Forecast-based Flood Control Operation at Folsom Reservoir Using Advance Release

Beth Faber, PhD
Hydrologic Engineering Center (HEC)
US Army Corps of Engineers
Beth.A.Faber@hec01.usace.army.mil

Outline

- Facts about Folsom Reservoir
- Discussion of Advance Release
  - Streamflow Forecasts
  - Tradeoffs
- Components of an Advance Release Strategy
- Simulation of an Advance Release Strategy
  - Synthetic Forecasts
  - Sample Results
- What next?

Facts about Folsom Reservoir

- 1,000,000 acre-foot reservoir on the American River
- Approximately 500,000 AF of flood storage reservation
  - adjusted based on storage in upstream reservoirs
- Currently, low outlet capacity ≅ 35,000 cfs
  - with proposed modifications, will be > 115,000 cfs
- "Non-damaging" release is 115,000 cfs

Outline

- Facts about Folsom
- Discussion of Advance Release
  - Streamflow Forecasts
  - Tradeoffs
- Components of an Advance Release Strategy
- Simulation of an Advance Release Strategy
  - Synthetic Forecasts
  - Sample Results
- What next?

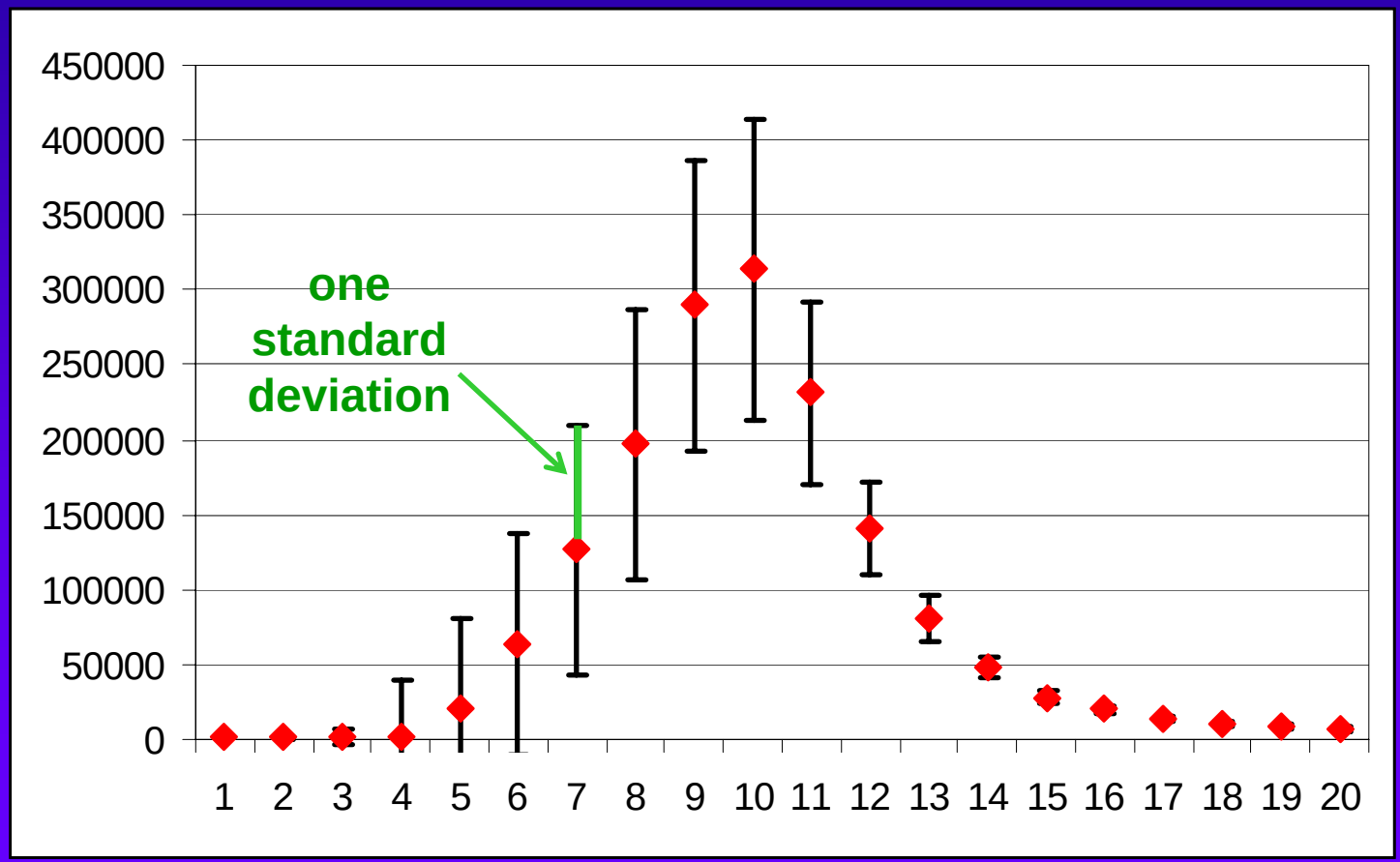
Forecast-based Advance Release

Why Advance Release?

- Both the size of the flood control pool and the operation of the reservoir determine flood protection.
- If a reservoir is drawn down in advance of a flood event, there will be a larger flood storage pool to contain that event.
- Acting in response to ***forecasts*** of streamflow would allow more time to effect a draw-down.

NWS Forecast Product

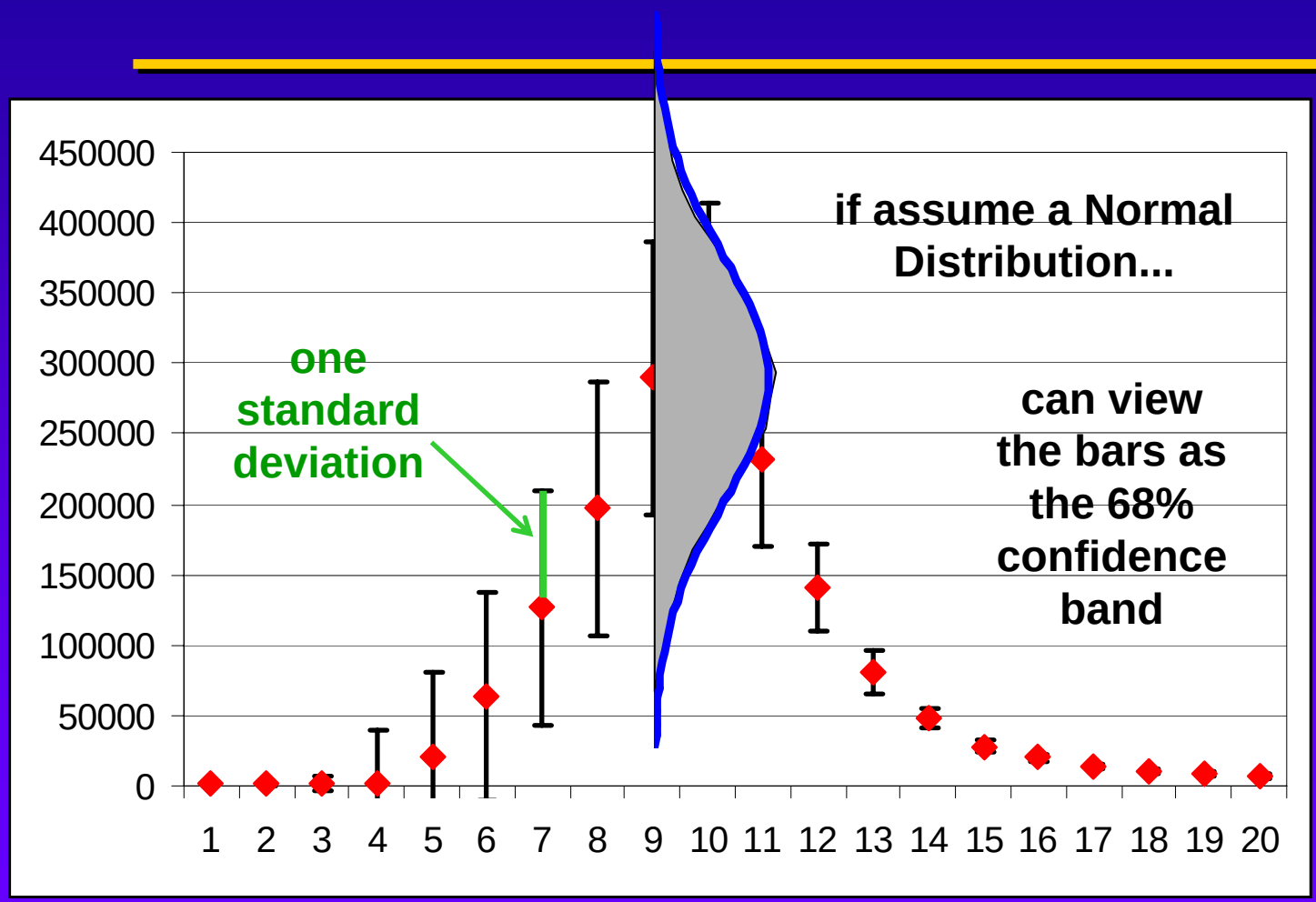
American River inflow to Folsom Reservoir (cfs)



6-hour time periods

NWS Forecast Product

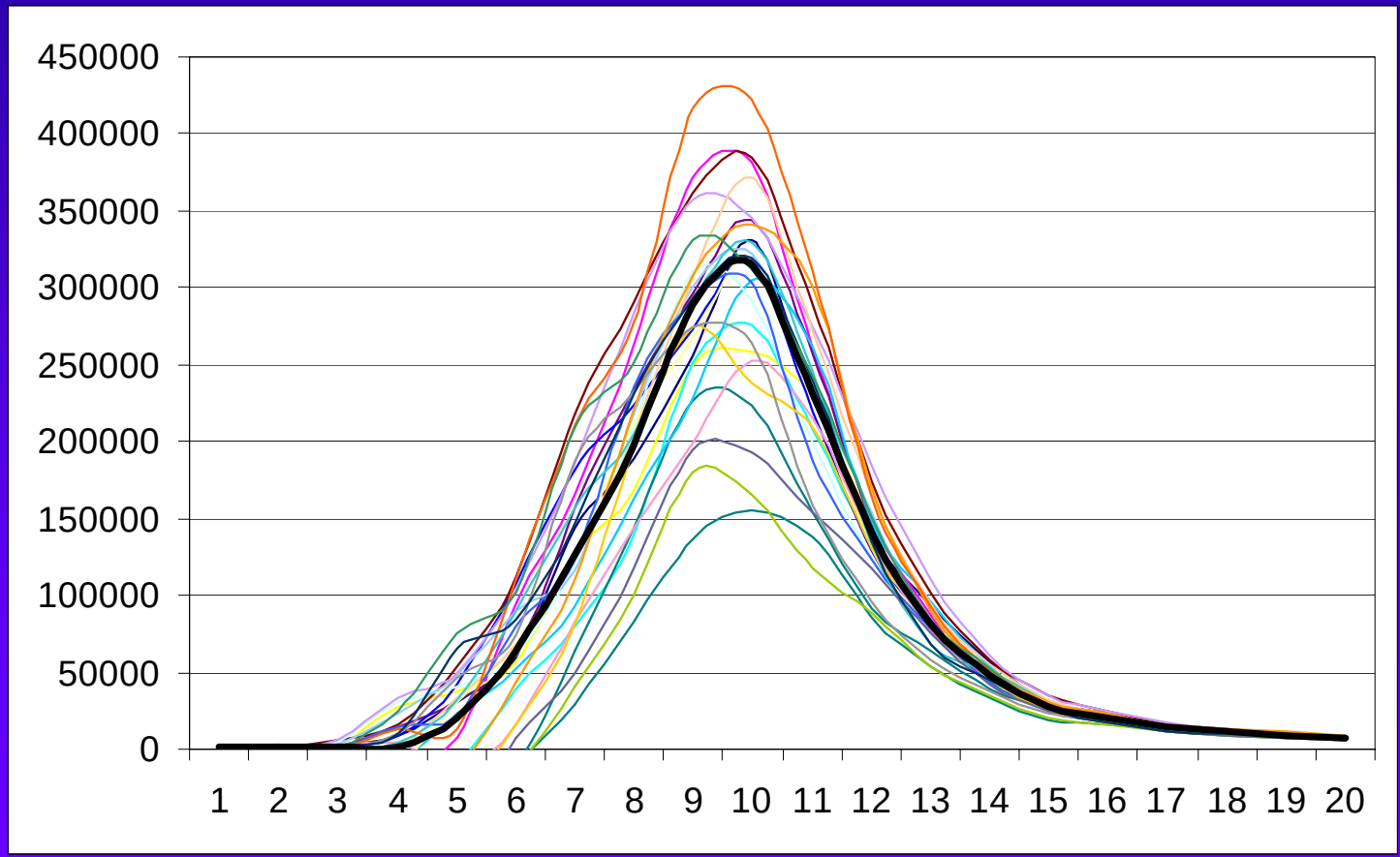
American River inflow to Folsom Reservoir (cfs)



6-hour time periods

USU Forecast Ensemble for RRFM

American River inflow to Folsom Reservoir (cfs)



"Base Case" OR, where are we now?

Current Operation of Folsom Reservoir

- Currently there is no "advance release" based on forecasts — ***not in the Reservoir Regulation manual***
- Only act based on precipitation that's already "on the ground," giving 12-18 hour lead-time
- Use of forecasts, and so better use of the available flood storage space, can only ***improve*** flood protection.

But it's not only flood protection we're concerned with...

Forecast-based Advance Release

When do we use Advance Release?

- Intending the Advance Release procedure to be implemented for storms with about 1% exceedance probability or less (100-year or larger).
- ***However***, it is likely that some smaller storms are forecasted as larger and so trigger Advance Release.
  - Therefore, the likelihood of triggering Advance Release is greater than the

Ways to be Wrong...

- **Small Forecast, Big Event**
  - doesn't trigger Advance Release, missed opportunity
- **Big Forecast, Bigger Event**
  - Advance Release, but small
- **Big Forecast, Small Event** ("*false alarm*")
  - Advance Release is too large
    - unnecessary impact downstream
    - perhaps don't refill reservoir drawdown

No worse than current operations

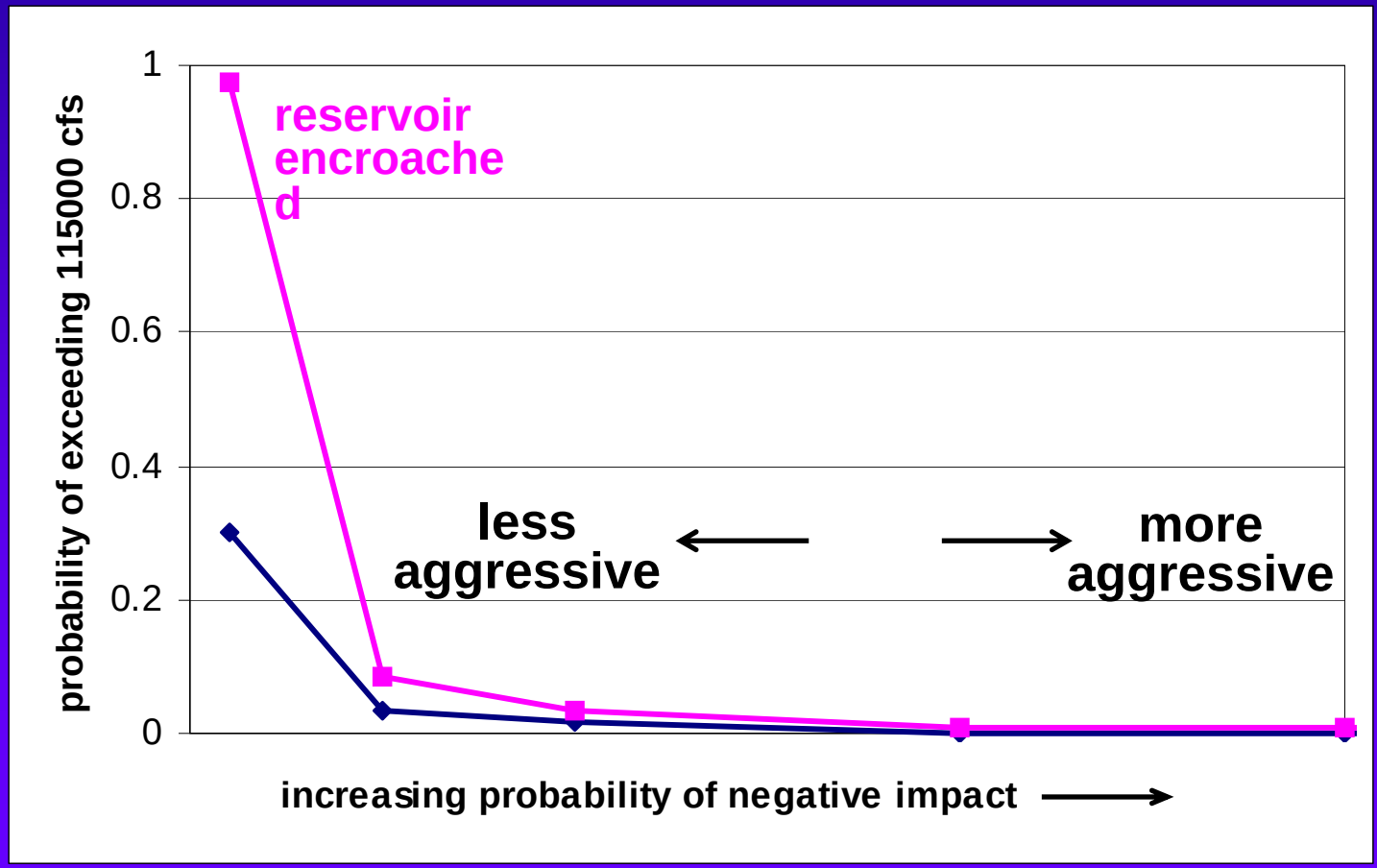
negative impacts

Tradeoffs

- There is a ***direct tradeoff*** between flood protection, and likelihood of negative impact (ie, unnecessary damage, failure to refill)
- As Advance Release becomes more aggressive, flood protection increases, and the risk of negative impact increases.
- ***Likelihood of negative impact arises because forecasts are uncertain (and also depends on our confidence in them).***

Tradeoffs

for a single event...



Outline

- Facts about Folsom
- Discussion of Advance Release
  - Streamflow Forecasts
  - Tradeoffs
- Components of an Advance Release Strategy
- Simulation of an Advance Release Strategy
  - Synthetic Forecasts
  - Sample Results
- What next?

Advance Release Strategy

Components of a Strategy

1) Forecast Trigger to initiate Advance Release
   – when do we start?
2) Level of Advance Release
   – how much do we release?
3) Trigger to stop or decrease advance release
   – at what point to we discontinue release when forecasts change and predict a smaller event?

1) Trigger to Initiate

When do we start the advance release?

triggers are based on the NWS 3 to 5 day forecast

A) peak flow greater than trigger value

B) event volume greater than trigger value

combine with OR condition

C) forecast hydrograph causes release greater than 115,000 cfs *(incorporates peak, volume and reservoir level)*

D) probability of exceeding 115,000 cfs is greater than trigger value (using USU ensemble and RRFM)

2) Level of Advance Release

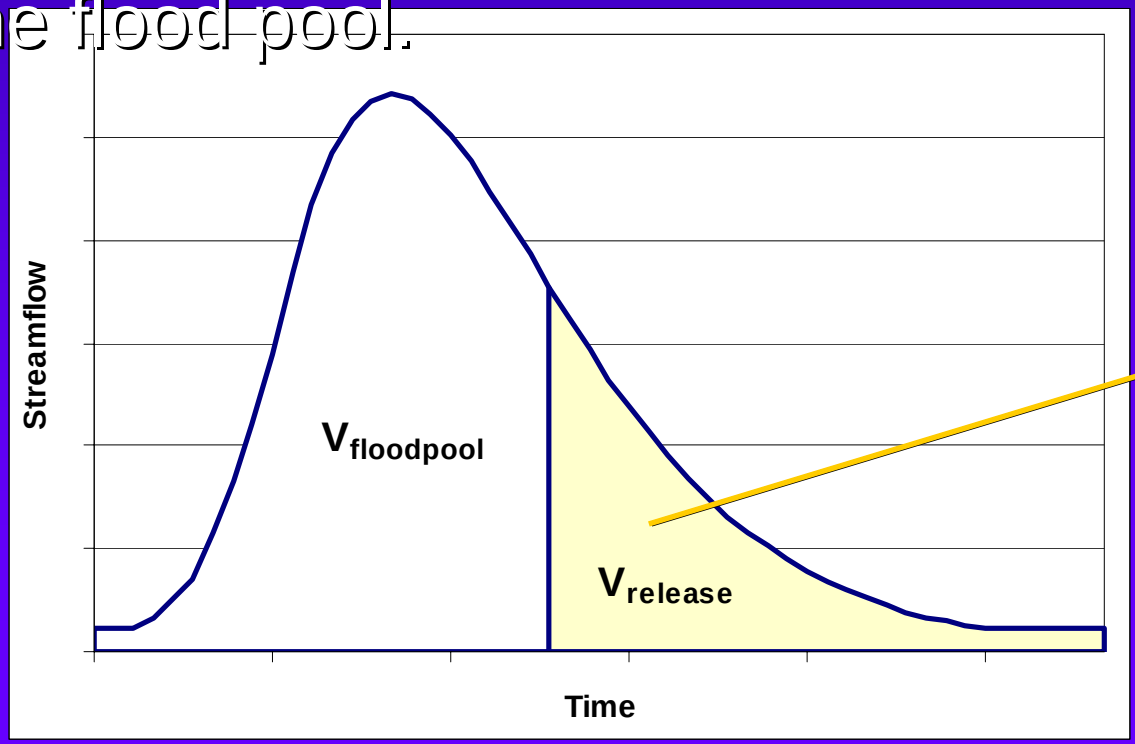
The Advance Release level can have a larger or smaller
dependence on the forecast

- **Less dependence on forecast:**
  set release to 25,000 cfs greater than inflow
- **More dependence on forecast:**
  set release based on the volume of forecasted inflow and the current reservoir level

today, we'll discuss this one...

Computation of Release

Basically, must release at least the volume that will not fit
in the flood pool.



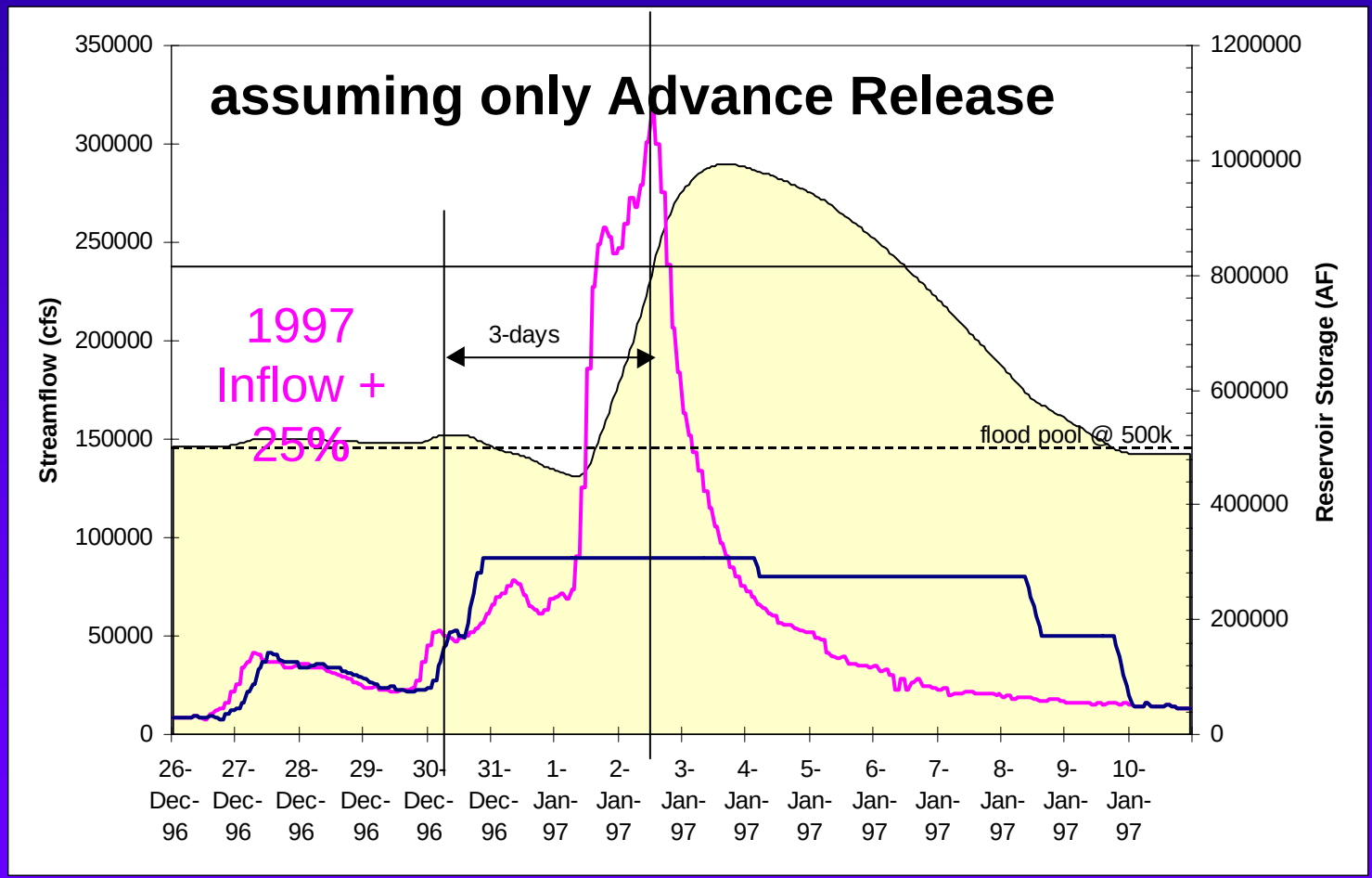
Note: no implication about timing of release...

Computation of Release

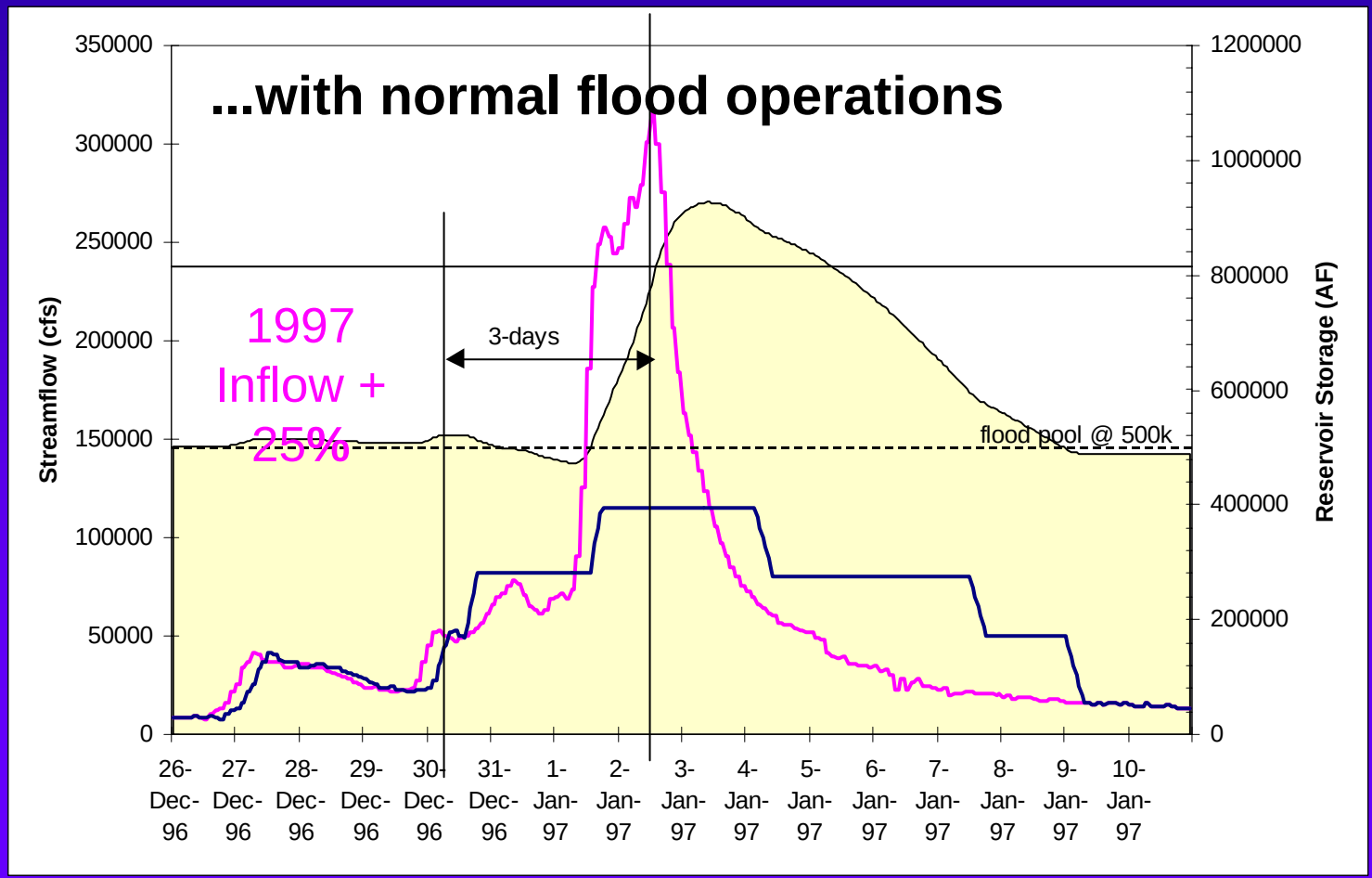
ExcessVolume = EventVolume - SpaceAvailable
AdvanceRelease = ExcessVolume / EventTime
[≤115,000 cfs]

- **When in the flood pool, the reservoir will be following flood operation rules for release.**
- Release is dependent on current state of the reservoir as well as the forecast of the event.
- When the lead time is longer, the necessary release is smaller. This allows the response to be gradual as forecast develops, which provides the ability to

1997 Event at Folsom +25%



1997 Event at Folsom +25%



Aiming for “No Impact”

- Would like to avoid impact on water supply and hydropower generation.
- Both of these functions would be no worse off if the reservoir ***ends*** the event with at least the initial storage volume (or, at the top of the conservation pool).

change in storage = total inflow volume - total release volume

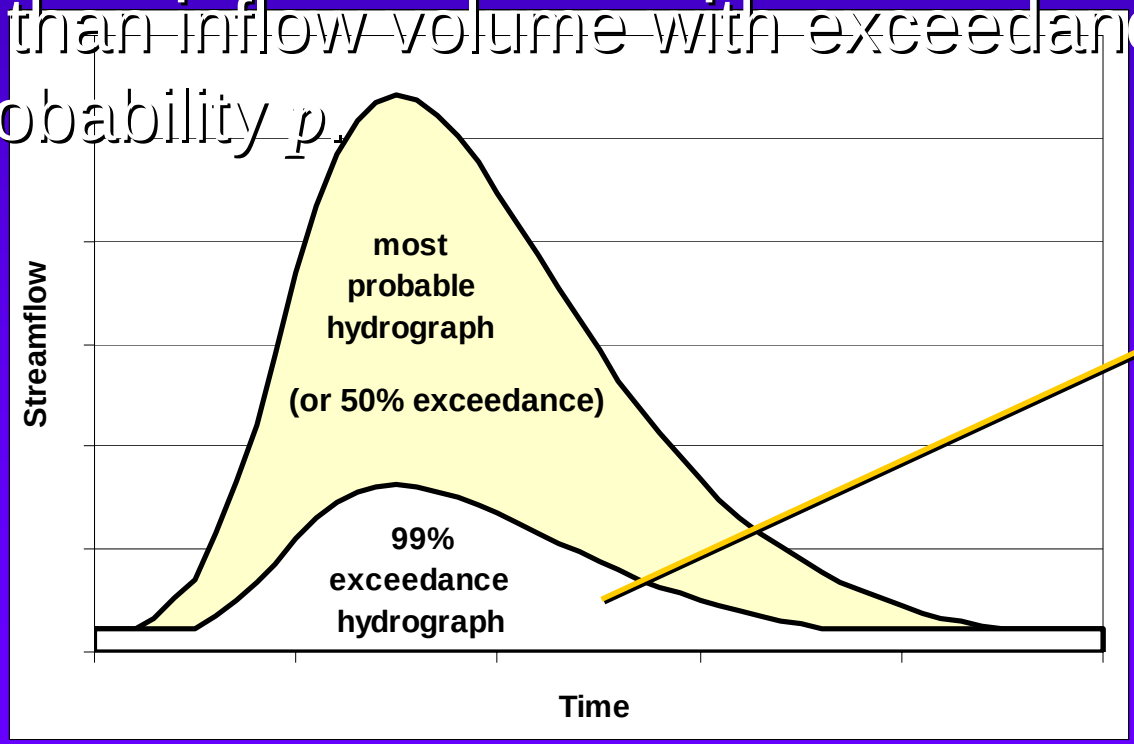
to end the event with a full conservation pool,

total release $\leq$ total inflow + *encroachment*

- But, what do we use as “total inflow” from the

Aiming for “No Impact”

To maintain refill probability p, total release must be
less than inflow volume with exceedance probability p.



dependant on forecast variance

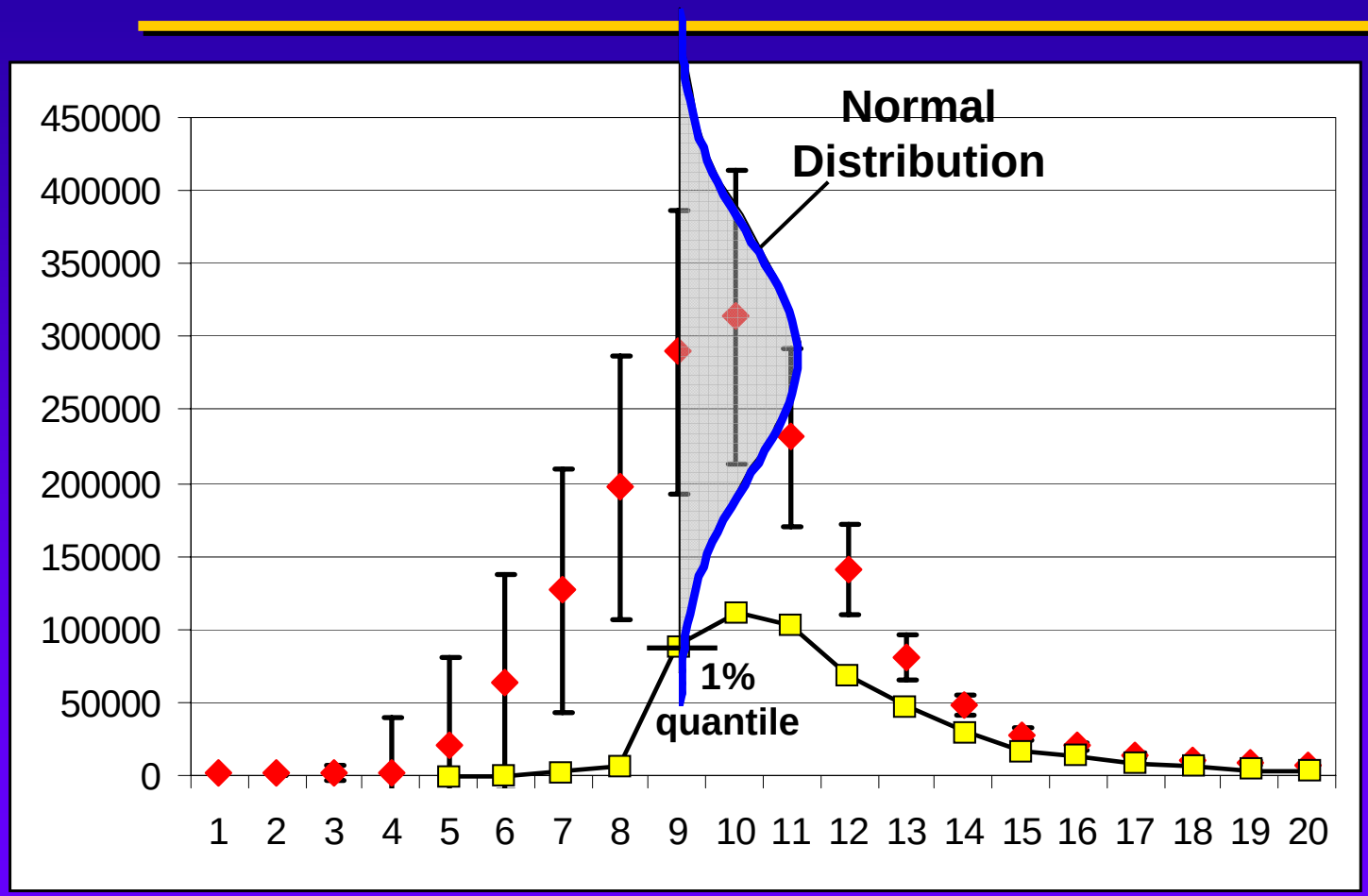
99%-Exceedance volume

There are various methods of computing an event volume
with a particular exceedance probability...

- Connecting quantiles of the Normal distribution assumed from the flow/variance combination.
  - An approximation. The higher the serial correlation between 6-hour flows, the closer this is to correct.
- Using USU forecast ensemble procedure.
  - Sum the volume of each event hydrograph in the sample and determine parameters of a volume

99%-Exceedance Volume

American River inflow to Folsom Reservoir (cfs)



6-hour time periods

3) Trigger to Stop Advance Release

When the latest forecast predicts a smaller, non-triggering event, should the release be decreased?

…only if the reservoir is now in danger of not refilling with that release…

- If the volume from the existing release is less than the latest forecast's 99% exceedance inflow volume, release can continue.
- If not, release will decrease.

Outline

- Facts about Folsom
- Discussion of Advance Release
  - Streamflow Forecasts
  - Tradeoffs
- Components of Advance Release Strategy
- Simulation of Advance Release Strategy
  - Synthetic Forecasts
  - Sample Results
- What next?

Simulation of the Strategy

- Demonstrate the effectiveness of an Advance Release Strategy, and approximate the impacts.
- The variable with the greatest influence on the outcome of the strategy is the set of streamflow forecasts.
  - The forecast series determines whether Advance Release is triggered, and when, and what release...
- To simulate the strategy for a single event, must

A Set of Forecasts

date/time	forecast 1	forecast 2	forecast 3	forecast 4	forecast 5	forecast 6	forecast 7	forecast 8
1/1 04:00								
1/1 10:00								
1/1 16:00								
1/1 22:00								
1/2 04:00								
1/2 10:00								
1/2 16:00								
1/2 22:00								
1/3 04:00								
1/3 10:00								
1/3 16:00								
1/3 22:00								
1/4 04:00								
1/4 10:00								
1/4 16:00								
1/4 22:00								
1/5 04:00								
1/5 10:00								
1/5 16:00								
1/5 22:00								
						...	...	...

Terminology: for this discussion, each column is called a "series" and all of them are a "set."

Generation of Synthetic Forecasts

Streamflow-component of Forecast:

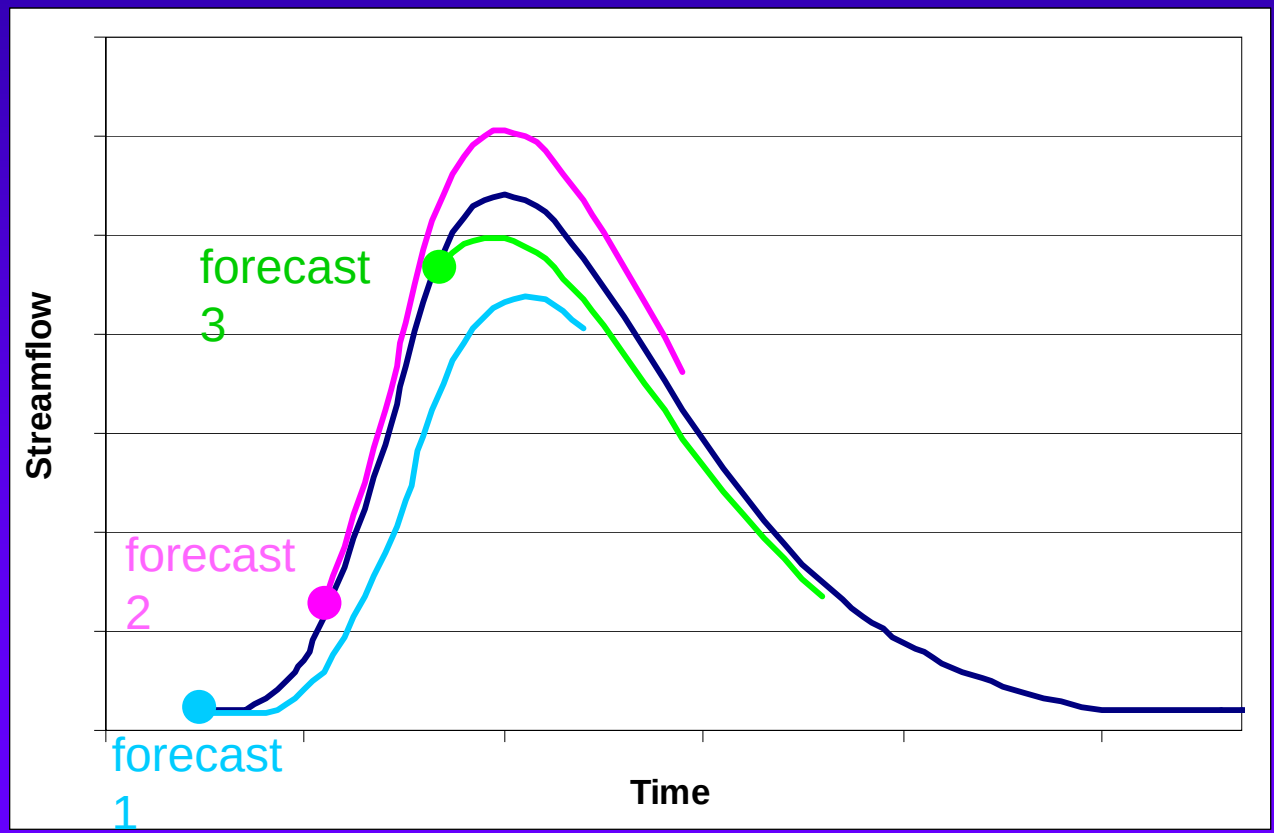
- Ideally, a sample of forecast sets for a given event would be generated by a hydrologic model.
- For this study, a sample of ***synthetic*** forecast sets is generated statistically.
- Each forecast series is based on the actual streamflow, multiplied by a random bias ~ N(0,σ) and shifted by a random time increment.
- The bias and time-shift values have some positive serial correlation within a forecast set, developed by AR(1).

Generation of Synthetic Forecasts

Bias3= -0.02

Bias2= 0.12

Bias1= -0.19



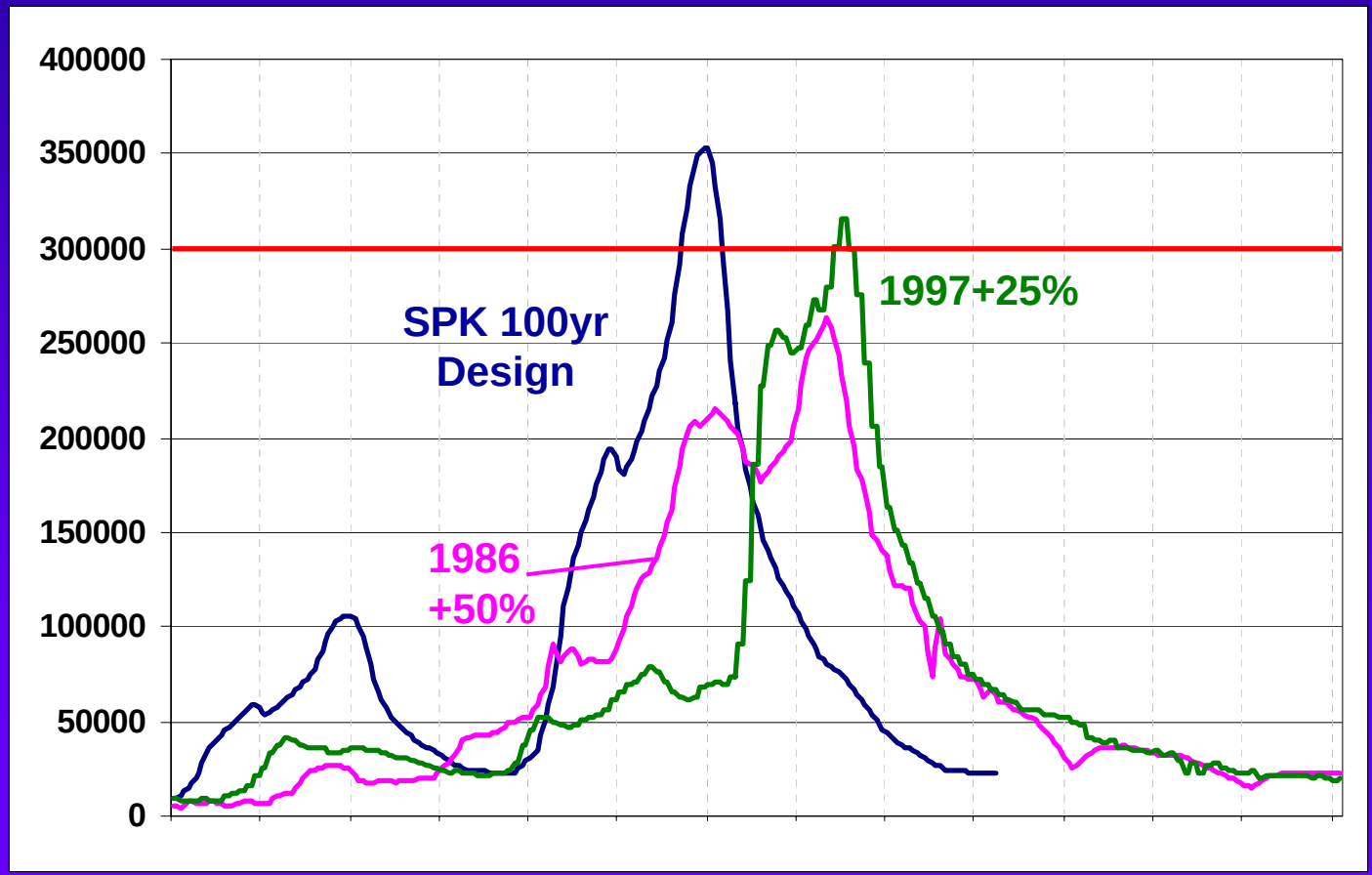
Generation of Synthetic Forecasts

Variance-component of Forecast:

- Variance of the forecast is the factor that has the ***greatest influence on the results*** when release is limited by the 99% volume for refill probability.
- Forecast flow variance is dependent upon lead-time, limb of hydrograph, magnitude of event…
- Data available to help estimate flow variance are relative-forecast-errors from the 1997-event, and several test events from January 2001 (using SS-SAC model).
- For this study, assumed standard deviation =

Events Simulated to Evaluate Strategy

American River inflow to Folsom Reservoir (cfs)



1-hour time step

Simulation Procedure

Summary:

- When simulating a given event, need to represent the uncertainty about the set of forecasts that occurs.
- For each event, generate a sample of forecast sets.
- Simulate reservoir operation with Advance Release for each set of forecasts.
- Evaluate the statistics of the outcomes.

Simulation Results

For **1986 + 50%** event:

peak inflow = 264,160 cfs
event volume = 1,591,640 AF

Release statistics:

	Max Rel. (cfs)		prob >	Drawdown (AF)
Refill Prob.	*mean*	*st.dev.*	115,000	*mean*	*st.dev.*
99%	118,094	5,183	30%	48,978	14,639
95%	115,250	1,352	3%	166,801	33,998

Simulation Results

For **1986 + 50%** event:

peak inflow = 264,160 cfs

event volume = 1,591,640 AF

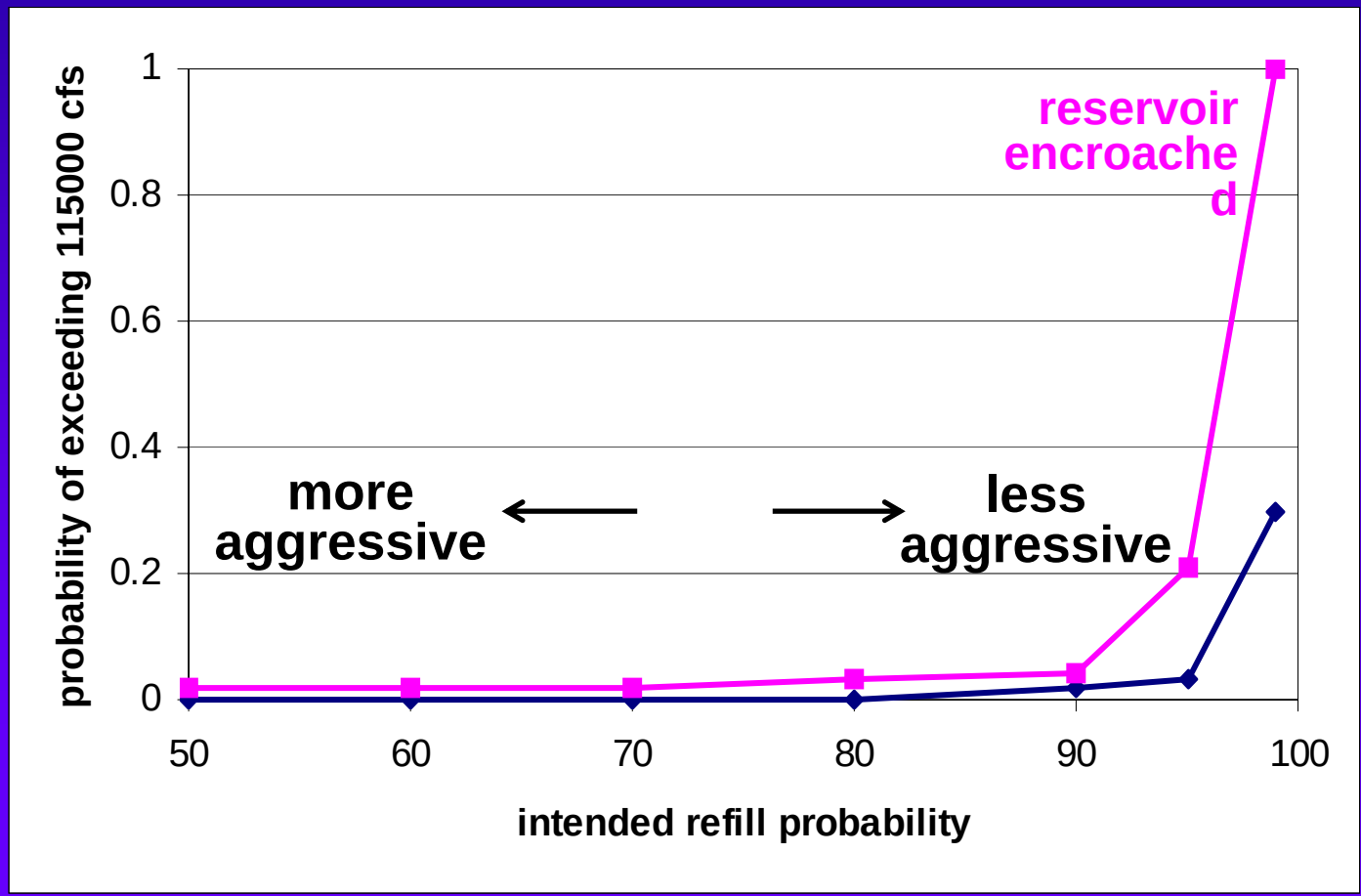
Flood Pool Encroached 100,000 AF

Release statistics:

	Max Rel. (cfs)		prob >	Drawdown (AF)
Refill Prob.	*mean*	*st.dev.*	115,000	*mean*	*st.dev.*
99% 20,240	141,544	15,824	98%	106,973	
95% 28,354	115,688	2,381	8%	216,915	

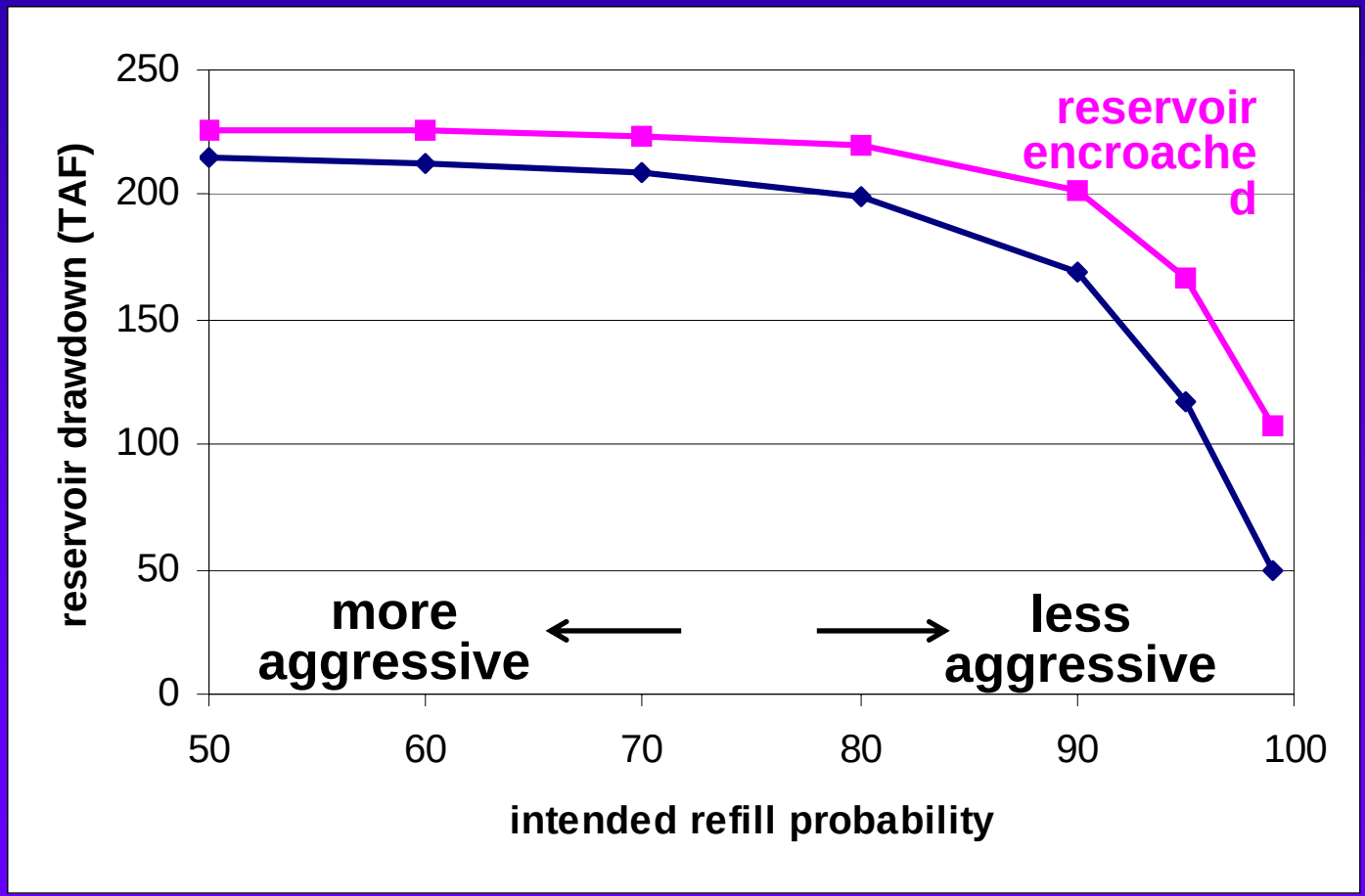
Some Results

for 1986 + 50%



Some Results

for 1986 + 50%



What We've Simulated...

- This simulation procedure has addressed the range of situations in which the forecasted event ***does*** occur, and is of a size for which Advance Release is intended.
- So far, it does not address situation in which a large forecast triggers Advance Release for an event which turns out small.
  - ie, situations which might impact water supply and hydropower generation

What is Needed...

- In order to assess the impacts that might occur due to this procedure, we need either:
  - statistics on the rate of “false alarms” (to compute impact)
  - forecast time series for historical hydrology which includes “false alarms” (to simulate impact)
- The NWS is working on both of these...