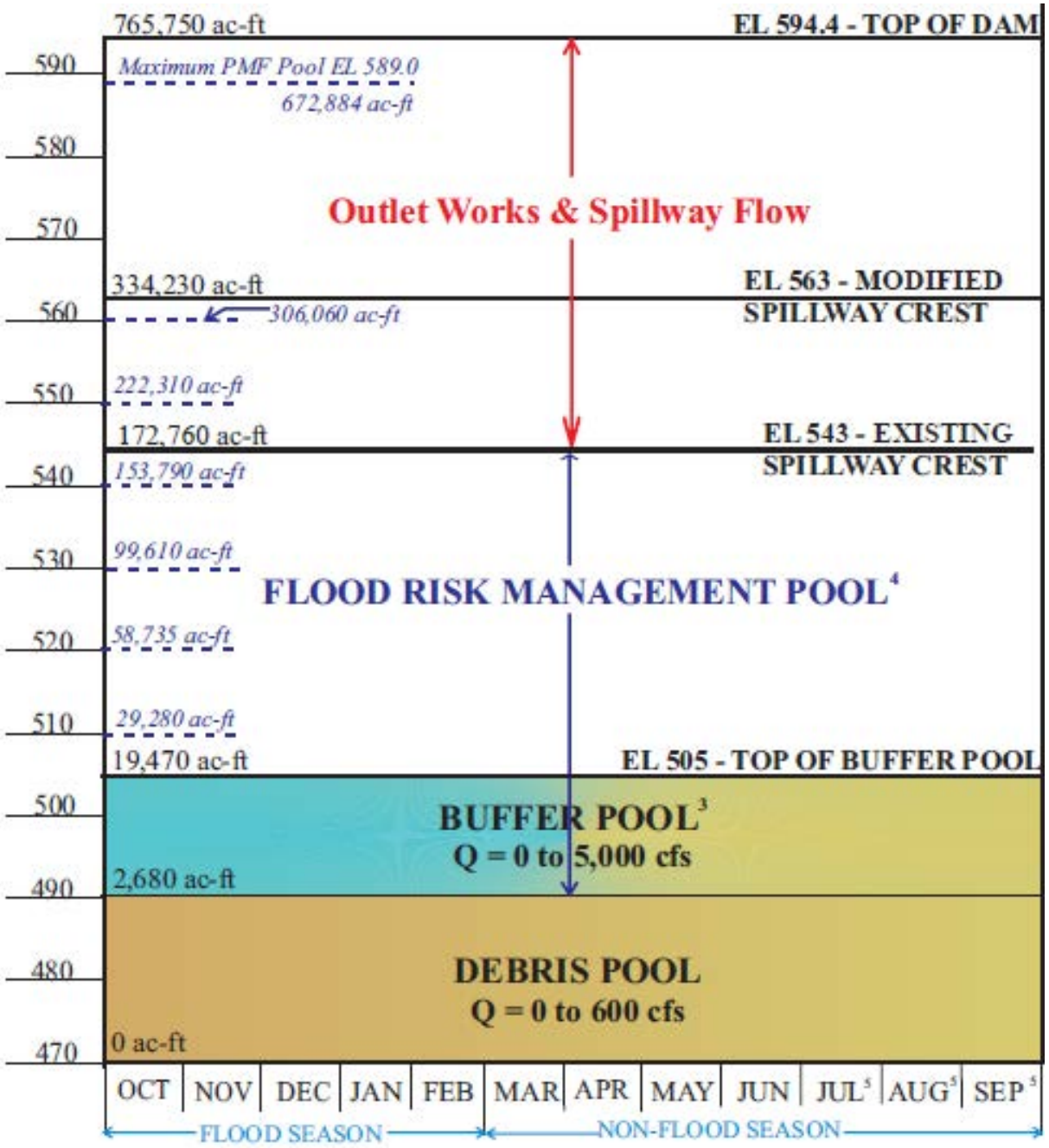
Prado Dam Water Management Operations January 2023



Background Info

- Storage at EL 505: 19,470 ac ft
  506 21,300
- OCWD
  - Diversion Capacity: 1350 cfs
  - Infiltration Capacity: 250 cfs

NOTE: all elevations are based on NGVD29



Major Considerations and Constraints

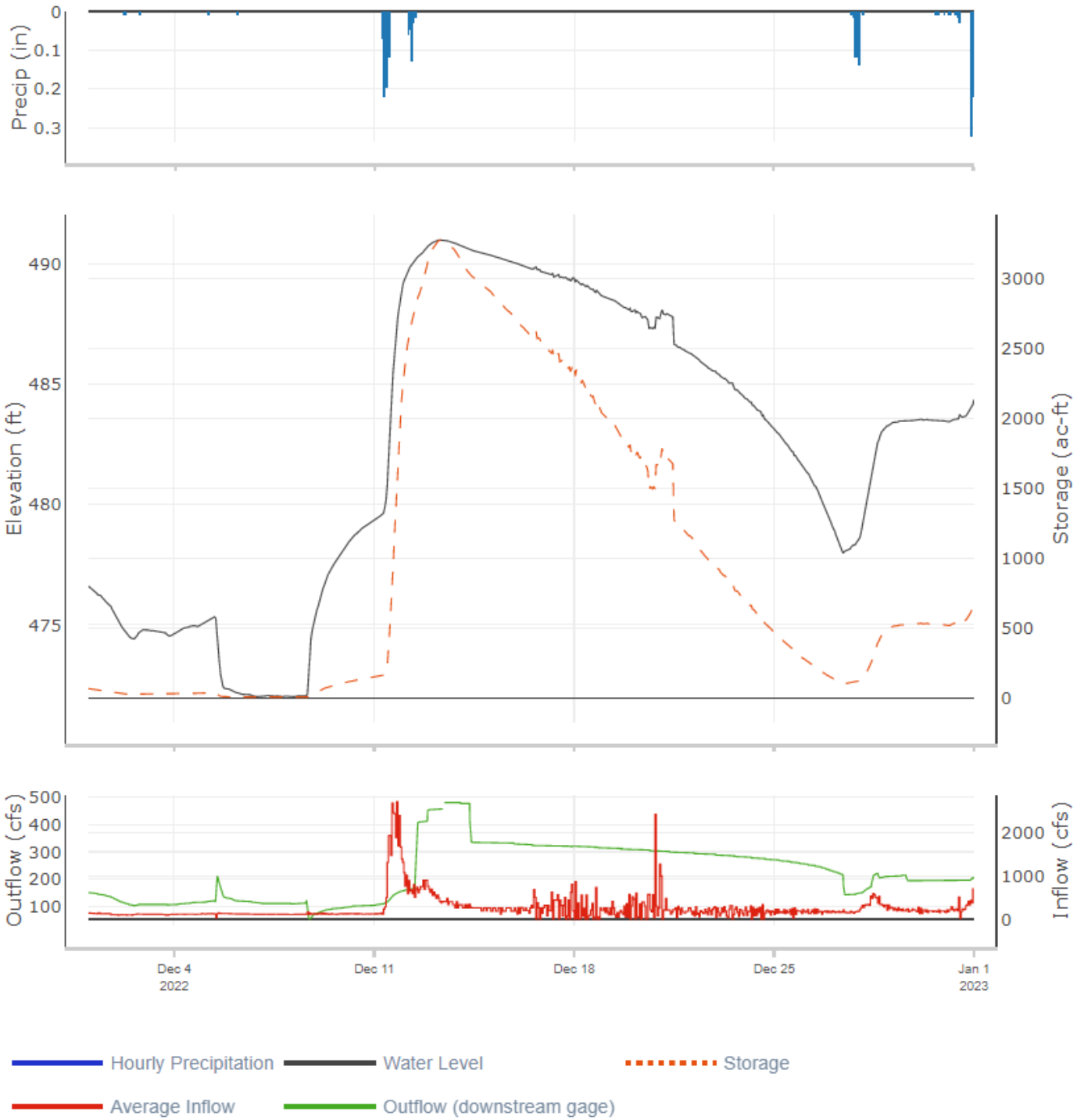
- Operations up to WSE 505
  - Significant consideration is to maximize OCWD capture of discharge
  - Minimize impacts to other upstream and downstream entities
- Operations approaching WSE 505
  - Water management focus changes from water con to Flood Risk Management
  - Minimize downstream impacts
  - As conditions allow, minimize impacts to upstream and downstream entities, including minimizing impacts to OCWD
- Operations approaching and exceeding WSE 543 (current spillway crest EL)
  - Dam safety is the priority

Conditions Going into January 2023

- Two events observed in DEC 2022
- Water con discharge maintained during both DEC 2022 events (<500 cfs)

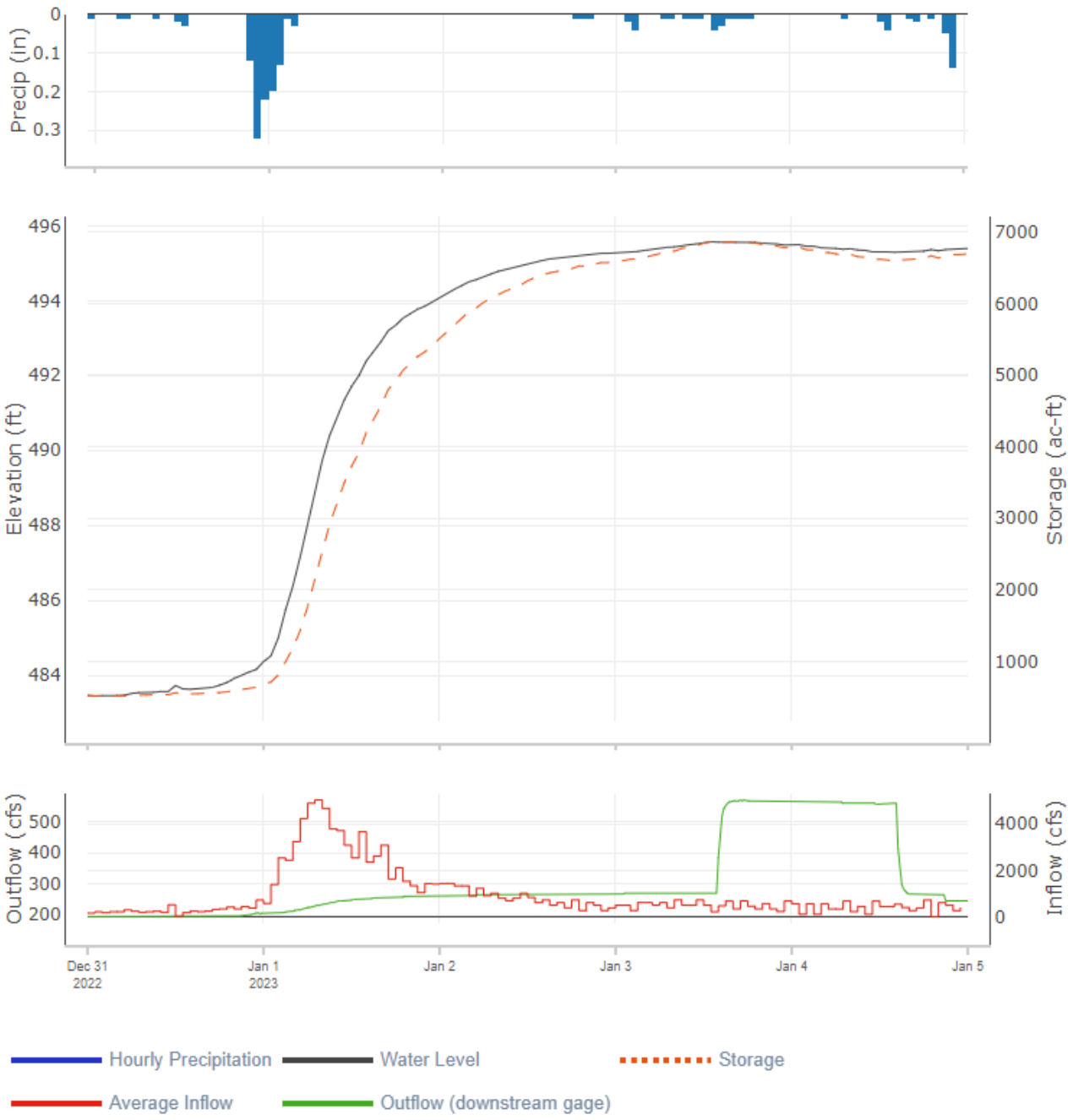
- On 13 Dec
- Peak WSE 491
- Peak Storage 3,300 ac ft
- Peak Inflow 2700 cfs 12 Dec

- On 30/31 Dec at midnight
- WSE 483.5
- Storage 515 ac ft



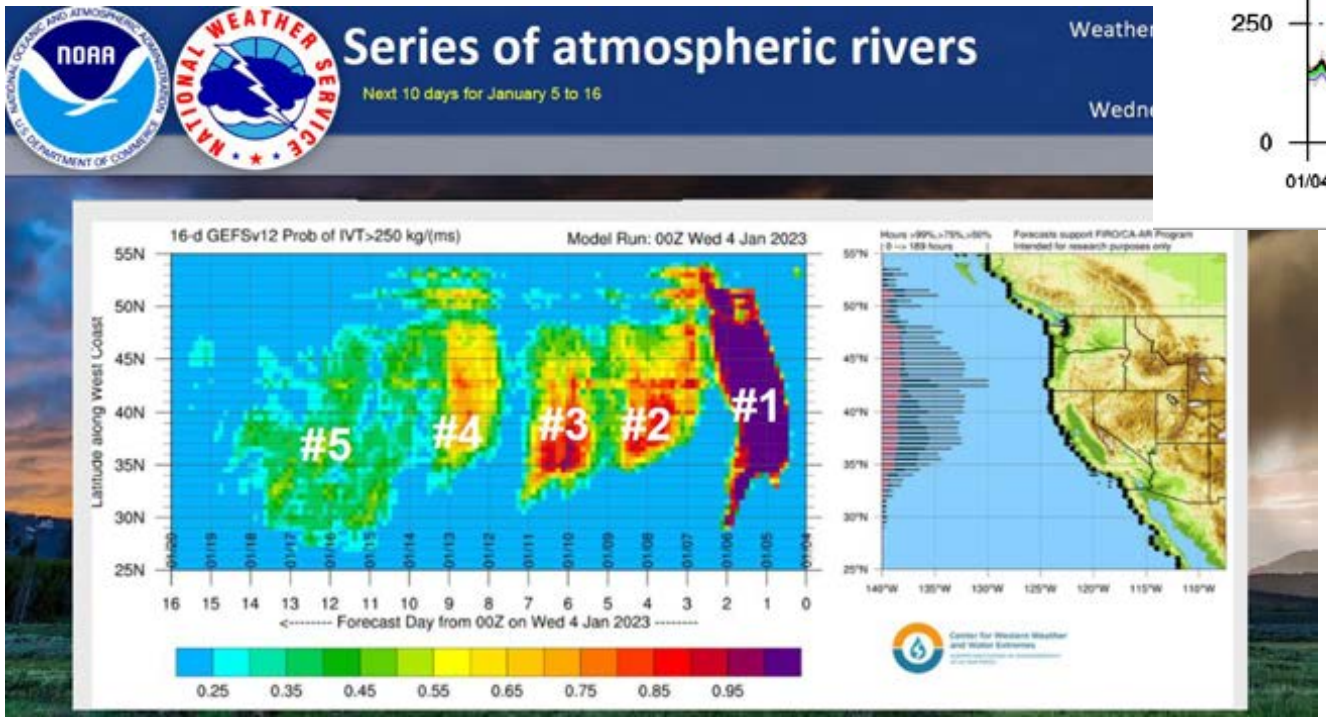
31 Dec – 04 Jan Rain Event

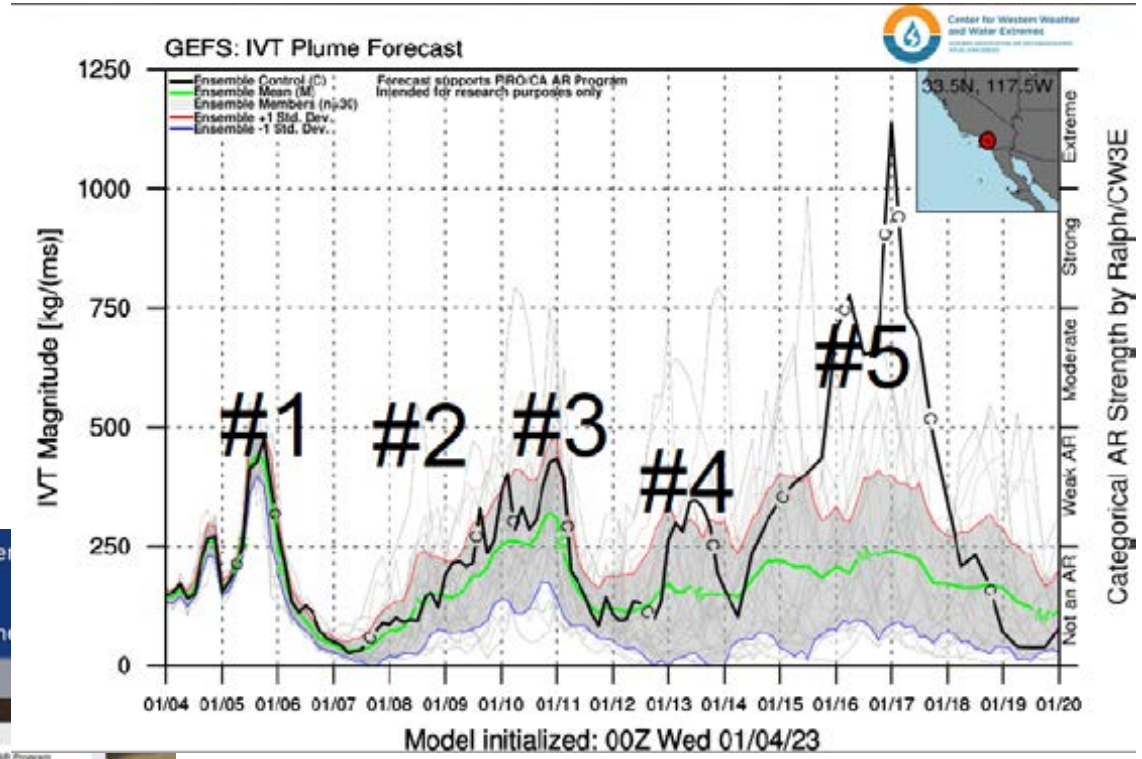
- Initial Plan: Based on forecast, estimated that sufficient storage was available to continue releases in coordination with OCWD.
- Actual Operation: Generally followed initial plan. Based on forecast (accounting for uncertainty with volume and timing), advised that OCWD to maximize what they can divert from Prado Dam.
- Impacts: Prado storage maximized to 6,800 ac ft



Jan 2023 Forecast

- In early Jan 2023, forecast started coming in of a series of storm events (atmospheric rivers) that could impact the SPL AOR





Prado Jan 2023 Inflow Forecast thru 14 Jan

- Initial Planning
  - Expected inflows not particularly concerning
  - Look at possibility of Exceeding top of water con buffer pool (WSE 505)
  - Maintain water con discharge
  - Continue monitoring forecast

SANTA ANA RIVER - PRADO RESERVOIR (ADOC1)

Latitude: 33.89° N Longitude: 117.64° W Elevation: 580 Feet
Location: Riverside County in California River Group: Southern California

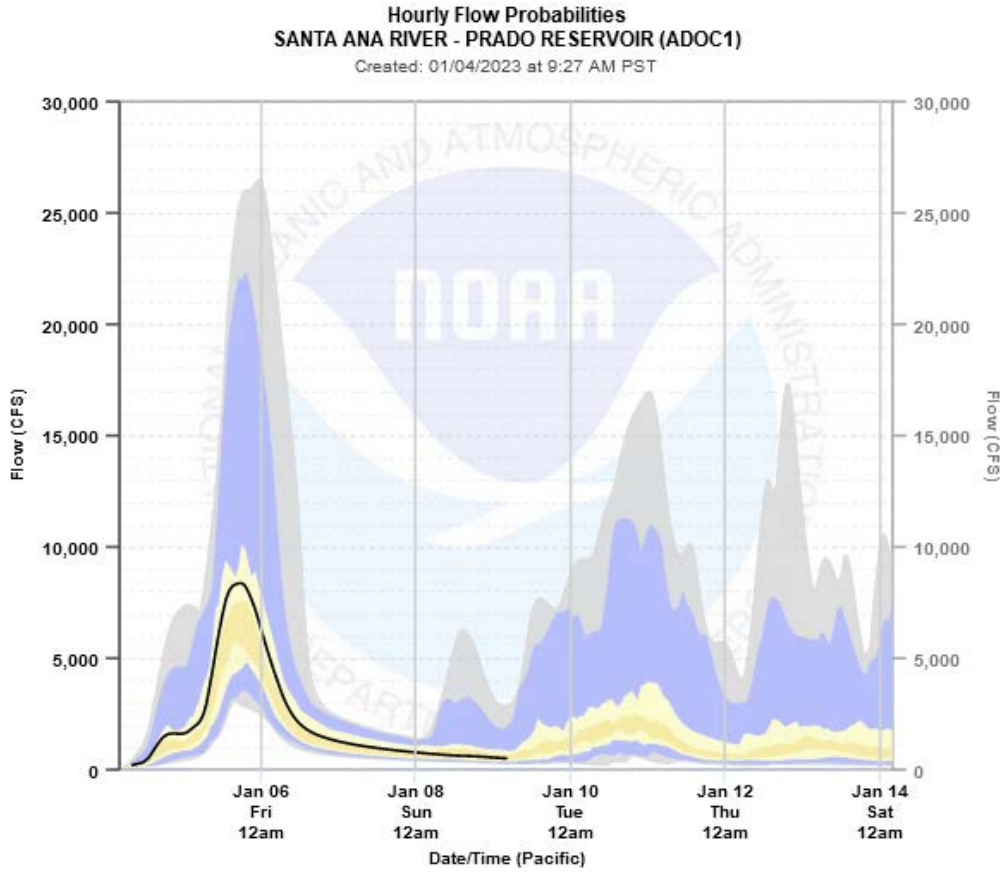
Issuance Time: Jan 04 2023 at 9:27 AM PST

Monitor Stage: N/A *Flood Stage: N/A*

PRODUCT NOTE: Ensemble forecasts produced by CNRFC only consider meteorological uncertainty and do not account for hydrologic uncertainty.

Short-Range Peak Exceedance Plot Product Information Plot Type: Ensemble Forecast

CSV Ensemble File Download (Data in kcfs): ADOC1



Chance of Flow Exceedance (CFS)
Forecast Period:
01/04/2023 4 am - 01/14/2023 4 am

Max	26,490
5%	23,362
10%	20,770
25%	11,913
50%	8,168
75%	5,916
90%	4,025
95%	3,597
Min	3,291

Custom Thresholds
Show: 5 Days 10 Days
Export Image
Export Chart Data (CSV)

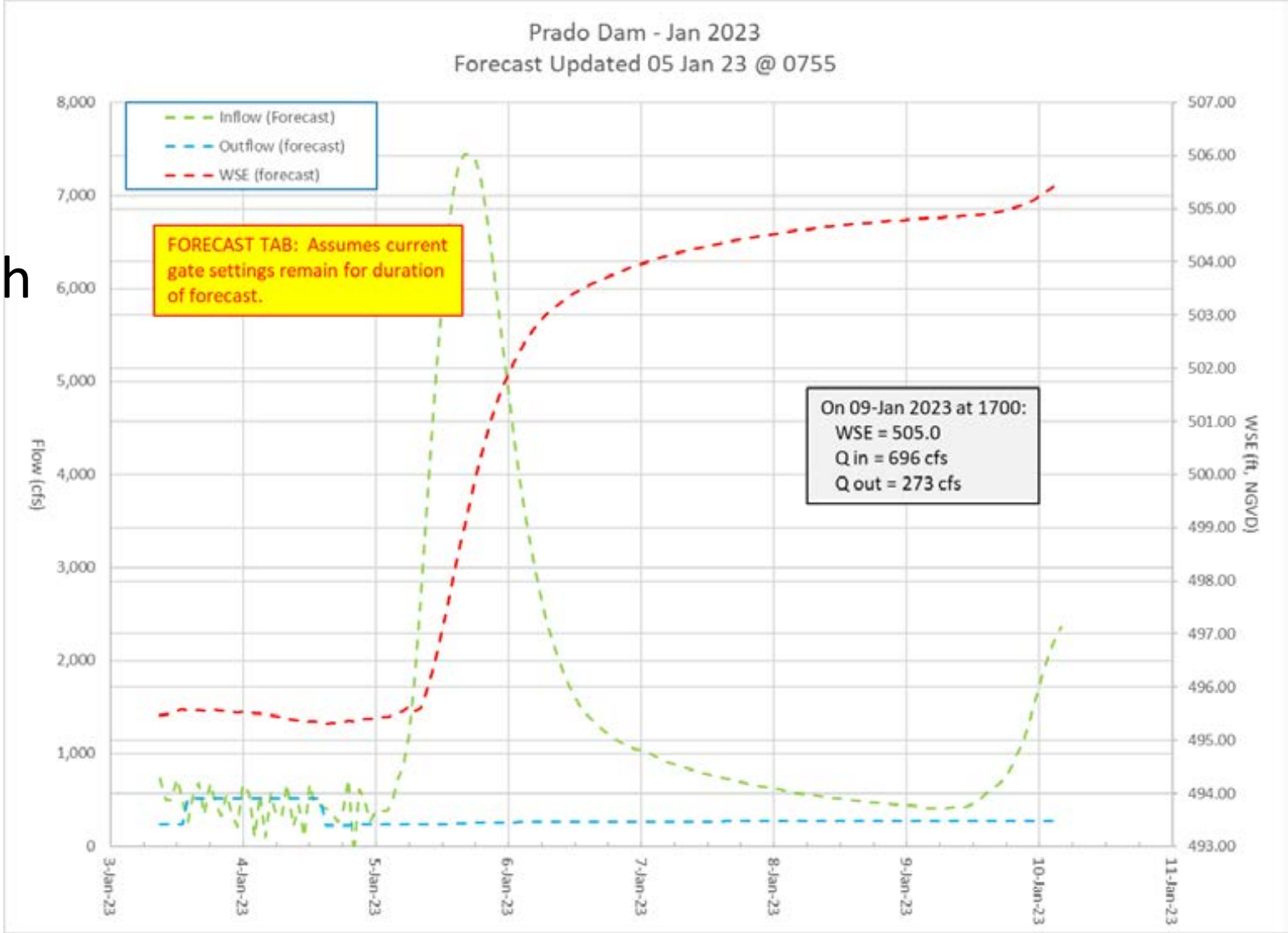
- [x] Official Forecast (Deterministic)
- [ ] Ensemble Mean
- [ ] Model Traces
- [x] Hourly Probabilities
  - 0-5% chance
  - 5-25% chance
  - 25-40% chance
  - 40-60% chance

What information is

05 – 08 Jan Rain Event

- Forecast: Based on CNRFC inflow forecast (05 Jan at 0755), WSE would approach but remain below 505 through 08 Jan
- Initial Plan: Continue release coordination with OCWD.

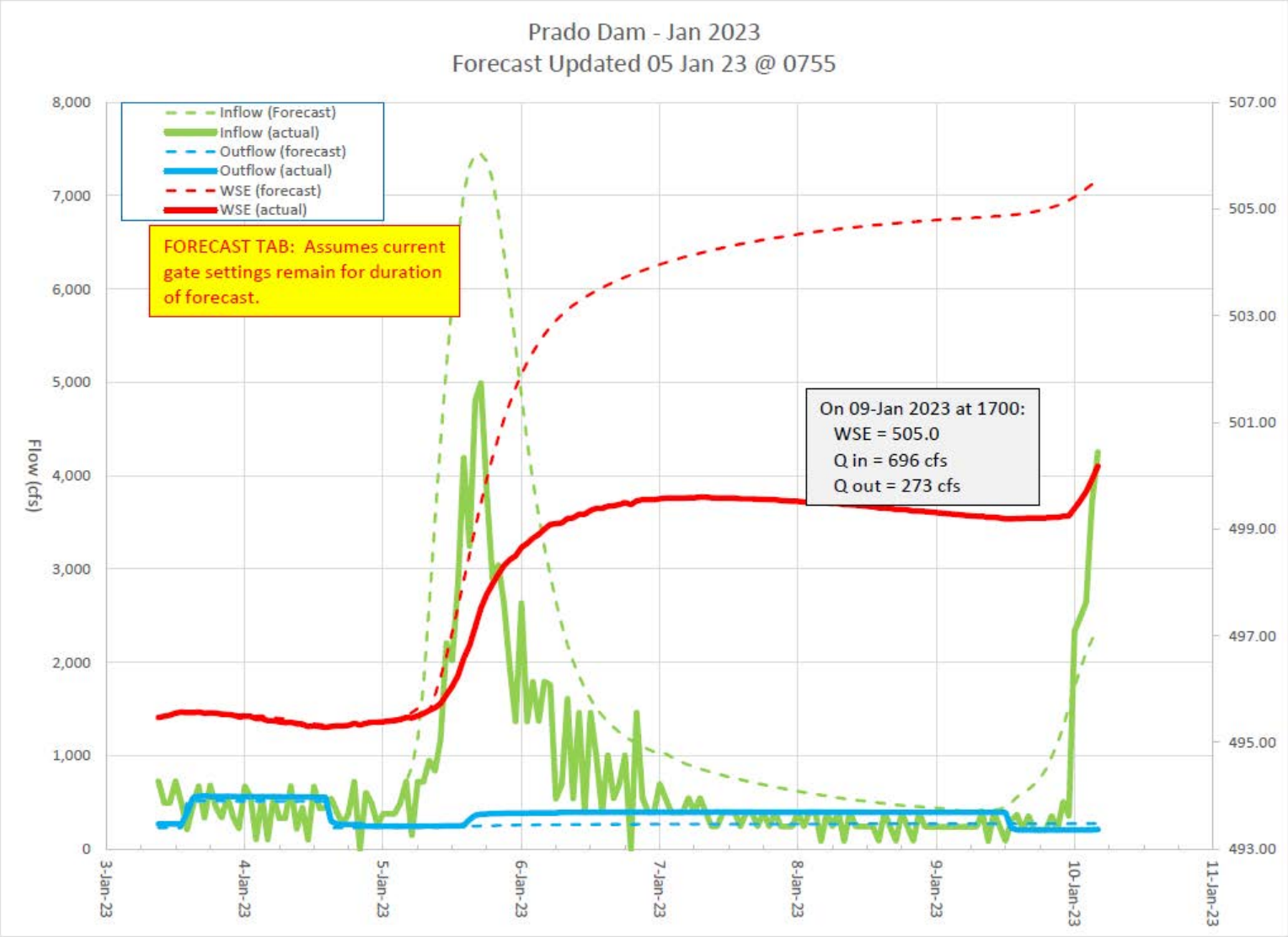
Forecast



05 – 08 Jan Rain Event

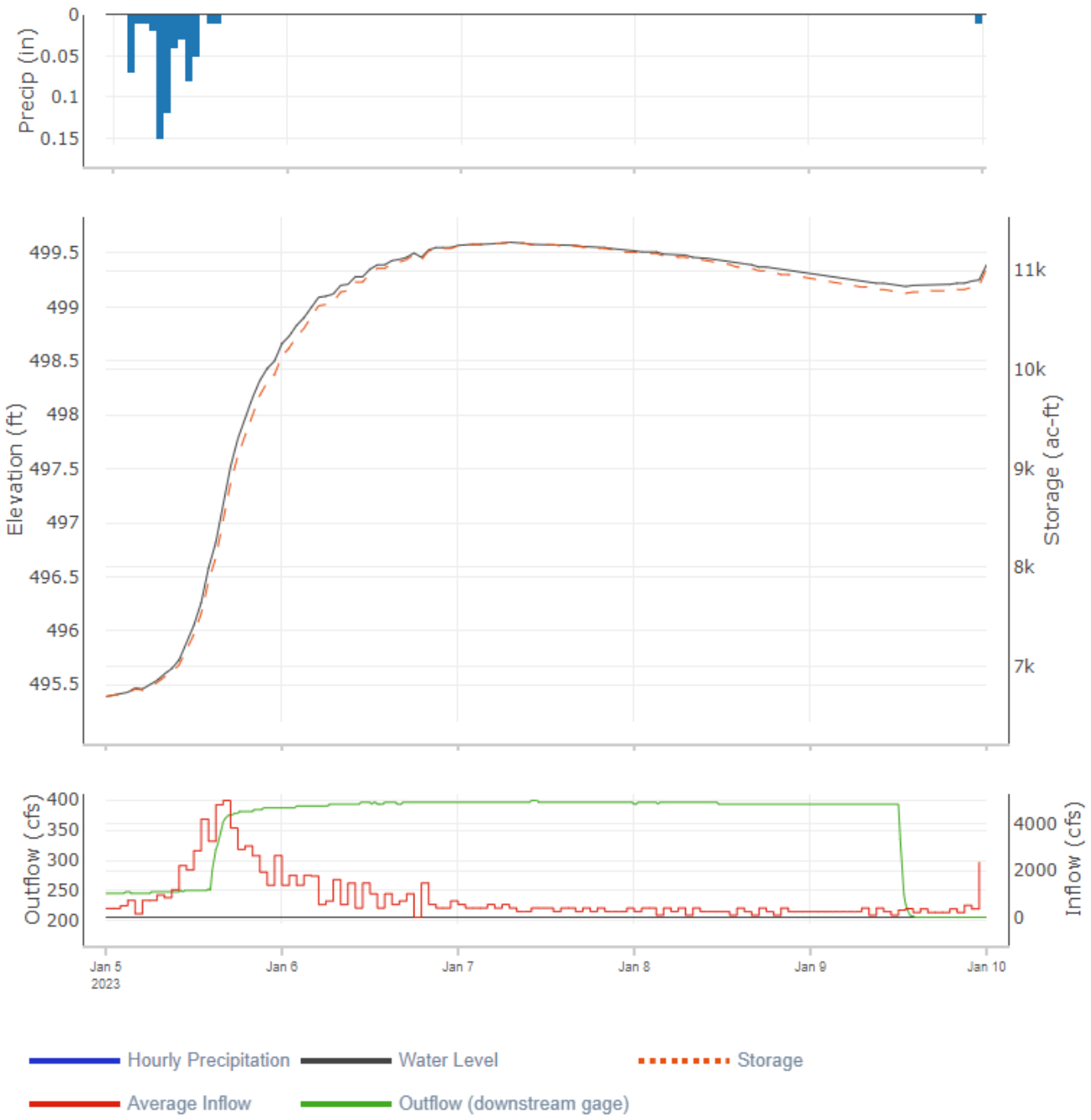
Actual

- Forecast: Based on CNRFC inflow forecast (05 Jan at 0755), WSE would approach but remain below 505 through 09 Jan
- Initial Plan: Continue release coordination with OCWD.



05 – 08 Jan Rain Event

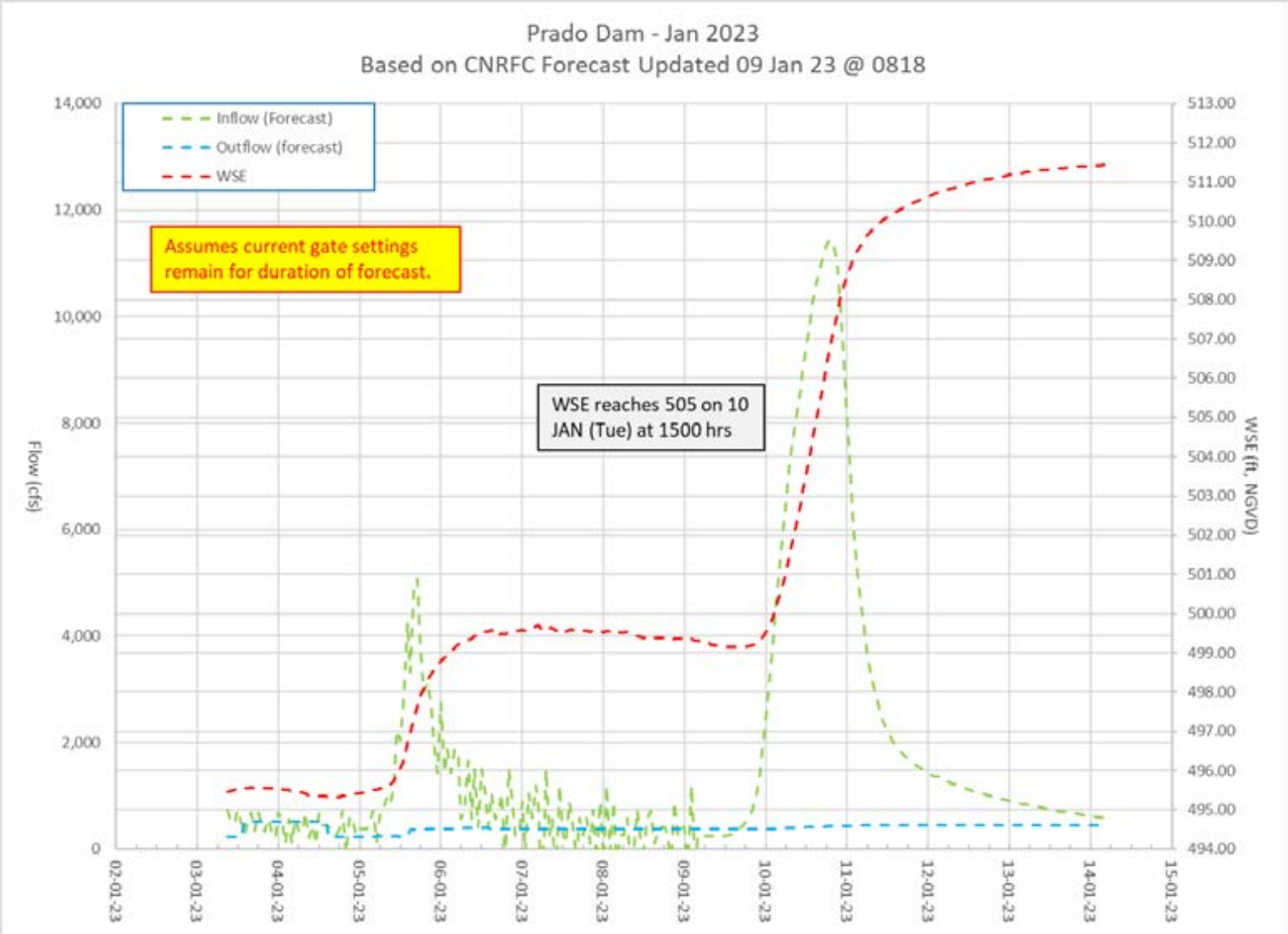
- Actual Operation:
  - WSE peaked at 499.6
  - Storage peaked at 11,300 ac ft
  - Discharges coordinated with OCWD and ramped up to 400 cfs
  - At end of 08 Jan, Storage was 10,900 ac ft



09 – 13 Jan Rain Event

Forecast

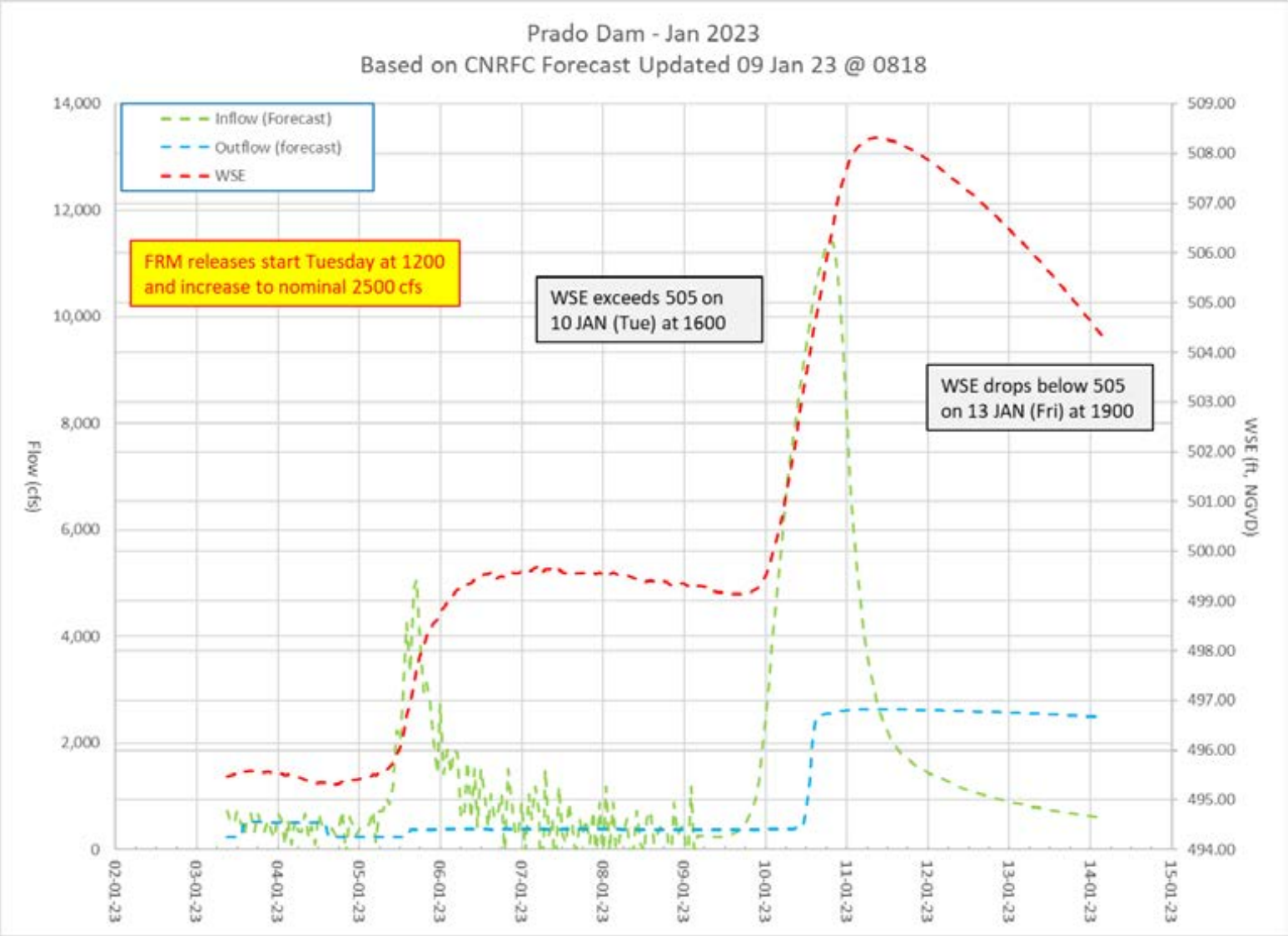
- Forecast: Based on CNRFC inflow forecast (09 Jan at 0818) and maintaining water con discharge:
  - WSE exceeds 505 on Tue, 10 Jan at 1500 hrs
  - Max WSE will exceed 511



09 – 13 Jan Rain Event

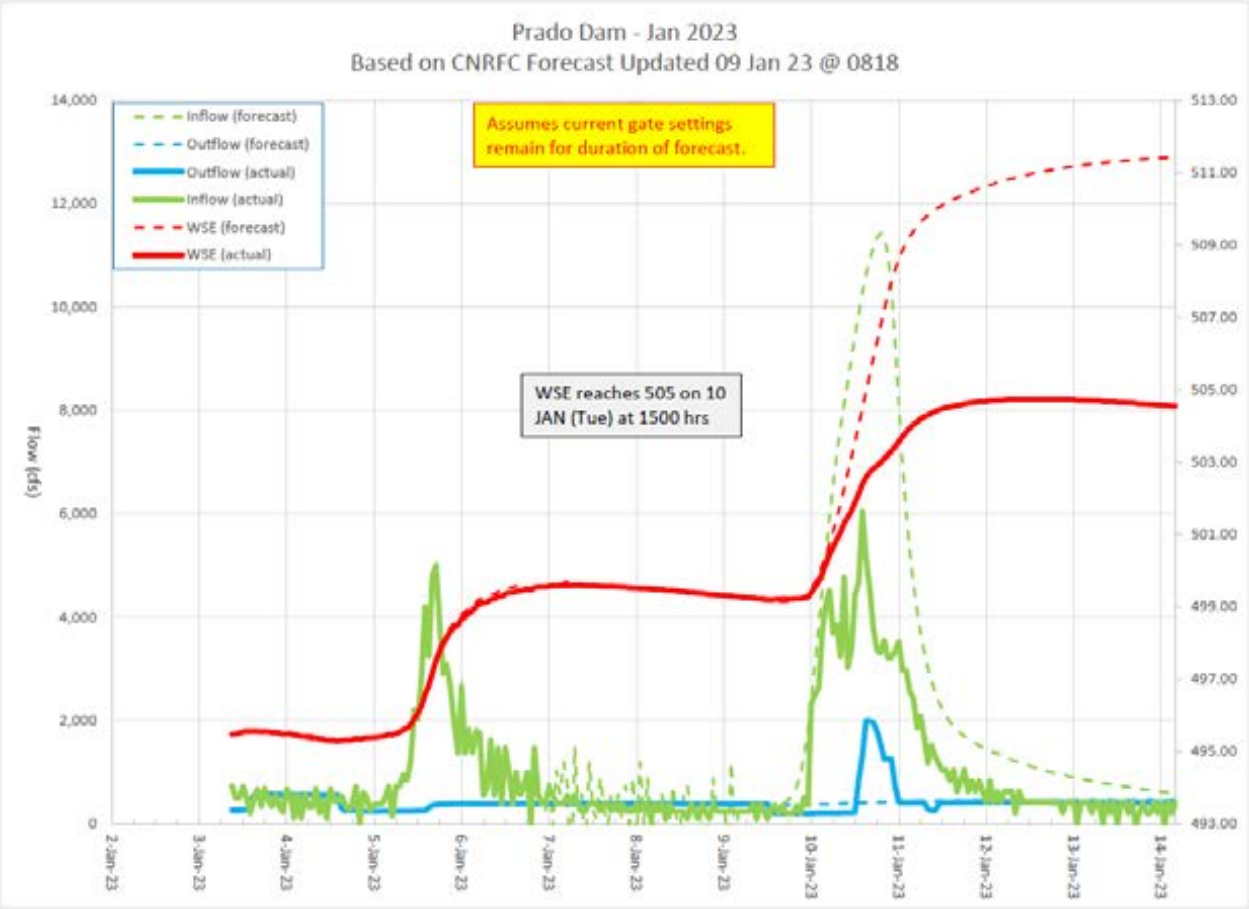
Forecast

- Initial Plan:
  - Objective: limit the rise of max pool, maybe <510
  - Ramp up FRM releases to 2500 cfs mid-day on Tue 10 Jan
  - Maintain releases until WSE pool shows downward trend towards 505 (approx. Fri 13 Jan)

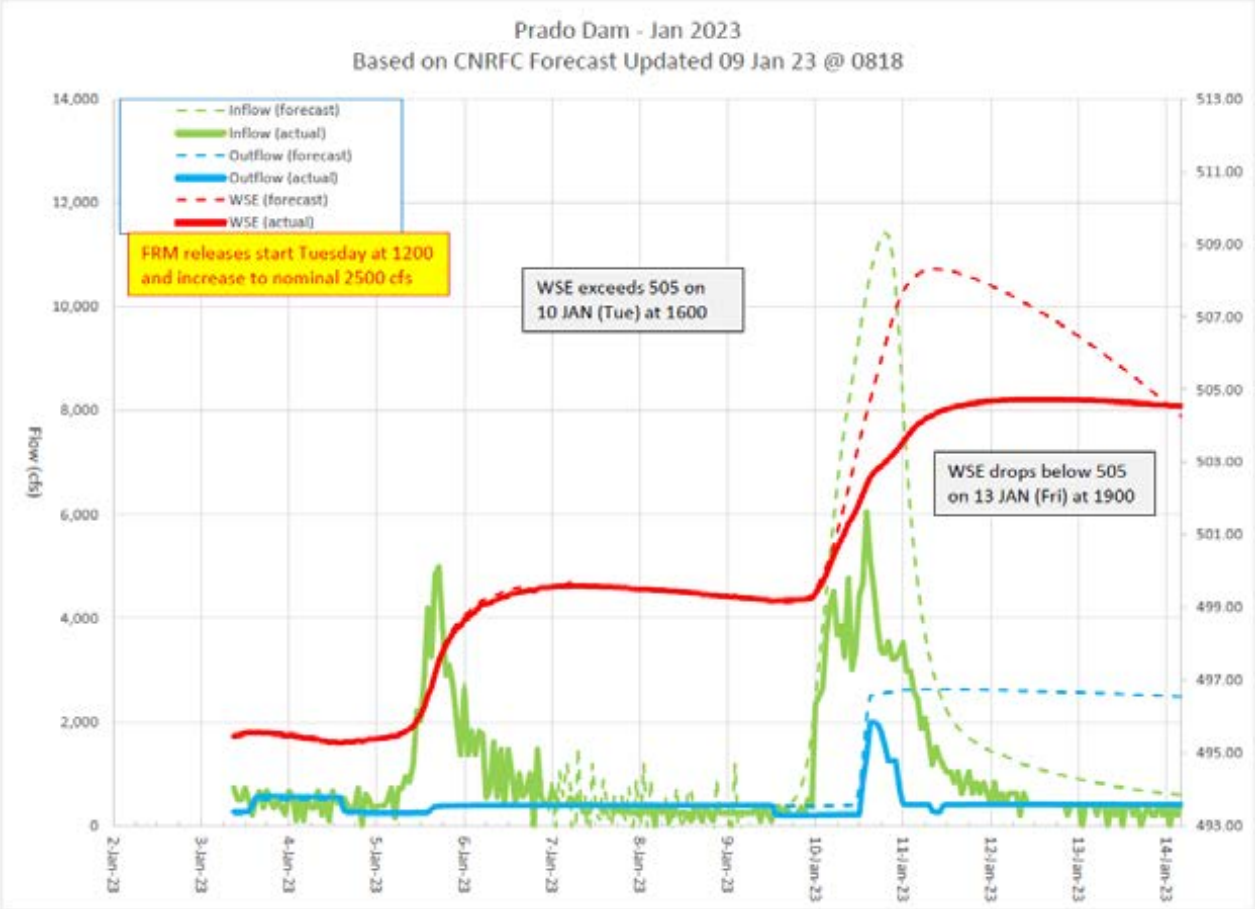


09 – 13 Jan Rain Event

Anticipated Runoff

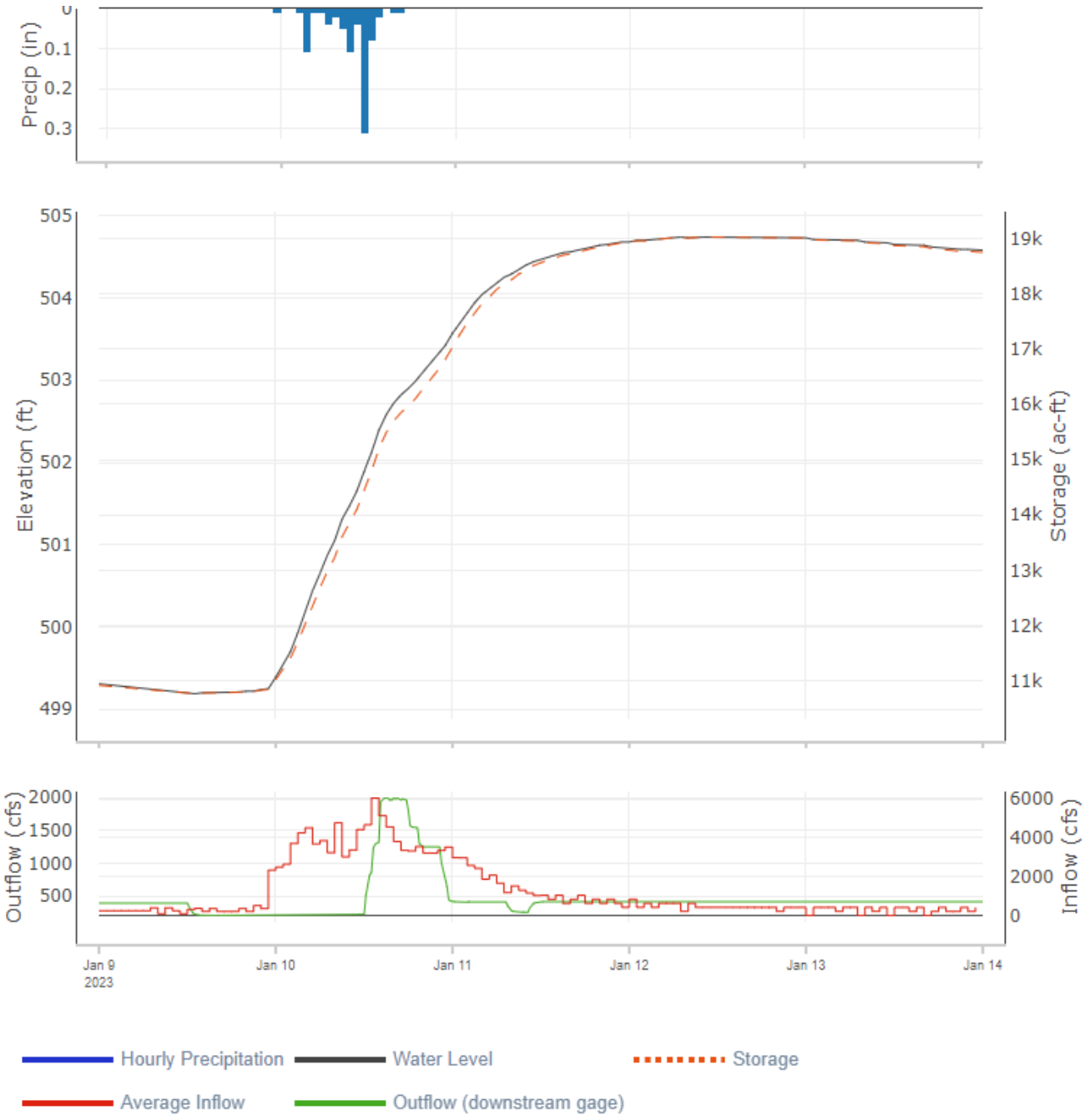


Actual Observed Runoff



09 – 13 Jan Rain Event

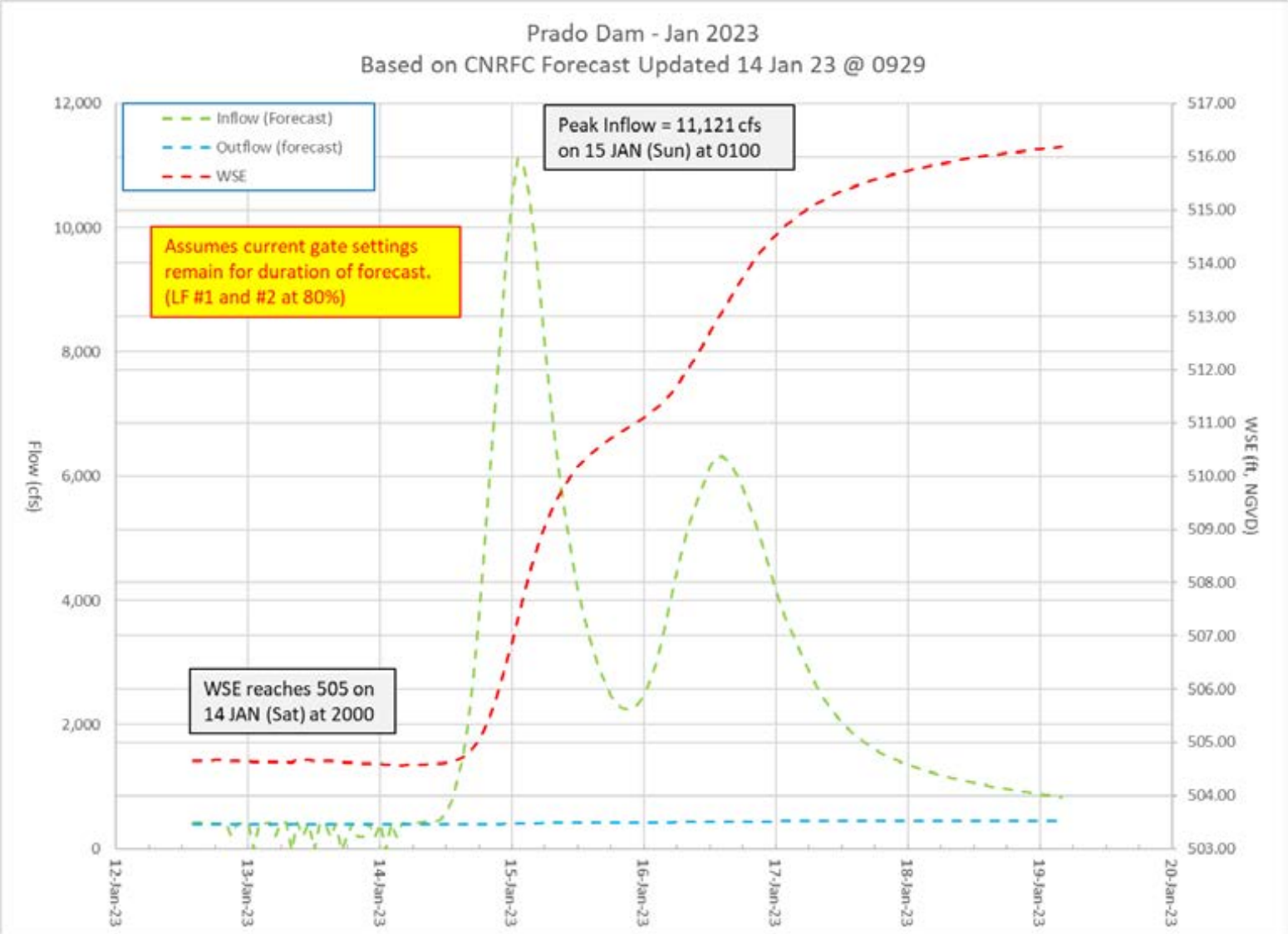
- Actual Operation:
  - During event, it became clear that the WSE would not significantly exceed 505
  - FRM releases reduced to attempt “soft” landing at 505
  - WSE peaked at 504.7
  - Storage peaked at 19,000 ac ft
  - At end of 13 Jan, Storage was 18,700 ac ft



14 – 20 Jan Rain Event

Forecast

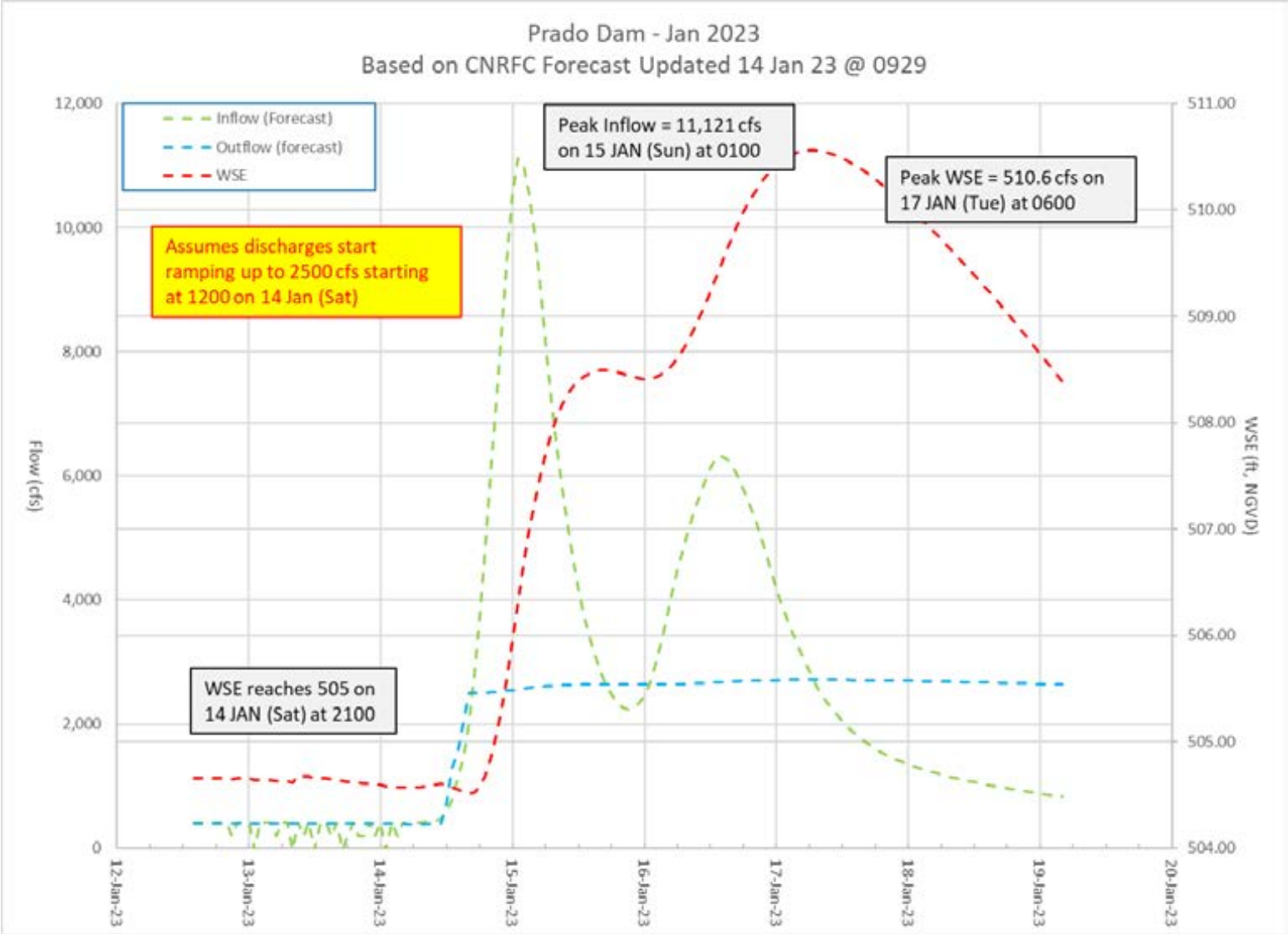
- Forecast: Based on CNRFC inflow forecast (14 Jan at 0929) and maintaining water con discharge:
  - WSE exceeds 505 on Sat, 14 Jan at 2000 hrs
  - Max WSE will exceed 516



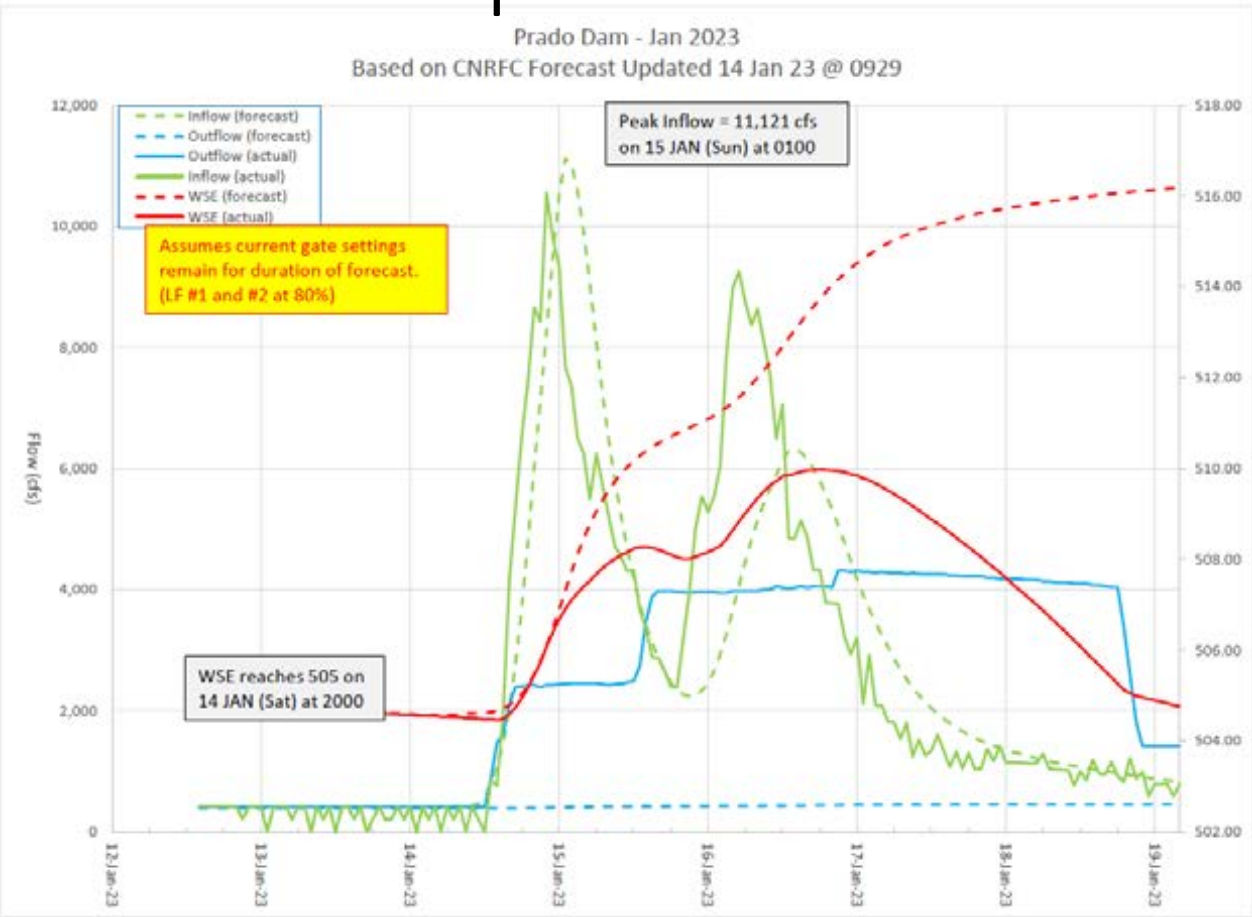
14 – 20 Jan Rain Event

Forecast

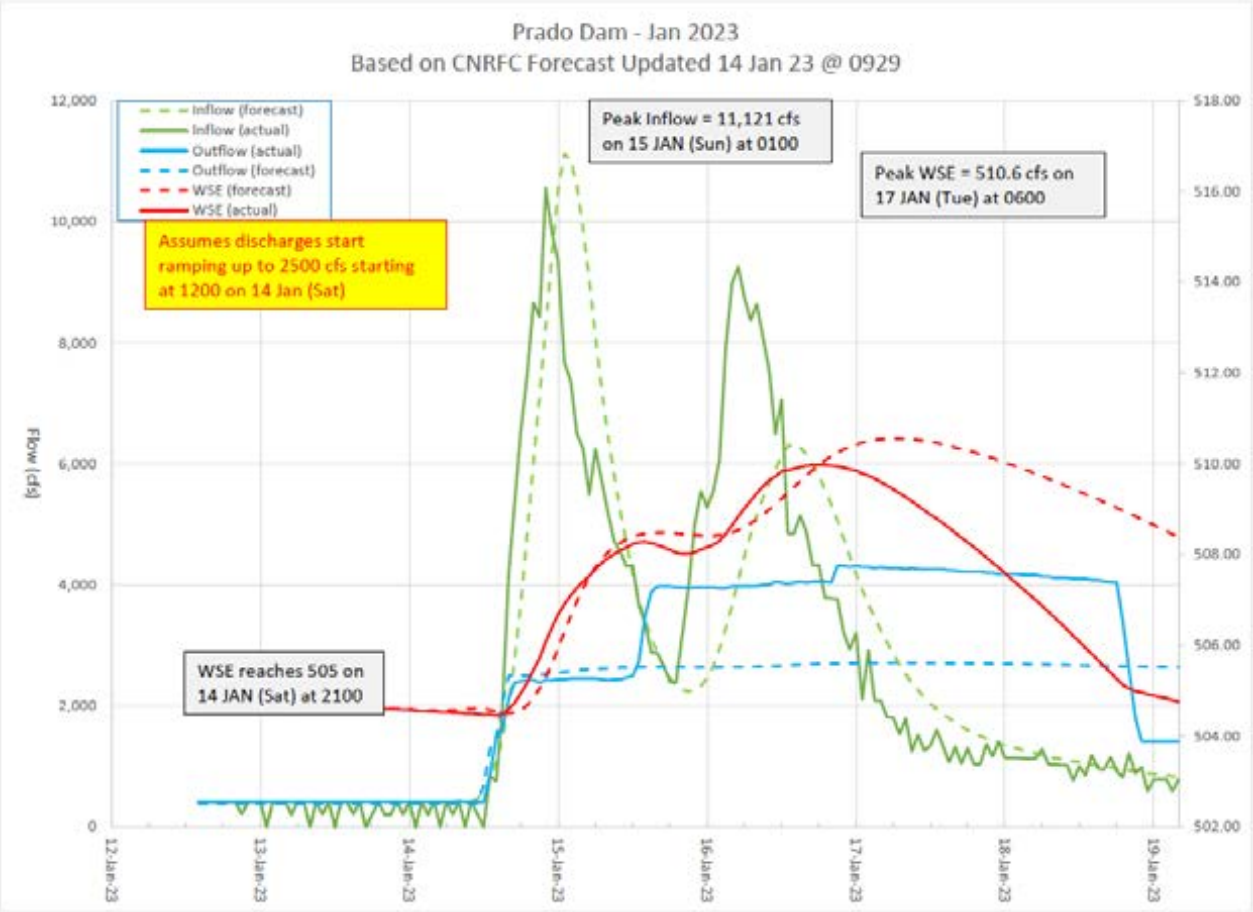
- Initial Plan:
  - Due to the WSE proximity to 505, it was considered certain that FRM releases would be required.
  - Objective was to limit upstream and downstream impacts from FRM releases and to minimize OCWD diversion downtime.
  - Ramp up FRM releases to 2500 cfs mid-day on Sat 14 Jan and maintain releases until WSE started downward trend



14 - 20 Jan Rain Event
Anticipated Runoff

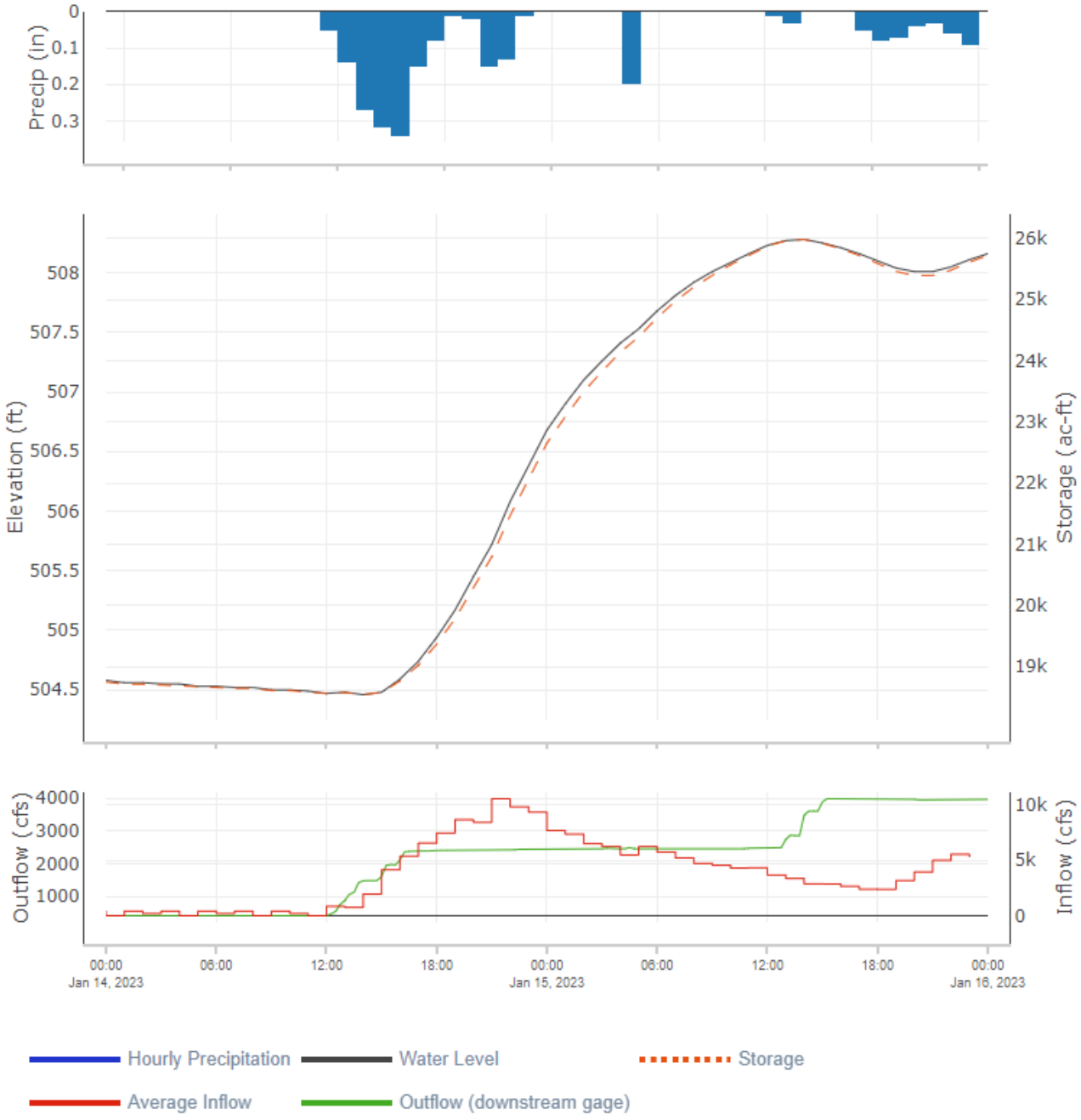


Actual Observed Runoff



14-20 Jan Rain Event First Storm

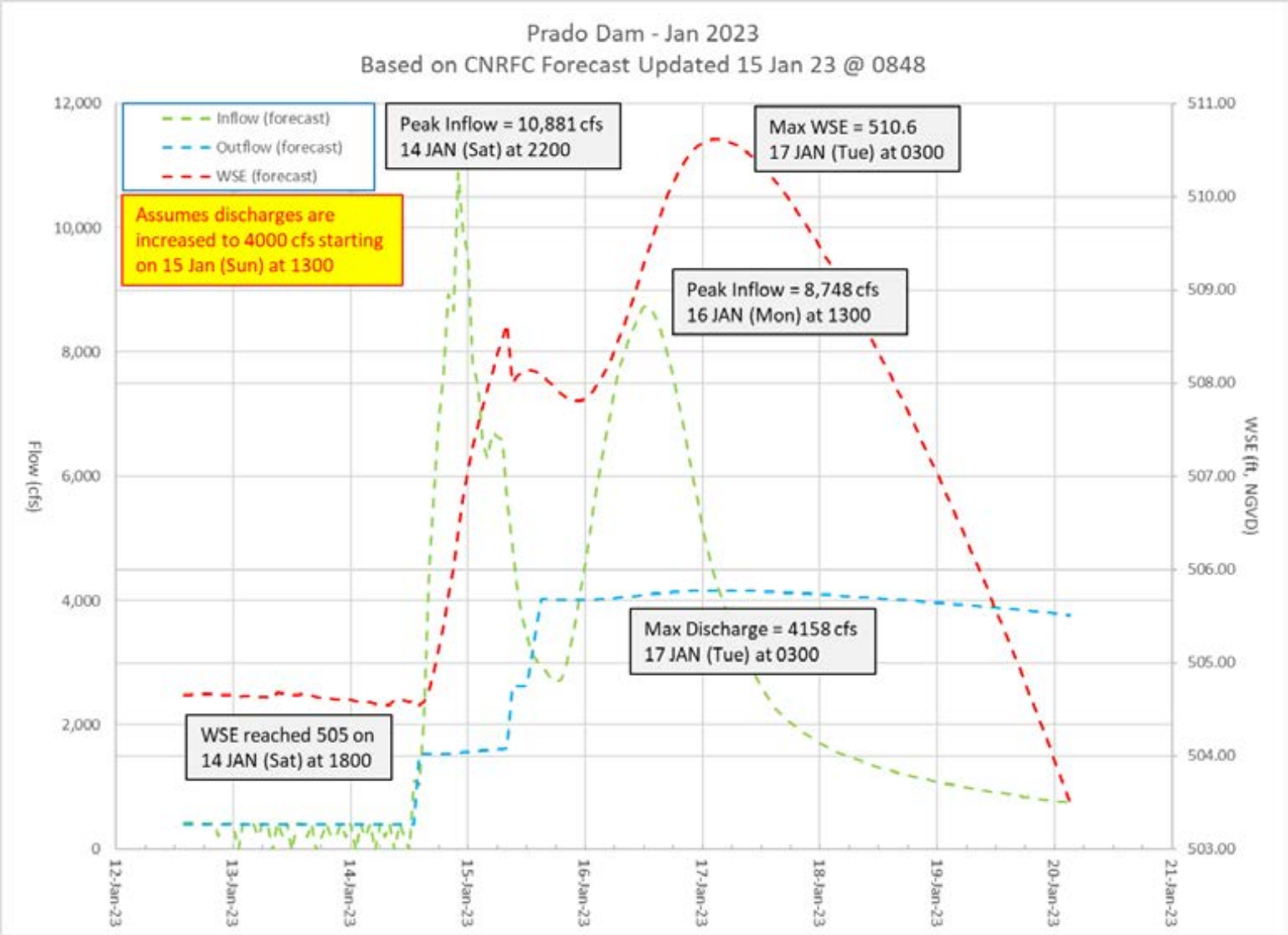
- Actual Operation:
  - Operations for the first storm event went nearly the same as planned.
  - The WSE was peaking as expected around 508 - 509
  - Discharges were a nominal 2500 cfs
- But the updated forecast showed for the 2nd storm of the series . . .



14 – 20 Jan Rain Event Second Storm

- Forecast: Based on CNRFC inflow forecast (15 Jan at 0848)
- Peak inflow for second storm increased from 6300 cfs to 8800 cfs
- Revised Plan: Increase discharge to 4,000 cfs to limit WSE <510, if possible

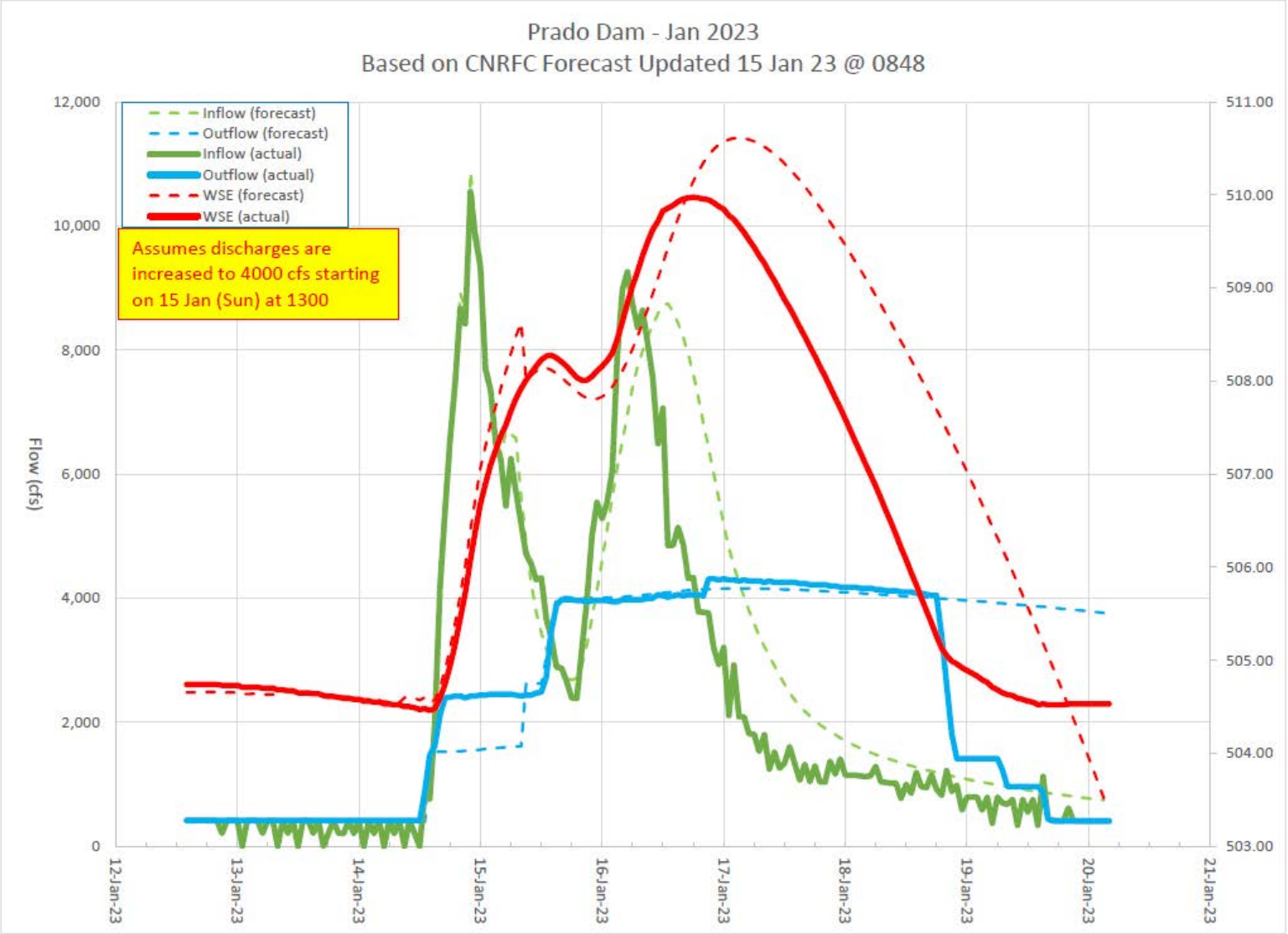
Forecast



14 – 20 Jan Rain Event Second Storm

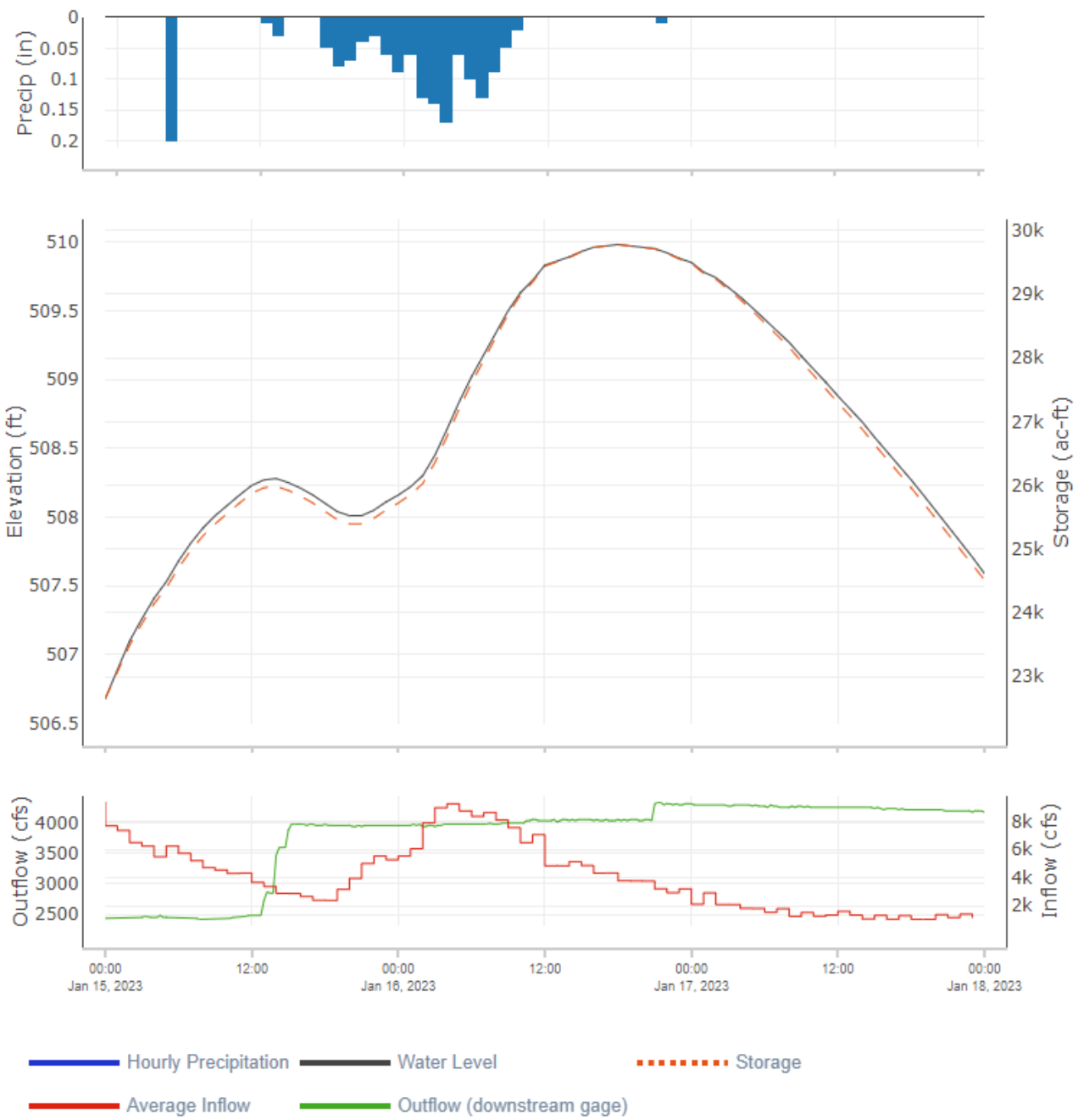
- Forecast: Based on CNRFC inflow forecast (15 Jan at 0848)
- Peak inflow for second storm increased from 6300 cfs to 8800 cfs
- Revised Plan: Increase discharge to 4,000 cfs to keep max WSE around 510

Actual



14 - 20 Jan Rain Event 2nd Storm

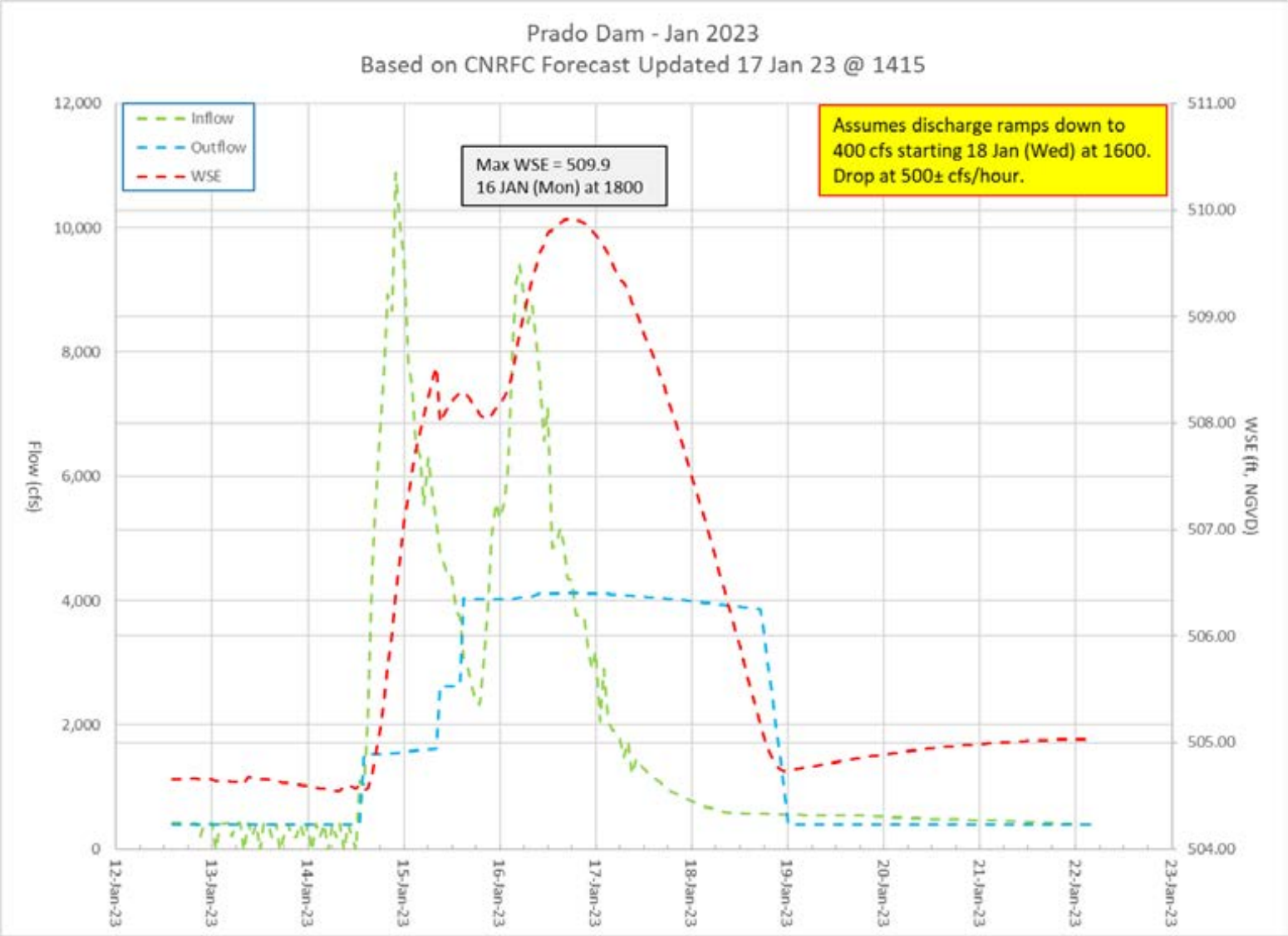
- Actual Operation:
  - Operation for second storm event generally went as planned.
  - FRM releases increased to 4000 cfs (by gate rating) to ensure max WSE of about 510
  - WSE peaked at 510.0
  - Storage peaked at 29,800 ac ft
- Next Step: Bringing down pool elevation and gradually decreasing FRM releases to a soft landing at 505



14 – 20 Jan Rain Event
FRM Release Ramp Down

- Forecast: Based on CNRFC inflow forecast (17 Jan at 1415)
- Objective: Settle near 505 without having to “yo-yo” into and out of FRM releases
- Revised Plan: Ramp down discharges to 400 cfs starting on Wed, 18 Jan at 1600. Create small “hole” to account for forecasted elevated inflow and small storm in forecast.

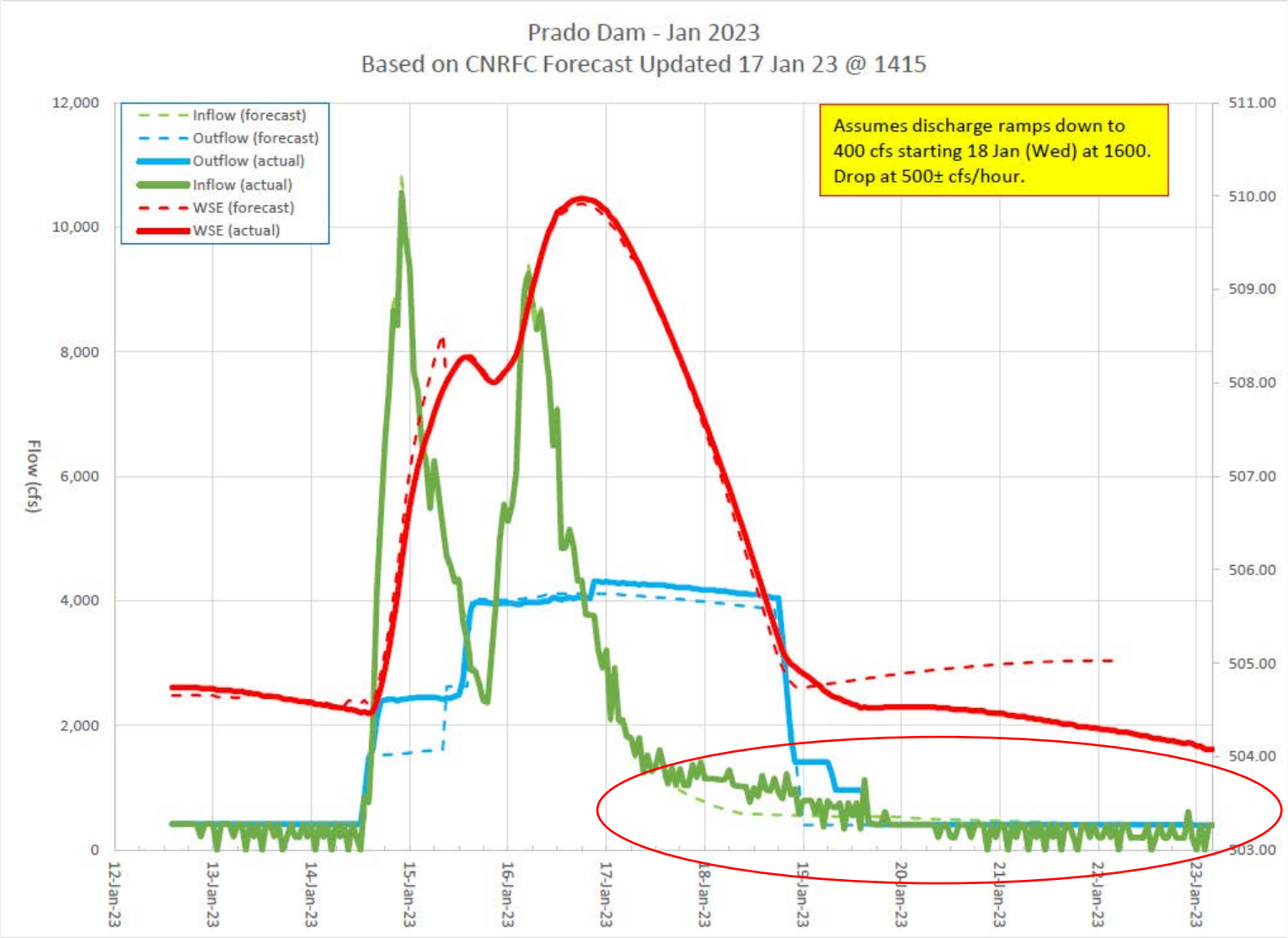
Forecast



14 – 20 Jan Rain Event
FRM Release Ramp Down

- Forecast: Based on CNRFC inflow forecast (17 Jan at 1415)
- Objective: Settle near 505 without having to "yo-yo" into and out of FRM releases
- Revised Plan: Ramp down discharges to 400 cfs starting on Thursday, 19 Jan at 1500.

Actual



14 - 20 Jan Rain Event FRM Release Ramp Down

- Actual Operation:
  - Updated CNRFC forecasts indicated that the higher than initially expected inflows would cause the WSE to exceed 505 and require FRM discharges based on the planned ramp down schedule.
  - Therefore, the ramp down was paused at 1400 cfs for about 10 hours and then again at 1000 cfs for about 8 hours.
  - Subsequent lower than expected inflows did not fill the “hole”
  - WSE at end of ramp down: 504.5
  - Storage at end of ramp down: 18,600 ac ft