

# *Integrating Weather Forecasts into Folsom Reservoir Operations*

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US Army Corps of Engineers  
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# Biography

- Brad Moore is a Lead Civil Engineer at the Sacramento District of the U.S. Army Corps of Engineers. He works in the Hydrology and Hydraulics Branch and is the Engineering Technical Lead for the Folsom Dam Water Control Manual Update. In addition to 10 years with the Sacramento District, he has 8 years experience in flood risk management in the Sacramento private sector. He holds a B.S. in Mechanical Engineering, M.S. in Hydrologic Science, and Civil P.E. license.



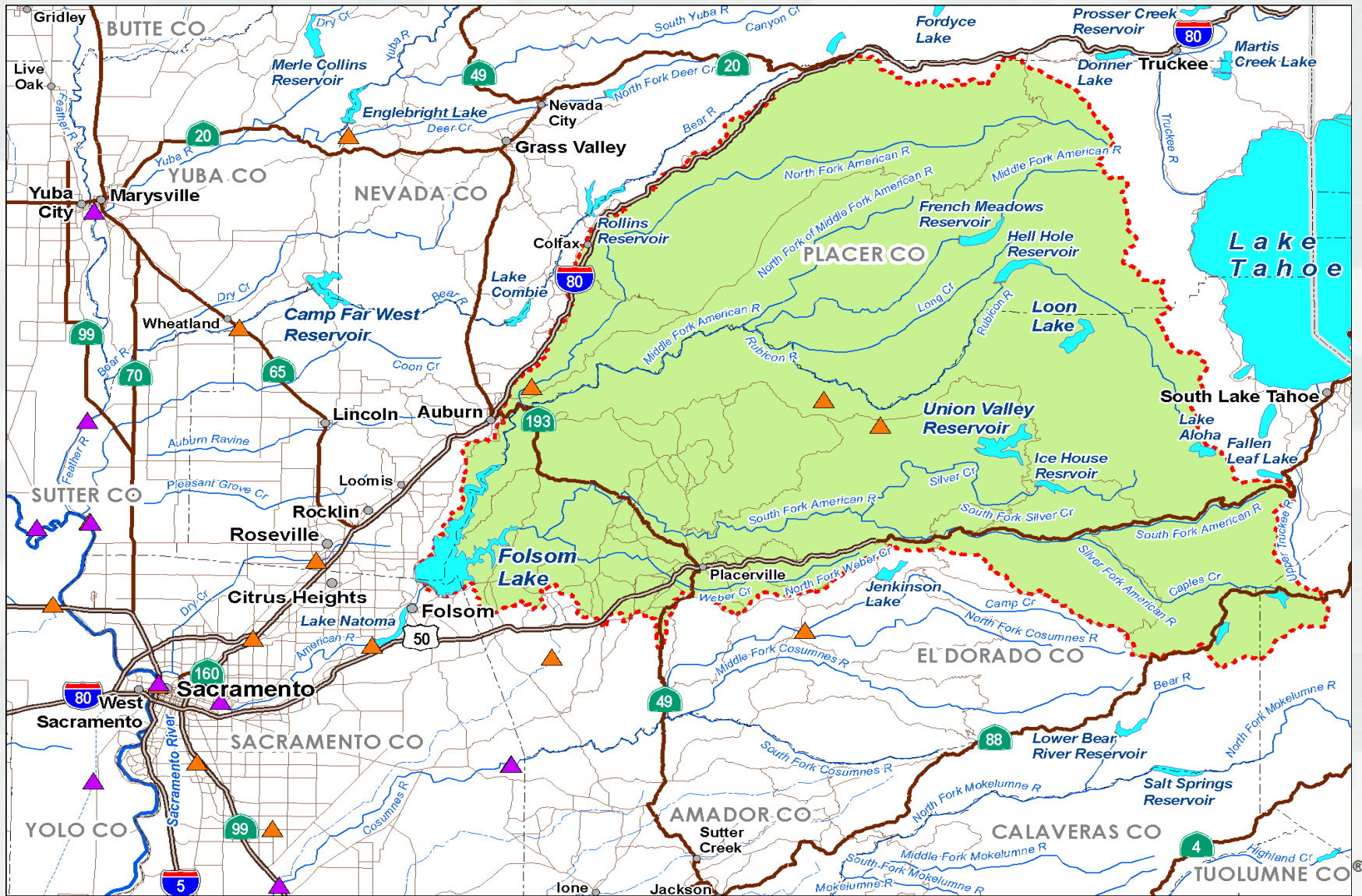
# Abstract

- Completion of the Joint Federal Project spillway at Folsom Dam requires the U.S. Army Corps of Engineers to update the Folsom Water Control Manual. The manual defines the maximum allowable storage before flood releases are required and required flood releases when the allowable storage is exceeded. This presentation will describe the tentatively selected flood operation, which relies on inflow forecasts provided by the California Nevada River Forecast Center. The presentation will compare the operation to other alternatives, describe how forecast information is processed and used, and describe testing to account for forecast uncertainty.





# American River Basin



# Folsom Lake and Dam

- 967 TAF storage (gross pool).
- Objective flood release is 115 kcfs.  
Channel capacity ~ 160 kcfs.
- Steep watershed – most precip is in reservoir within 12 hours of hitting ground.
- Winter snow pack – relied upon for Spring refill.
- No downstream control point.



# Folsom Dam





# JFP Gate Install



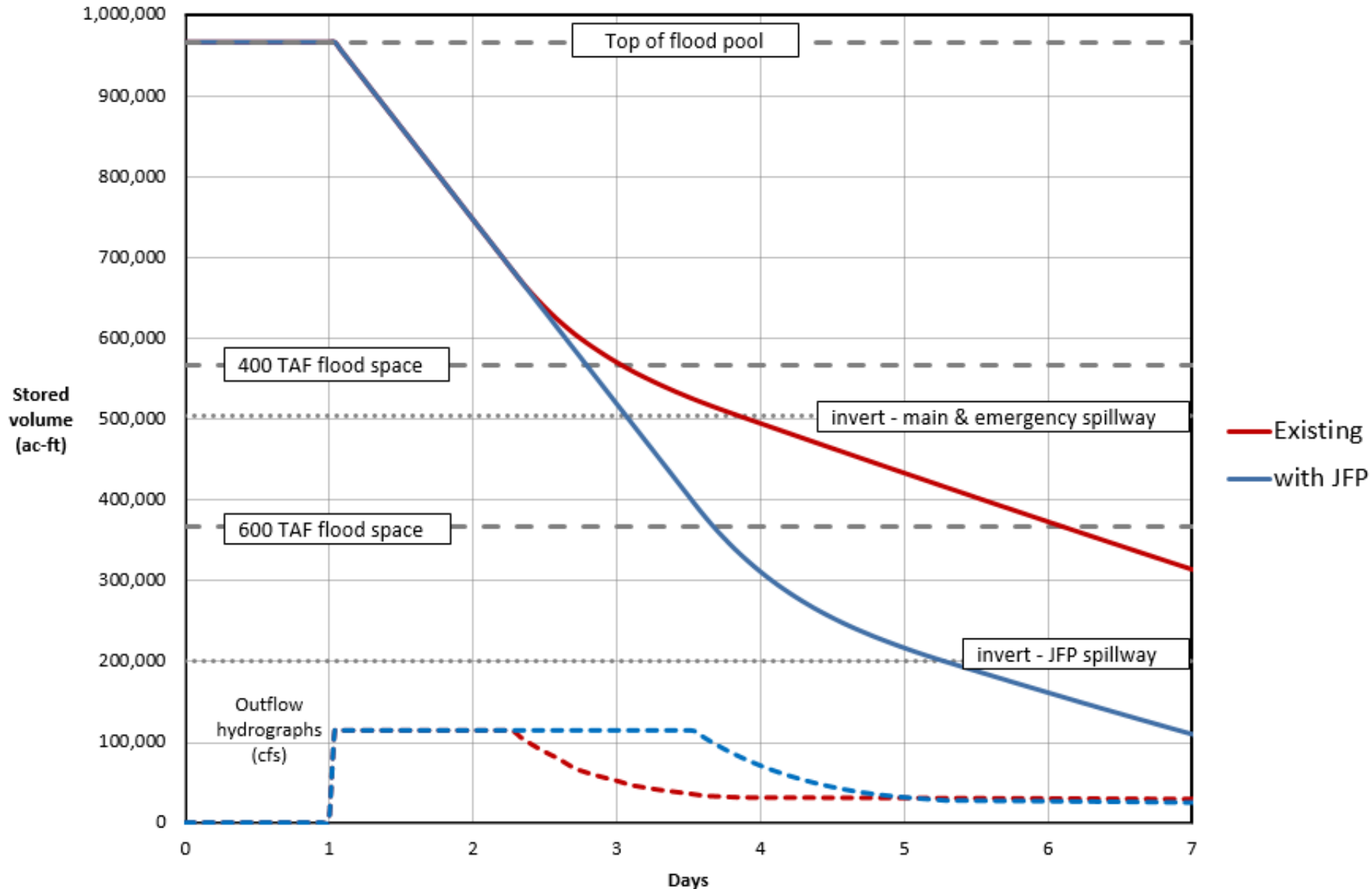
# Main Dam and JFP



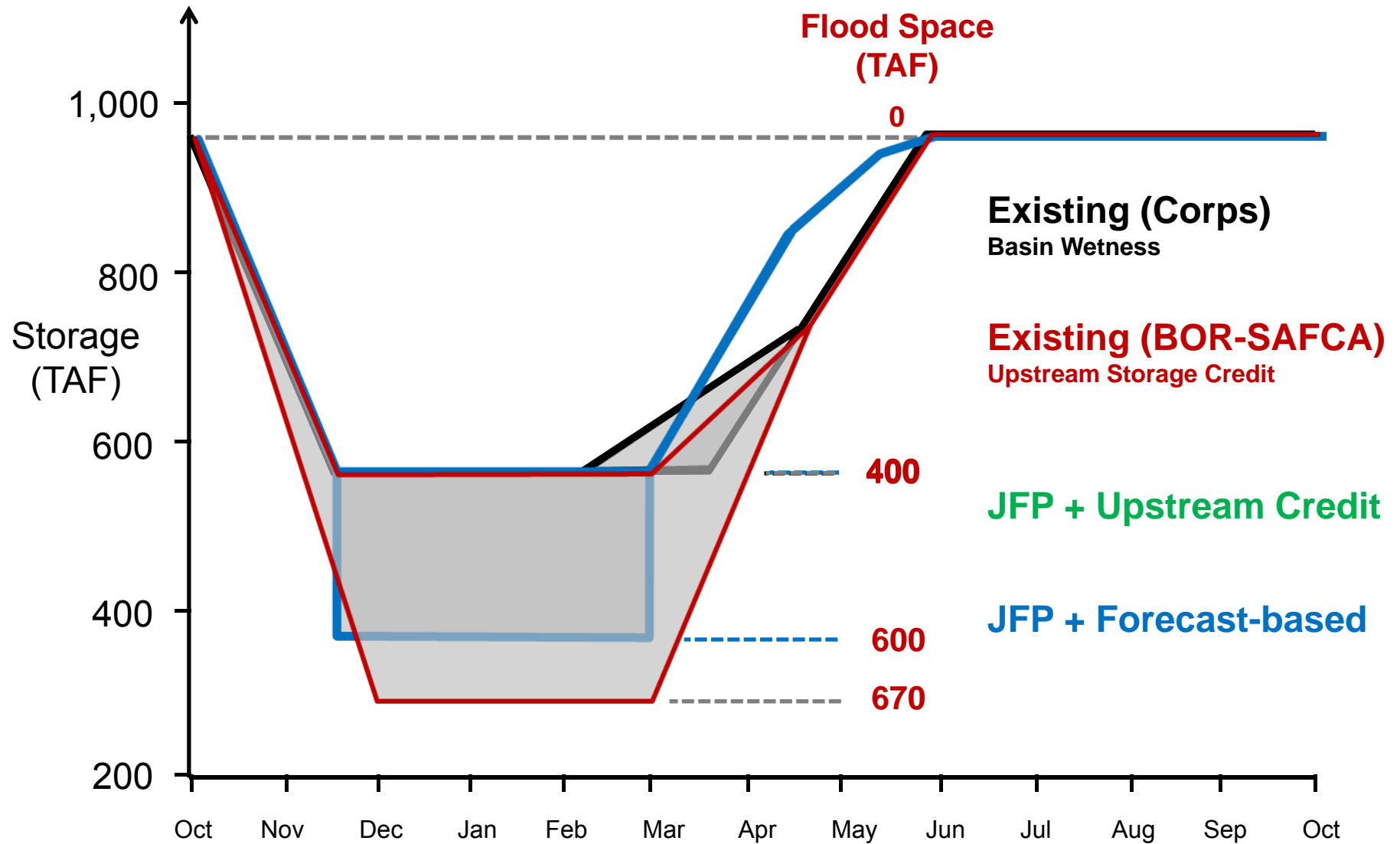


# Rapid drawdown capacity (no inflow)

reflects 115k max discharge as only operational restriction, max physical release capacity



# Water Control Diagrams



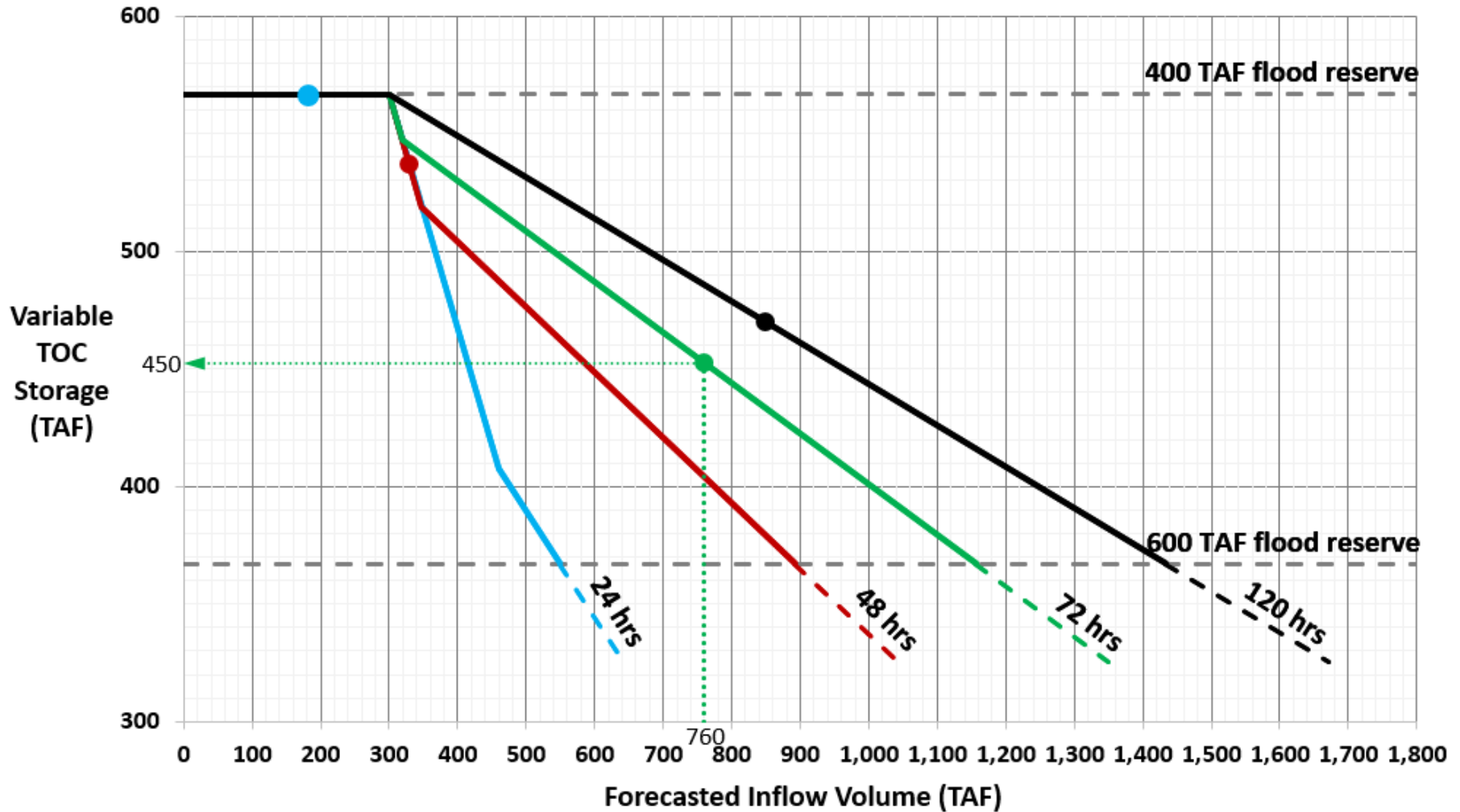
# Forecast-based Operation

- Components
  - ▶ CNRFC ensemble forecasts – 6 hour updates
  - ▶ Forecast-based top of conservation (TOC)
  - ▶ Forecast-based releases

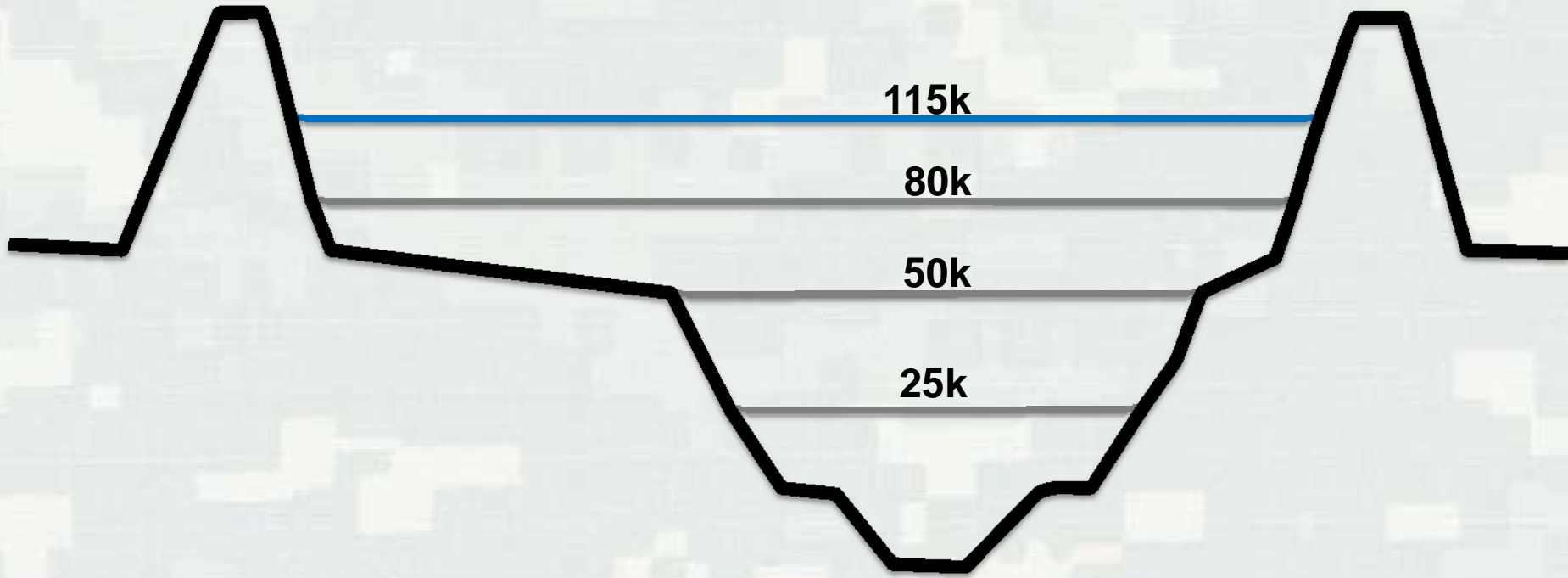




# Forecast-based TOC



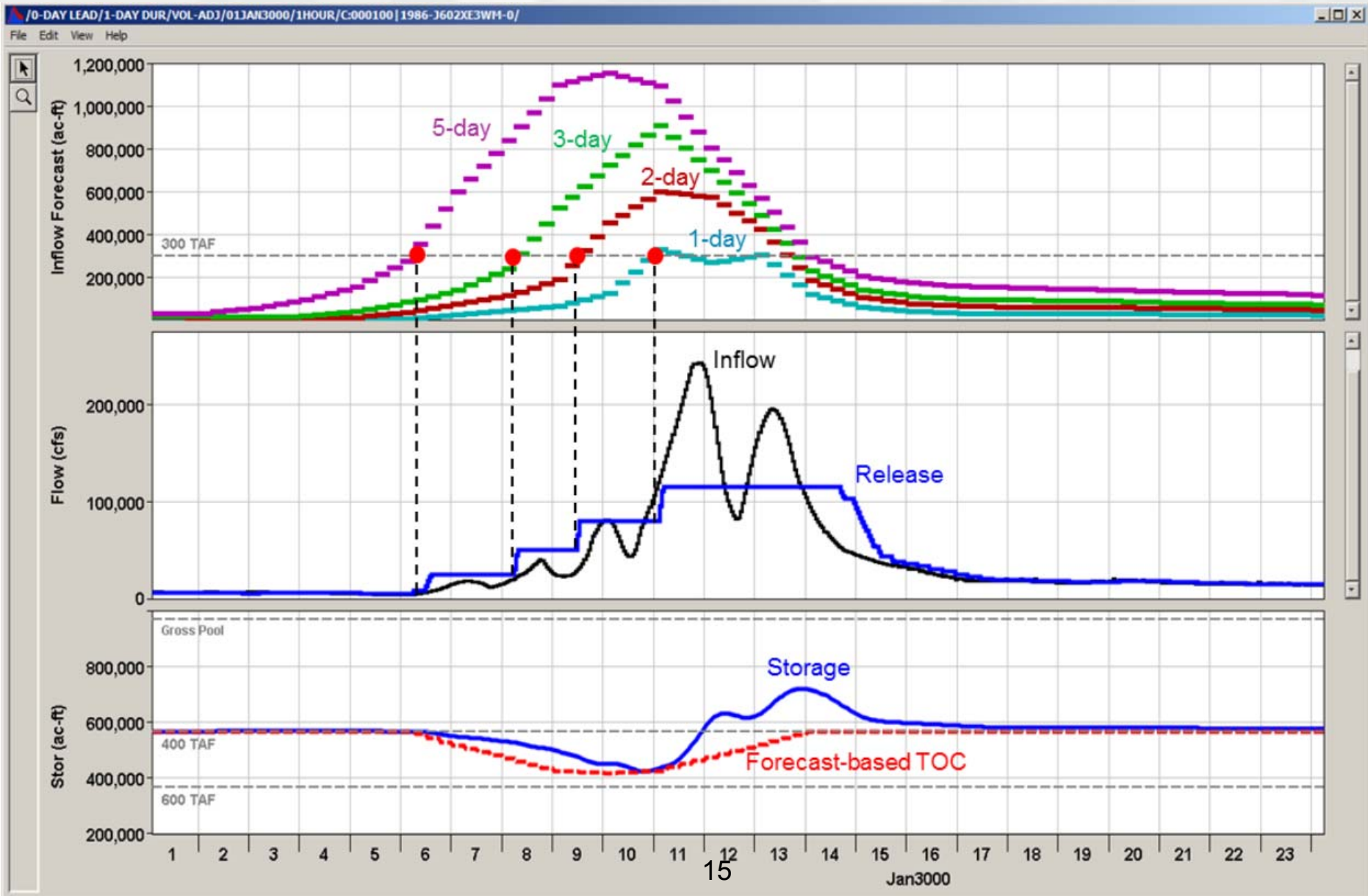
# Forecast-based Release



**Typical American River Cross Section**

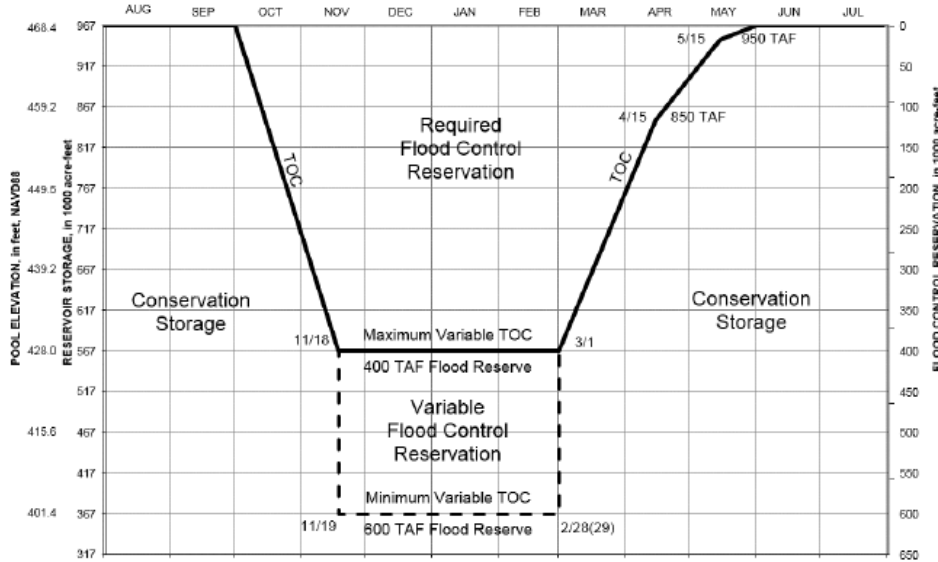


# Forecast-based Release

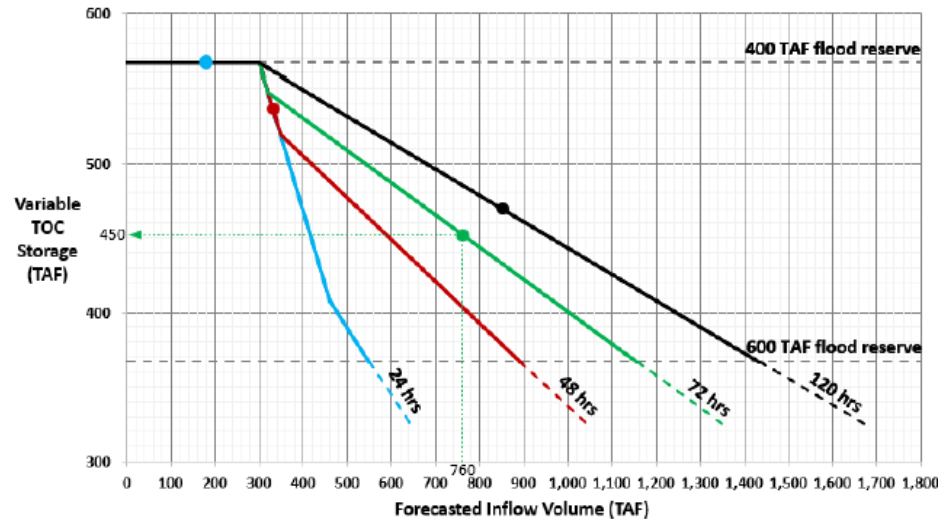


# Water Control Diagram

**FIGURE A**



**FIGURE B**



**USE OF FLOOD CONTROL DIAGRAM**

Folsom Dam and Lake shall be operated for flood control in accordance with the Flood Control Diagram (Figure A). The flood control diagram defines the required Flood Control Reservation (FCR). Except when larger releases are required by the accompanying Emergency Spillway Release Diagram (ESRD), water stored within the FCR shall be released as rapidly as possible subject to the Release Schedule (Table A). The Corps of Engineers may direct flood releases to be increased or decreased from the computed release when warranted by existing conditions.

**COMPUTATION OF VARIABLE FLOOD CONTROL RESERVATION**

Forecasted inflow volumes are obtained from NWS-CNRF and are developed for the purpose of supporting Folsom Dam forecast-based operations. Volumes for the following four durations are required: 24, 48, 72, and 120 hours. Figure B provides relationships relating inflow forecast volume to Top of Conservation (TOC) storage for each duration. Each relation is labeled by the duration for which it applies.

**FIGURE B - INSTRUCTIONS:** Locate each of the four forecast volumes provided on the horizontal axis. For each forecast volume, identify the corresponding candidate TOC storage value on the appropriate curve. Of the four candidate TOC storage values, the lowest value is the adopted TOC storage value. The corresponding FCR value is given by:  $FCR = 966.9 \text{ TAF} - \text{TOC}$ .

**FIGURE B - EXAMPLE:** Inflow forecast volumes of 180, 330, 760 and 850 TAF are provided, corresponding to 24, 48, 72, and 120 hours respectively. As shown in Figure A, the volumes are located on the horizontal axis, and candidate TOC values are located on the corresponding curves (indicated by large dots). Of the four candidate TOC values, the 72-hour volume is lowest. This value, 450 TAF, is therefore the adopted TOC storage value. The corresponding FCR value is:  $FCR = 966.9 \text{ TAF} - 450 \text{ TAF} = 546.9 \text{ TAF}$ .

**TABLE A - FOLSOM RELEASE SCHEDULE**

Date	Storage Condition	Description
Mar. 1 to Nov. 18	Storage > TOC	Release peak inflow for current event.
Nov. 19 to Feb. 28/29	Storage > TOC	Release greater of Table B indicated release or observed inflow. Do not reduce releases while pool is rising.

**RAMPING RATES**

- A1) Releases between 8 kcfs and 30 kcfs will not be increased by more than 5 kcfs during any 2-hour period.
- A2) Releases between 30 kcfs and 180 kcfs will not be increased by more than 30 kcfs during any 2-hour period.
- A3) Releases between 8 kcfs and 180 kcfs will not be decreased by more than 10 kcfs during any 2-hour period.

**STEPPED RELEASES**

- A4) Coordination efforts should be initiated in advance so as to eliminate or minimize the need for release holds.
- A5) Maximum 6-hour release holds, if needed, may be implemented at releases of 8, 25, 50, and 80 kcfs.
- A6) A 6-hour hold at 115 kcfs is required before further increasing releases.

**TABLE B - FORECAST-BASED RELEASES**

INFLOW FORECAST VOLUMES	Indicated Release
120-hr volume < 300 TAF	8 kcfs
120-hr volume > 300 TAF	25 kcfs
72-hr volume > 300 TAF	50 kcfs
48-hr volume > 300 TAF	80 kcfs
24-hr volume > 300 TAF and inflow >= 115 kcfs	115 kcfs

**FOLSOM DAM AND LAKE**  
American River, California

**WATER CONTROL DIAGRAM**

APPROVED \_\_\_\_\_

DRAFT

APPROVED \_\_\_\_\_

Effective Date \_\_\_\_\_ File No. \_\_\_\_\_

# Routing comparisons



# 1986 event pattern scaled to 100-yr

Forecast operation reflects perfect forecast

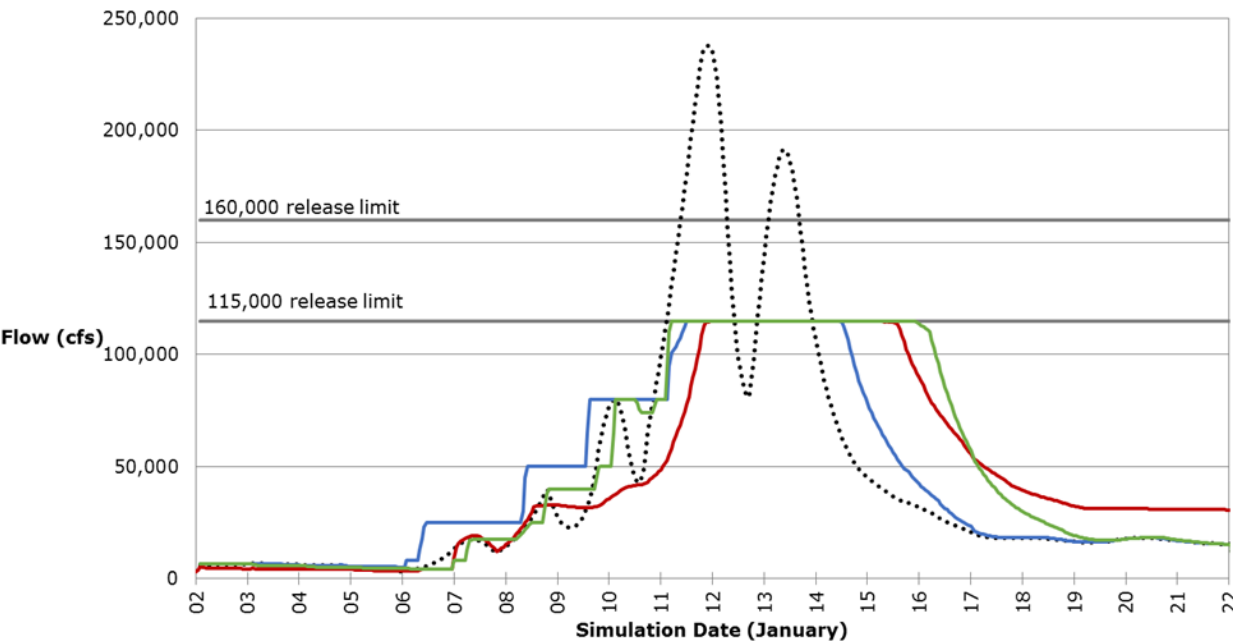
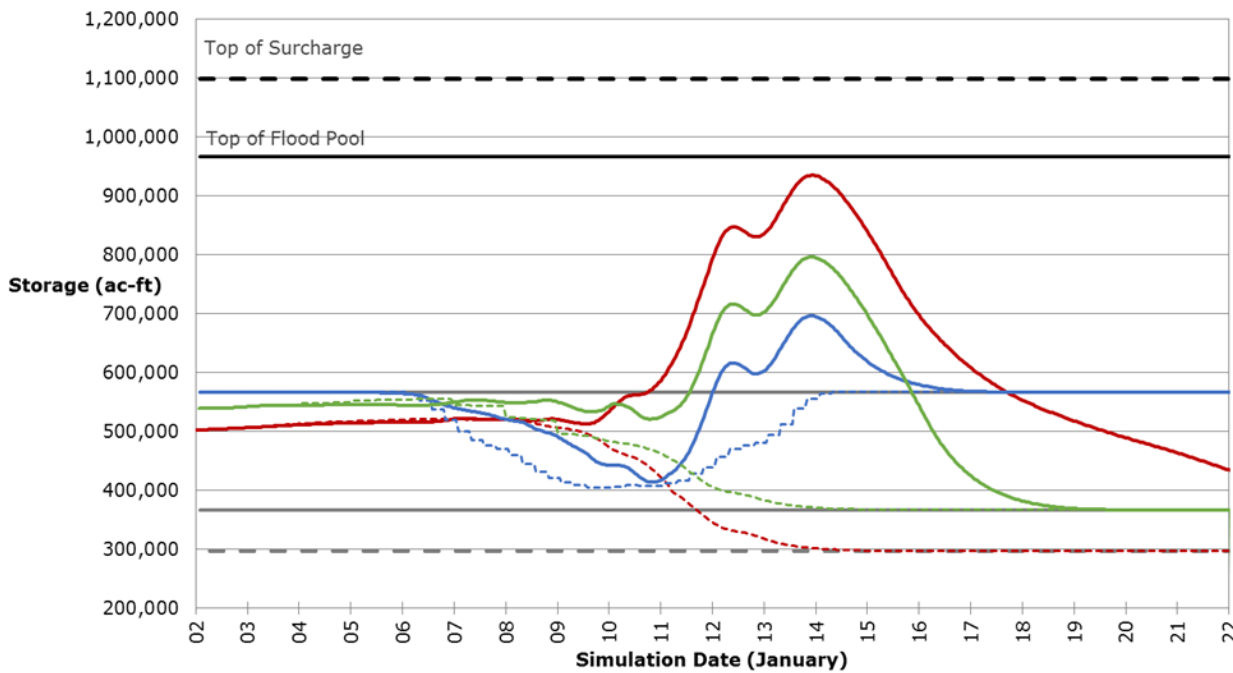
**Existing (BOR/SAFCA)**

**JFP + US credit**

**JFP + Forecast-based**

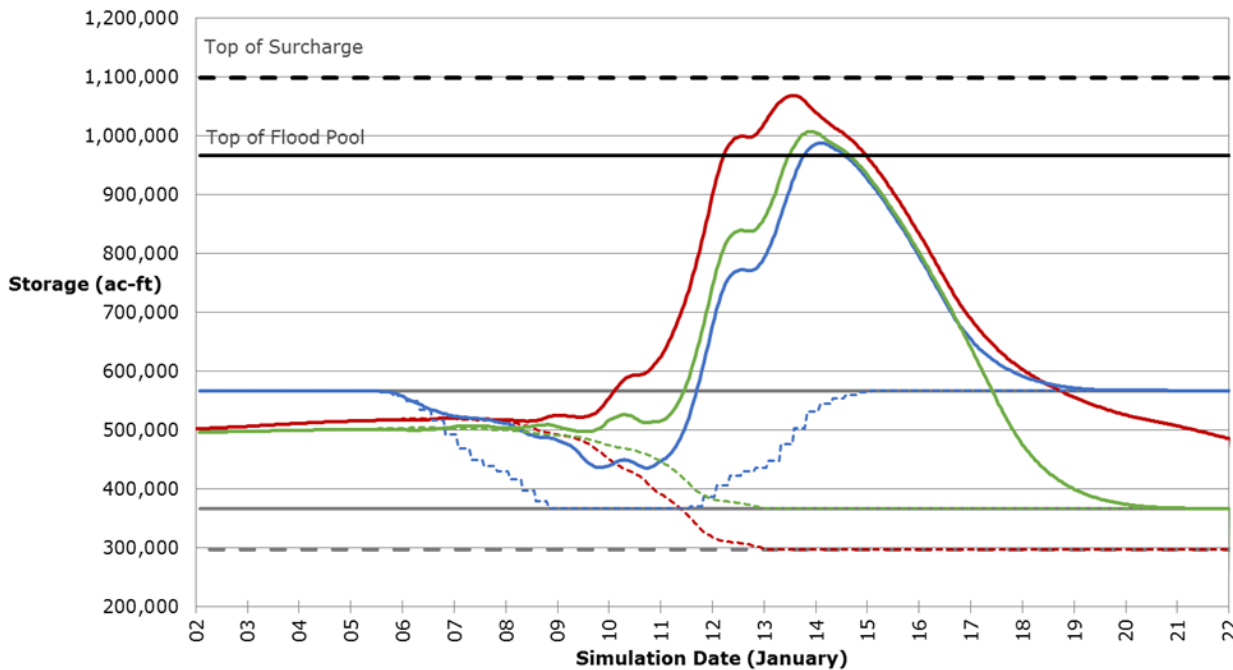


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# 1986 event pattern scaled to 200-yr

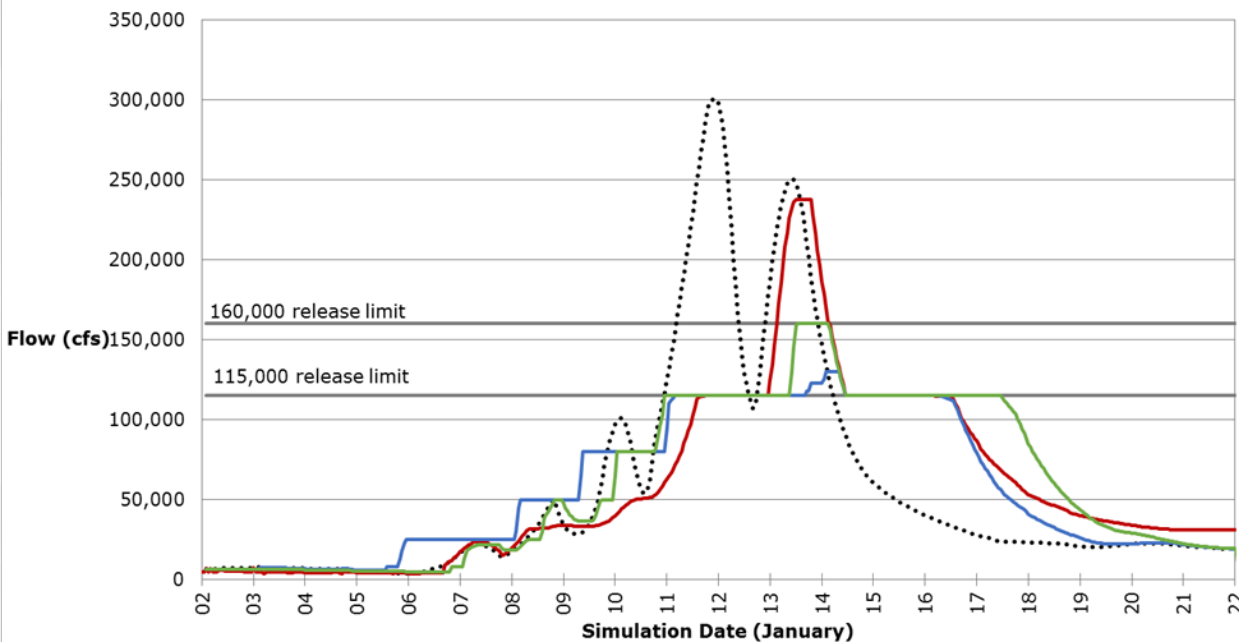
Forecast operation reflects perfect forecast



**Existing (BOR/SAFCA)**

**JFP + US credit**

**JFP + Forecast-based**

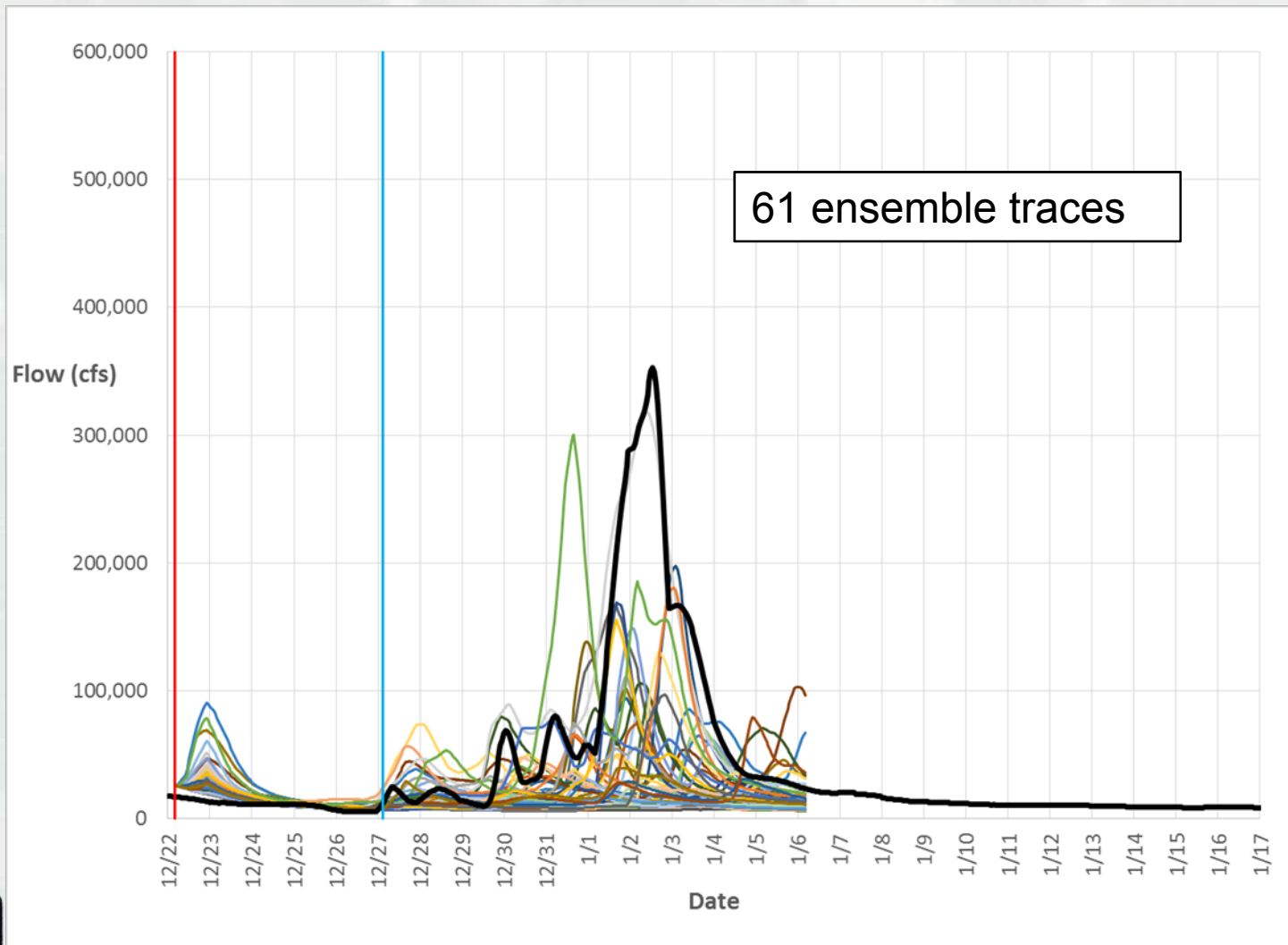


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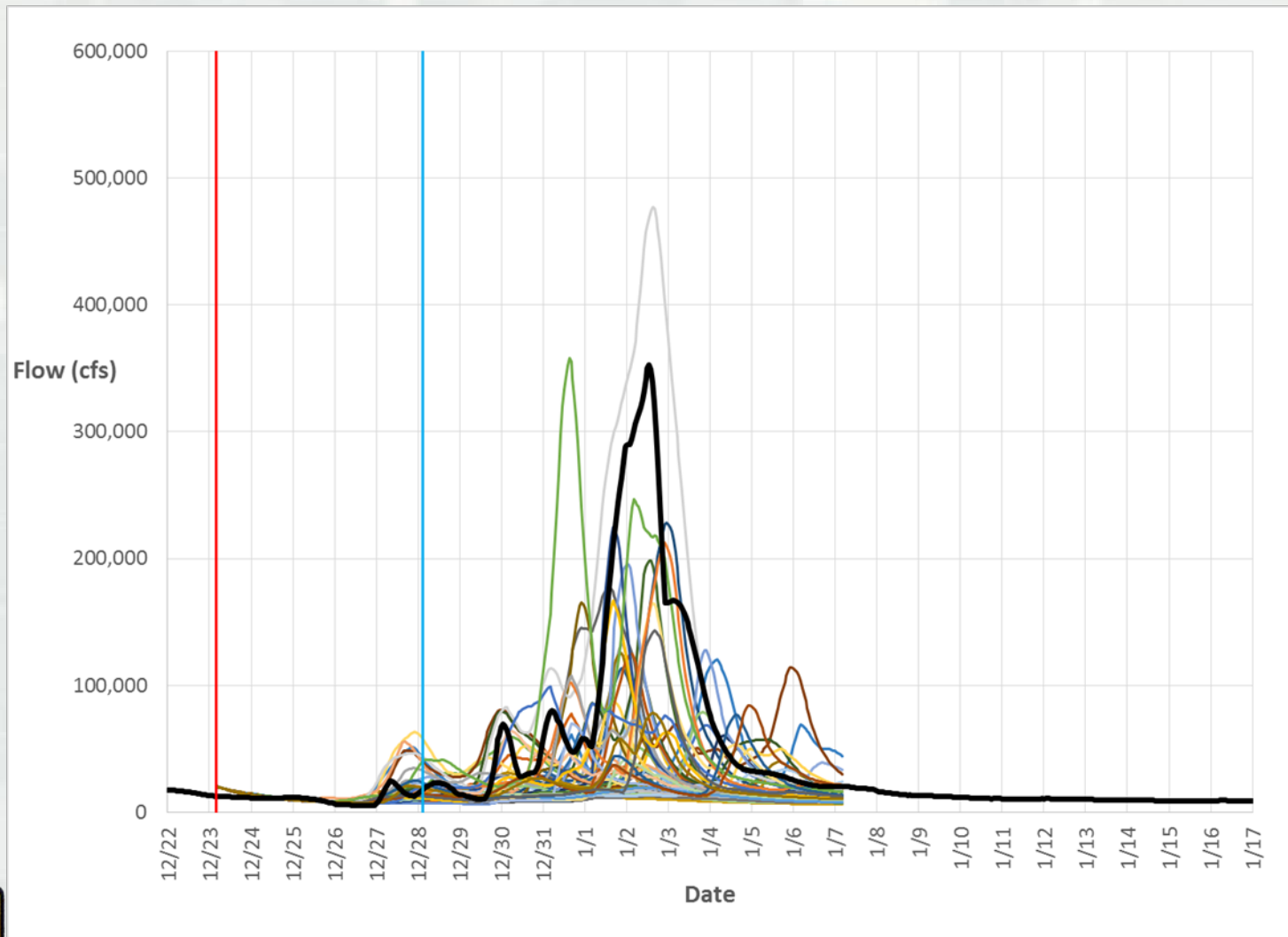
# Use of Forecast Ensembles



# Forecast Ensemble 12/22

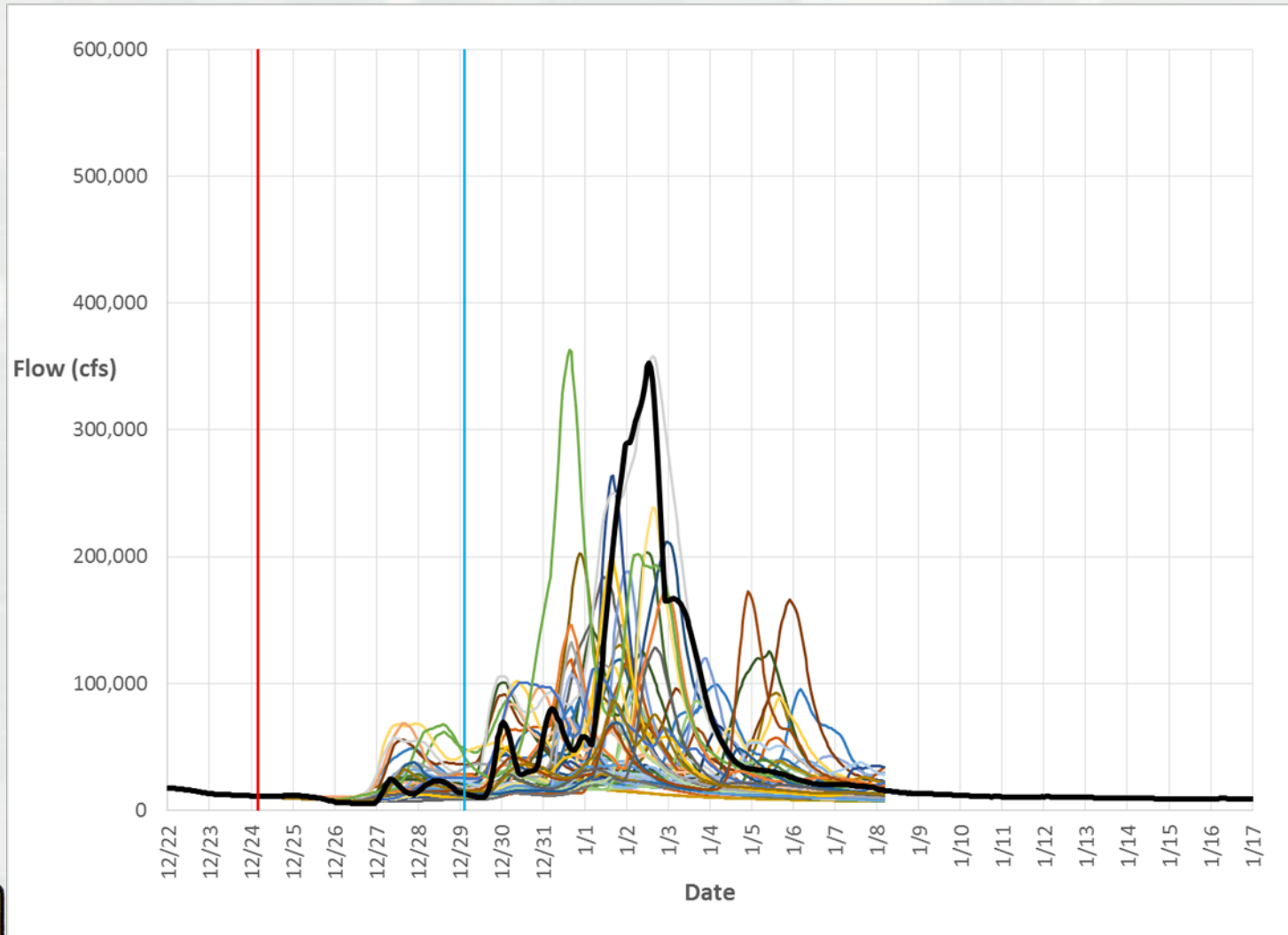


# Forecast Ensemble 12/23

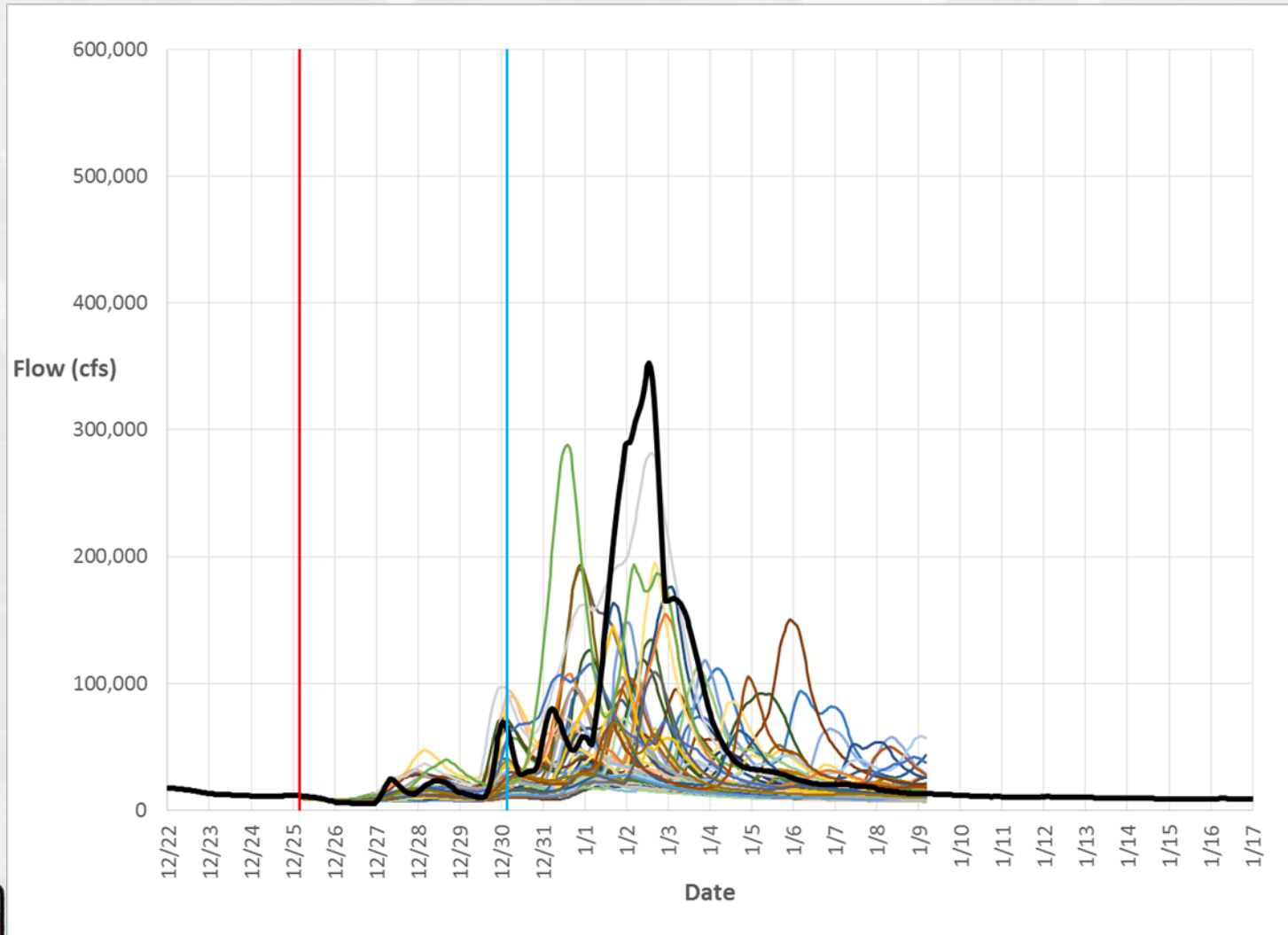




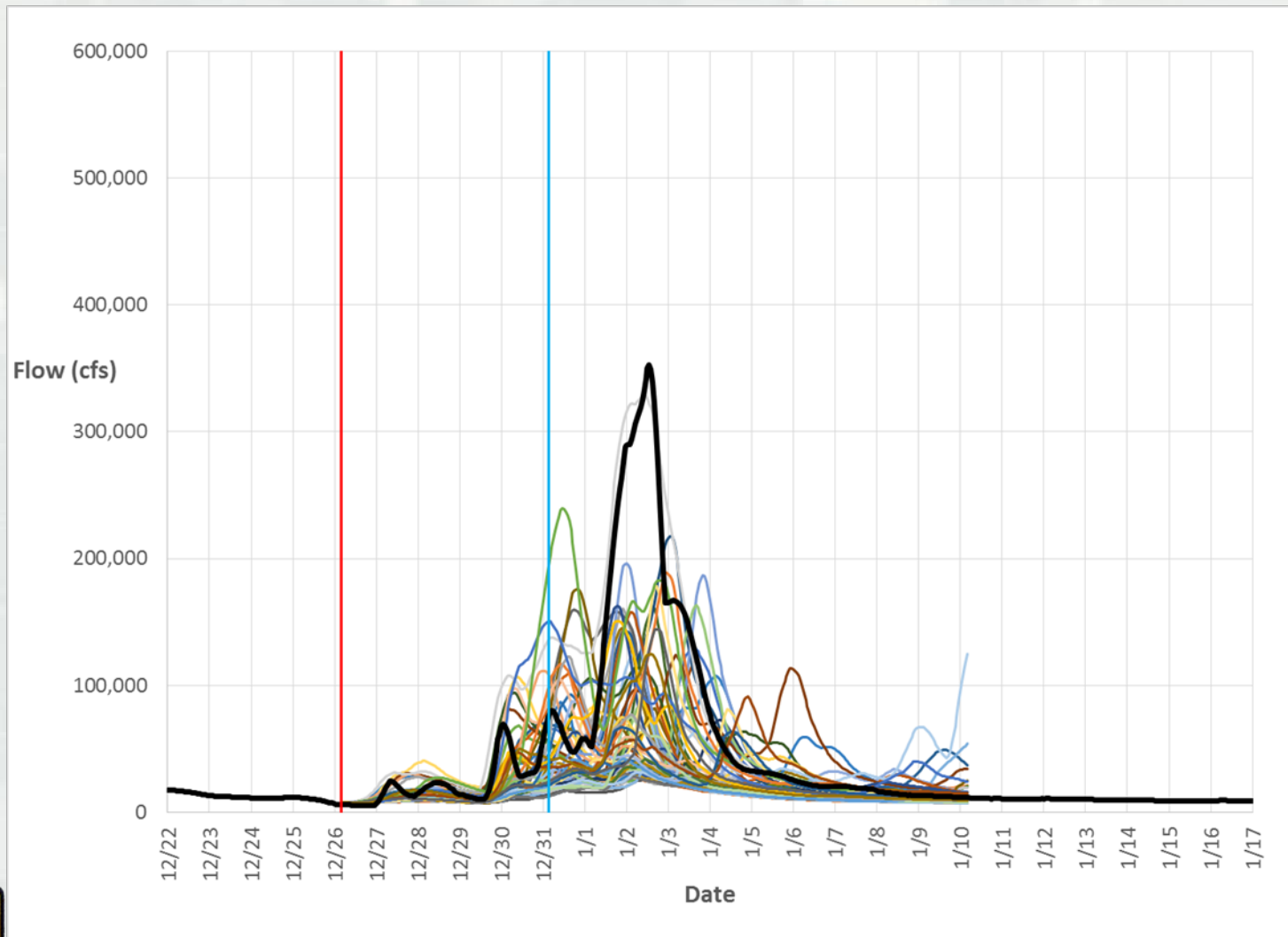
# Forecast Ensemble 12/24



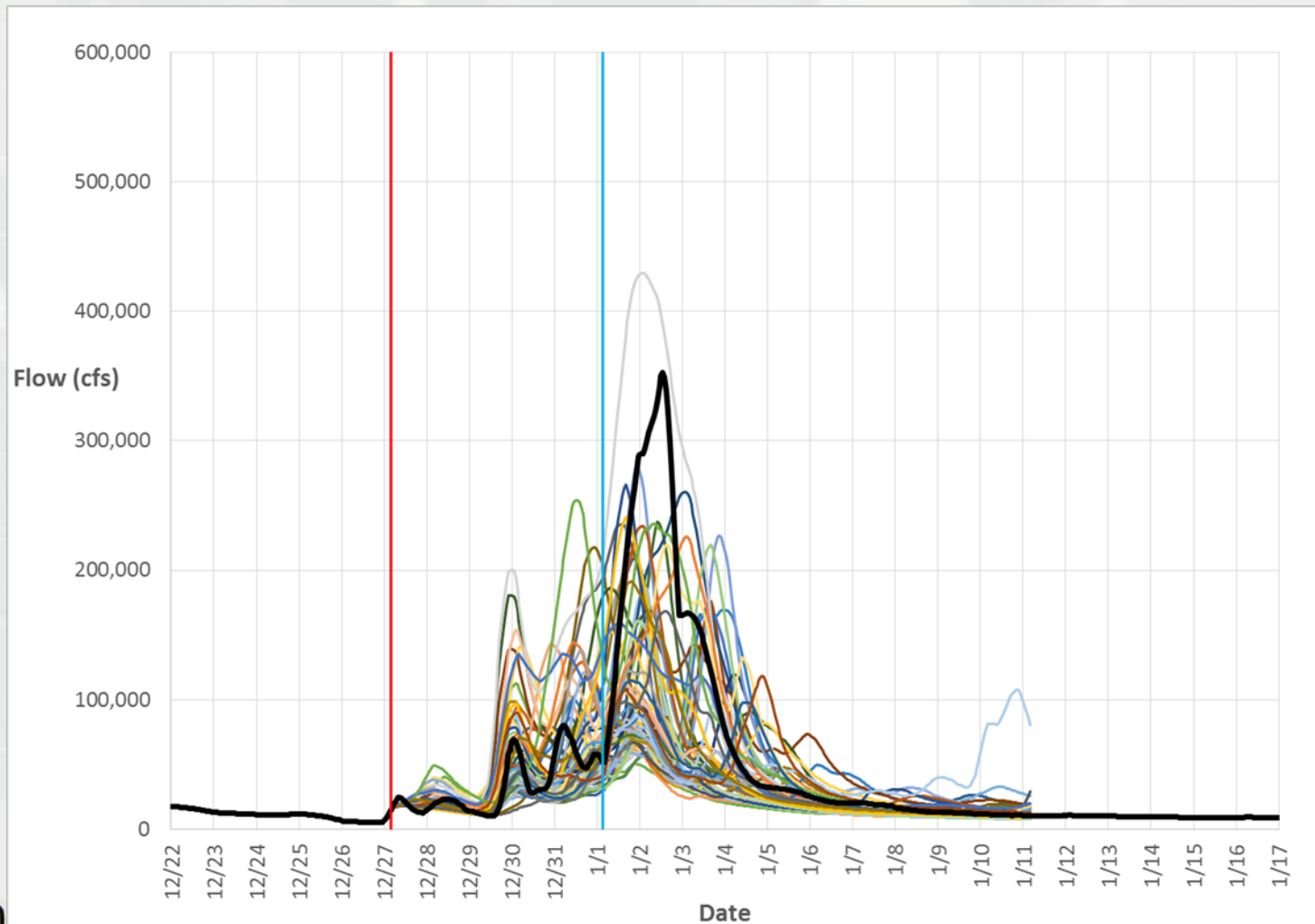
# Forecast Ensemble 12/25



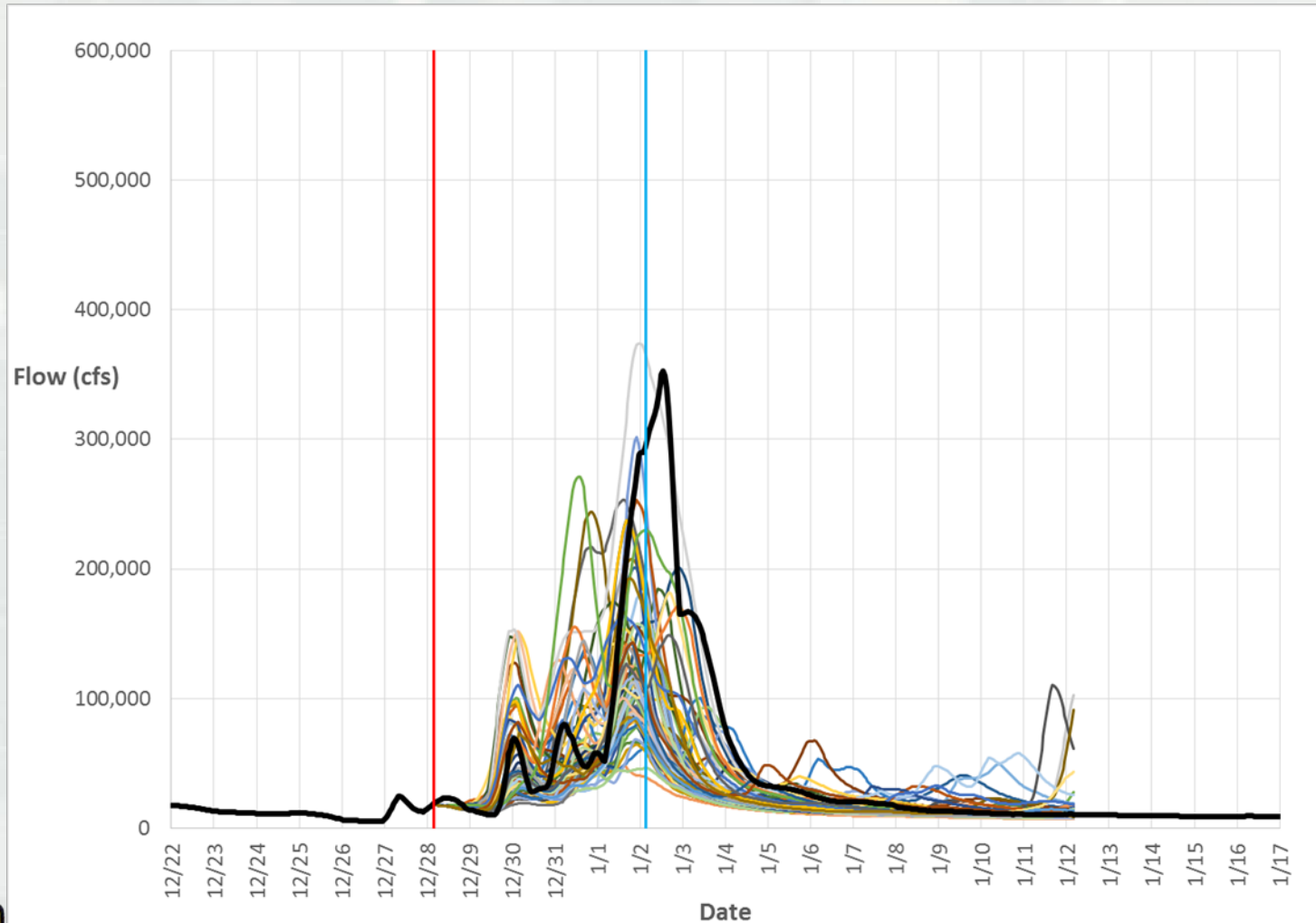
# Forecast Ensemble 12/26



# Forecast Ensemble 12/27

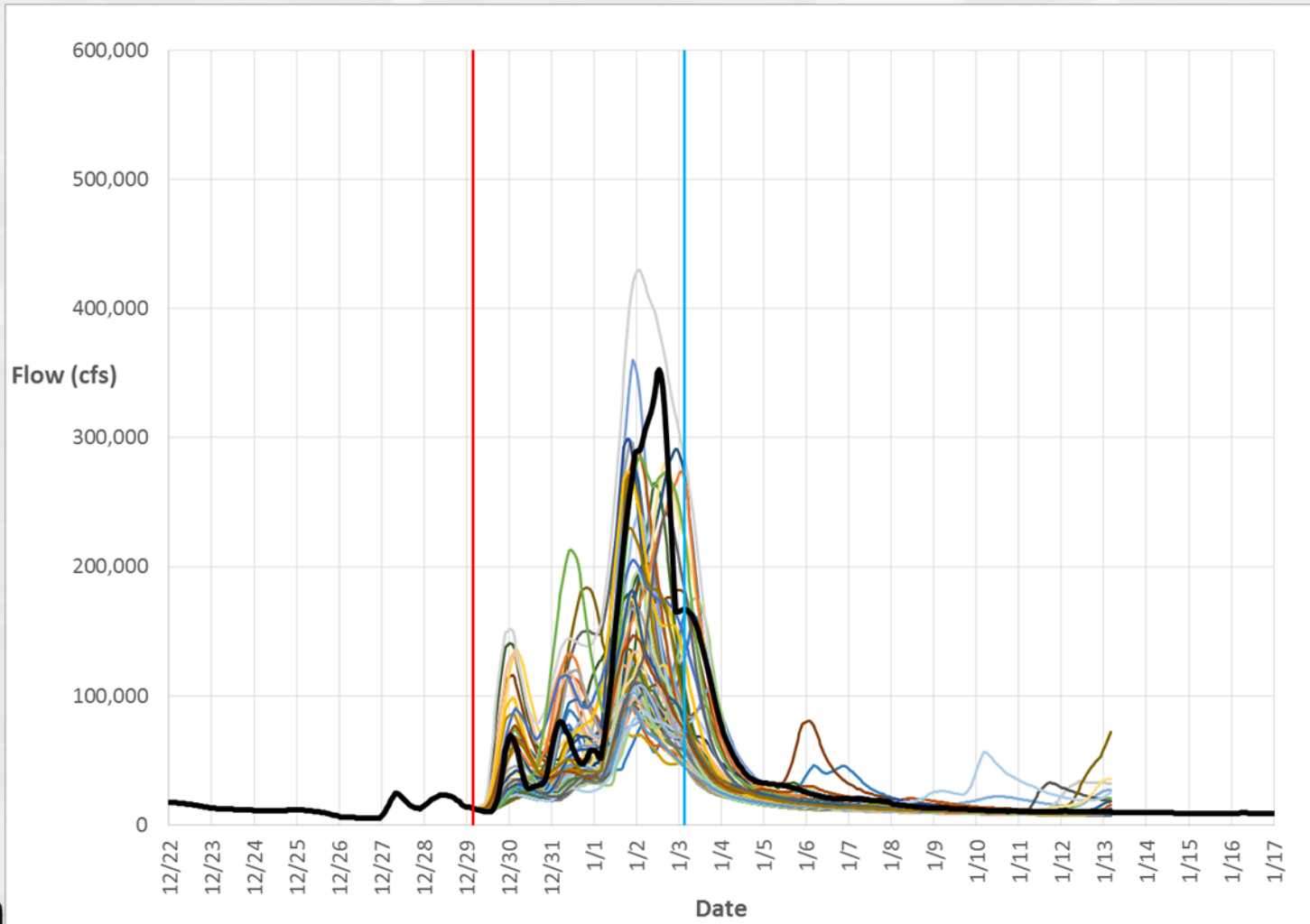


# Forecast Ensemble 12/28

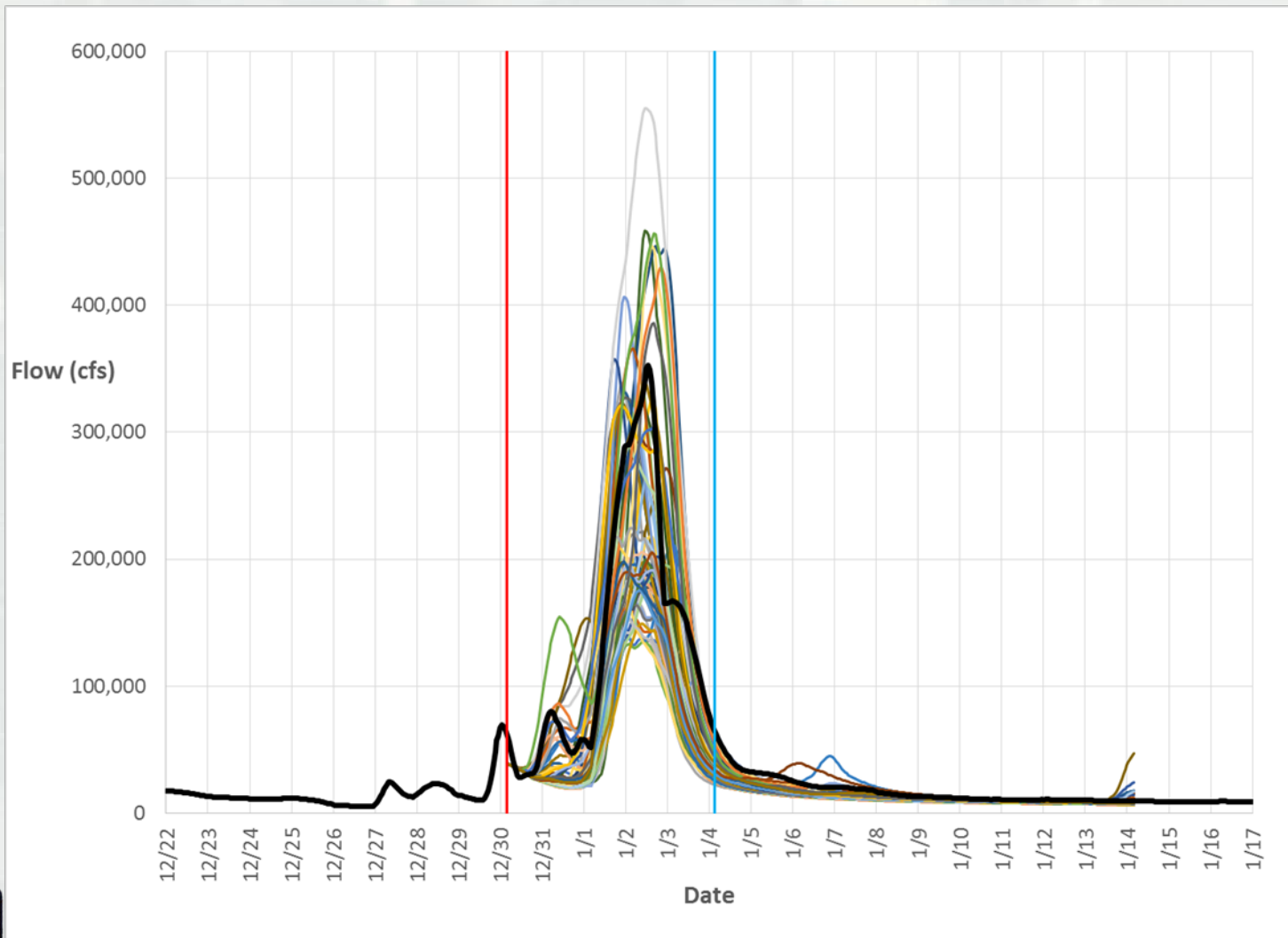




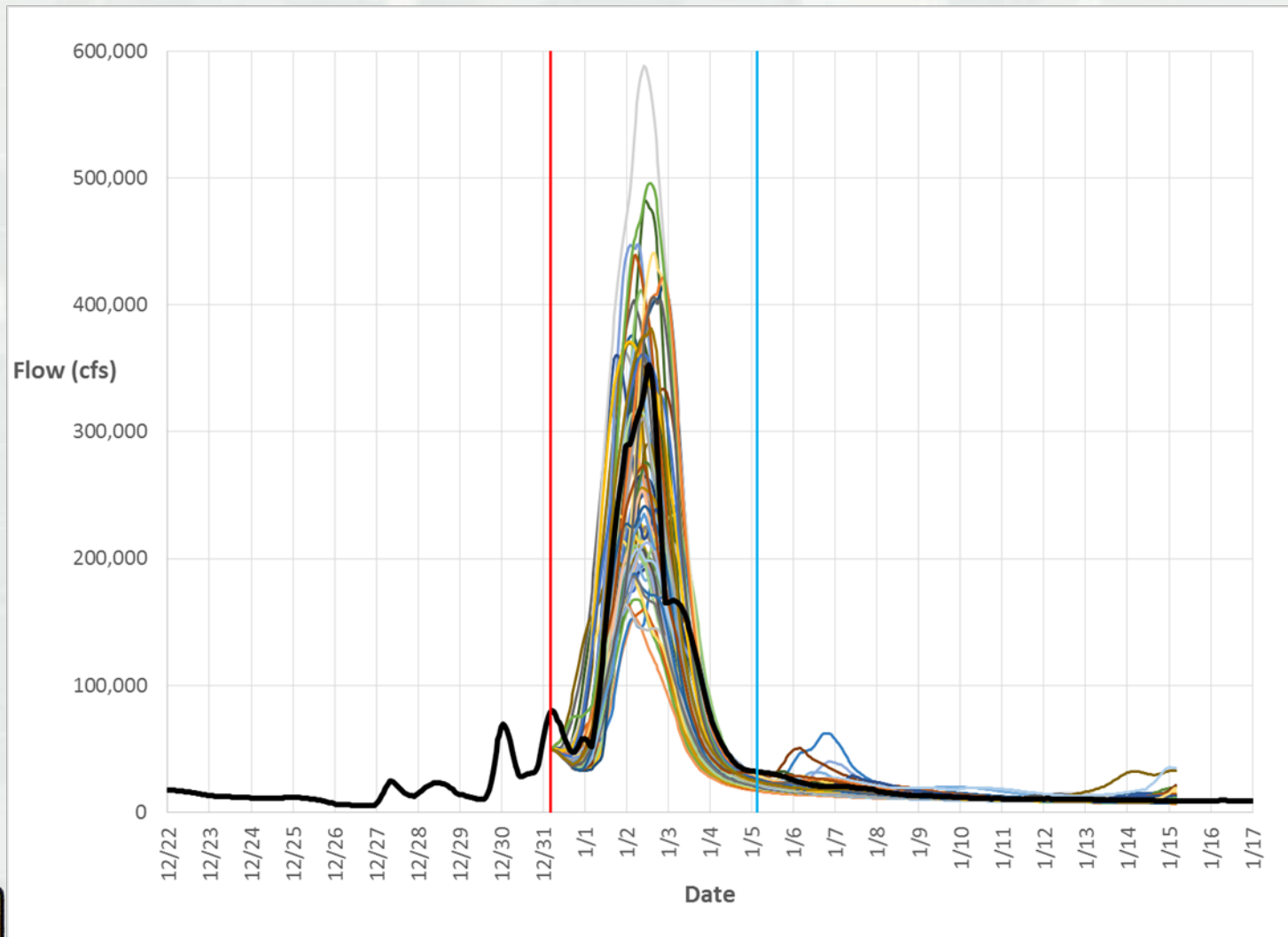
# Forecast Ensemble 12/29



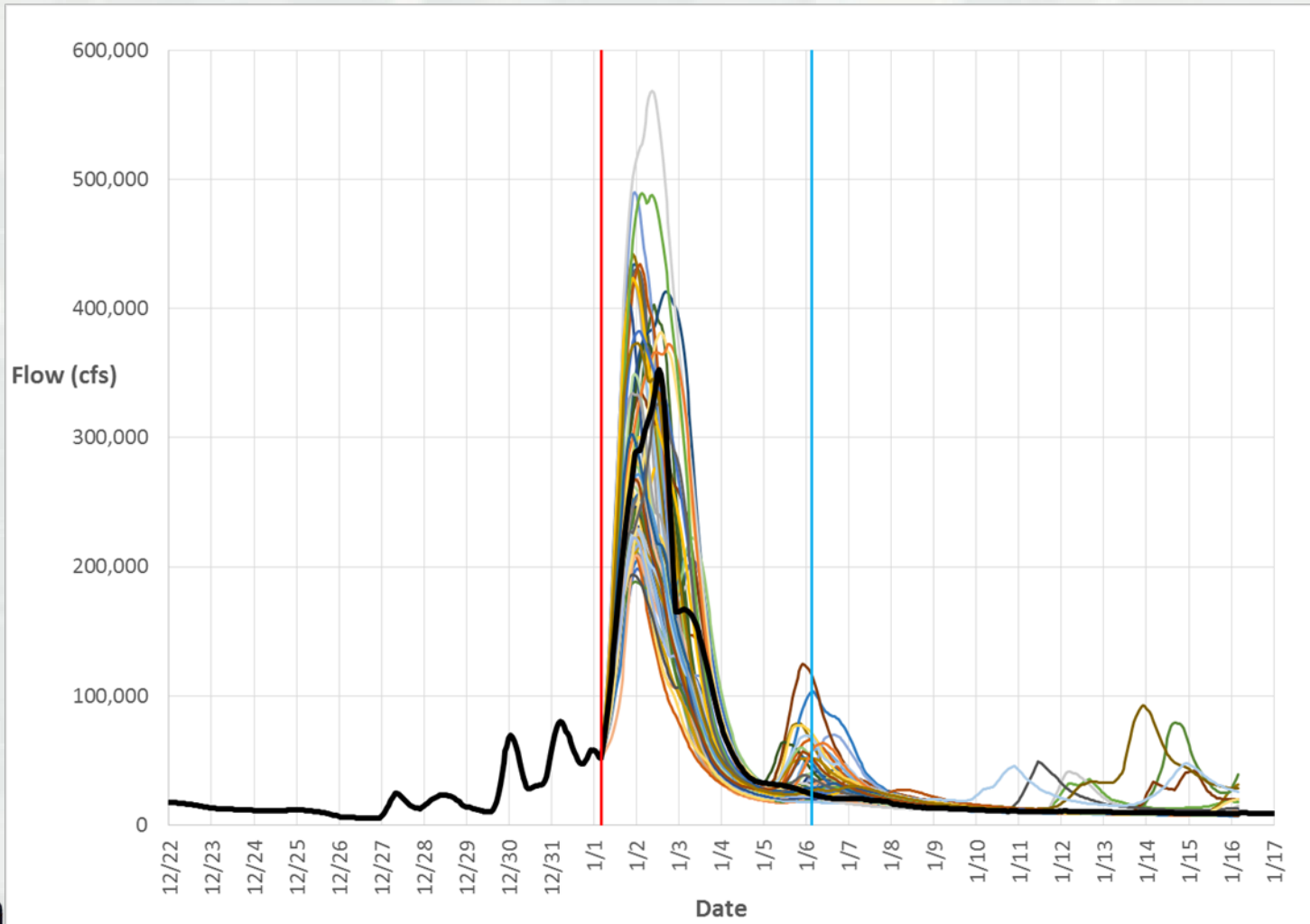
# Forecast Ensemble 12/30



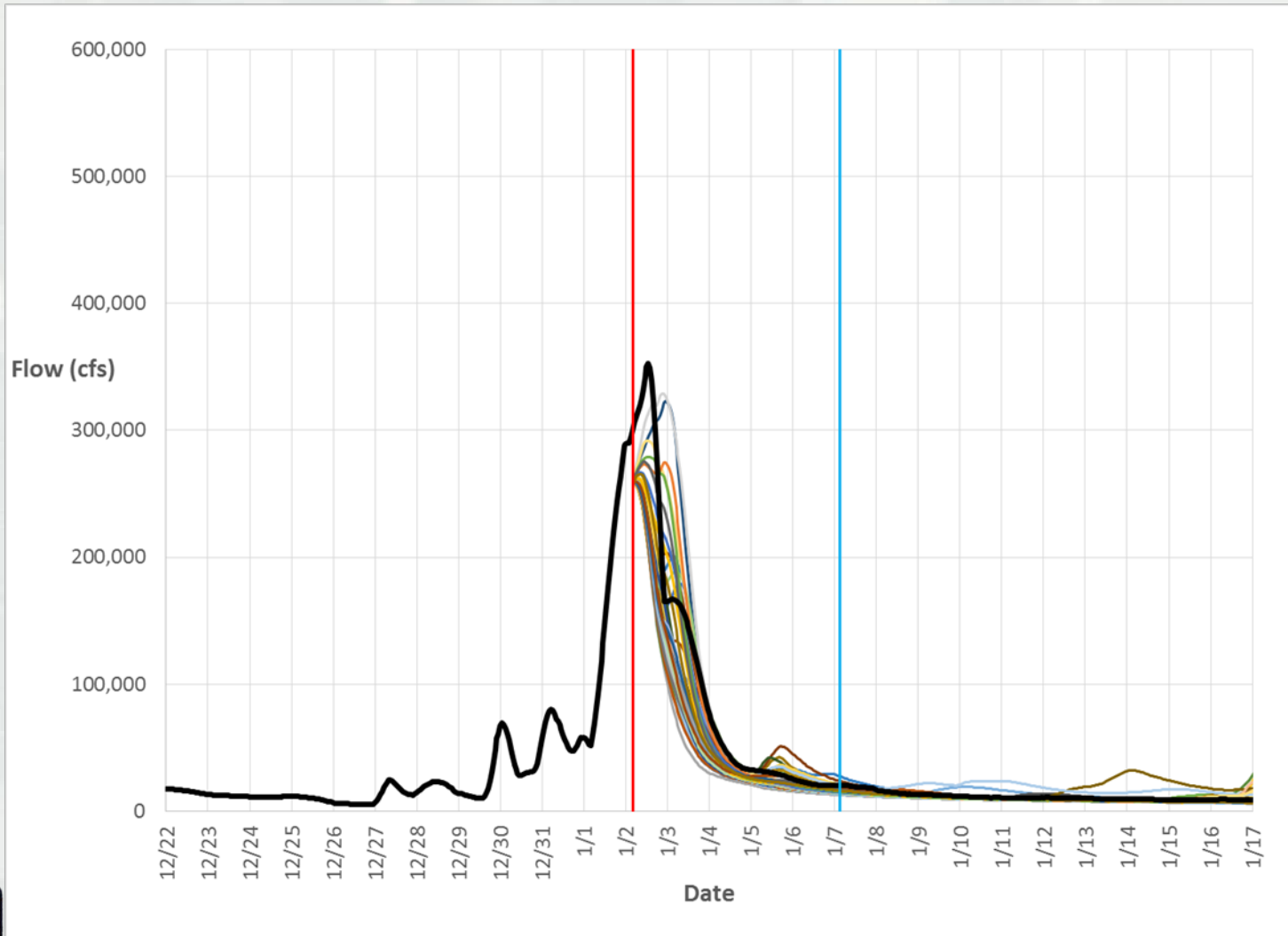
# Forecast Ensemble 12/31



# Forecast Ensemble 1/1

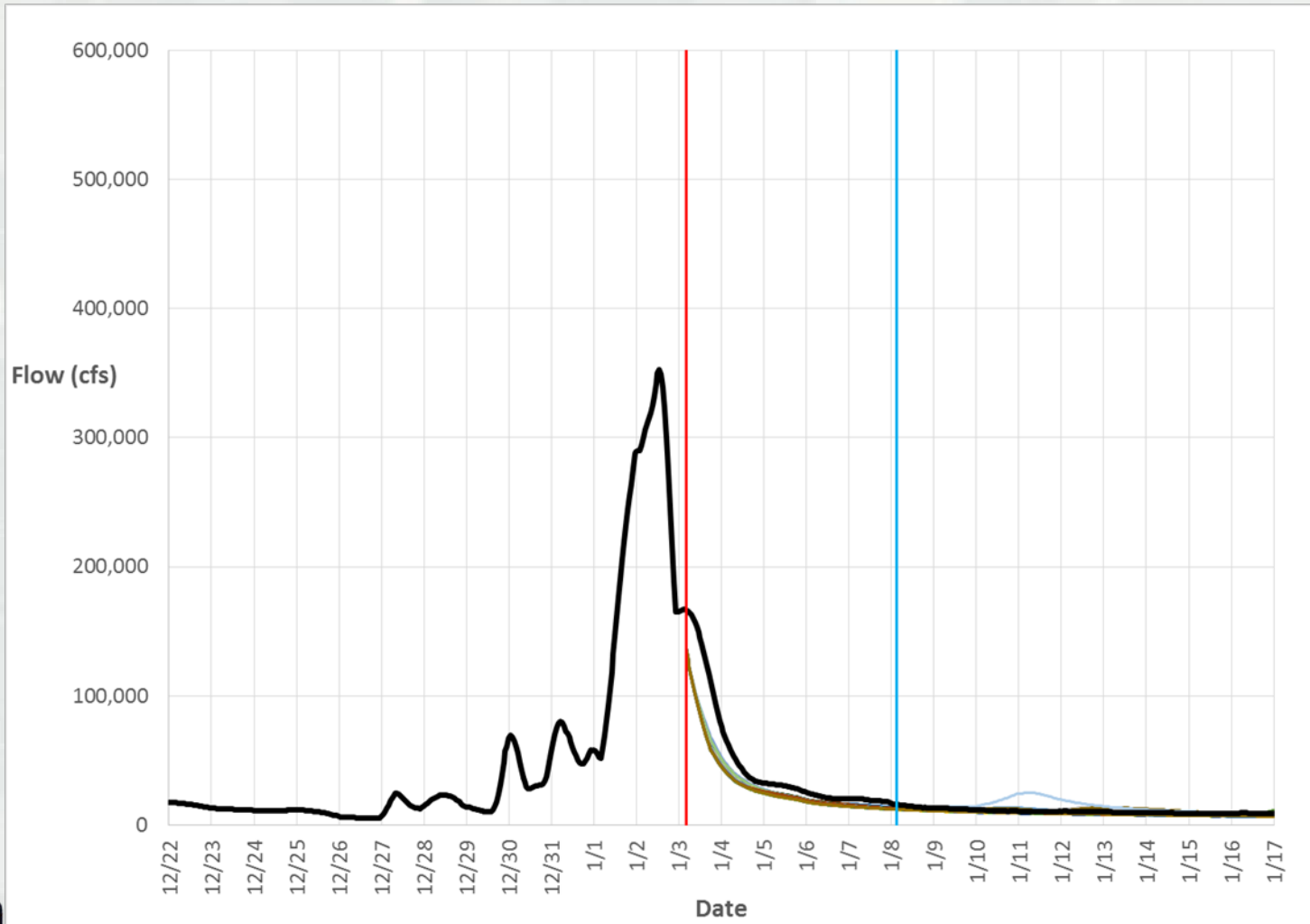


# Forecast Ensemble 1/2

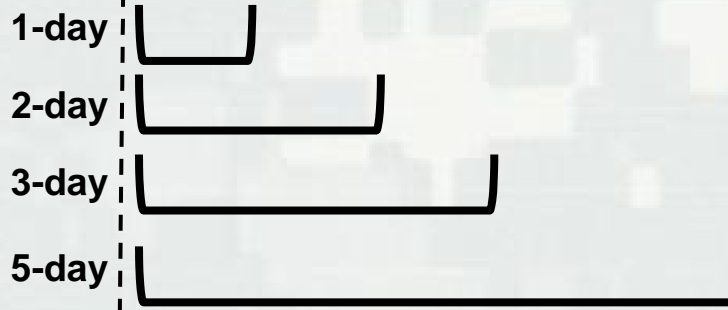
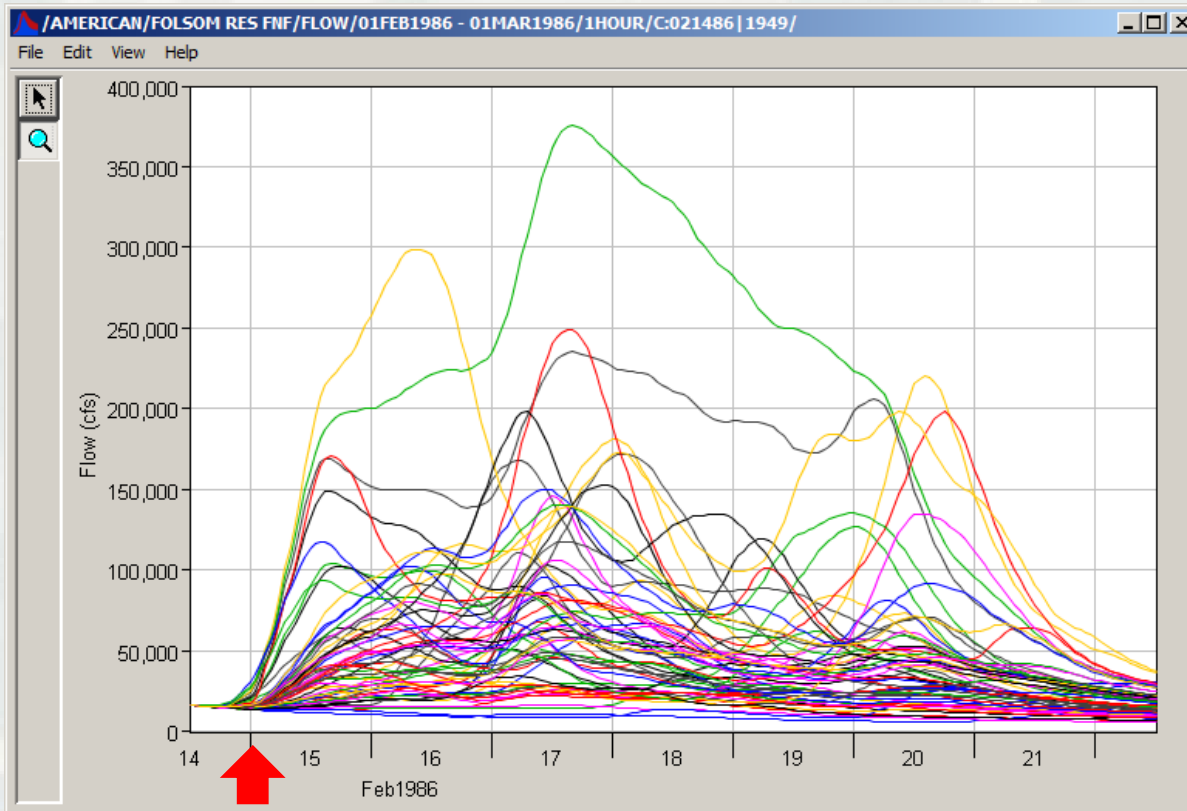




# Forecast Ensemble 1/3

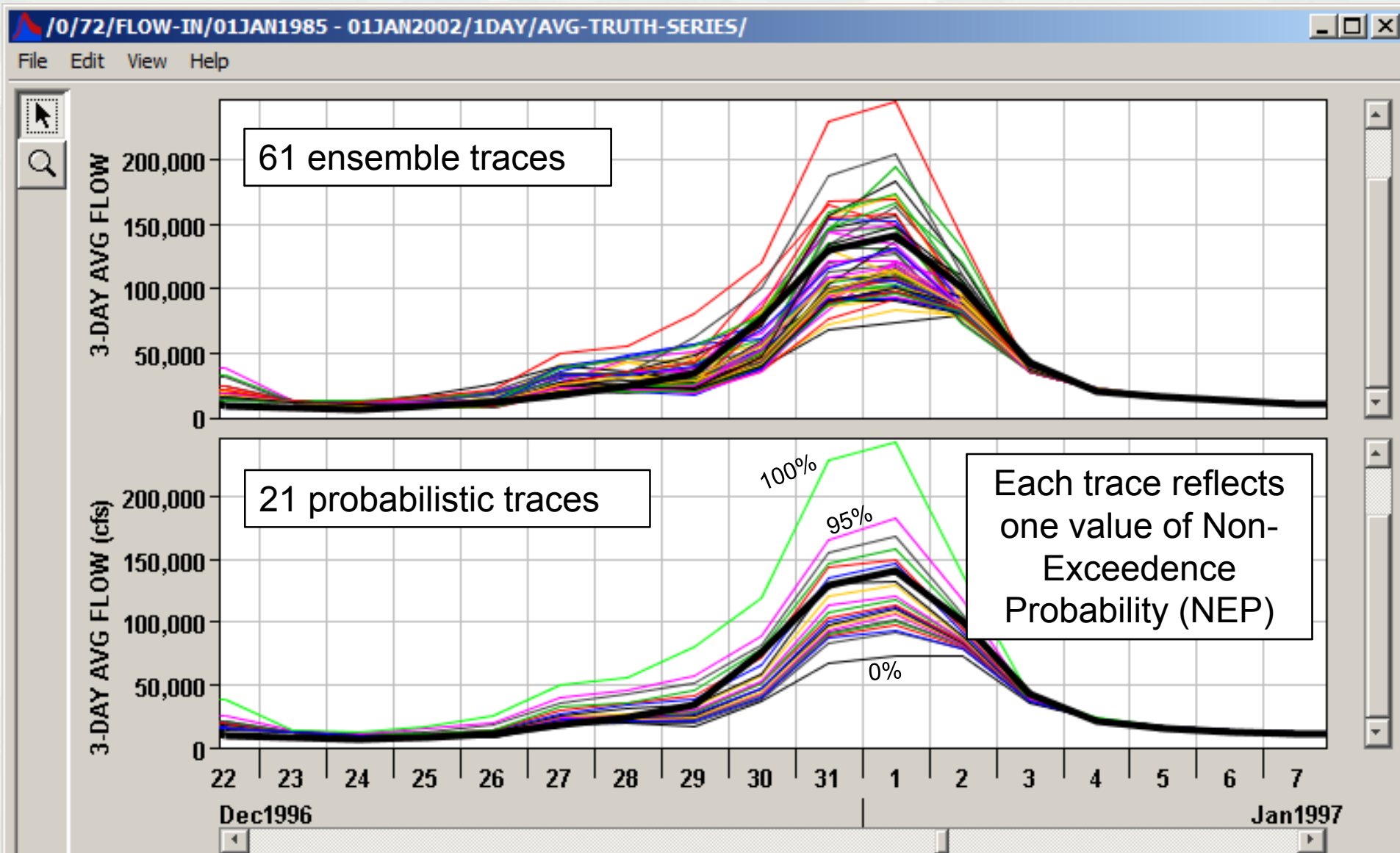


# Compute Forecasted Inflow Volumes



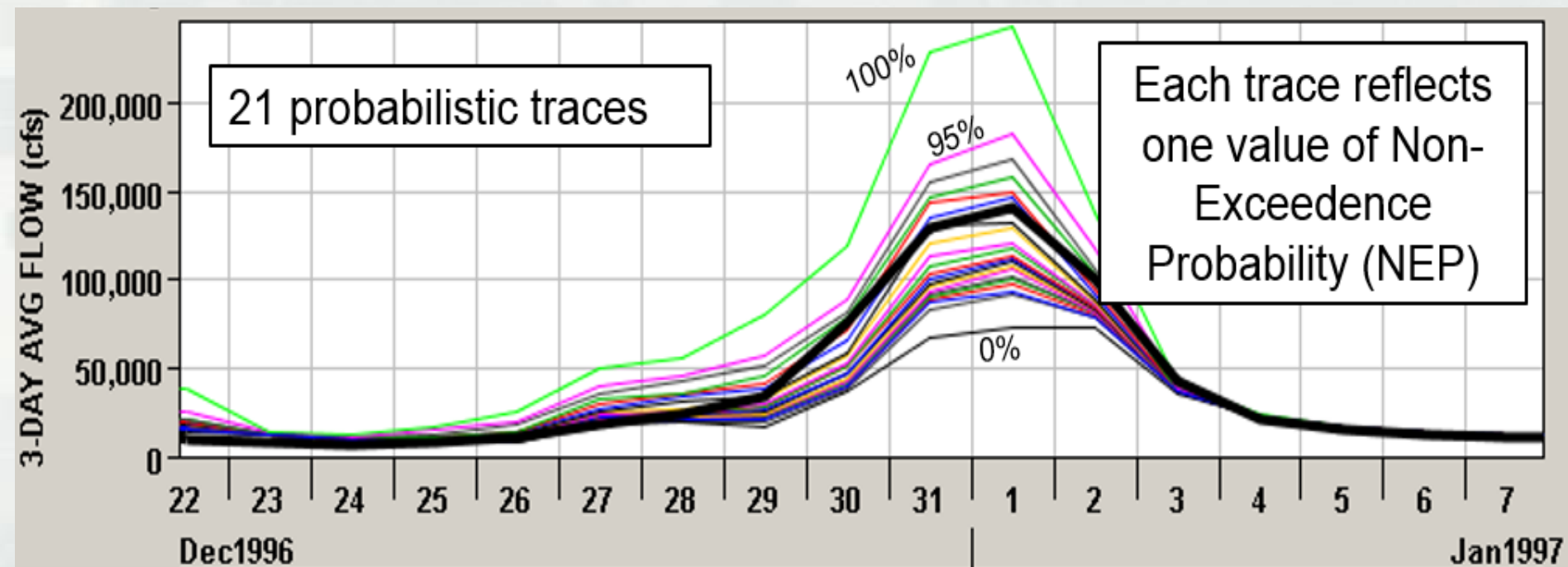
# 1997 event hindcast series

3-day volume updated daily

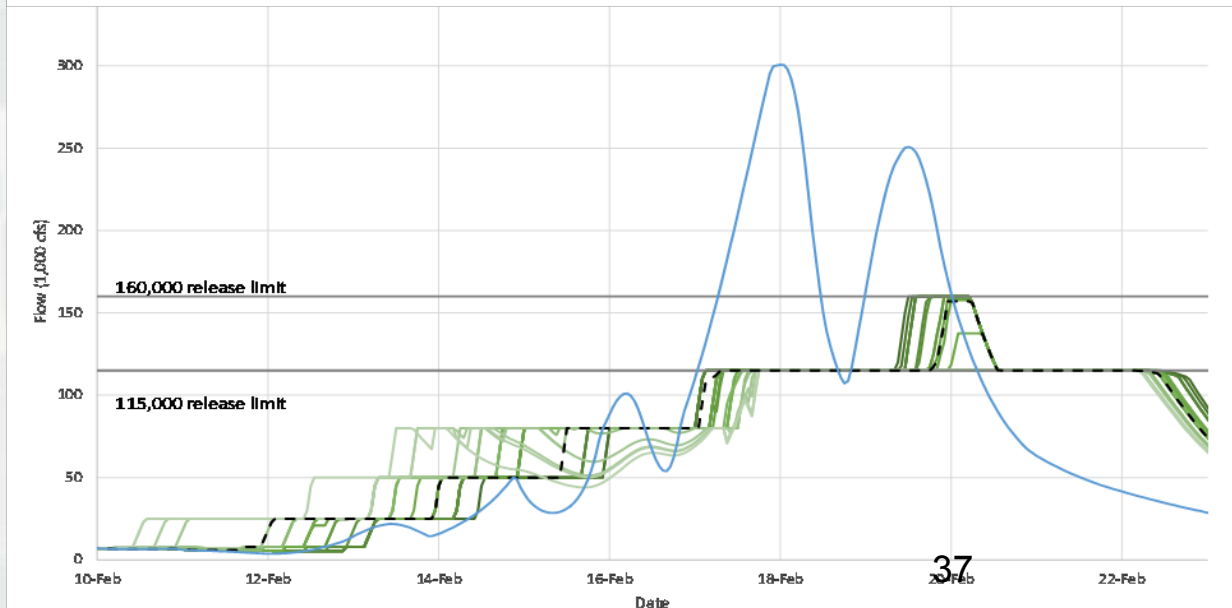
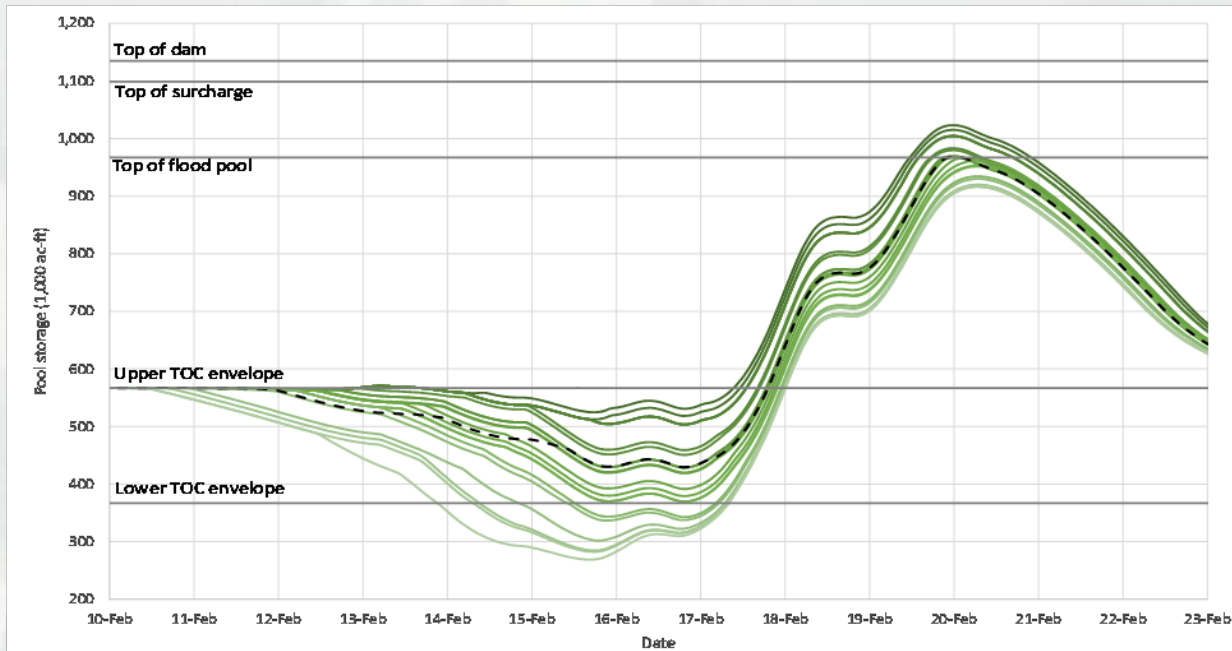


# Robustness Testing

- Considers uncertainty in forecast indicated by the forecast ensemble.
- Tests operation using imperfect forecasts.
- Used to identify operational NEP value.



# Robustness Test Example



**1986 event pattern  
scaled to 200-yr**

21 simulations  
corresponding to NEP  
values ranging from 0%  
to 100% (5%  
increments).

Perfect forecast shown  
as black dashed line for  
reference.



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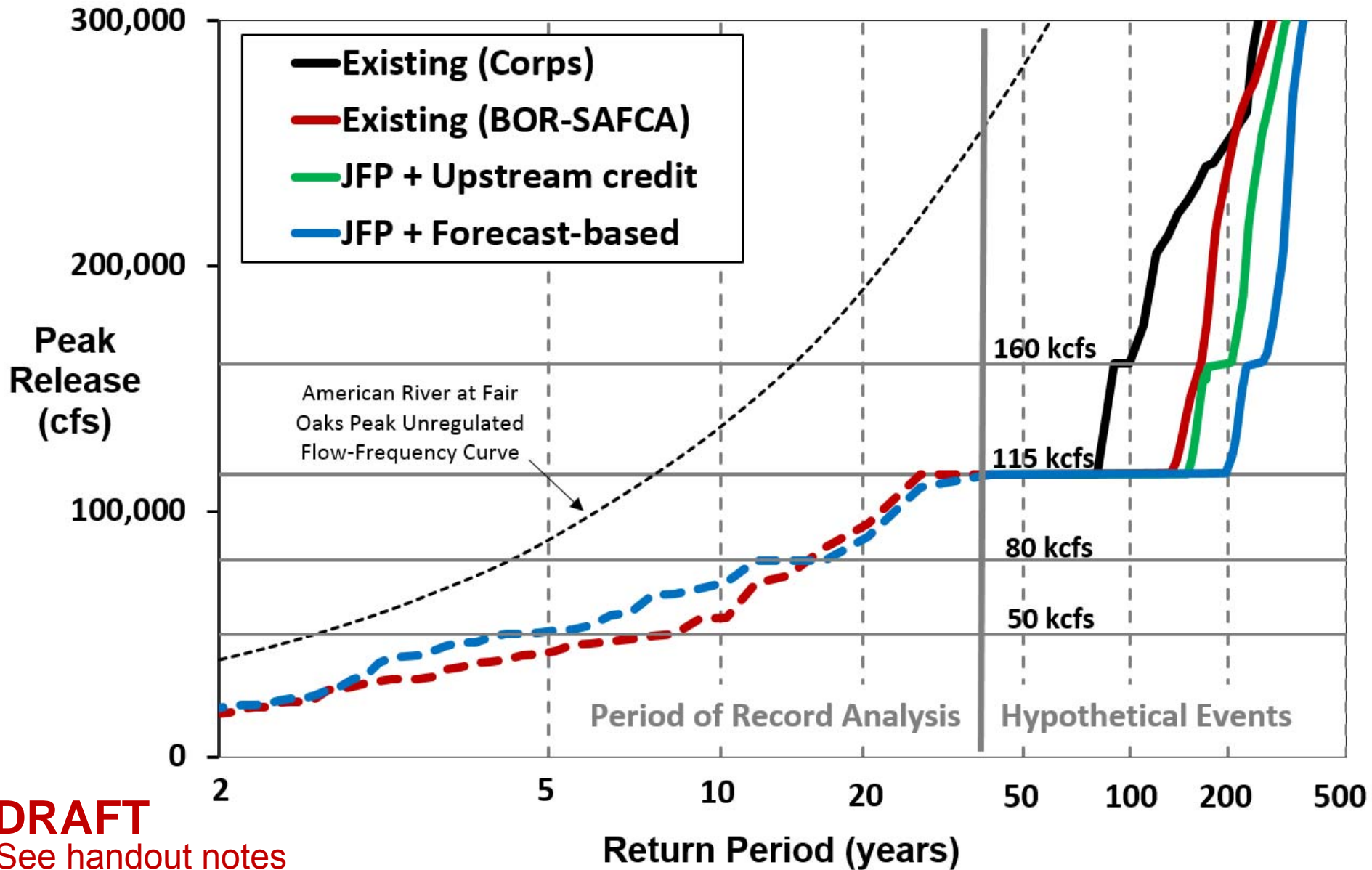


# Robustness Summary

Metric	Minimum NEP (%) (1986 / 1997 patterns)
Pass 100-yr event at 115 kcfs	0% / 0% (ALL PASS)
Pass 200-yr event at 160 kcfs	0% / 0% (ALL PASS)
Pass 200-yr event at 160 kcfs (24-hr late forecast)	55% / 60%



# Peak Flow-Frequency



**DRAFT**  
See handout notes

# Lessons Learned

- Simple vs. Complex
- Corps more comfortable with:
  - ▶ designated (and limited) variable flood space
  - ▶ work within TOC framework
  - ▶ demonstrate well-behaved releases



# Moving Forward

- Draft engineering report complete
- Agency Technical Review of final report
- Division / Headquarters / IEPR review
- 4/15/2017 – final signatures



# Questions?

