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Decision-Making under Uncertainty: Explaining Use of Streamflow Information for USACE Reservoir Operations and Adaptation to Climate Change

June 16, 2009

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Outline

- Decision-making with Uncertain Information
- How Information is Used for Reservoir Operation
  - Historical data
  - Current year climate/conditions
  - “Short-term” Forecasts
- Adapting to Climate Change
  - Flexible Operations
  - Adaptive Management

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Decision-Making

- The goal of decision-making is to produce the best outcome, or maximize benefit
- Decisions are made based on information about factors that are unknown or outside our control
- Information reduces uncertainty

More information

= Better Decisions

= Greater Benefits

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Using Probabilistic Information

- Information *reduces* uncertainty, but doesn't always *eliminate* it
- When the available information is probabilistic, it must be used carefully
- The decisions must consider:
  - The likely range of the true value of the information,
    ie, the remaining uncertainty
  - The likelihood that a decision is "wrong"
  - The consequences of being "wrong"

"wrong" = decision worse than one made with no info

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Reservoir Decision-Making

- Reservoir operation is a series of decisions on how much water to hold or release
  - Readiness: what size flood pool each season?
  - Response: how to store and release during flood or runoff
- Decisions are based on information about streamflow
  - Streamflow is variable in seasonal volumes, size and timing of flood events, …
- Information about streamflow *decreases* uncertainty of the future, and so *decreases* the amount of variability that decisions must span (hedging)
  - Less uncertainty = more precise decisions

Opposing Needs

- Many of our reservoirs are operated for both flood protection and water supply purposes
- In general, the strategies for these purposes are in opposition
  - for water supply, want to catch all available inflow and keep the reservoir as full as possible
  - for flood protection, want to keep the reservoir empty to have space to catch snow-melt or rain-flood flows and release slowly

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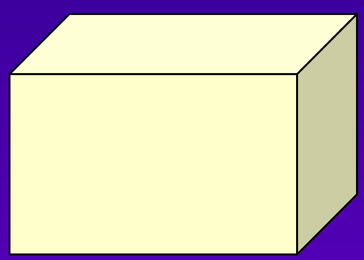
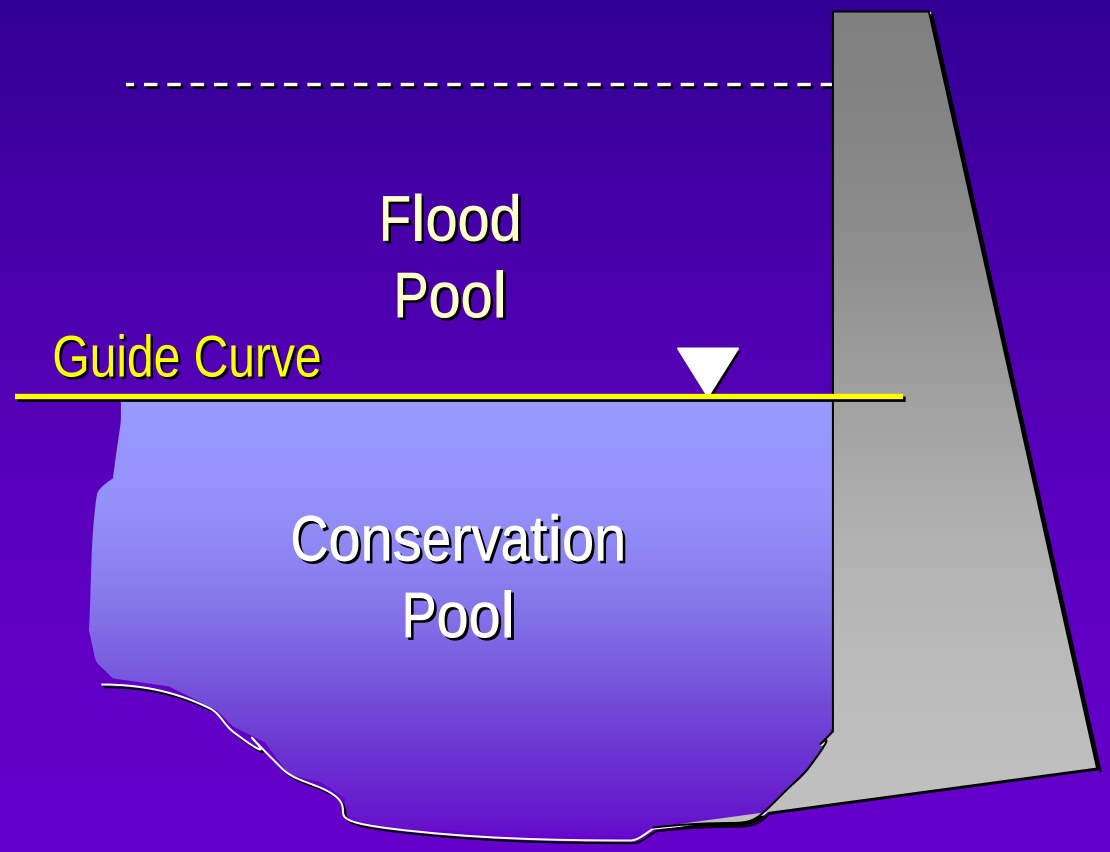
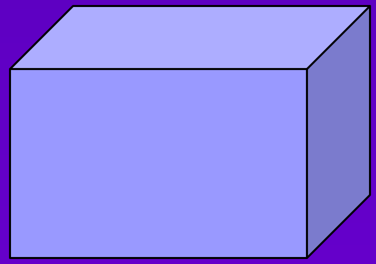
More Information Increases Benefits
(value of information)

flood benefits are proportional to flood volume





supply benefits are proportional to supply volume



Flood Operation with Complete Uncertainty *(no information)*

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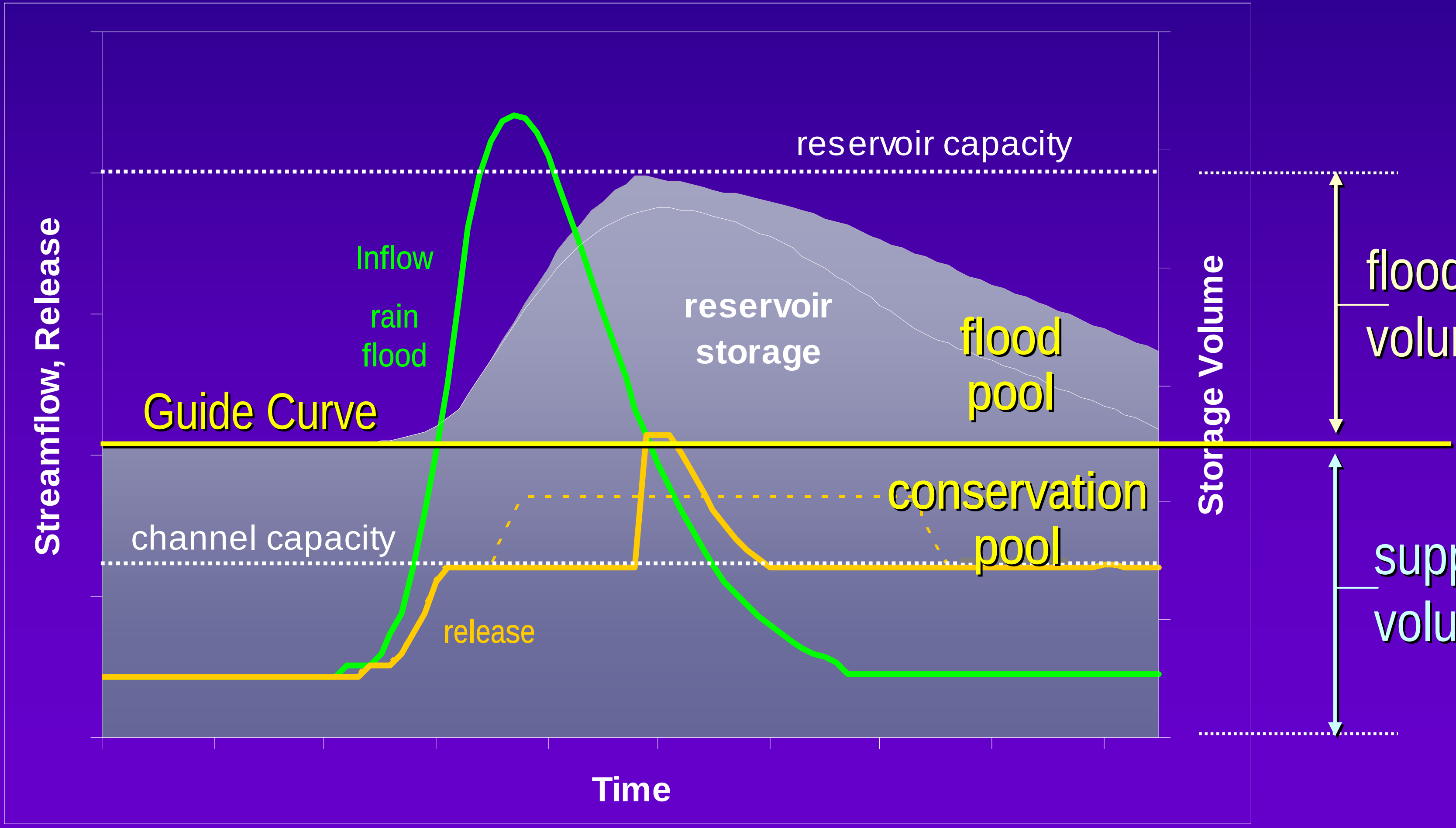

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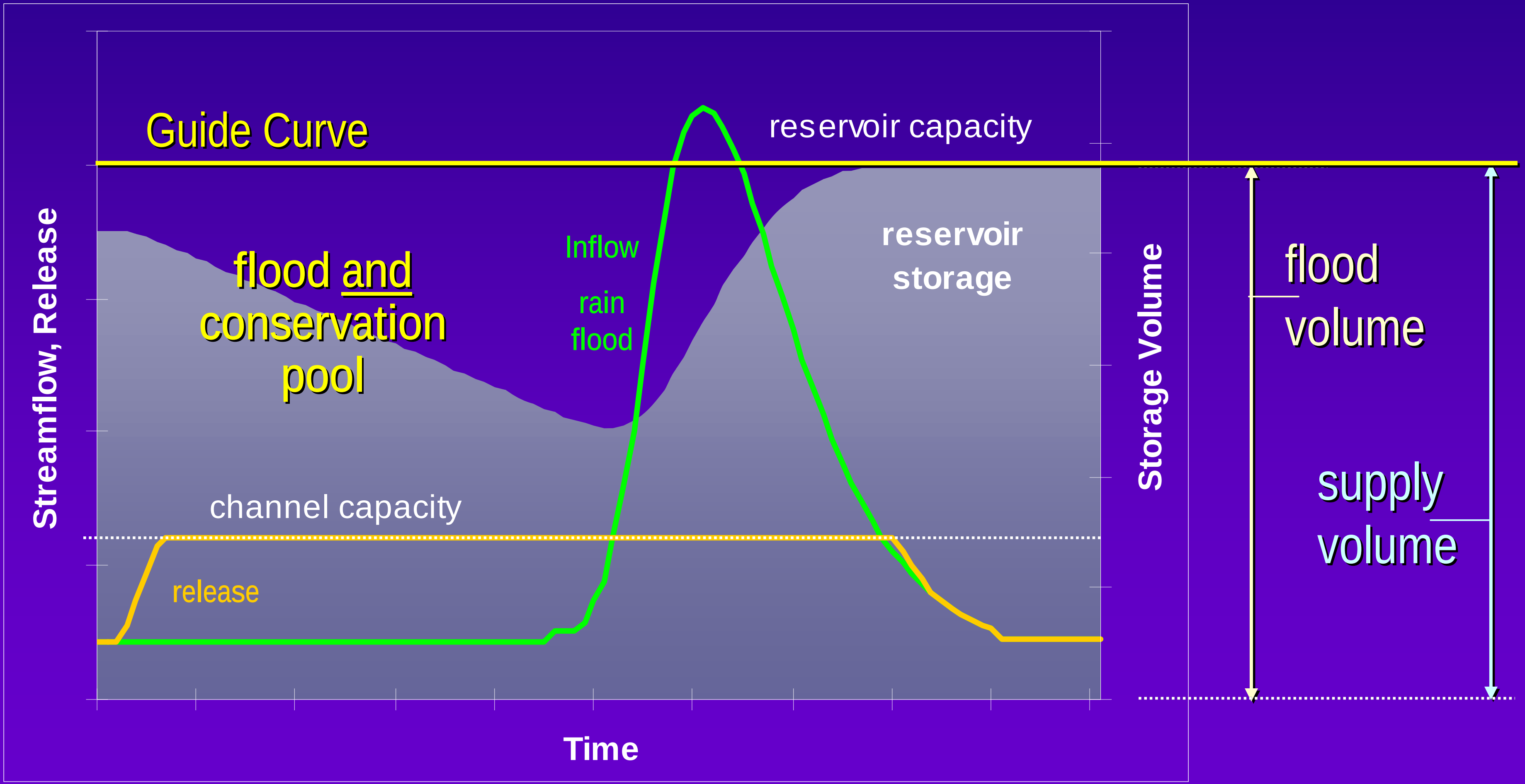
Flood Operation with No Uncertainty *(perfect information)*



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In Reality…

- In reality, we're somewhere between complete uncertainty and no uncertainty
- Streamflow information brings us closer to the no-uncertainty operation
- Available information
  - historical streamflow data *long-term (variability)*
  - current-year basin conditions *mid-term (potential)*
  - streamflow forecasts *short-term (imminent)*

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Use of Historical Information

...defines Annual Variability

- Historical streamflow data provides statistics about seasonal volumes, flood volumes, and timing of floods
  - With annual maximum flood volumes, can size the reservoir's flood pool to contain an event of a certain exceedance probability
    - info on VOLUME
  - With dates of flood occurrence, can define a likely flood season - info on TIMING
  - *NOTE: assumes future will be similar to the past...*

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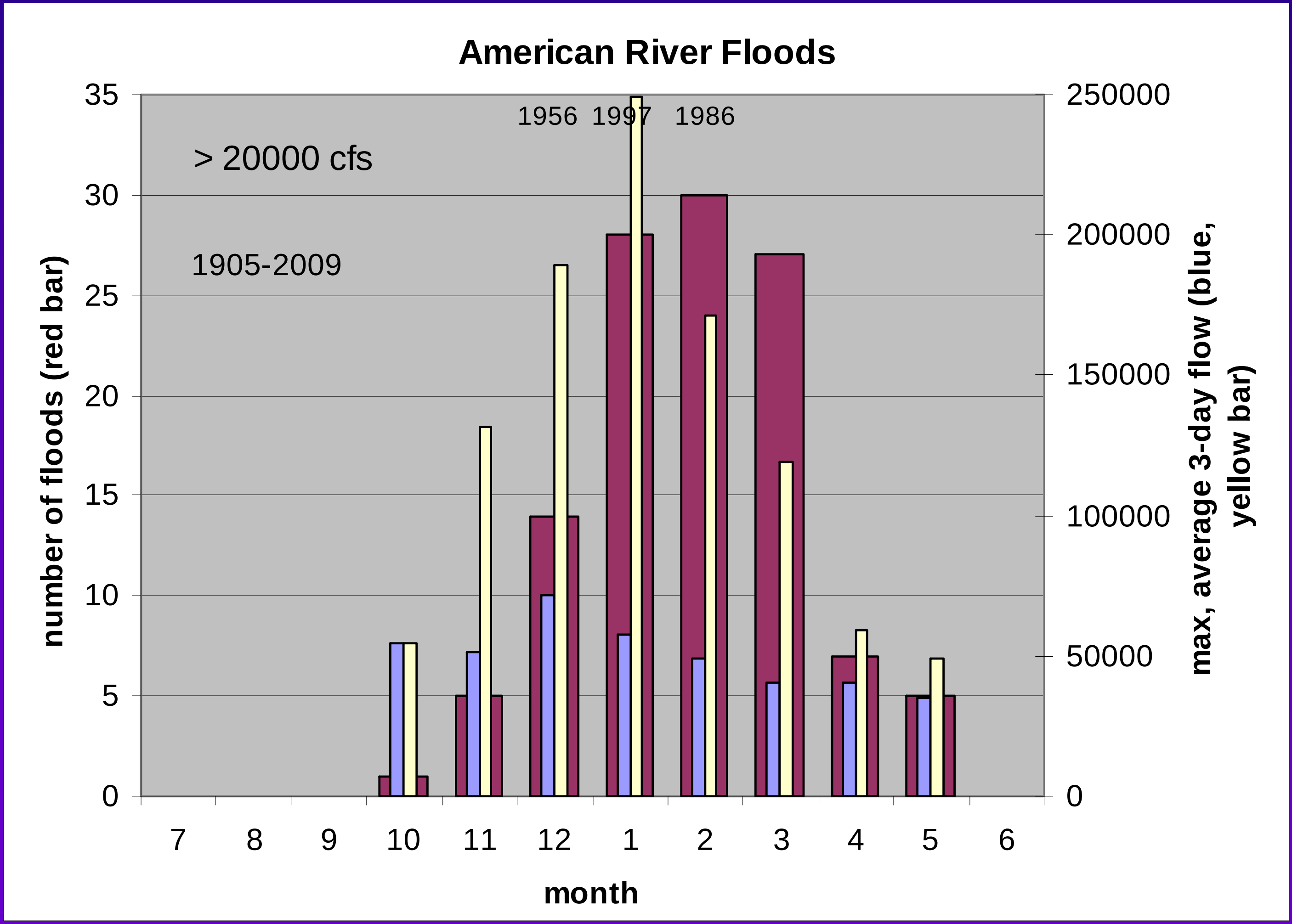
Use of Historical Information



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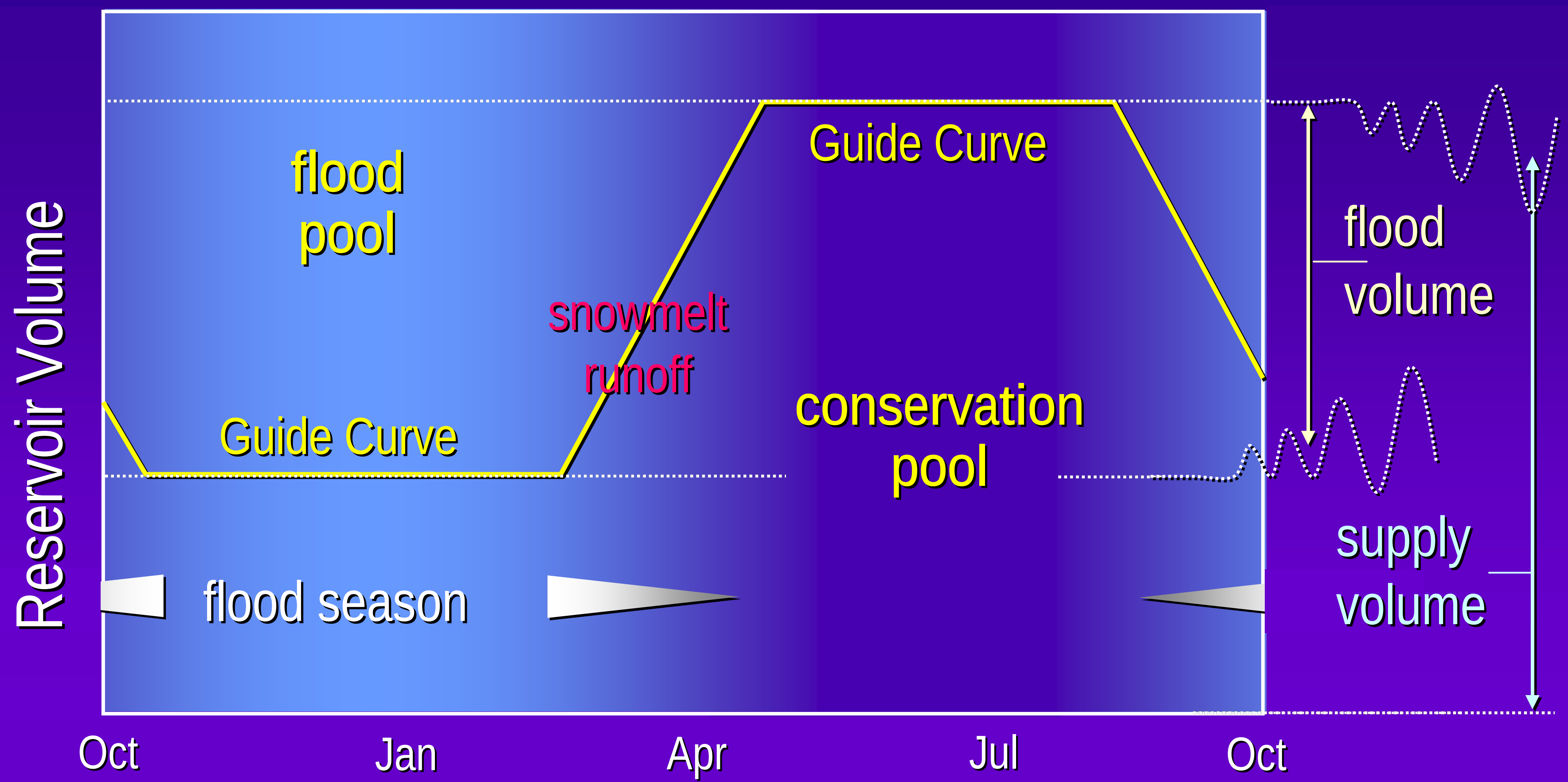
Given a Flood Pool Size and a Defined a Flood Season...



Use of Annual Information

...defines *Potential*

- Climate indicators and current basin conditions give information on likelihood for the current year
  - Additional info on potential VOLUME (but not TIMING)
  - No need to account for the full annual variability

Flooding: potential for large floods, based on basin wetness and/or ENSO/PDO

- wetness = how much runoff from given rain storm
- ENSO/PDO = how much rain is likely

Water Supply: seasonal snowmelt runoff forecasts, how much runoff there will be

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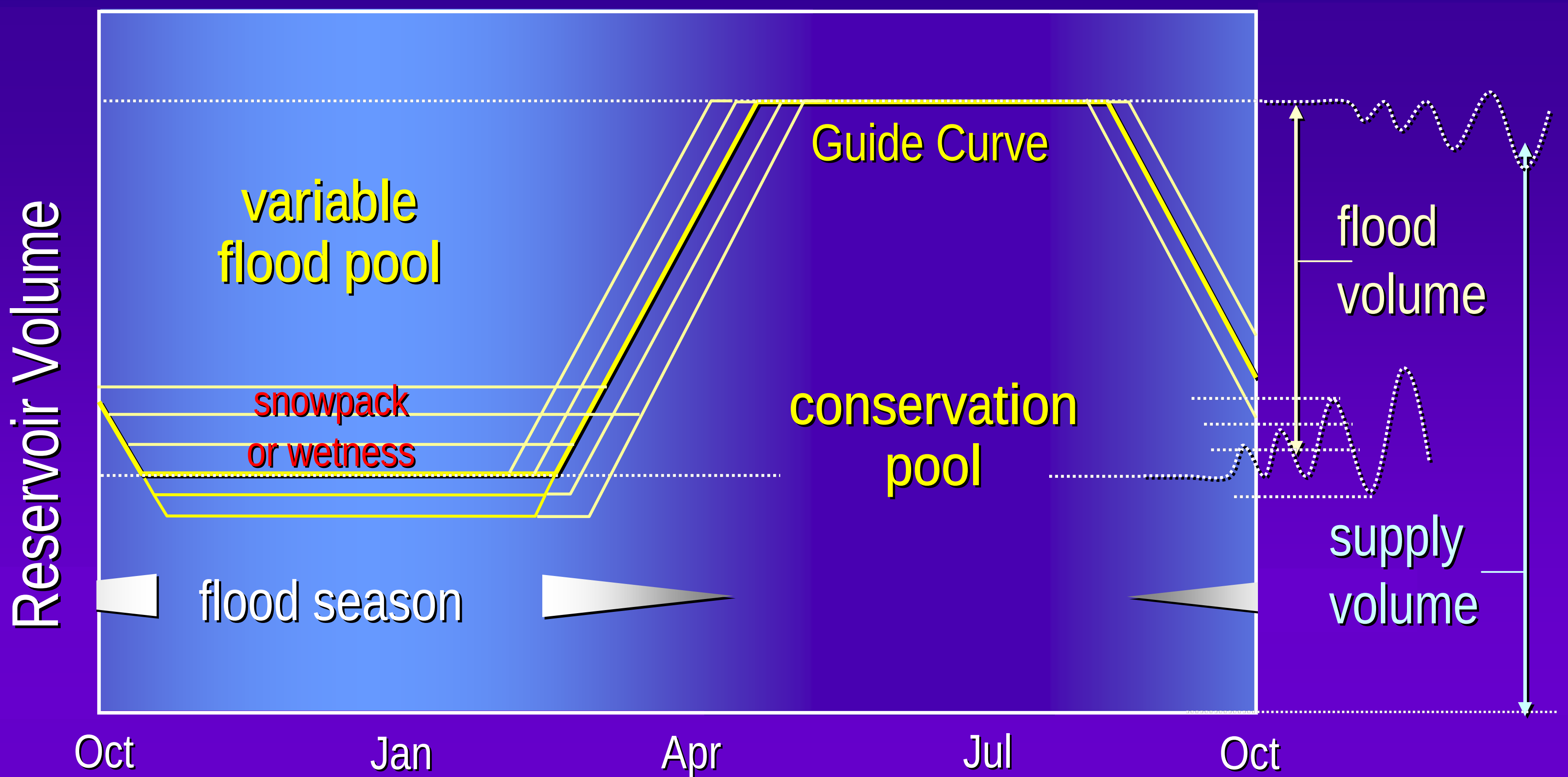
Given Current Basin Information to describe flood probability…



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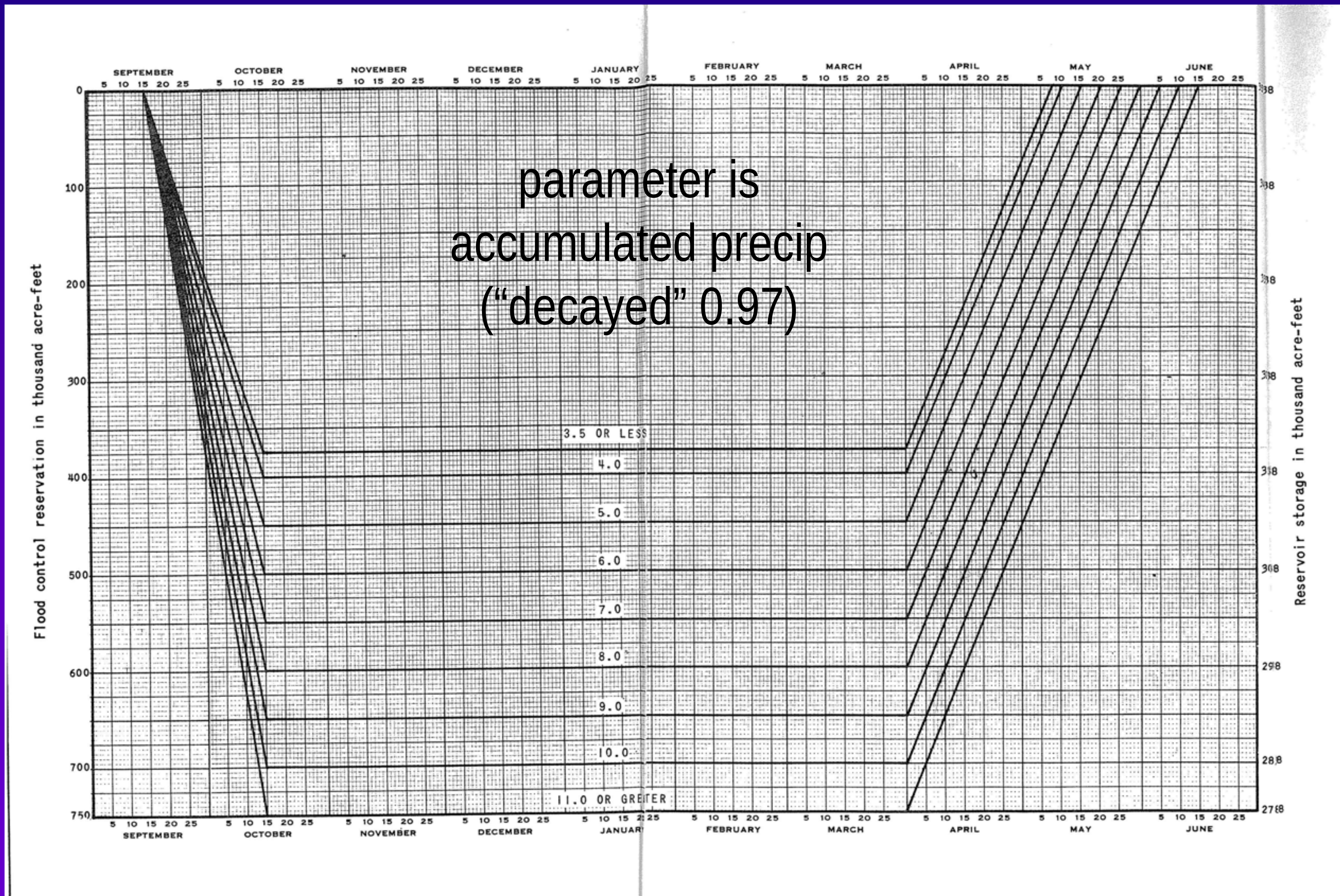
Oroville Water Control Diagram



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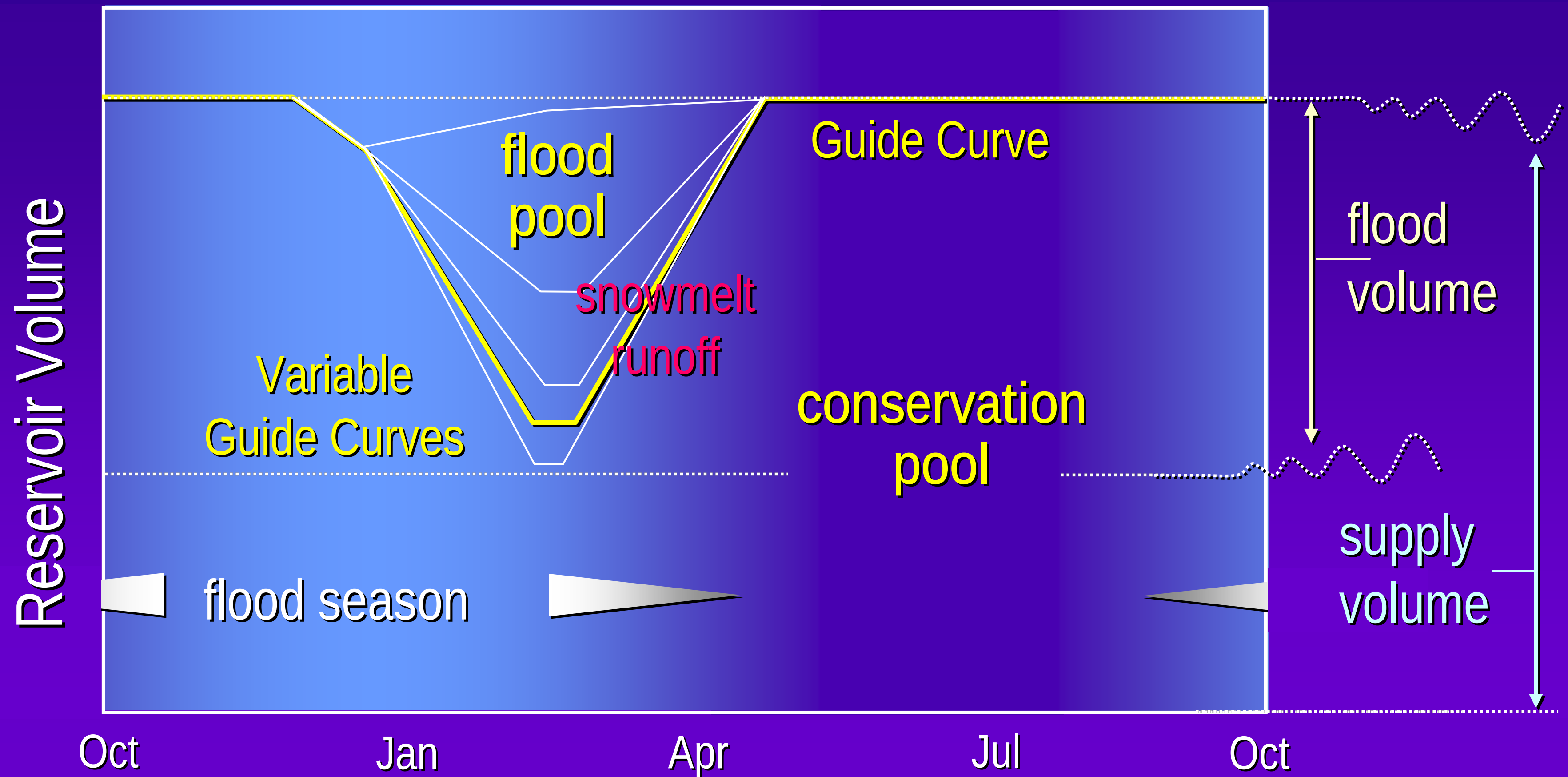
In Pacific NW, draw down for the forecasted snowmelt runoff

With seasonal information, draw down enough to catch flood peak



Libby Storage Reservation Diagram

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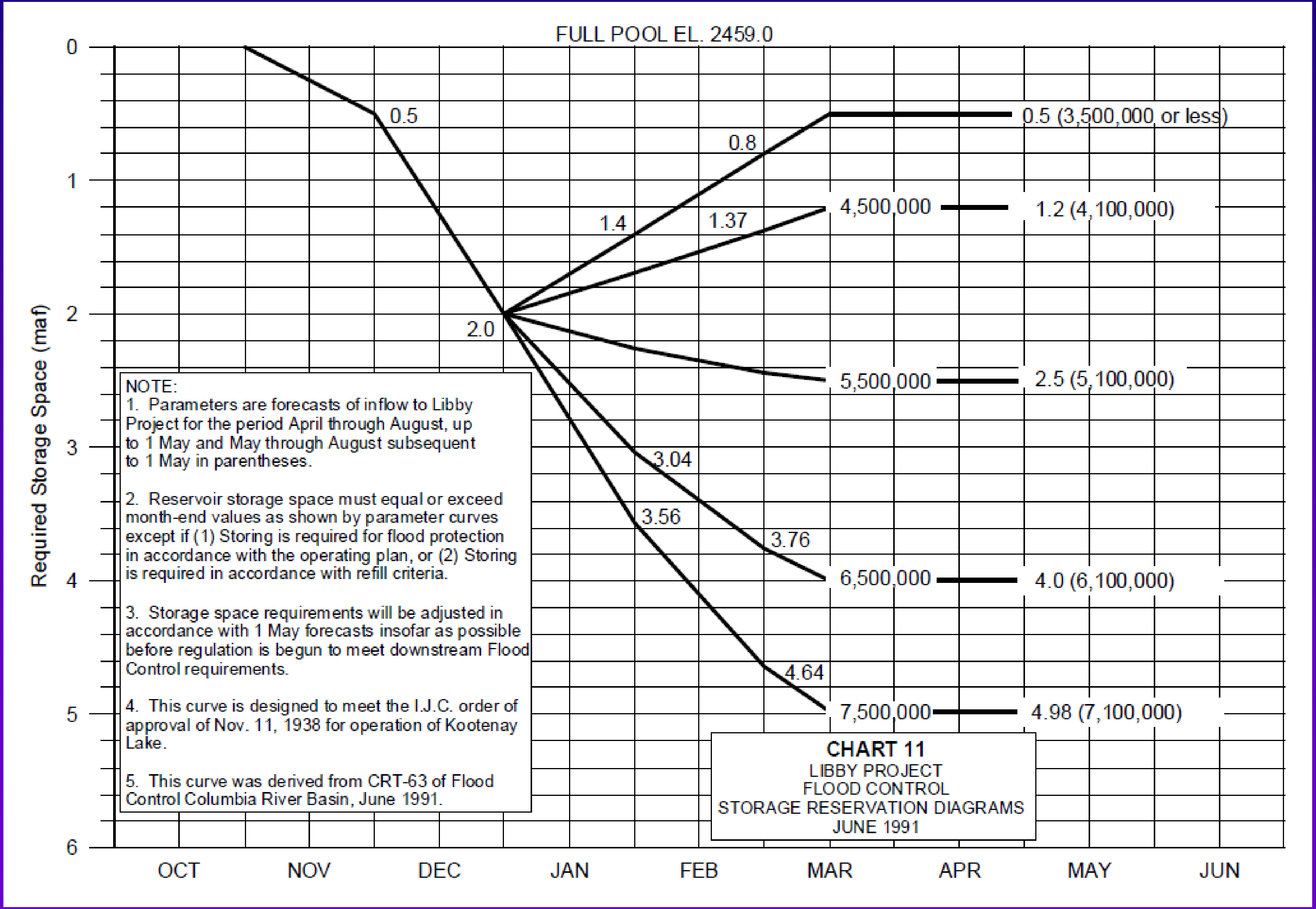

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Use of Rain-Flood Forecasts

- Real-time forecasts provide up-to-date (3 to 5-day) information on both VOLUME and TIMING of an imminent flood event
  - Based on precipitation forecasts and state of basin
  - When forecasts predict a large flood event, begin additional release to reduce reservoir storage
    - Allows a portion of the Conservation Pool to be evacuated for flood storage *- increased flood protection*

      OR
    - Allows conservation storage in the Flood Pool, which can be evacuated before a flood event *- increased water supply*

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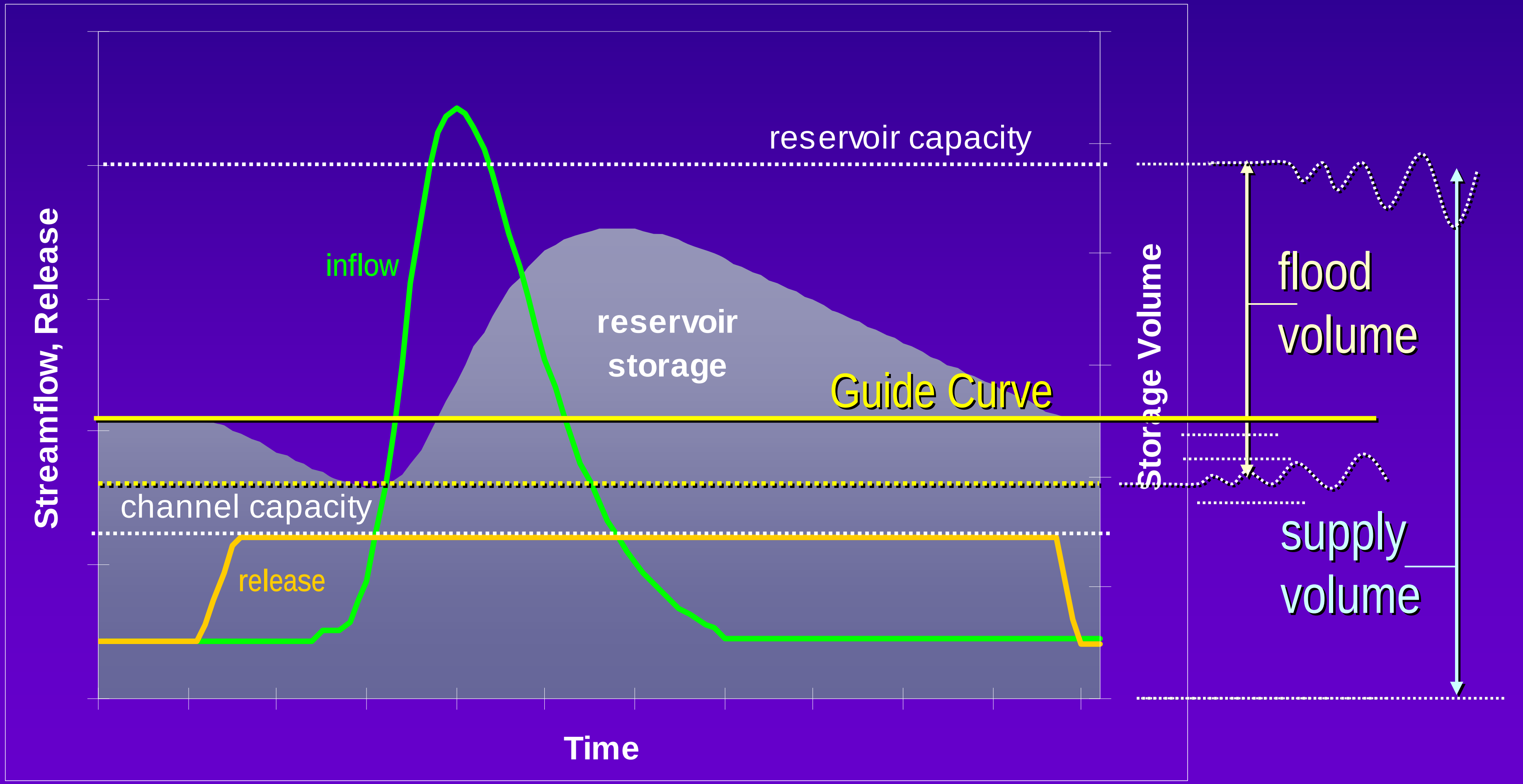
Given Forecast Information…

enlarge flood pool at need...



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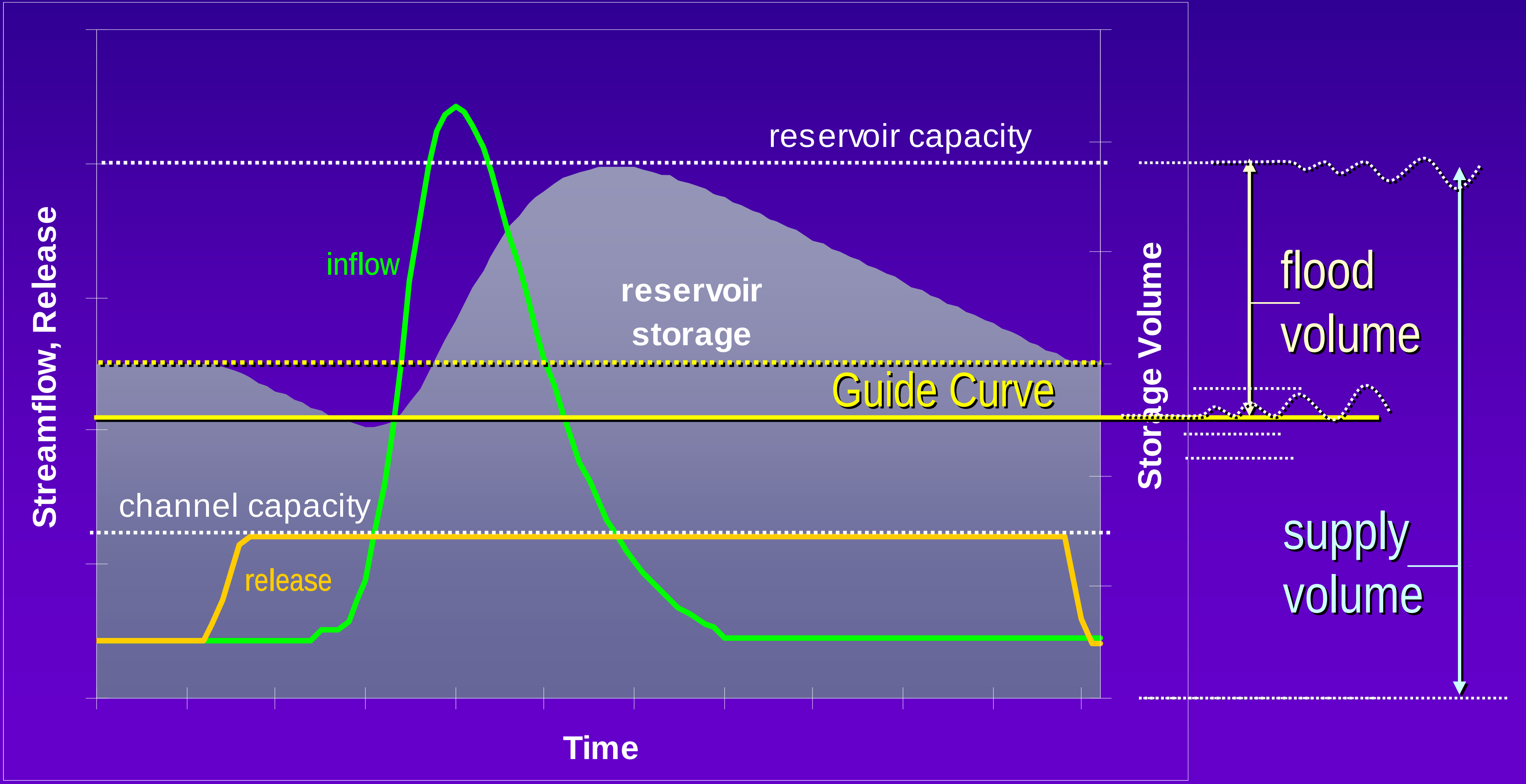
Given Forecast Information…

…or store for supply until need flood space



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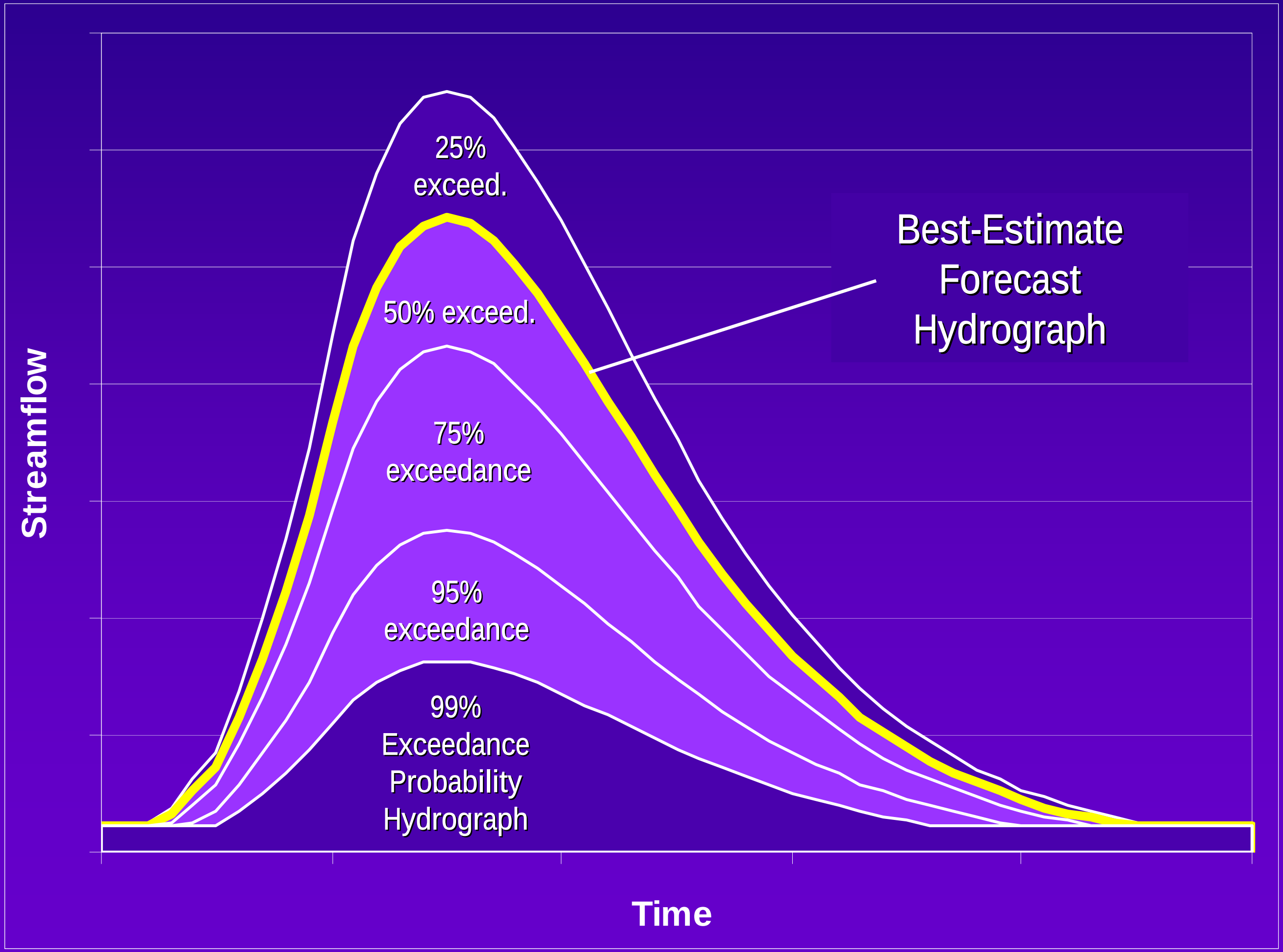
Forecast Volume Quantiles



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Summary of Use of Information

	long-term *Historical variability*	**mid-term** *current year potential*	**short-term** *current week*
Available Information	**Historical record** of precipitation and extreme flows (peak and volume) and seasonal volume	**Climate indicators** (El Niύo, etc), basin wetness, snowpack, 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 potential flood magnitude, basin wetness, potential runoff, upstream storage levels, etc.	• Use the best-estimate forecast to **simulate and specify operations** • Develop **probability distribution of event volume** to compute Advance Release
Use of information in Reservoir Operation	• **Size the flood pool** to manage an event of the selected frequency. • **Maintain the flood pool** when flood events are highly probable.	• **Maintain variable flood pool** of the size determined above.	• Make **advance releases** as the event nears and forecast uncertainty decreases.

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Trade-offs

- What if snow melts too early, and runoff comes before the rain-flood season is over?
  - Do we catch that runoff anyway, and give up flood protection, or bypass it and give up supply?
- What if don’t expect enough snowmelt runoff to refill the flood pool?
  - Do we maintain a smaller flood pool that year?
  - But less snowpack doesn't coincide with less rain-flood risk, so this would also mean giving up flood protection…

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Using "Potential" Information to size variable flood pool

<table>
<tr><th colspan="2"></th><th colspan="3">Water Supply Potential</th></tr>
<tr><th colspan="2"></th><th>small</th><th>medium</th><th>large</th></tr>
<tr><th rowspan="3">Rain-flood Potential</th><th>high</th><td>early fill…?</td><td colspan="2">large flood pool</td></tr>
<tr><th>medium</th><td></td><td rowspan="2">mid-size flood pool</td><td rowspan="2">large flood pool</td></tr>
<tr><th>low</th><td>small pool, early fill</td></tr>
</table>

↑ more danger (rain-flood potential, from low to high)

← more danger (water supply potential, from large to small)

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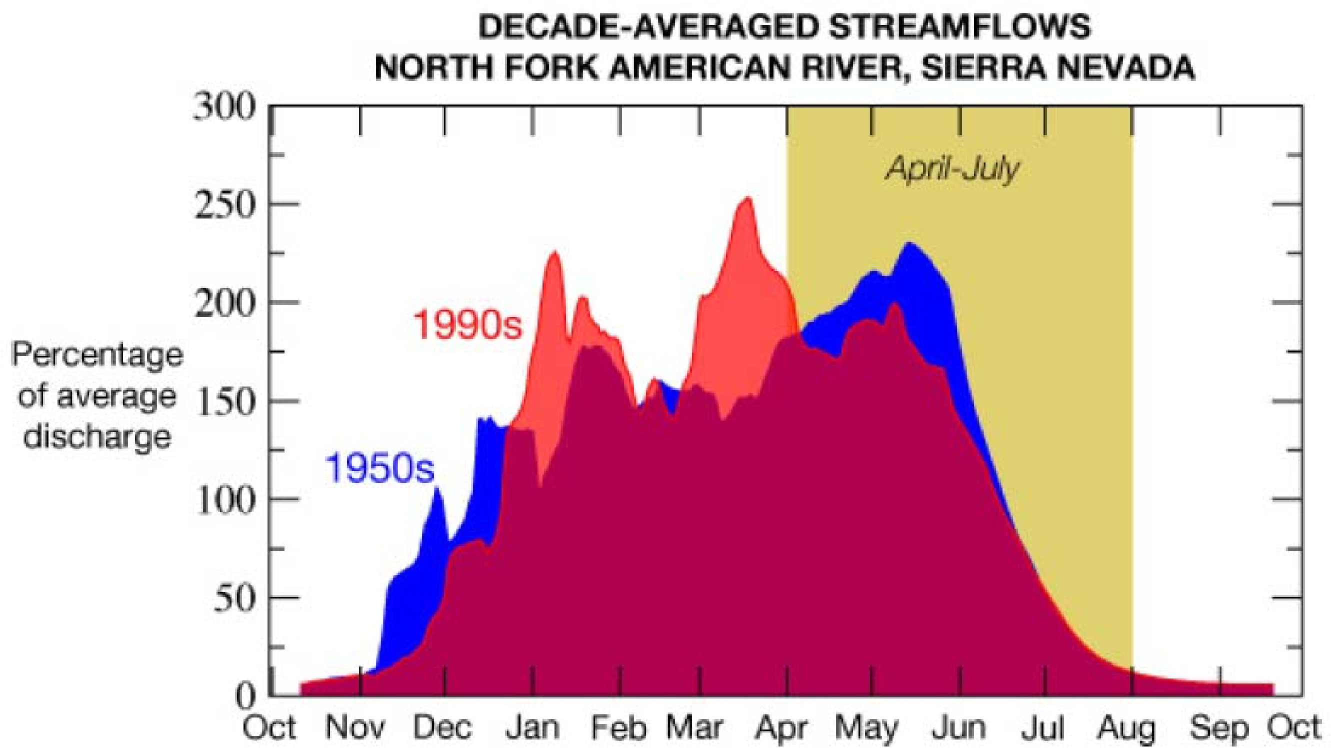
USACE Plan for Water Management Adaptation to Climate Change

- Update water control manuals to account for new and changing information, system regulation, and emerging needs. Evaluation of potential climate change impacts should be included when updating water plans and manuals.
- USACE should review existing authorities to determine how much flexibility they have in current water control plans and recommend legislative changes as necessary.
- In the future when updating water control manuals, consider the use of programmatic Environmental Impact Statements (EIS) to allow for additional operational flexibility. The collaborative process should be used to develop more robust EIS.
- Updated water control plans should include greater flexibility to use adaptive management.

Winter Floods in California



Percentage of average annual discharge throughout the year for the 1950s and 1990s

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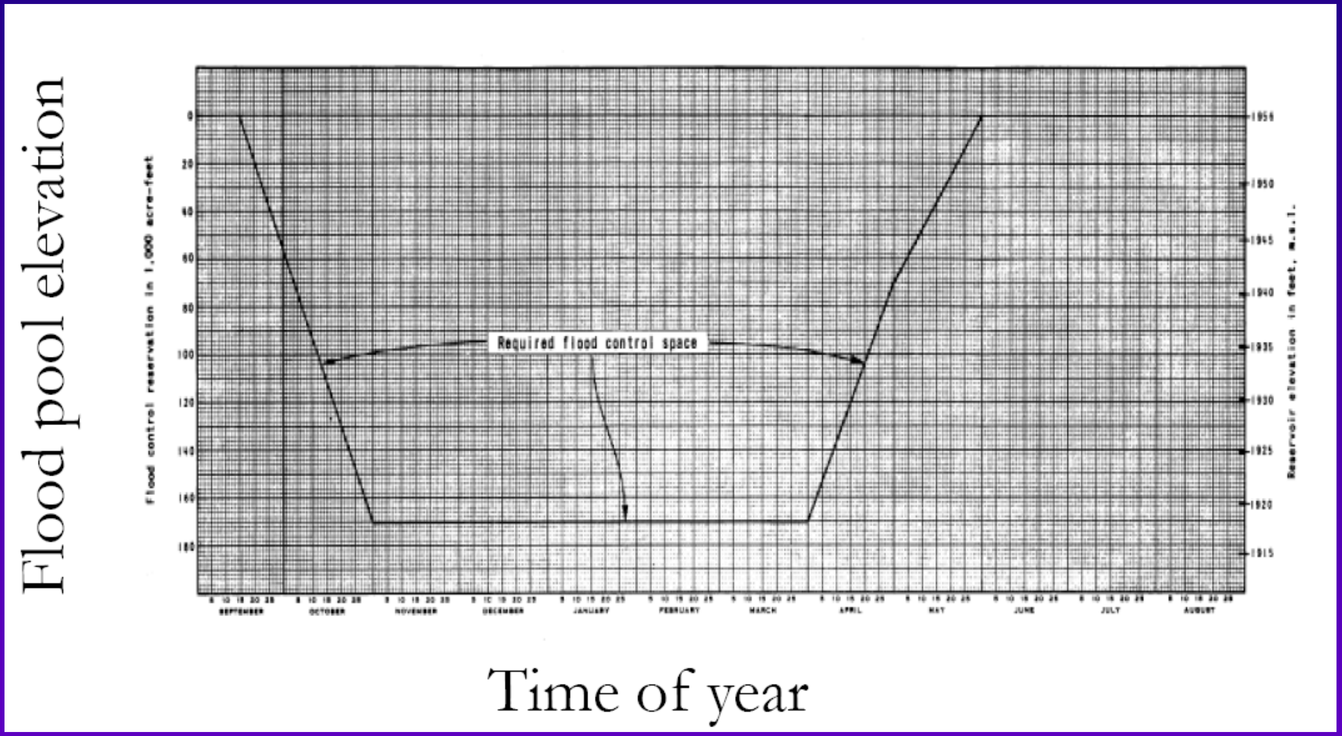
Climate Change and California Flood Rule Curves



New Bullards Bar rule curve

- Simulated changes in flow due to higher temperatures and changes in precipitation.
- For New Bullards Bar, reservoir pool elevations exceeded flood pool zone during 19 of 144 sampled and overtopped the dam during eight sampled flood events indicating a need for more flood control space in the reservoir.

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Adaptive Management Process

- An adaptive management process can have flexibility to adapt to observed climate conditions on an annual basis.
- Committed to this process in Missouri River Master Water Control Manual.
- Representatives of all stakeholders and other interests involved in providing proposed actions or experiments which could result in changes to System regulation.
- Corps and Fish & Wildlife Service approve proposed actions to be tested for potential integration.
- Monitoring key to determining future course of action.

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MRRIC Members

Stakeholders 28

2 Agriculture
1 Major Tributaries
2 Conservation Dist
1 Navigation
2 Environ/Cons Orgs
2 Recreation
2 Fish & Wildlife
2 Thermal Power
2 Flood Control
2 Water Quality
1 Hydropower
1 Water Supply
2 Irrigation
2 Waterway Industries
2 Local Government
2 At Large

Tribes 18

Cheyenne River Sioux
Chippewa-Cree of Rocky Boy's
Eastern Shoshone
Flandreau Santee Sioux
Fort Belknap
Oglala Sioux Pine Ridge
Ponca of Nebraska
Santee Sioux
Northern Arapaho
Spirit Lake Sioux
Yankton Sioux
Kickapoo Tribe in Kansas
Three Affiliated Tribes
Winnebago of Nebraska
Prairie Band of Potawatomi of Kansas
Iowa Tribe of Kansas & Nebraska
Assiniboine and Sioux of Fort Peck
Sac and Fox Nation of Missouri in Kansas & Nebraska

Federal Agencies 15

USACE
US Coast Guard
USFWS
USDA Forest Service
Bureau Indian Affairs
USDS NRCS
Bureau of Land Mgmt
US Geological Survey
Bureau of Reclamation
Maritime Admin
EPA
National Park Service
Fed Highway Admin
NWS / NOAA
WAPA

States 8

Iowa
Nebraska
Kansas
North Dakota
Missouri
South Dakota
Montana
Wyoming

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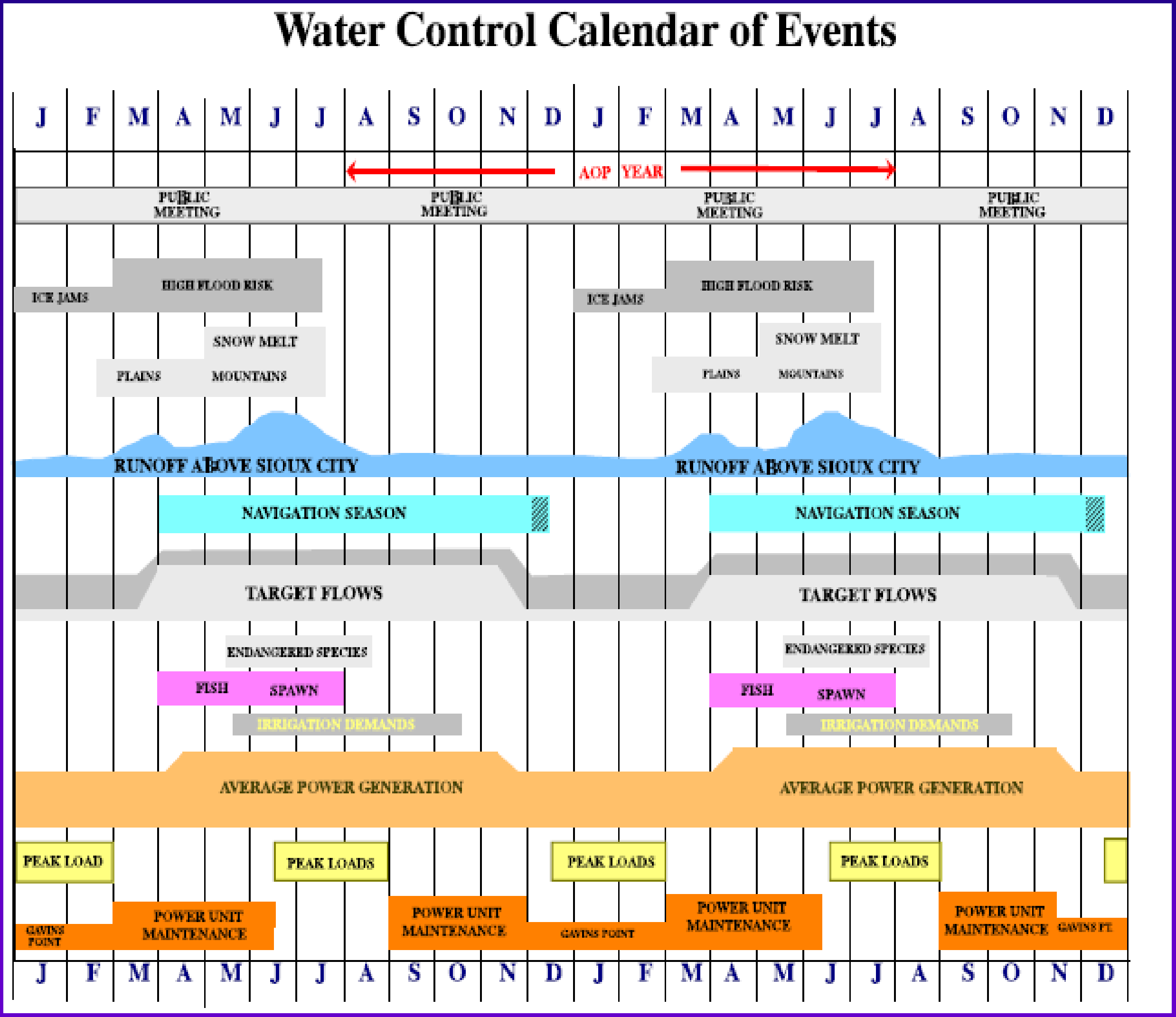
Missouri River Annual Plan



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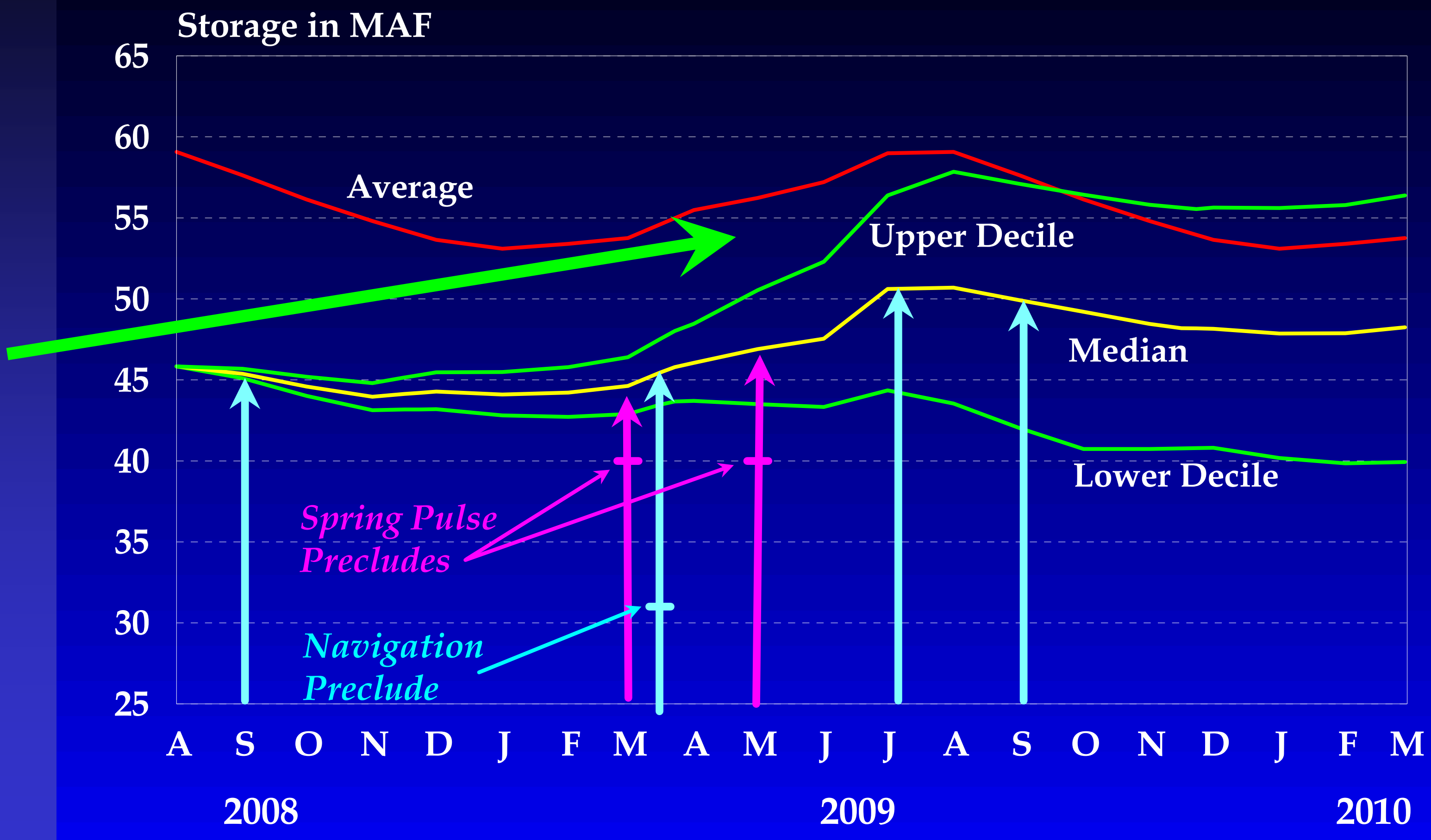
System Storage
2008 - 2009 AOP Decision Points



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Summary

- Reservoir operations and operating rules are developed based on streamflow information of various types, from historical to annual outlooks to short-term forecasts.
- Each type of information reduces uncertainty in what's to come that year and allows less hedging in operation.
- Uncertainty includes climate change and how the future might differ from the past.
- Adapting USACE water management to climate change:
  - Use adaptive management
  - More flexibility to account for new information