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Managing Water in the West

Hydrologic Hazard Curves and Extreme Flood Probabilities for Dam Safety

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Introduction

- Purpose: Develop a procedure for estimating hydrologic hazard curves
- Desire peak flow and volume (for specified durations) versus Annual Exceedance Probability (AEP)
- The range of AEPs that are displayed on these graphs are from 0.99 to 0.00000001

Background

- Bureau of Reclamation's dam safety mission is as follows: "To ensure that Reclamation dams do not present unacceptable risks to people, property, and the environment"
- Reclamation uses a risk assessment process to determine an appropriate level of public protection by evaluating a full range of loading conditions and possible dam failure consequences
- Dam Safety Criteria: Annual probability of dam failure < .0001;average annual loss of life < .001

Hydrologic Loads and Risk Analysis

Annual Failure Probability f =

$$\left[\text{Probability of Load}\right] * \left[\text{Probability of Adverse Response Given Load}\right]$$

Hydrologic Loading Estimate

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Hydrologic Risk Analysis Needs: Floods and Probability Estimates

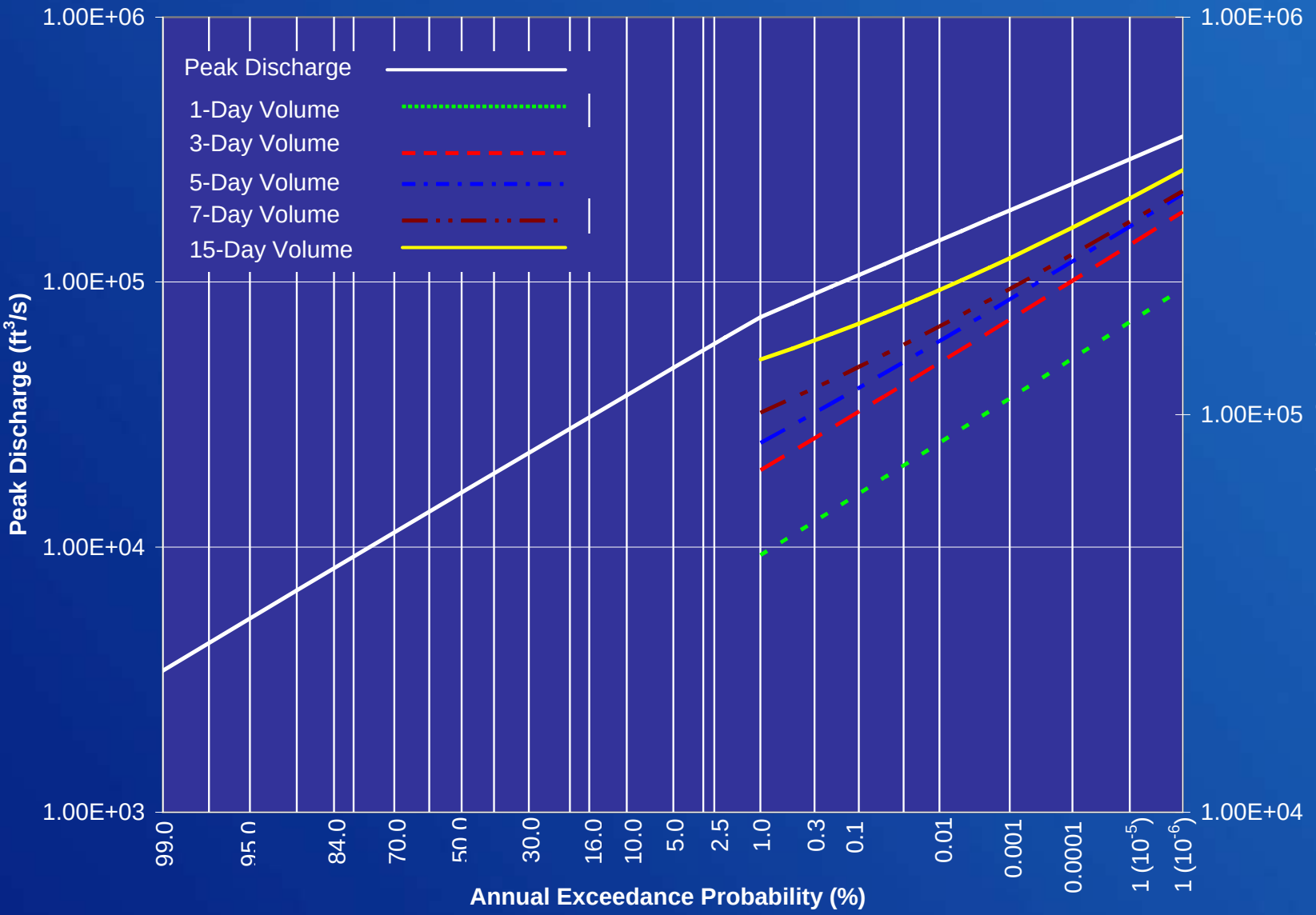
- Hydrologic Hazard Curves
  - (Peak Flow and Volume Frequency Curves)
  - 1,000-year and 10,000-year (typical)
  - up to 100,000,000-year Return Periods; extrapolation!
- Hydrographs
  - range of basin response- volume, timing, shape and include uncertainty
- Maximum Reservoir Levels
  - integrate initial reservoir, hydrographs, probabilities

Hydrologic Hazard Characterization

- Make use of prior studies (PMF, FFA, etc.)
- Staged approach; balance study cost and solution cost
- Begin with initial characterization – streamflow and paleoflood frequency; scaled hydrographs

- Conduct other studies on an as needed basis
- Application of several methods will increase credibility and confidence in results

Initial Hydrologic Hazard Curve



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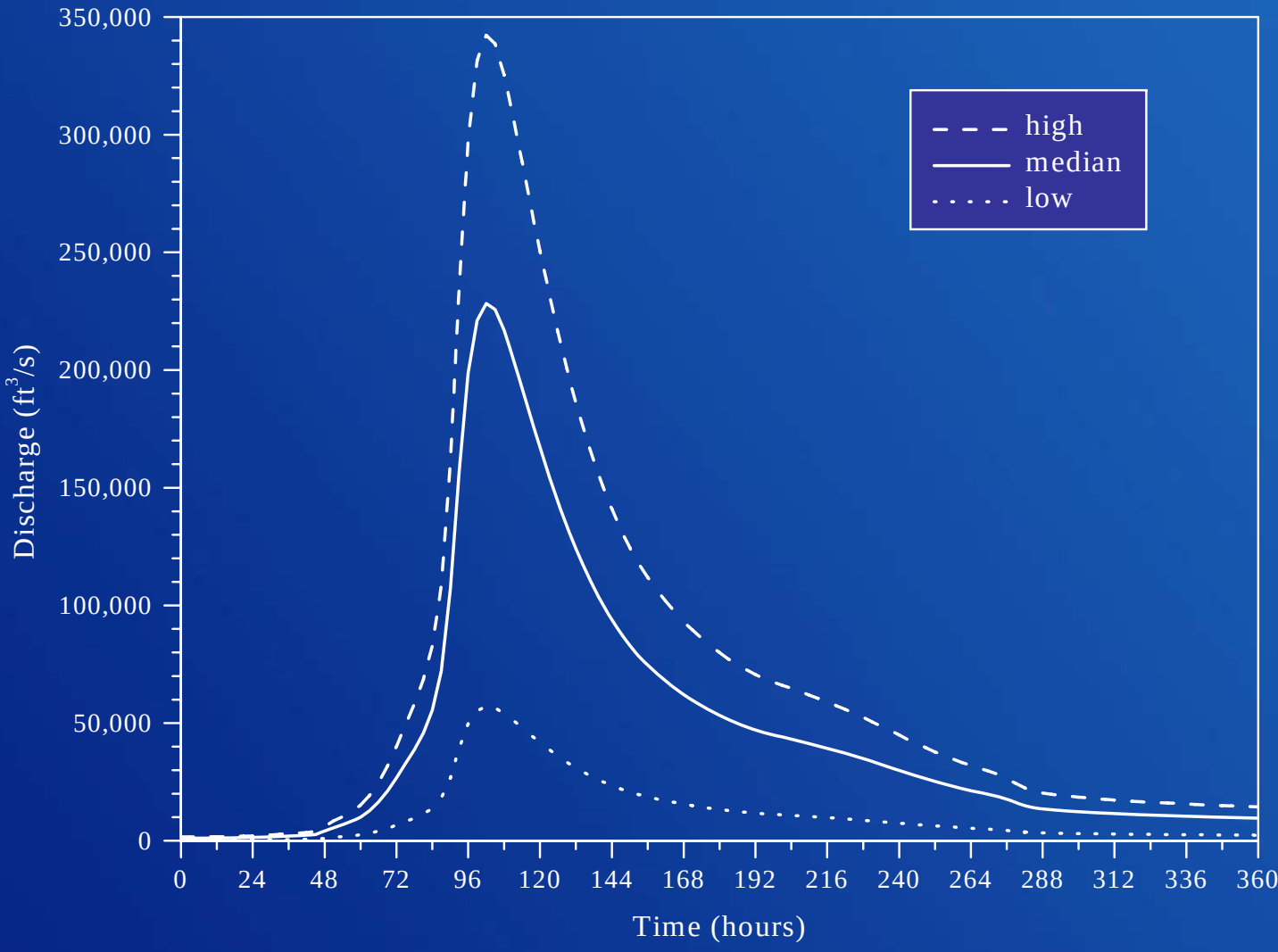
Example Extreme Flood Hydrographs



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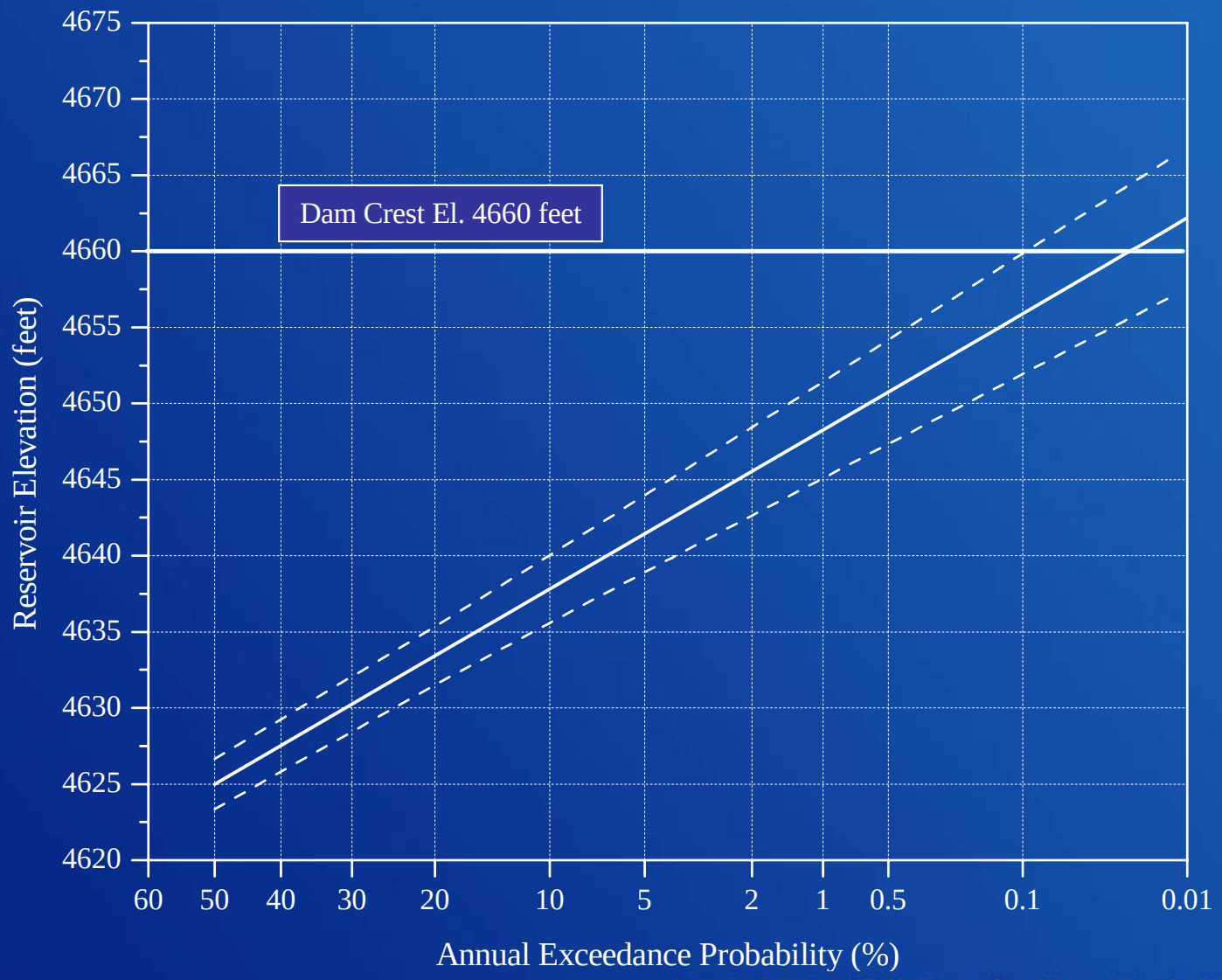
Example Reservoir Elev. Frequency Curve



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Detailed Hydrologic Studies

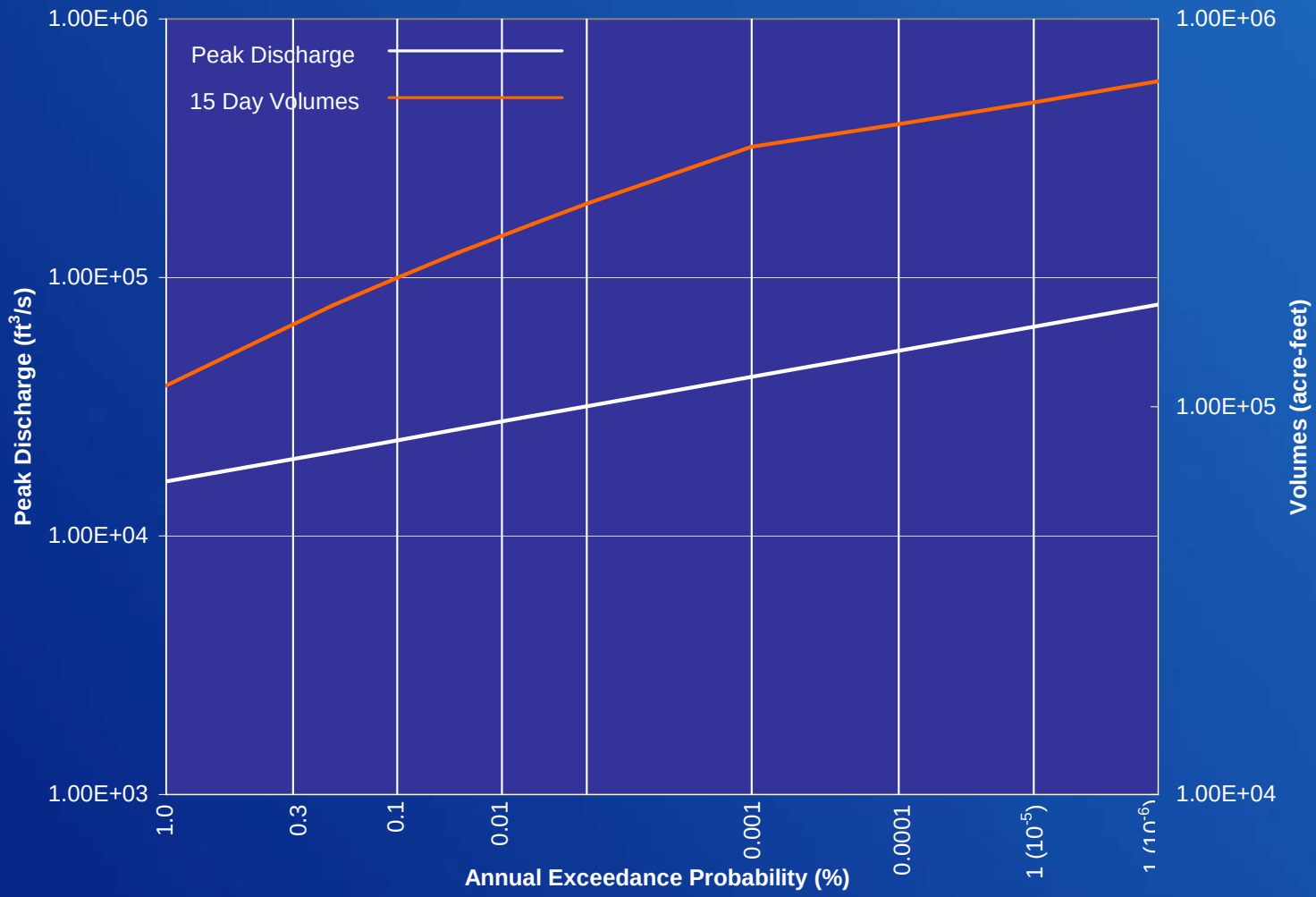
- After the initial characterization of hydrologic risk, more detailed hydrologic studies may be necessary to better define the hydrologic problem, reduce uncertainty, and develop solutions
- Additional studies should address issues at the least cost possible; balance study cost with solution cost

Final Hydrologic Hazard Curve

- When multiple methods are used, best estimate is based on sound physical and scientific reasoning for weighting or combining results
- Initial characterization is usually replaced by more detailed studies

- Reclamation uses the PMF as the upper limit of flood potential at a site for storm durations defined by the PMP

Example Final Hydrologic Hazard Curve



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Dam Safety Research Program

Hydrologic Hazard Curve Estimating Procedures

Research Report DSO-04-08

U.S. Department of the Interior
Bureau of Reclamation

June 2004

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Extreme Flood/Probability Estimation Techniques

- Flood Frequency Analysis with Historical/Paleoflood Data
- Hydrograph Scaling and Volumes
- GRADEX Method
- Australian Rainfall-Runoff Method
- Stochastic Event-Based Precipitation Runoff Modeling (SEFM)
- Stochastic Rainfall-Runoff Modeling with TREX (Two-Dimensional Runoff, Erosion and Export)

- Probable Maximum Flood Approach

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Hydrologic Hazard Data

- Streamflow Data
  - peaks, volumes, hydrographs
- Paleoflood Data
- Rainfall Data
- Snowpack Data
- Soils Data
- Basin Characteristics

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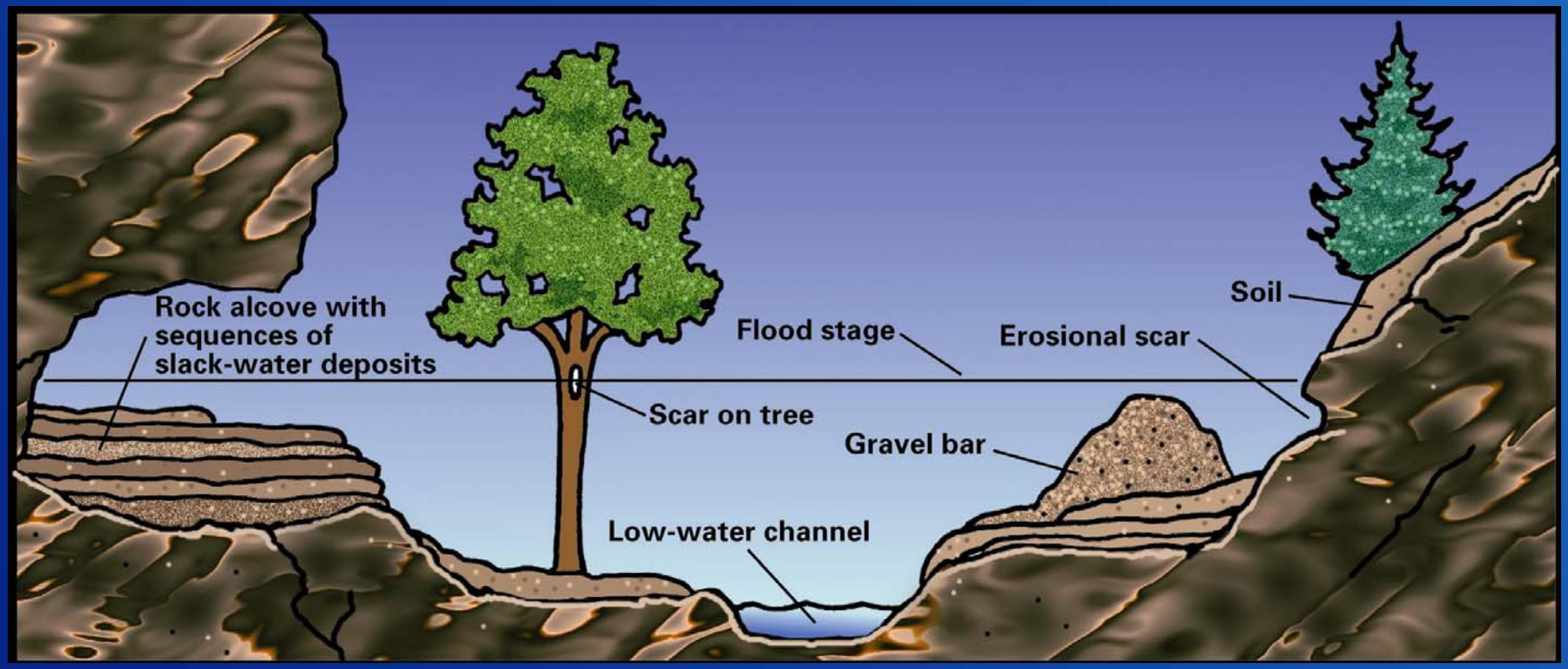
Paleofloods -Paleostage indicators (PSIs)



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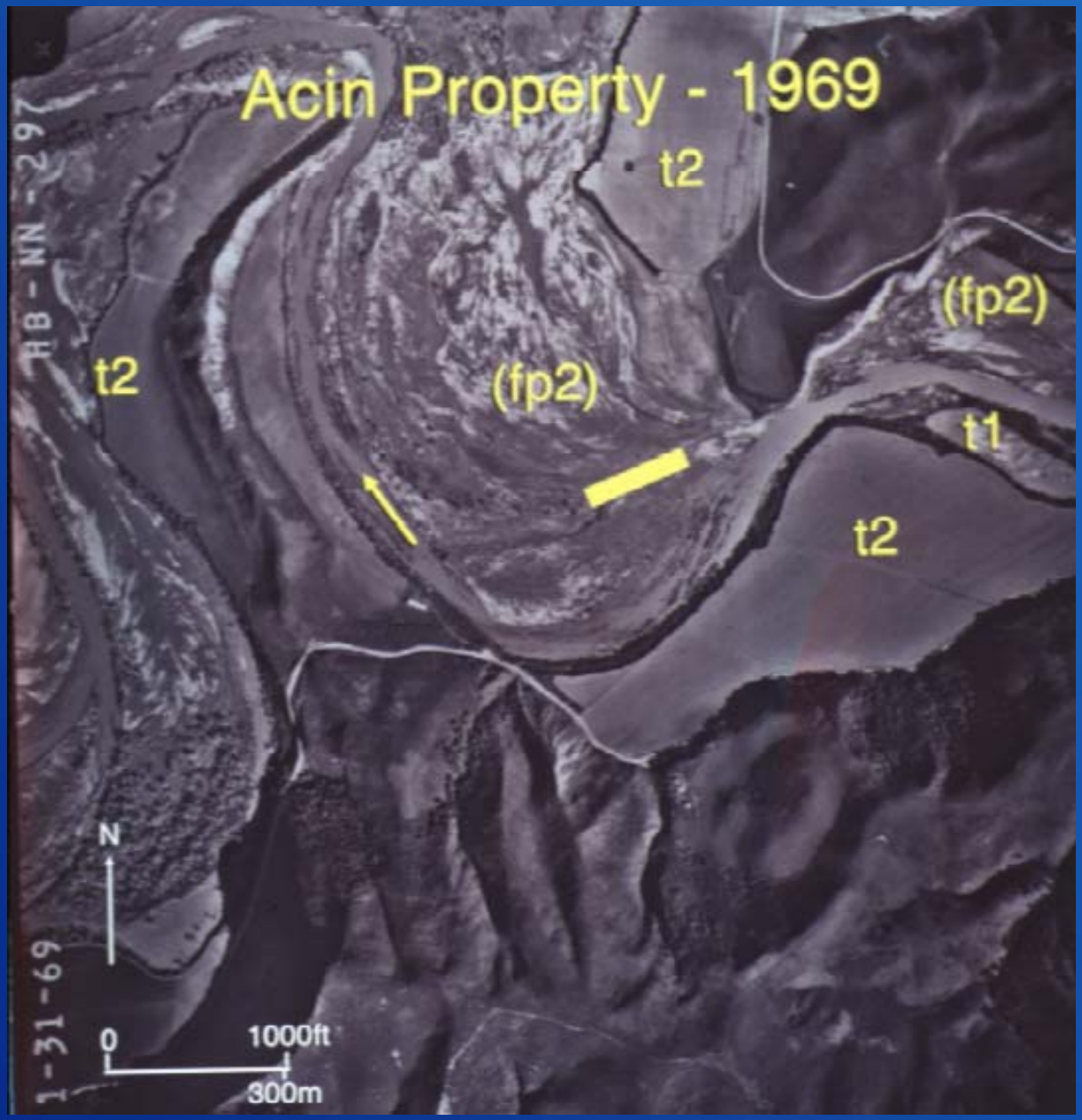
Flood Modified Surfaces



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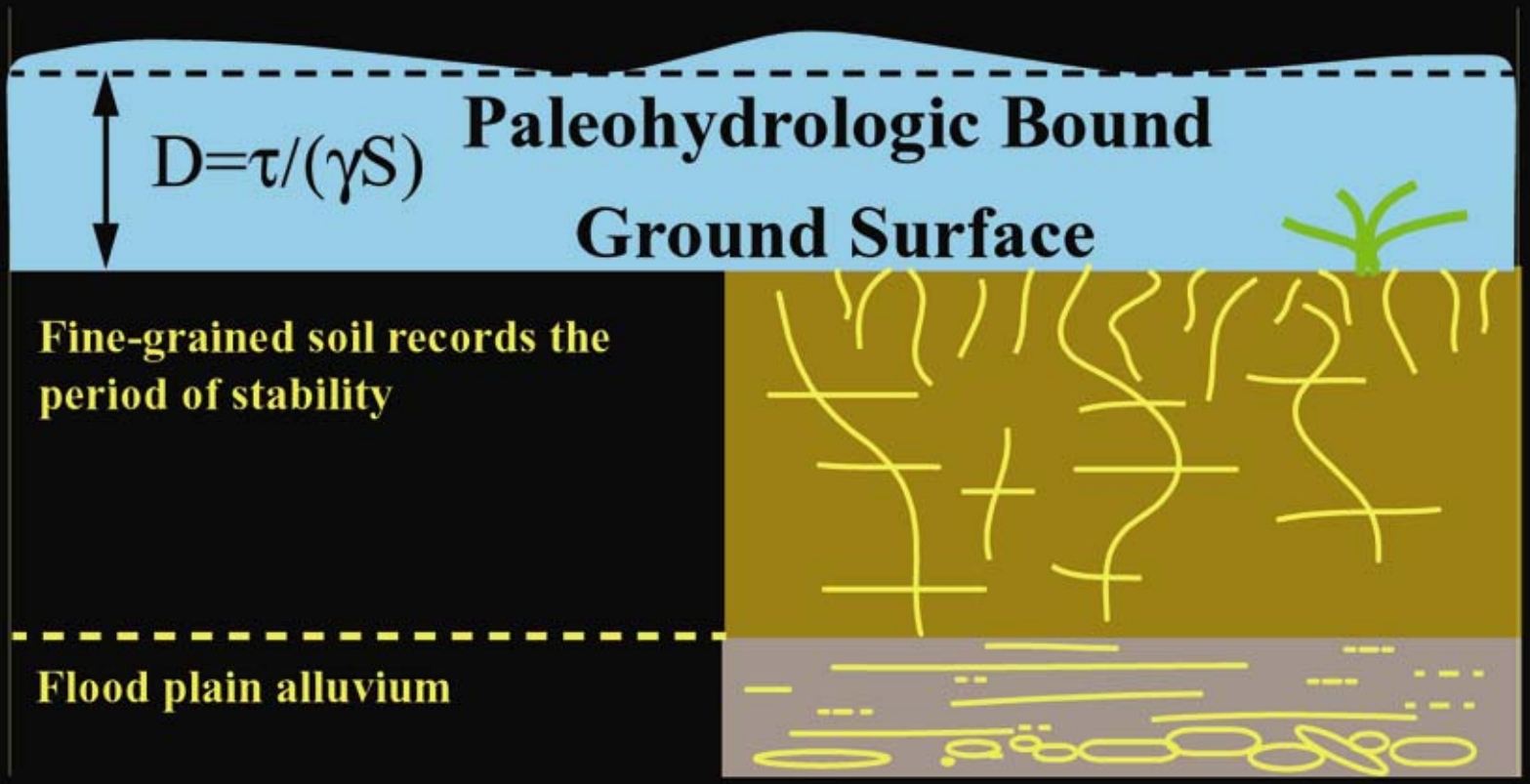
Paleohydrologic Bound

"A time interval during which a given discharge has not been exceeded"



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Limits of Floods

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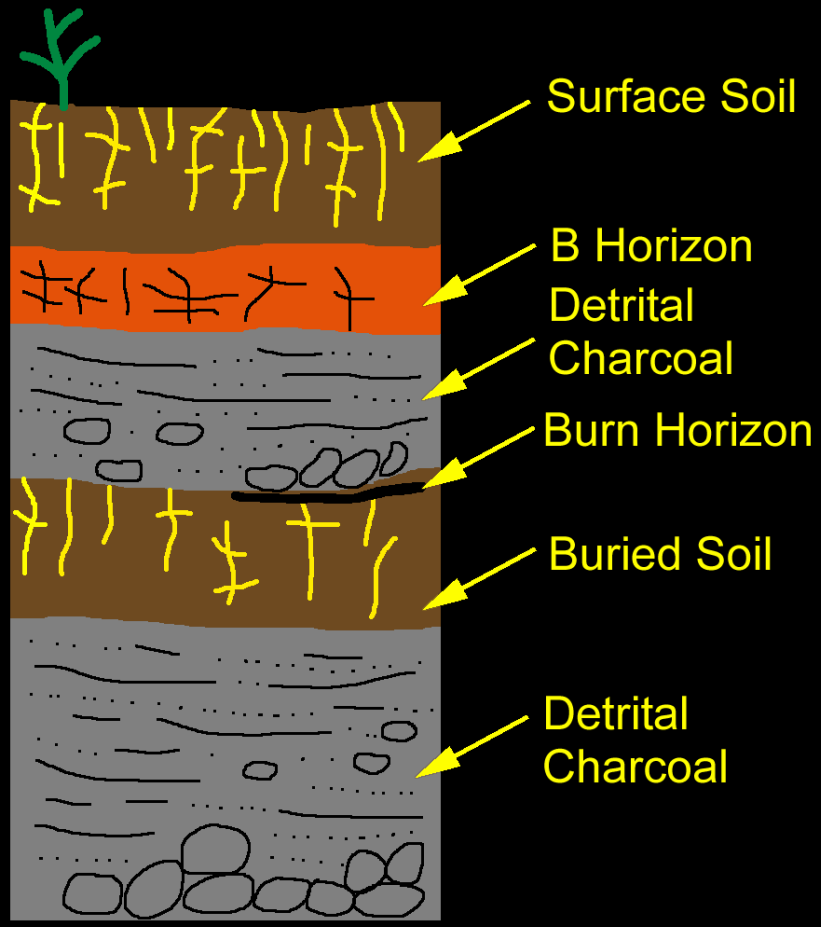
Soil Stratigraphy and Radiocarbon Ages



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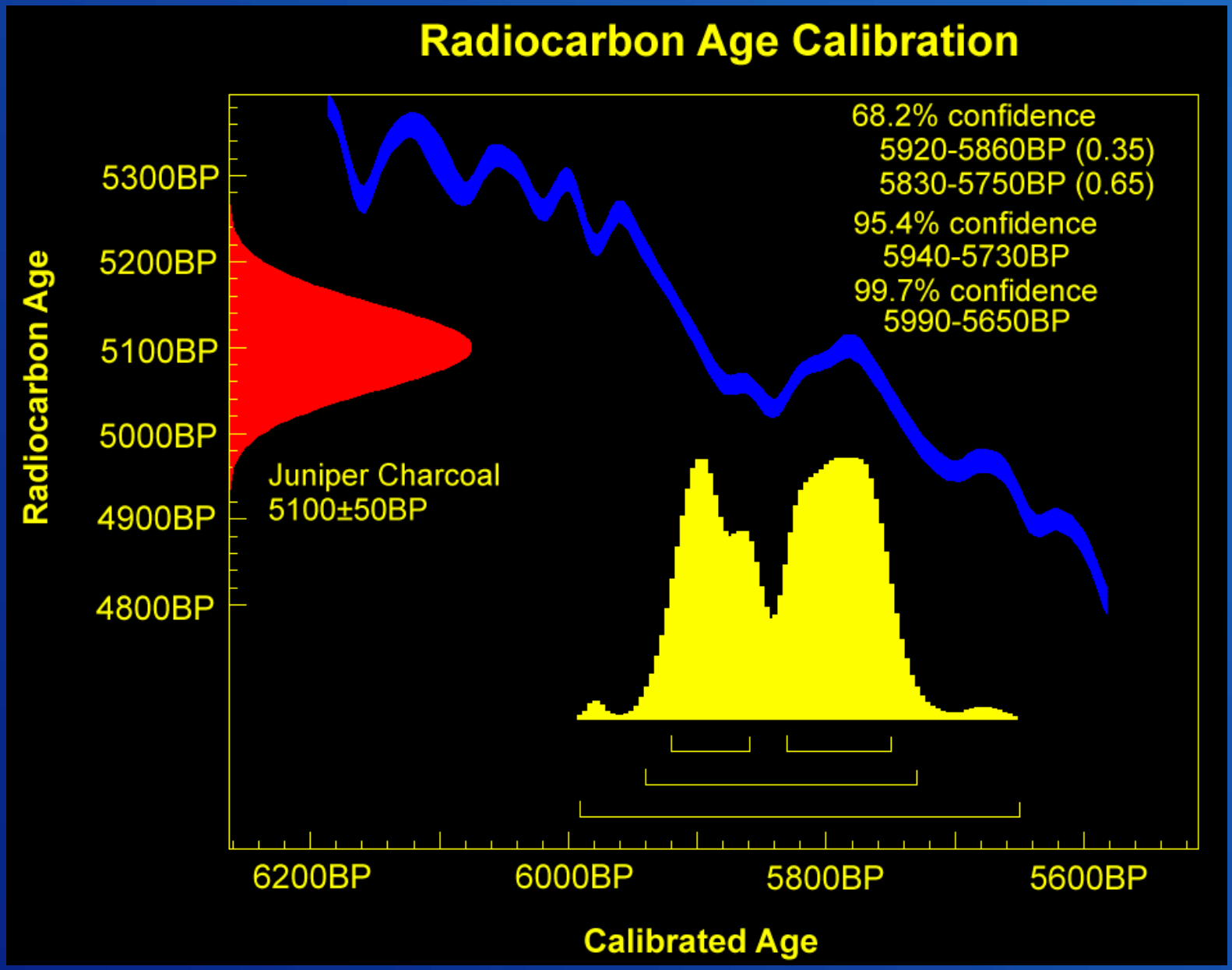

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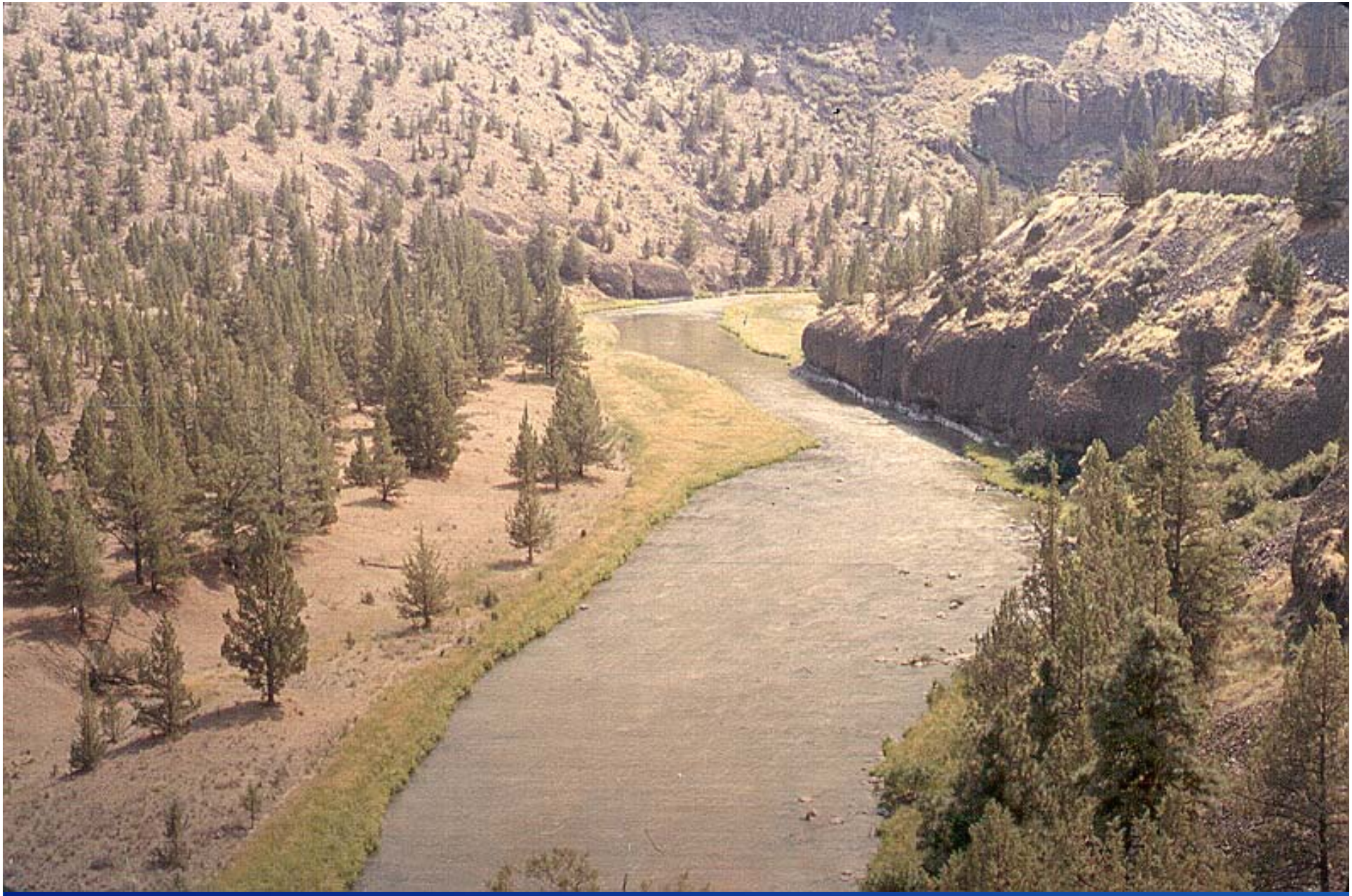

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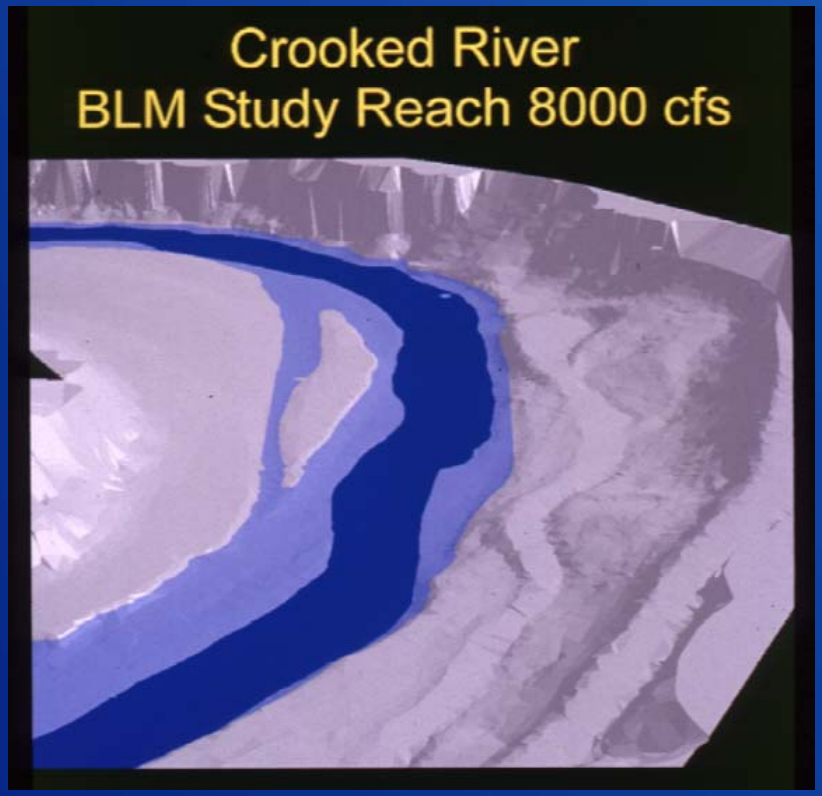

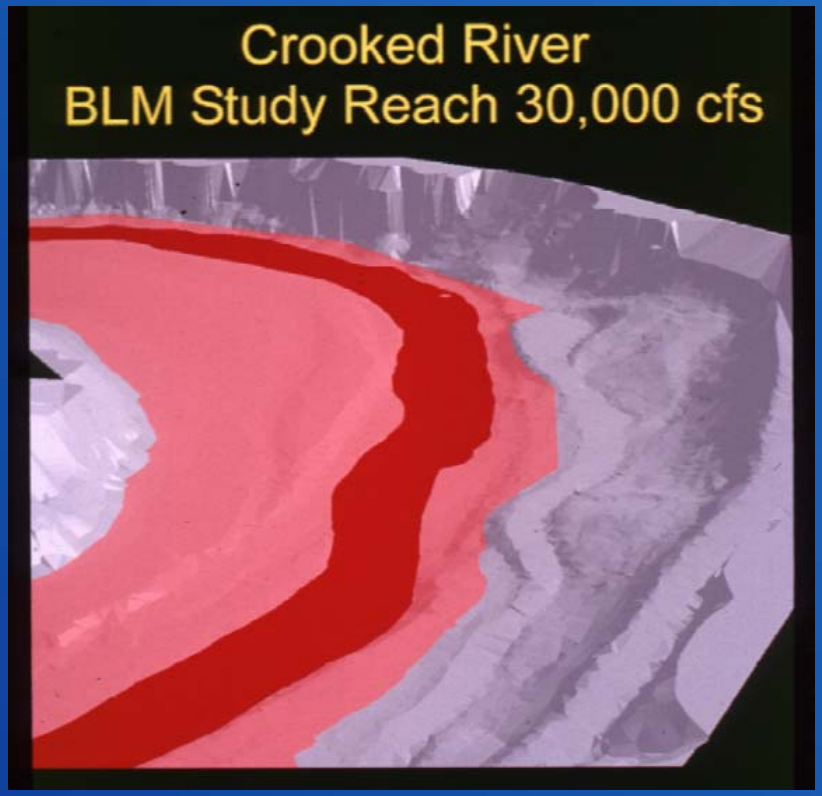

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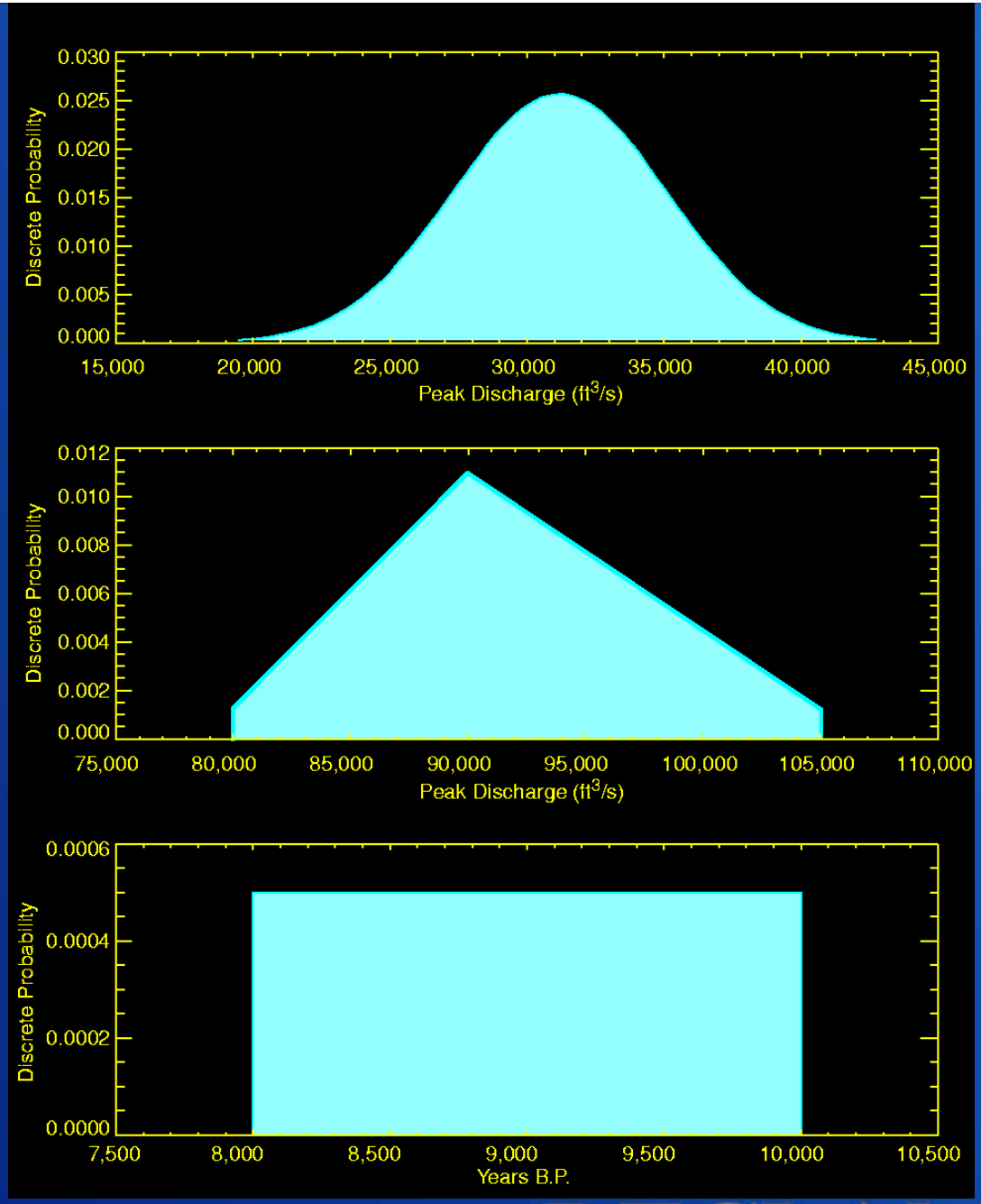

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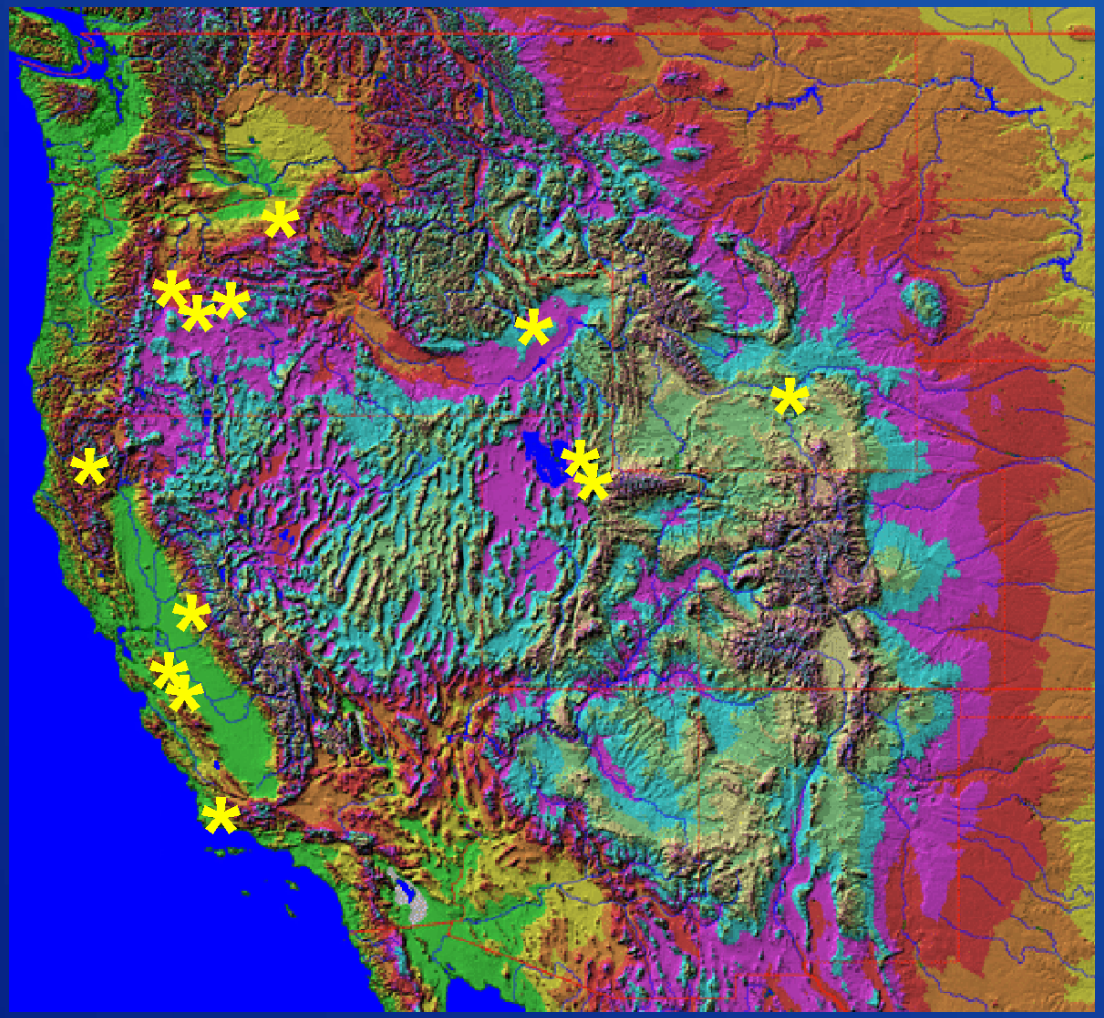
Reclamation Detailed Paleoflood Study Sites in Western U.S.



CALIFORNIA: Bradbury Dam, Cantua Stream Group, Los Banos/Little Panoche Dams, Folsom Dam, Trinity Dam

OREGON: Bowman Dam, Ochoco Dam, Lane and Meyers Canyons

IDAHO: Big Lost River

UTAH: Pineview/Causey Dams, Lost Creek Dam

WYOMING: Seminoe/ Glendo Dams

Colorado: Pueblo, Ridgway Dams

Many CFR sites

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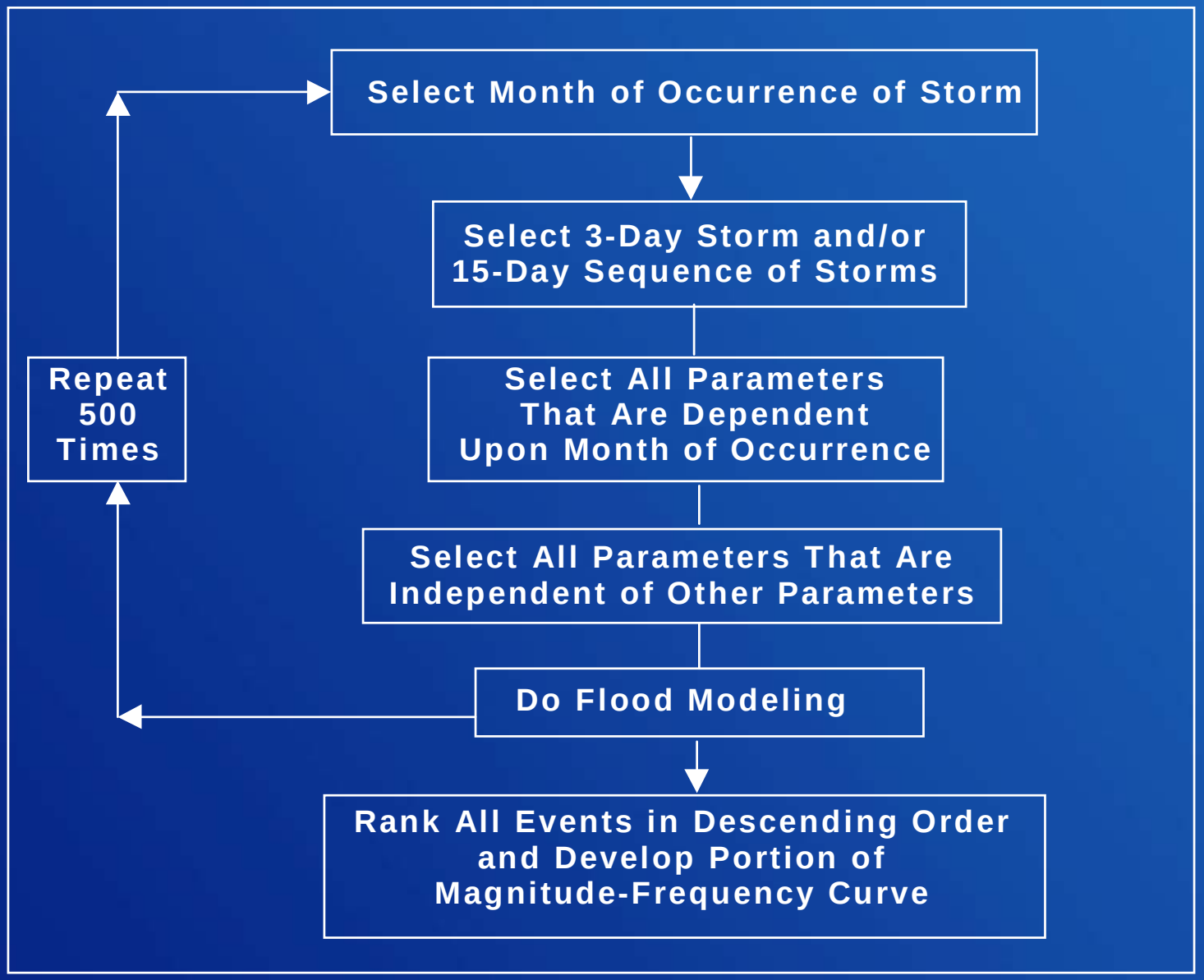
Stochastic Event-Based Rainfall-Runoff Model (SEFM) - Key Elements

- Regional Precipitation Frequency Analysis using L-Moments
- Hydrometeorological Parameters Treated as Variables
- Utilized 3-Day Storms and 15-Day Sequence of Storms
- Runoff Computed using Distributed Approach
- Perform 2500 Simulations to Examine Combinations Conducive to Large Floods



Stochastic Simulation Flow Chart

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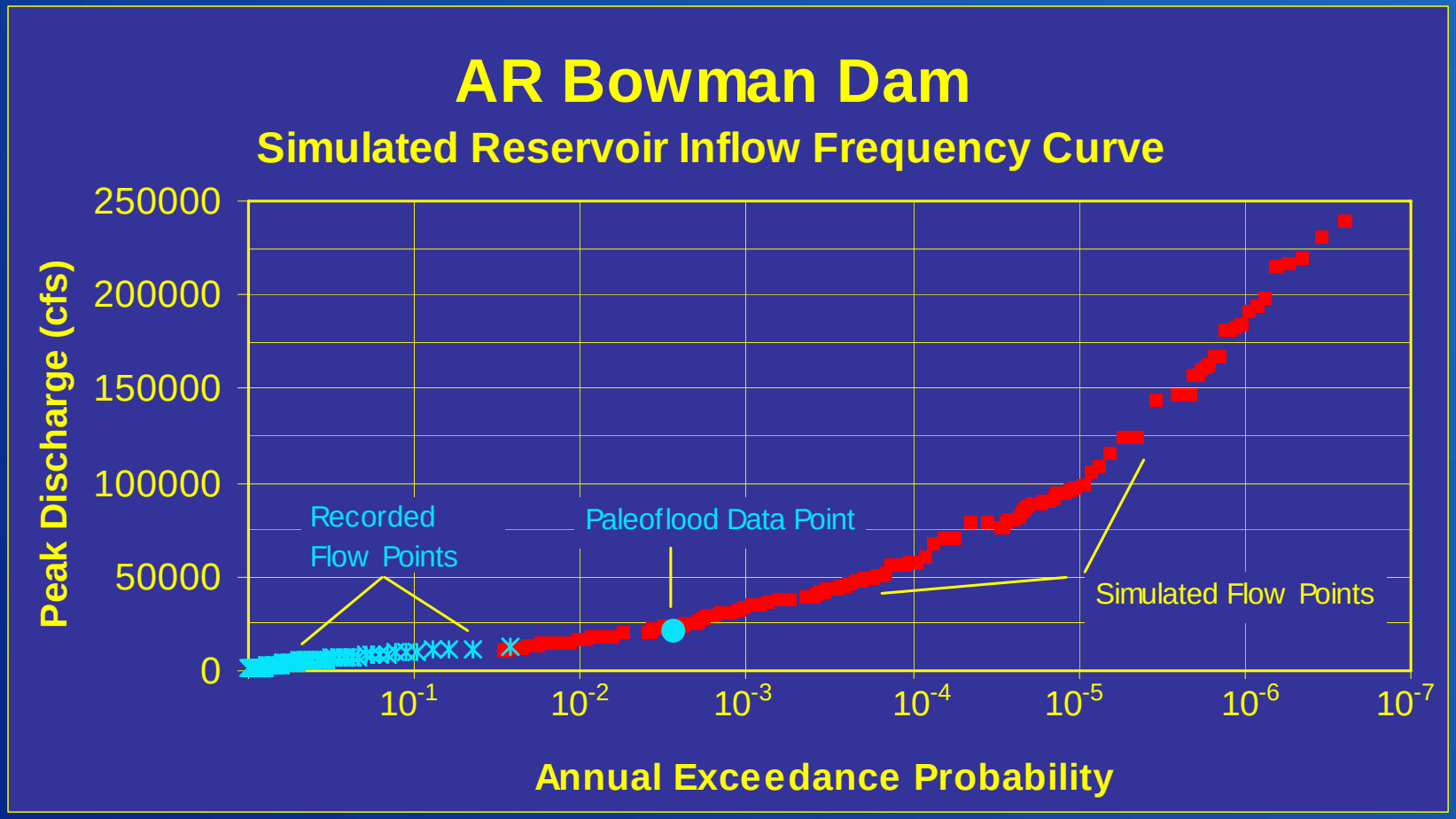
AR Bowman Dam

Simulated Reservoir Inflow Frequency Curve



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Two-Dimensional Runoff, Erosion and Export Model (TREX)

- Stochastic Storm Transposition for storm probabilities
- Physically-based, distributed runoff model
- 2D diffusive wave overland flow
- 1D diffusive wave channel flow
- Green/Ampt Infiltration

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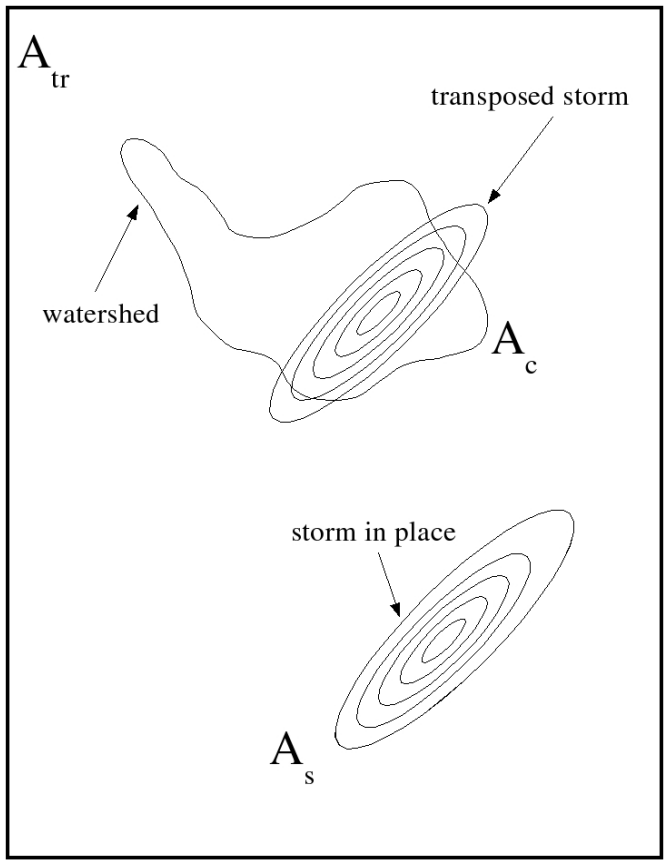
Stochastic Storm Transposition

$$G^a(d) = p_a(\bar{d}_c \geq d) = \hat{p}_s \sum_{j=1}^{N_s} \hat{p}_j(\bar{d}_c \geq d)\left(\frac{A_{eff,j}}{A_{tr}}\right)$$



Idea: space-for-time substitution

- DAD extreme storm catalog

Basin-Average Rainfall for Time Δt

Joint Probability: reduce extrapolation

- Extreme storms occurring in transposition region → extreme storm probability
- Extreme storm causing a depth exceedance over catchment of interest

→ transposition probability

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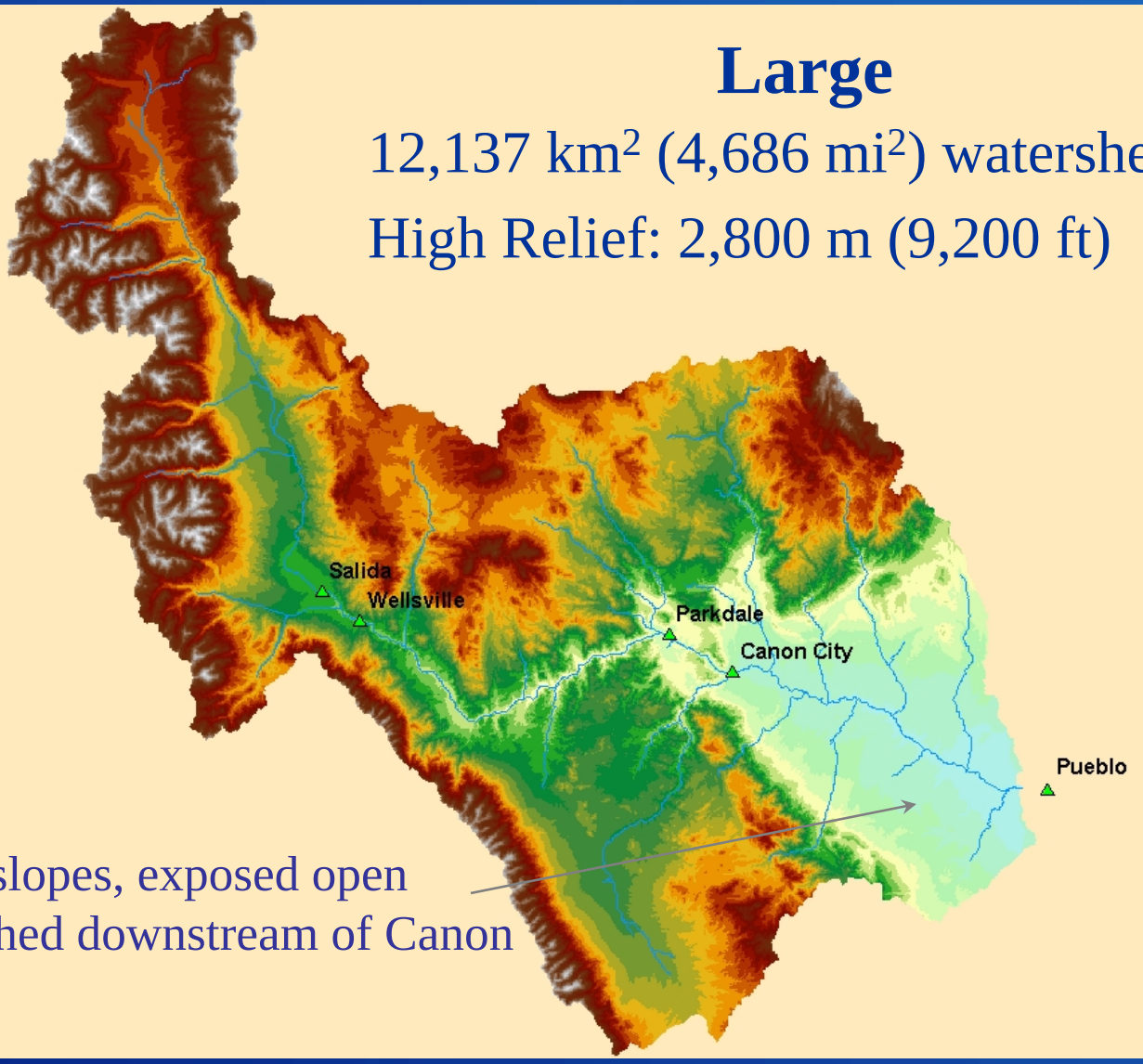
Application Site: Arkansas River Basin



Large

12,137 km^2 (4,686 mi^2) watershed

High Relief: 2,800 m (9,200 ft)

lower slopes, exposed open watershed downstream of Canon City

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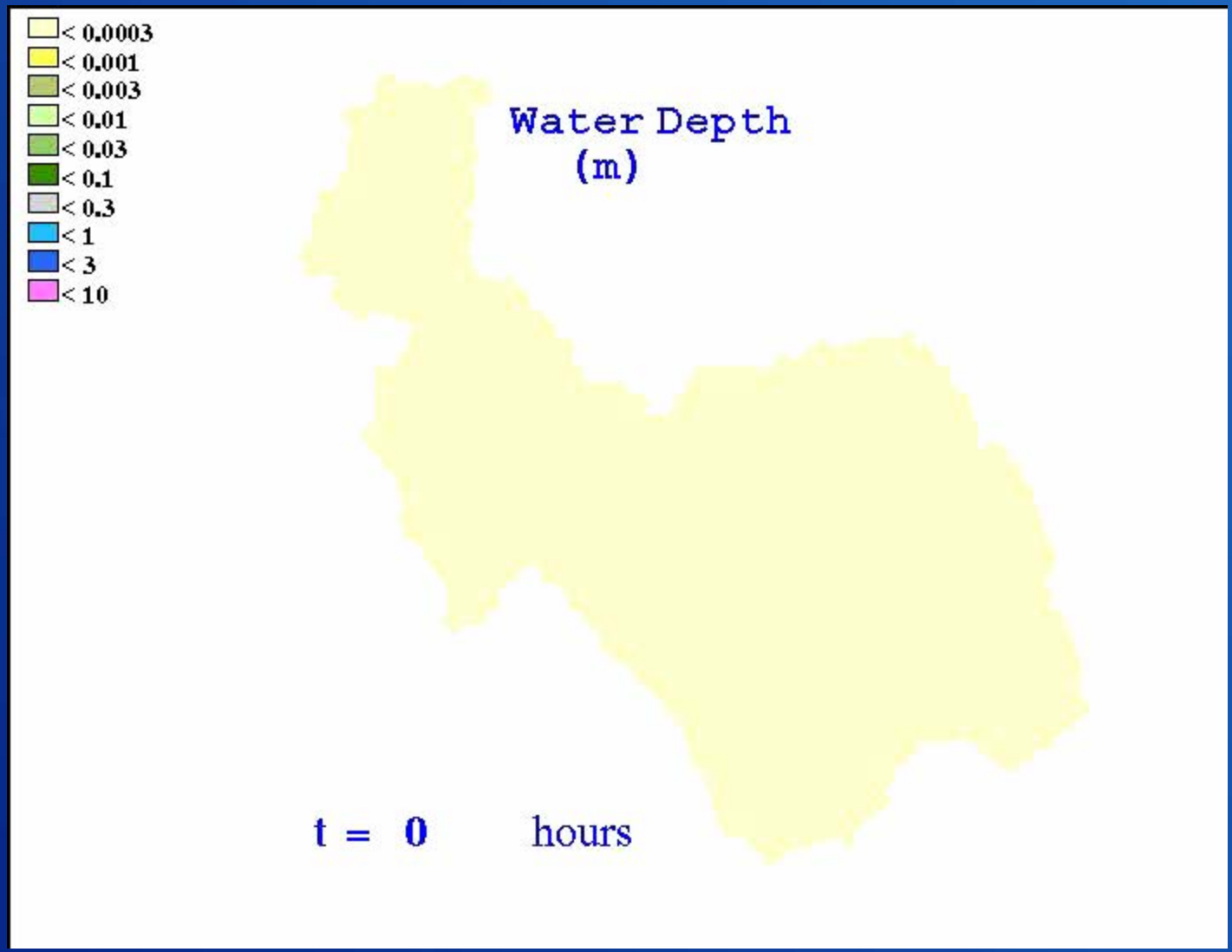
TREX Flood Frequency – Extreme Flood



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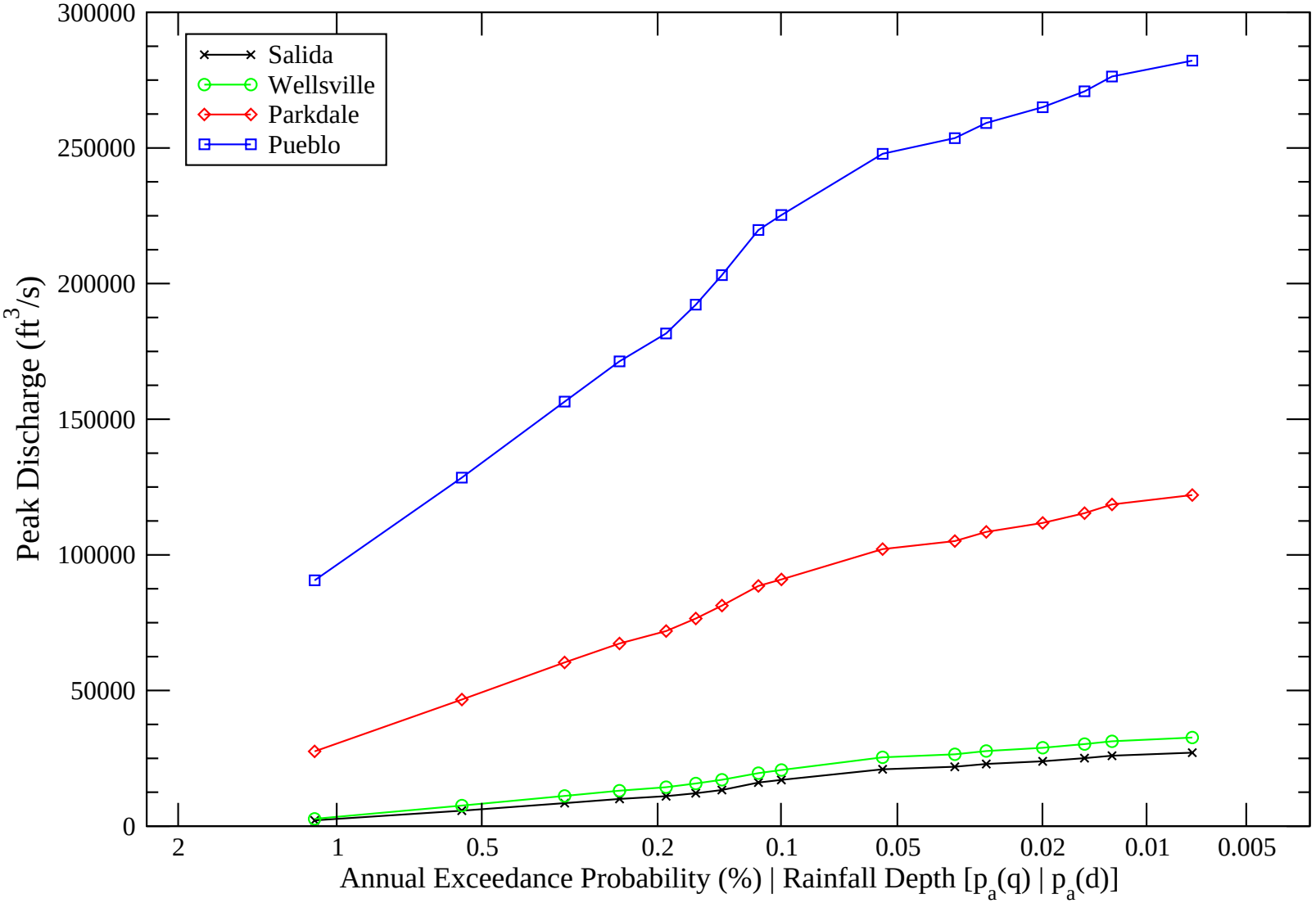
TREX Flood Frequency



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Extreme Flood Probability Estimation and Research

- Reclamation No Longer Strictly Relies on Standards-Based Measures (PMF)
- Risk Analysis Requires the Development of New Tools for Probabilistic Flood Hazards and Integration of Different Methods
- Challenging - Faced with Solving Problems Today with Limited Tools
- Applied Research – Ongoing Funded by Dam Safety Office

Summary

- Combining streamflow, paleoflood and rainfall data allows more confidence in extrapolated flood frequency curves
- Reclamation has developed a prescriptive approach for generating hydrologic hazard curves for use in dam safety evaluations
- The procedure relies on extracting information from existing studies and available data
- Initial characterization of hydrologic risk can usually be accomplished with minimal effort

Summary

- The amount of effort expended on analyzing a hydrologic hazard is dependent on the nature of the problem and potential cost of the solution
- Additional detailed tools available for estimating hydrologic risk
- A weighting procedure is used for combining results from different methods
- PMF is believed to represent the upper limit to hydrologic risk

Presentation and Report

- This presentation (pdf) and report (in pdf) titled:

- Swain, R.E., England, J.F. Jr., Bullard, K.L. and Raff, D.A. (2004) Hydrologic Hazard Curve Estimating Procedures. Dam Safety Research Report DS-04-08, Bureau of Reclamation, Denver, CO, 79 p.

- can be downloaded from our temporary ftp site (files deleted in 10 days):

ftp://ftp.usbr.gov/jengland/FERC/

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