The Potential for Adaptive Reservoir Operations Provided by Forecast Information

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BIOGRAPHICAL SKETCH

Beth Faber received her Bachelor of Science degree in Civil Engineering from the University of Colorado at Boulder in May 1991. From June 1991 to July 1995, she was employed by Denver Water in Denver, Colorado, performing analysis and operation of the city's reservoir system. During that period she also completed a Master's degree in Civil Engineering at the University of Colorado at Boulder.

Between 1995 and 2000, she completed the doctoral program at Cornell University, interspersed with brief periods of employment with Pacific Gas & Electric in San Francisco and Denver Water. She is currently employed at the U.S. Army Corps of Engineers' Hydrologic Engineering Center in Davis, California.

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Decision-Making

- The goal of decision-making is to maximize return or benefit
- Decisions are made based on information about factors outside our control

More information
= Better Decisions
= Greater Benefits

Uncertain Information

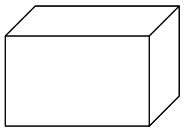
- When the available information is uncertain, it must be used differently
- The decisions must consider:
  - The likely range of the information's true value
  - The likelihood of being wrong
  - The consequences of being wrong

Reservoir Operations

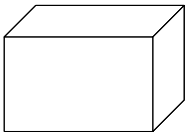
- In reservoir operations, the factor outside our control is streamflow
- Streamflow has a great deal of variability, both in seasonal volume and extreme flows
- Information about streamflow decreases uncertainty, and the amount of variability that must be absorbed

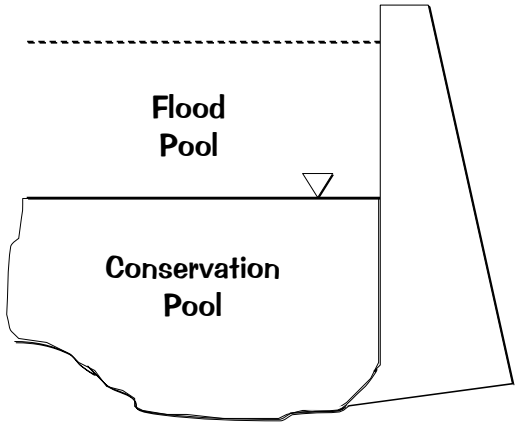
Multi-Use Reservoir

flood benefits are proportional to flood volume

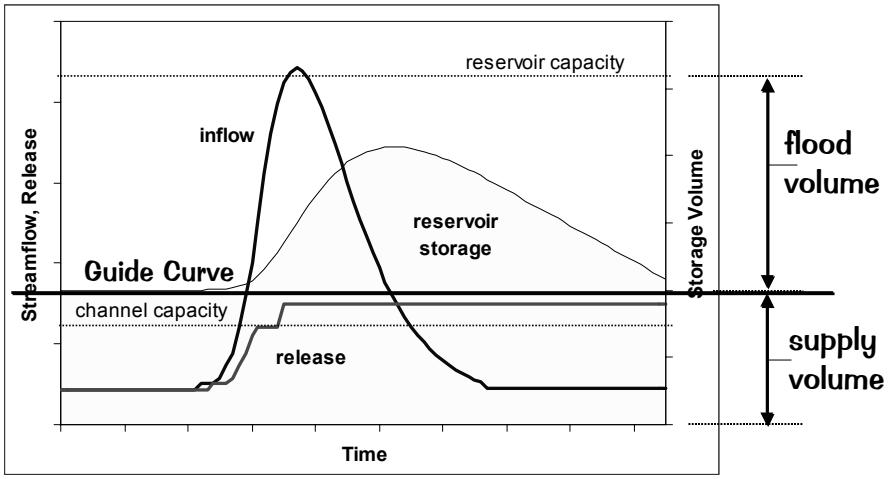


supply benefits are proportional to supply volume

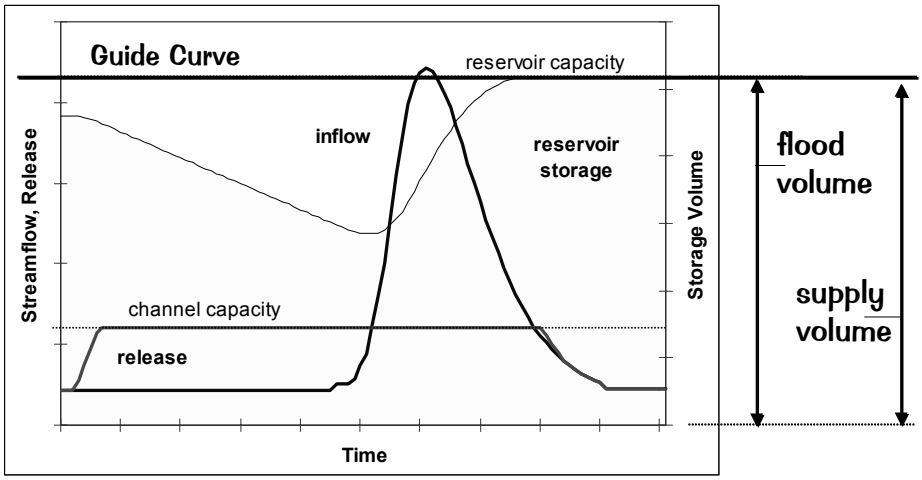




Flood Operation with Complete Uncertainty



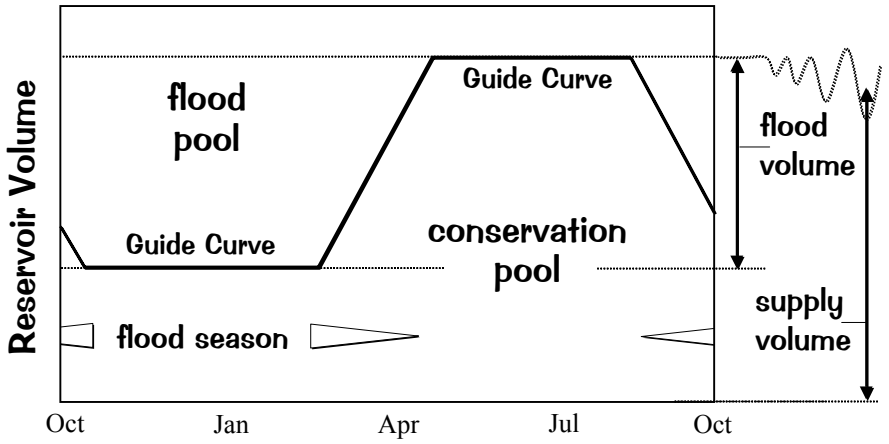
Flood Operation with No Uncertainty



Use of Historical Information

- What if operators make use of the historical information about precipitation and flood volume?
  - With annual maximum flood volume, can size the reservoir's flood pool for a certain exceedance probability (info on **VOLUME**)
  - With precipitation data, can define a likely flood season (info on **TIMING**)

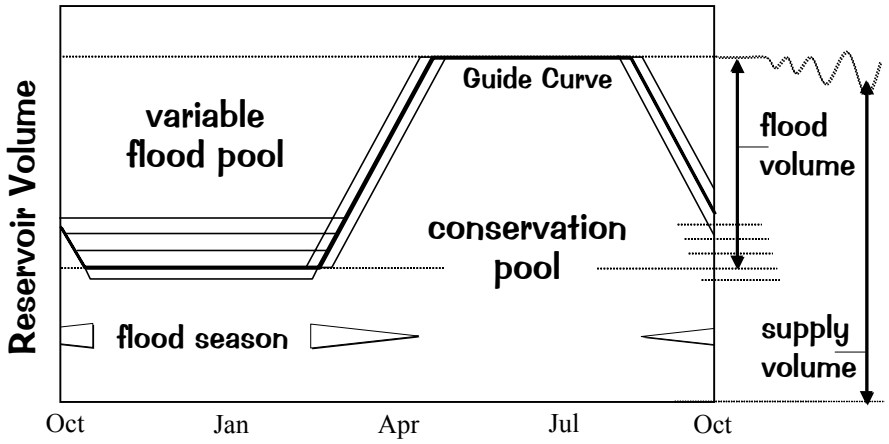
Given a Defined a Flood Season…



Use of More Current Information

- Annual climate indicators and basin conditions such as wetness give information on the current year
  - Additional info on VOLUME (but not TIMING)
  - No need to account for the full annual variability
  - Can resize the flood pool for current conditions

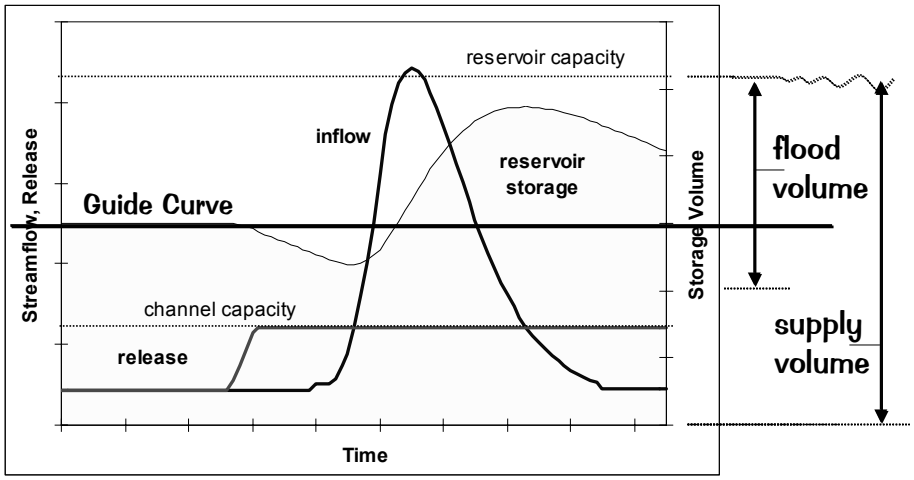
Given Current Basin Information…



Use of Forecast Information

- Real-time forecasts provide up-to-date information on both VOLUME and TIMING of an imminent flood event
  - Can increase the size of the flood pool to respond to the forecast
  - Can perhaps decrease the size to store more for supply, knowing the a forecast would enable an increase when needed

Given Forecast Information…

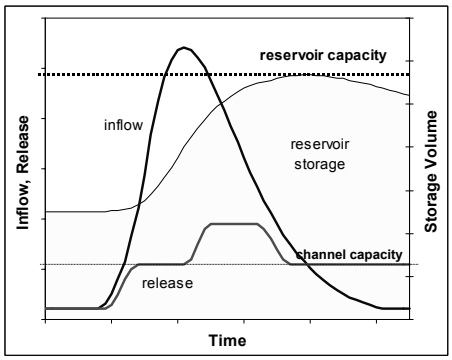


Summary of Use of Information

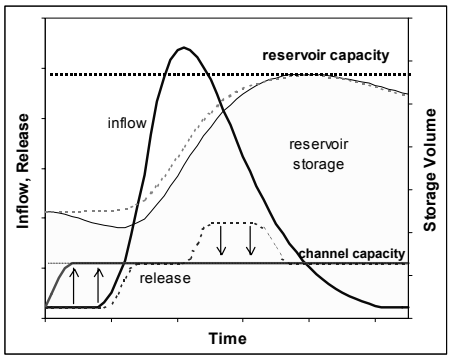
	Long-term *year to year*	**Mid-term** *current year*	**Short-term** *current week*
Available Information	**Historical record** of precipitation and extreme flows (peak and volume)	Annual **climate indicators** (El Niño, etc), basin wetness, upstream storage	5-day, 6-hourly streamflow **forecasts**
Processing of information	• Develop peak & volume **frequency curves** • Define a **flood season**, based on the seasonal flood risk throughout the year.	• Designate ***variable* flood space**, based on likely flood magnitude, basin wetness, upstream storage levels, etc.	• Use the best-estimate forecast to **simulate and adjust operations** • Develop **distribution of event volume** to compute Advance Release
Use of information in Reservoir Operation	• **Size the flood pool** to contain an event of the selected frequency. • **Maintain the flood pool** when flood events are highly probable.	• **Maintain the variable flood pool** of the size determined above.	• Make more **decisive releases** as the event nears and forecast uncertainty decreases.

Advance Release

normal operation



advance release



Recall... Uncertain Information

- When the available information is uncertain, it must be used differently
- The decisions must consider:
  - The likely range of the information's true value
  - The likelihood of being wrong
  - The consequences of being wrong

Categorize Events based on Consequences

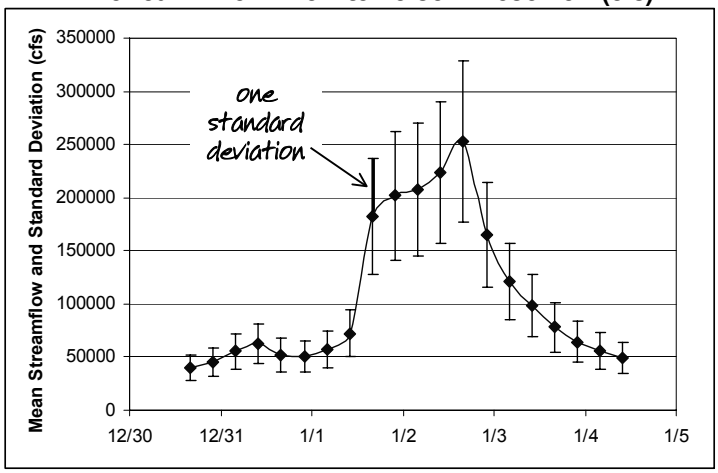
Event Size	Event Description	Response	Recovery if no event
Very Large	Requires Advance Release to maintain channel capacity	Advance Release	would recover
Large	Does not require Advance Release, but able to refill if AR initiated	none	would recover
Small	Would be unable to refill after Advance Release	none	would NOT recover

Define Consequences of Advance Release

		Forecast		
		Very Large event	Large event	Small event
		Forecast suggests Advance Release	Forecast does not suggest Advance Release	
Outcome	Very Large Event	Reduced Flood Damage	Flood Damage (missed opportunity)	
	Large Event	No Damage or Impact	Not an Advance Release Situation	
	Small Event	Negative Impacts Occur		

NWS Forecast Product

American River Inflow to Folsom Reservoir (cfs)



Forecast Uncertainty

- Streamflow forecast uncertainty is based on precipitation uncertainty
- Uncertainty is greater for time-periods that are further in the future
- Uncertainty is greater on larger flows (near the flood peak) than smaller
- Forecasts of extremely large events are more certain than smaller events, because the weather systems are slow moving and stable

NWS Forecast Product

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								
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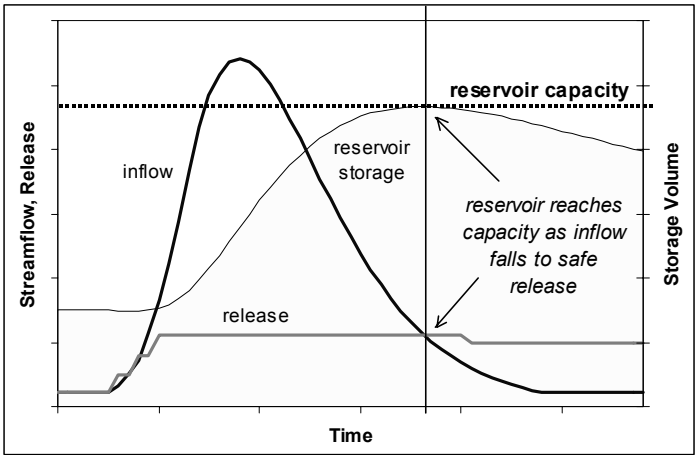
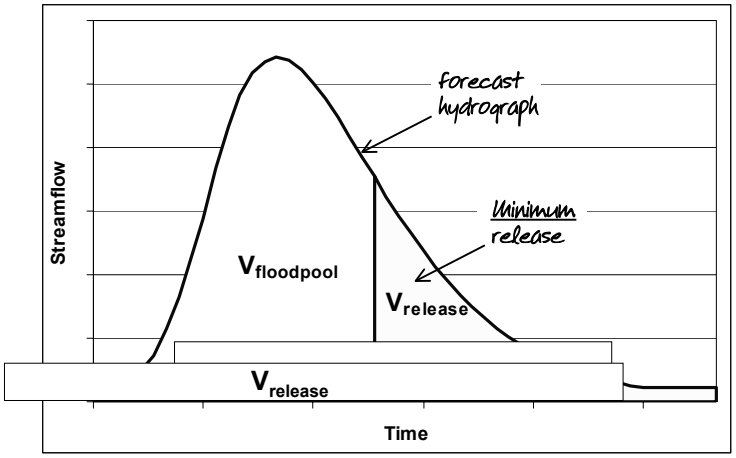
consecutive forecasts

reevaluate the situation with each forecast

Completely Efficient Flood Operation



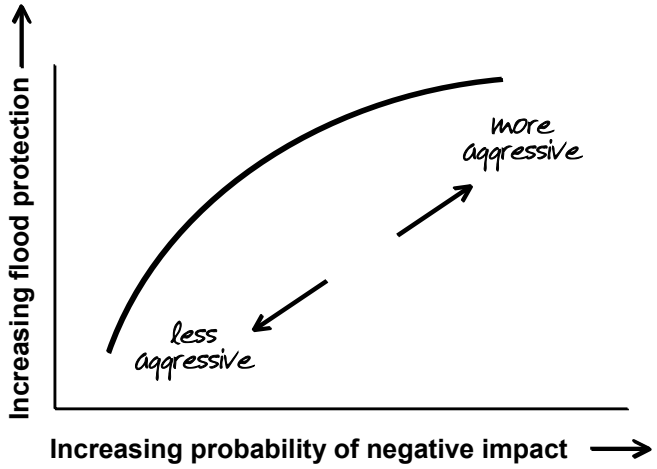
Minimum Release During Flood



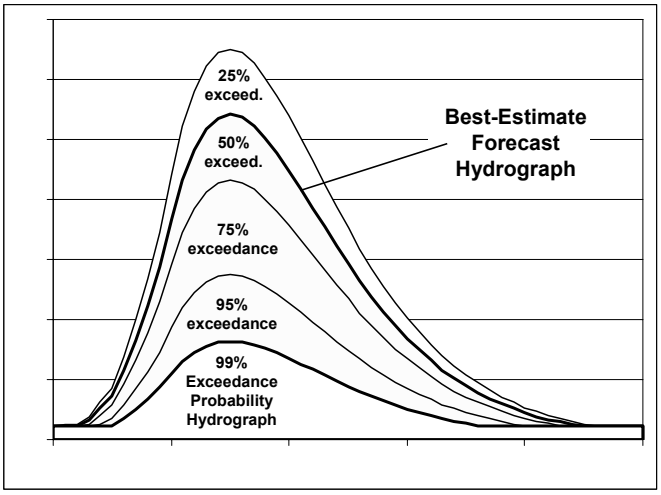
Likelihood of Negative Impact

- There is a direct tradeoff between improved flood protection and avoidance of negative impact from Advance Release
  - As Advance Release becomes more aggressive to provide more flood protection, the risk of negative impact increases.
- The HEC study aimed for "no impact" (...1%) but evaluated sensitivity to various probabilities of impact

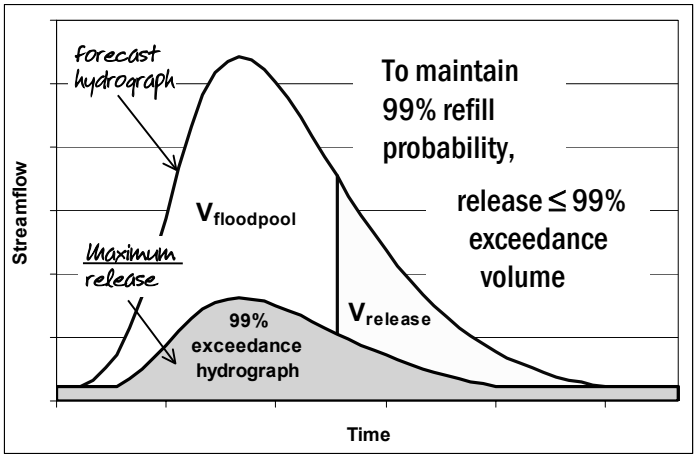
Flood Protection vs Negative Impact Tradeoff Curve



Breaking Down the Forecast



Maximum Release to Limit Probability of Impact

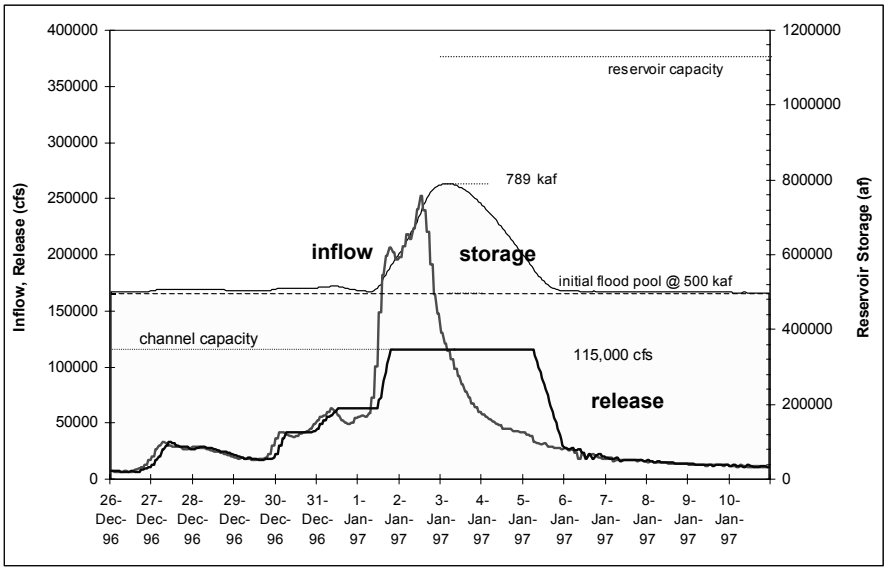


Summary of Concepts

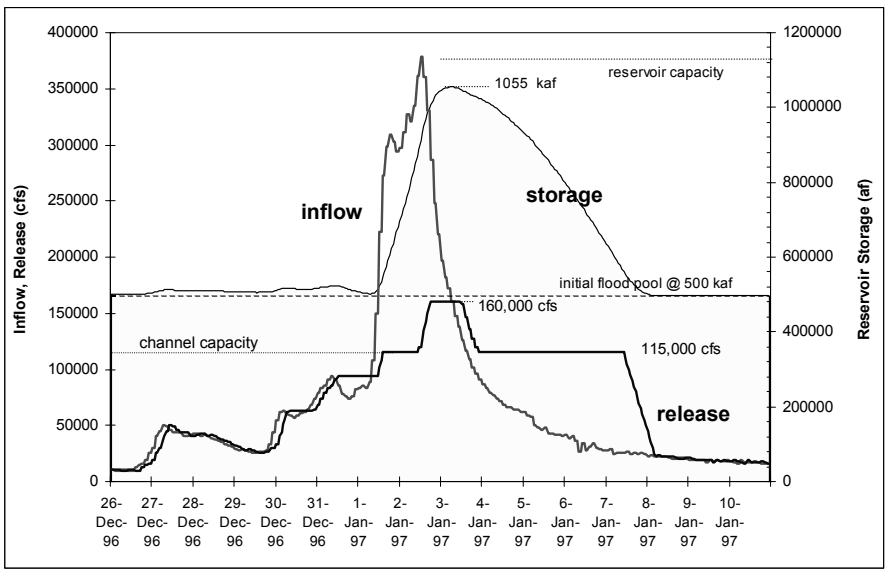
This Advance Release method does two things:

- Computes the minimum required release from the most probable forecast
- Limits to the maximum allowable release based on the desired probability of impact to other users

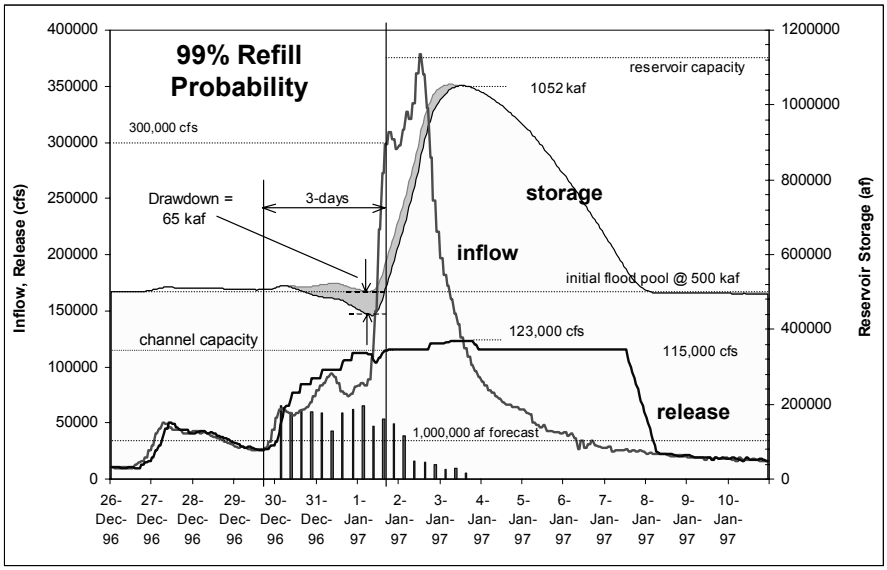
Simulated 1997 Event



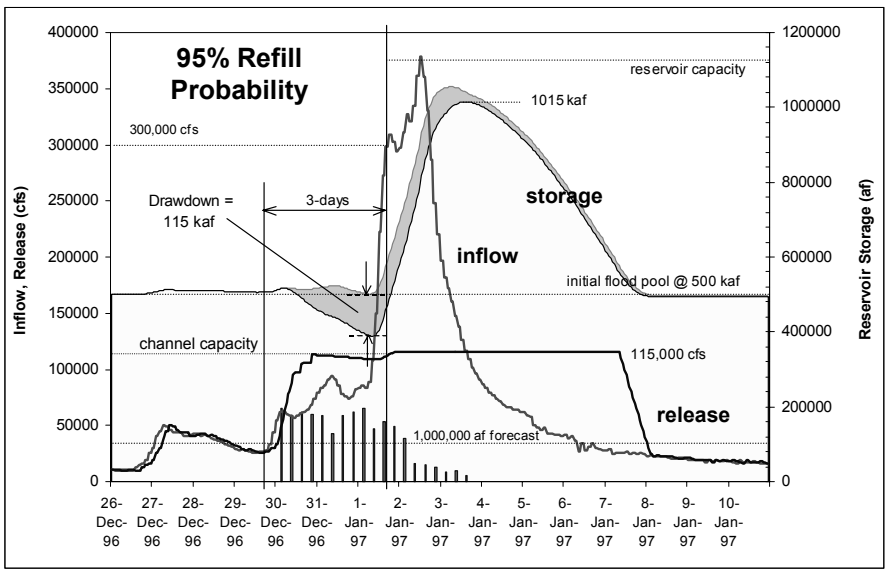
1997 Event+50%



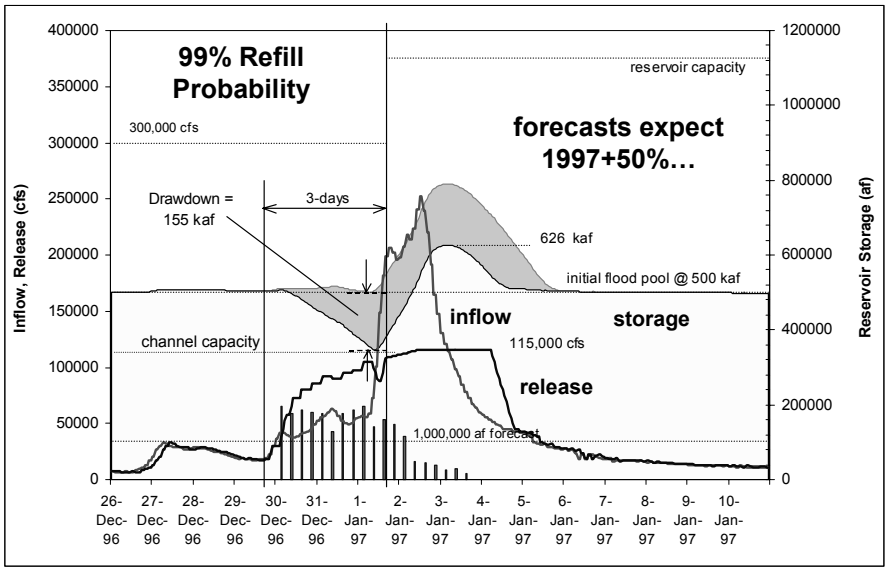
1997 Event+50%, Advance Release



1997 Event+50%, Advance Release

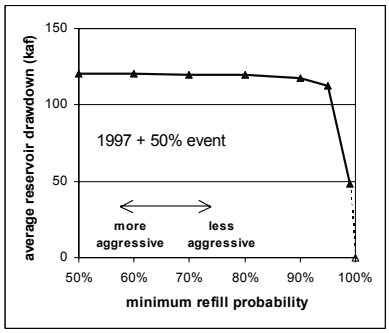


1997 Event, Advance Release



Outcome Based on Forecasts

- In these simulations of the 1997+50% event and the 1986+70% event, we assumed a particular forecast series
- What if the forecasts were different?
- Also modeled the events with 120 different forecast sets...



Results based on simulation with 120 forecast-sets