Bulletin 17C Flood Frequency and Extrapolations for Dams and Nuclear Facilities

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NRC 4th Annual Probabilistic Flood Hazard Assessment Workshop

May 1, 2019

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US Army Corps of Engineers
Dam Safety Program
Levee Safety Program

Outline

- Risk-Informed Decision Making (RIDM)
  - ▶ Dam and Levee Safety
- Bulletin 17C Overview
- Extrapolation Guidance in Bulletin 17C
- Key Ingredients for PFHA
  - ▶ Rainfall-Runoff
- Some Methods to Weight and Combine Hazard Curves
- Some PFHA Examples for Dam Safety

Oroville Dam, Feather River, Oroville, CA
770 feet
(tallest embankment dam in US)
Spillway Failure February 2017

Web resources indicated by URLs or underlined text

example - Flood Hazards

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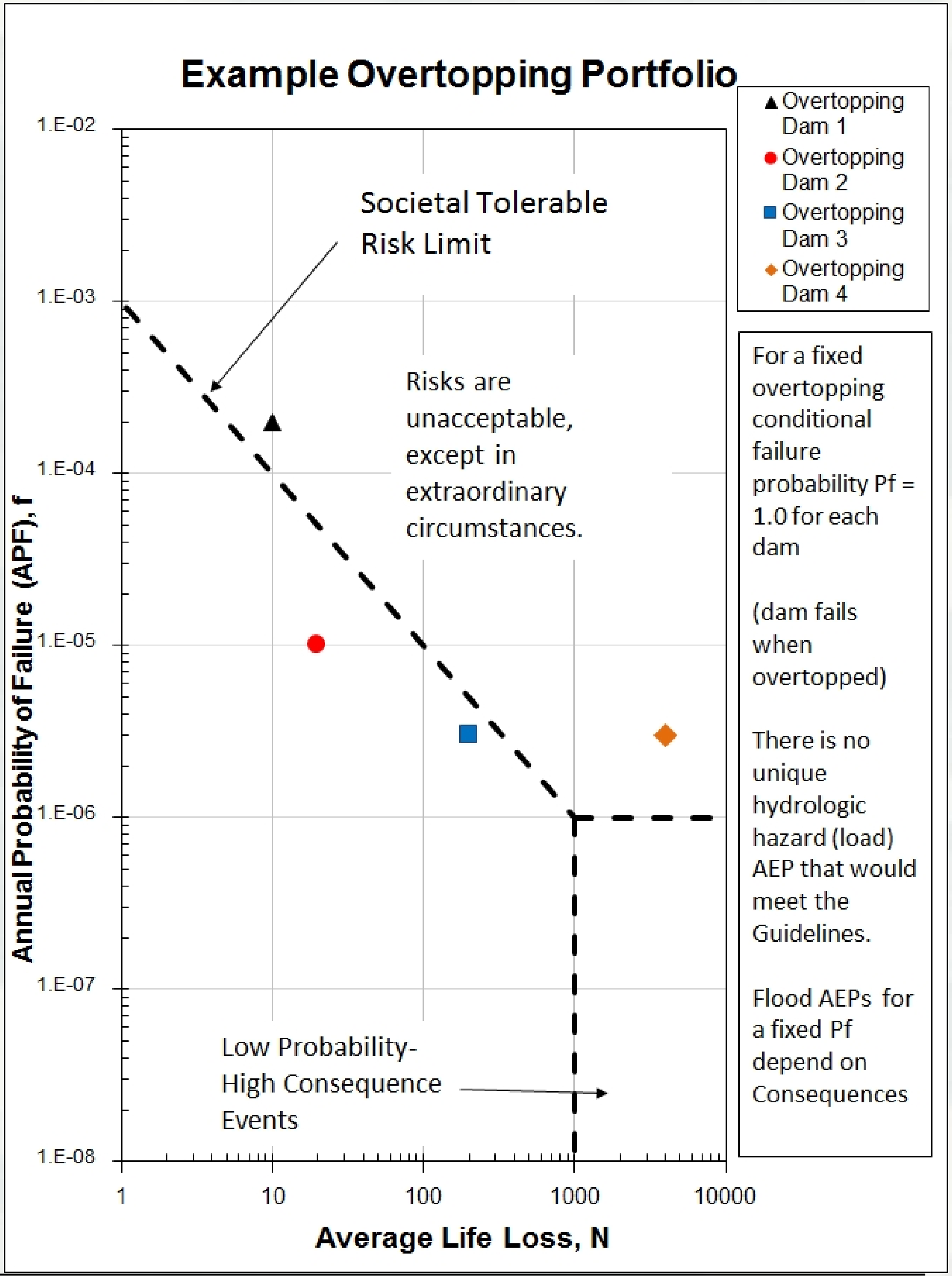
Risk-Informed Decision Making (RIDM) for Dam Safety

Risk Guidelines f-N chart

Annualized Loss of Life
1 in 1,000 (0.001) per year
(diagonal line)

Hydrologic Hazard
Annual Exceedance Probability
(AEP) (design flood)
not a fixed value
depends on failure probability
and consequences



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Hydrologic Hazards, Hydraulics and Risk Informed Decision Making

$$Risk = P_l * P_{r|l} * C$$

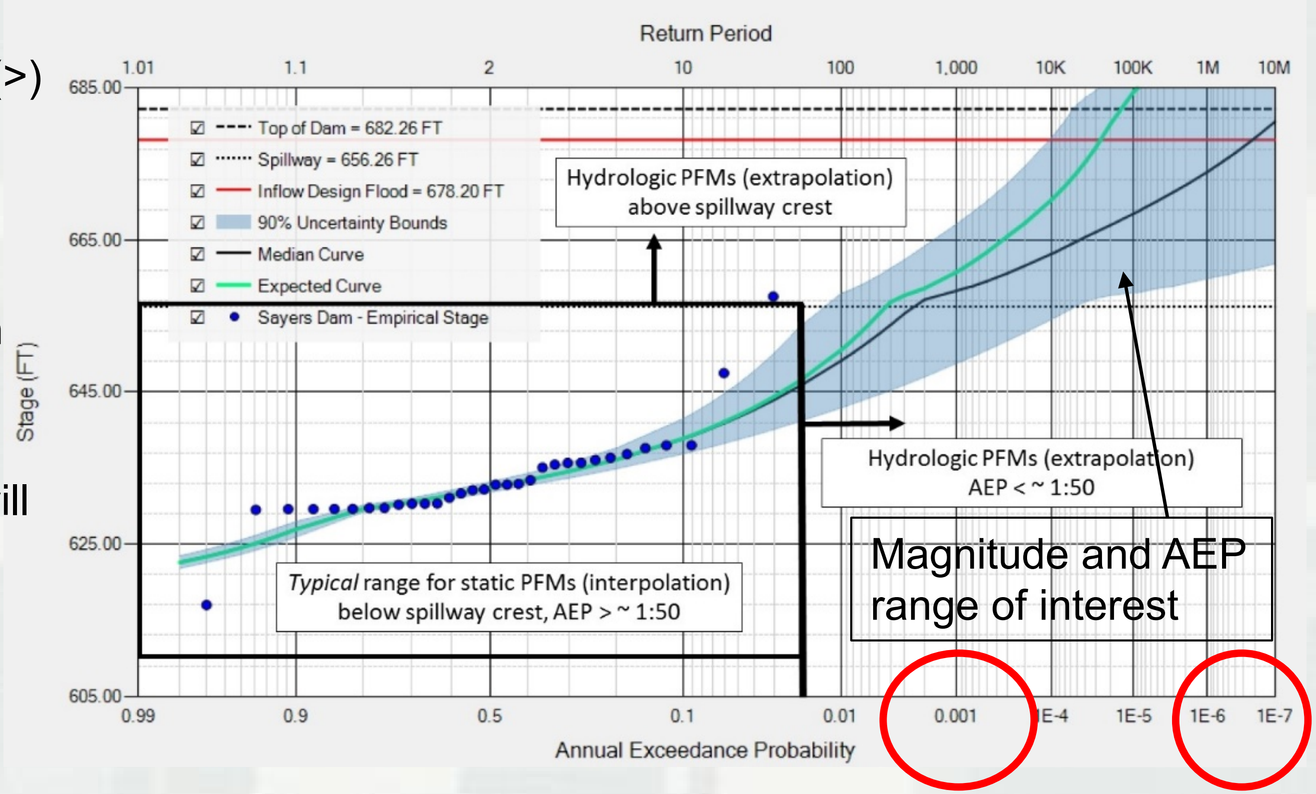
P_l = Probability of Load –
Hydrologic Hazard Curve

$P_{r|l}$ = Probability of Adverse Response Given Load –
Hydraulics, Engineering

C = Consequences (or Loss of Life, N)

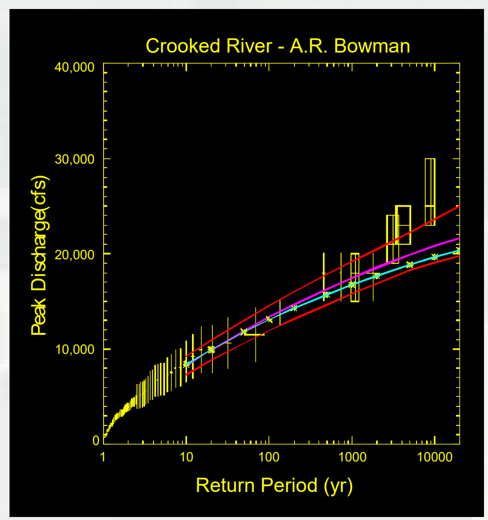
Example Hydrologic Hazard Curve – Stage Frequency

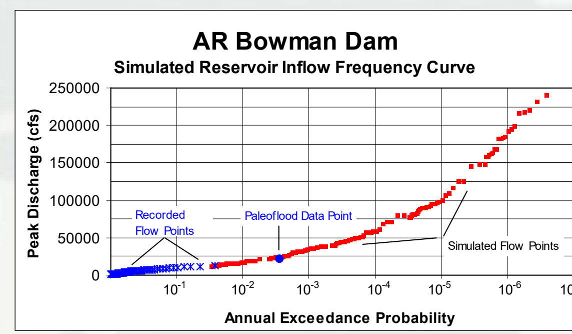
- Annual probability that stage will be exceeded (>)
  - **Same applies for discharge, volume, velocity, etc.**
- Risk estimates need the full range of values, with uncertainty (*focus on Expected Curve*)
- Range that drives risk will depend on PFMs and consequences
  - *< 1 in 10,000 (dams)*
  - *< 1 in 1,000 (levees)*



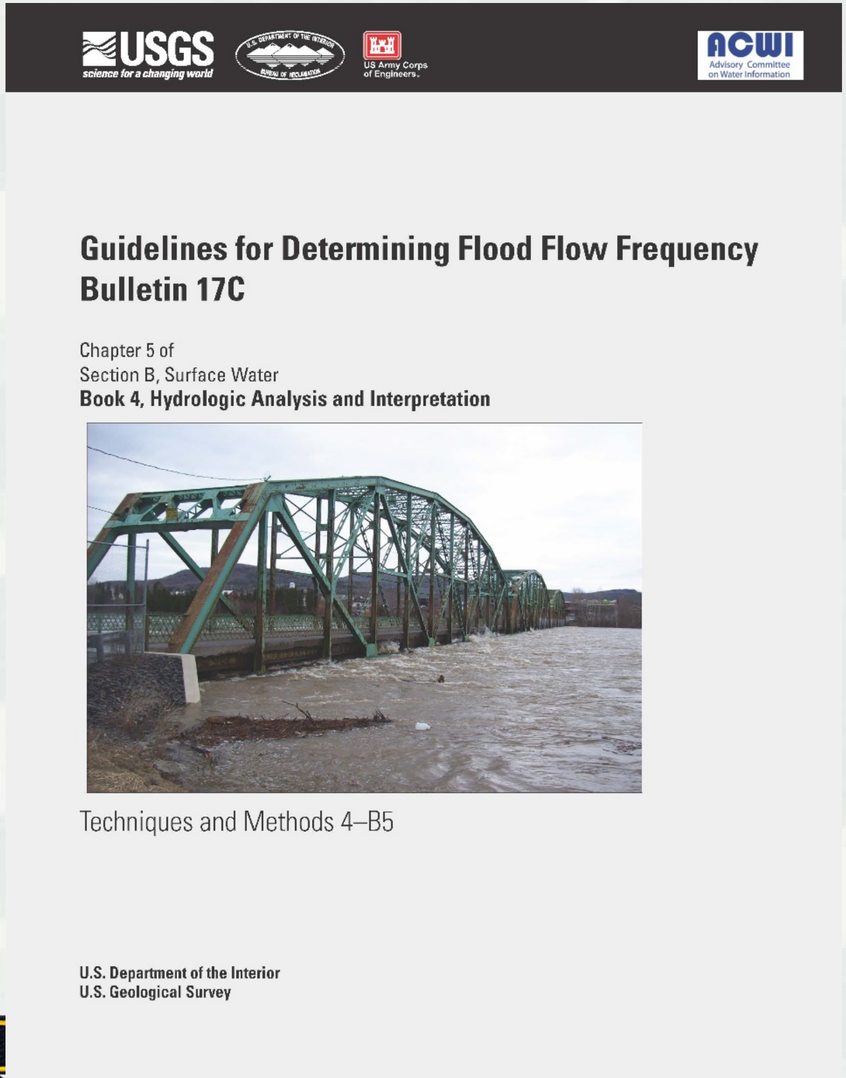
Hydrologic Hazards and Risk-Informed Overtopping Improvements

- A.R. Bowman Dam, Prineville, OR
- New 6-foot parapet and spillway wall raise, completed ~ 2011
- Hydrologic Hazards – basis for risk design – Paleoflood studies and Stochastic Rainfall-runoff modeling





Bulletin 17C Overview


Guidelines for Determining Flood Flow Frequency
Bulletin 17C

Chapter 5 of
Section B, Surface Water
Book 4, Hydrologic Analysis and Interpretation

Techniques and Methods 4–B5

U.S. Department of the Interior
U.S. Geological Survey

- Log-Pearson Type III distribution
- Method of Moments
  - Expected Moments Algorithm
  - Diverse Data
- Weighting of at-site and regional skew
- Accurate Confidence Intervals

https://doi.org/10.3133/tm4B5

https://acwi.gov/hydrology/Frequency/b17c

Applicability of Bulletin 17C Guidelines

Page 36:

- Accurate determination of floods for small AEPs (0.01) generally requires more data; estimations of floods for AEPs smaller than 0.005 generally require augmentation of the systematically observed flood records with general regional information, insight from precipitation records, or paleoflood information.

Comparisons of Frequency Curves - Bulletin 17C

Pages 31-32 [synopsis]:

- Other procedures for estimating floods can sometimes be used for evaluating rare exceedance probabilities, procedures are not standardized. *Guidelines describe the information to incorporate but allow considerable latitude in application*.
- Prior to making comparisons, ensure all data at the site and within the region have been adequately considered and incorporated into the frequency analysis. In this way, the flood frequency curve may reflect the following: **temporal information** such as historical and paleoflood data; **spatial information** such as regional skew and watershed characteristics; and **causal information** such as hydroclimate information and mixed-population data.

Frequency Curve Extrapolation - Bulletin 17C

Page 34:

- The amount of extrapolation depends on the *quantity and quality of flood information* at the site of interest, data and information within the larger region, *the designs and decisions to be made, and tolerance for uncertainty in the extrapolated results*. It is not simply based on the at-site data record length; there are variations in quantity and quality of flood information, as well as in the purposes of the designs and decisions to be made using the flood frequency estimates. *A flexible approach using multiple lines of flood evidence for extrapolation is appropriate.*

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Frequency Curve Extrapolation - Bulletin 17C

- As described in the section Comparisons of Frequency Curves, **all types of analyses should be incorporated** when estimating flood magnitudes for exceedance probabilities **less than 0.01 AEP**. … Include additional information as follows [p. 34].

1. Expand flood data in time at location of interest;

   [Temporal information expansion - Merz and Bloschl (2008)]

2. Expand and improve regional skew models; and

   [a particular form of Spatial information expansion - Merz and Bloschl (2008)]

3. Expand with regional independent information

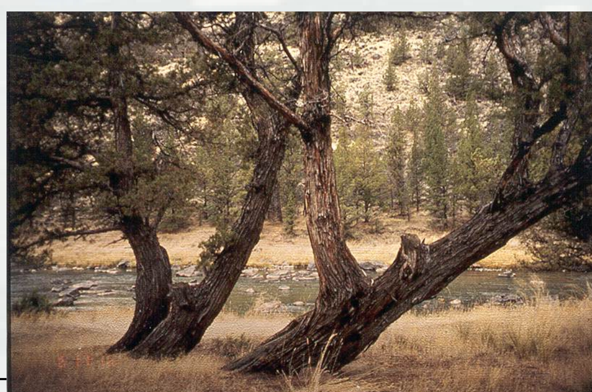
   [Spatial and Causal information expansion - Merz and Bloschl (2008)]

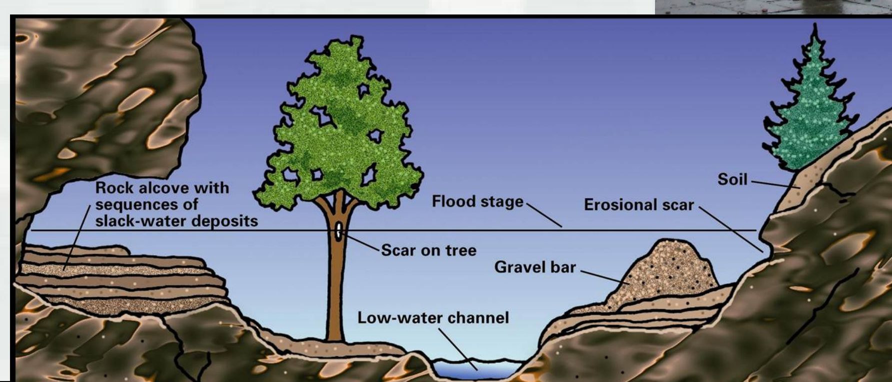
   - Extreme floods from rainfall runoff in watershed
   - Regional frequency estimates (streamflow or rainfall-runoff)
   - Physical and causal estimates

4. Carefully examine the upper tail and quantify uncertainty.

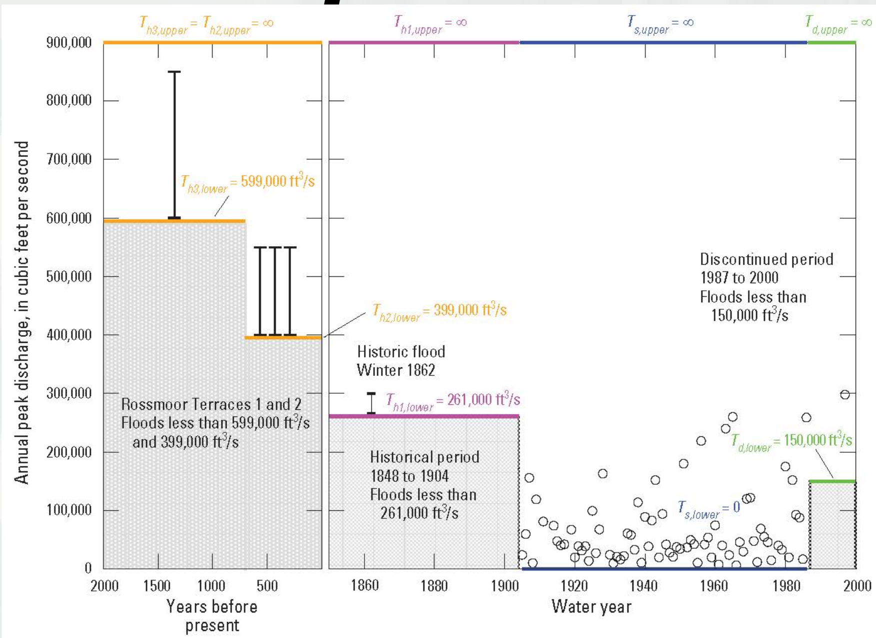
Bulletin 17C [Temporal]
Expand Flood Data in Time

- Historical Flood Information
  - ► Gather (libraries, newspapers, interviews, …) and interpretation
- Paleoflood and Botanical Information
  - ► ***Data collection in field is recommended*** *[p.34]*
- Data sources and Hyperlinks to sources – Appendix 3



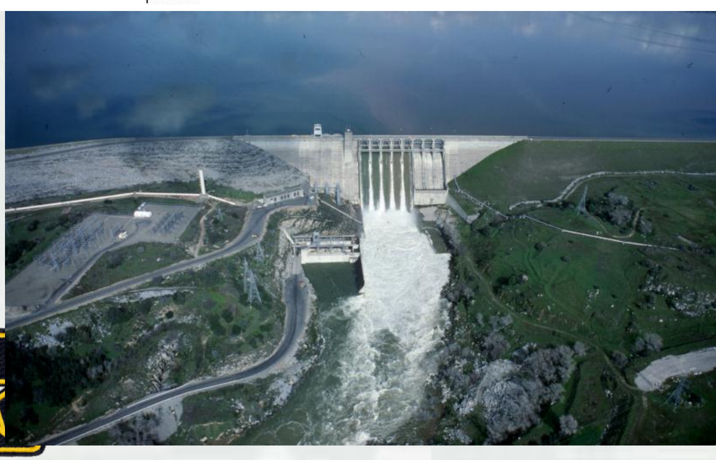


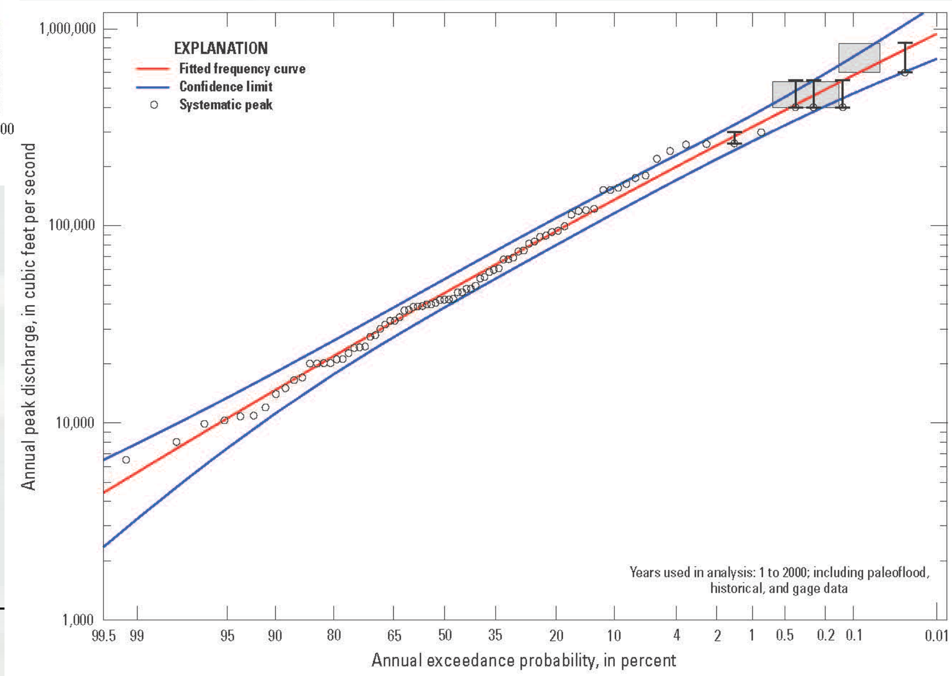
Bulletin 17C [Temporal]
Expand Flood Data in Time



- Hydrologic hazards for Dam and Levee Safety, with longer historical and paleoflood records

(see **Frequency Curve Extrapolation** section and Appendix 10 Examples)





Expand with Regional Independent Information

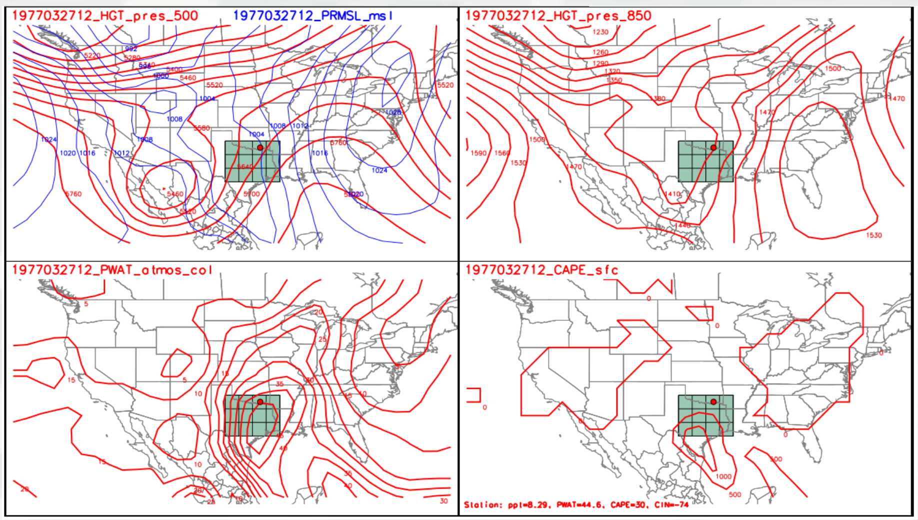
Frequency Estimates from Rainfall-Runoff Models

- **Physics**
  - Rainfall-runoff model, flood typing, processes
    - (spatial rainfall, infiltration, snowmelt, channel routing, etc.)
  - Extreme precipitation mechanisms/classification
    - (storm type, season, …)
- **Key Ingredients**
  - Regional Extreme Storm Data Catalog: space-time patterns
    - https://maps.mmc.usace.army.mil/esd/
  - Storm Typing – classify annual maxima for precipitation frequency
  - Regional Annual Maximum Precipitation Frequency (critical duration) **[Spatial]**
  - Rainfall-runoff watershed model and calibration data **[Causal]**

Storm Typing and Regional Precipitation Frequency

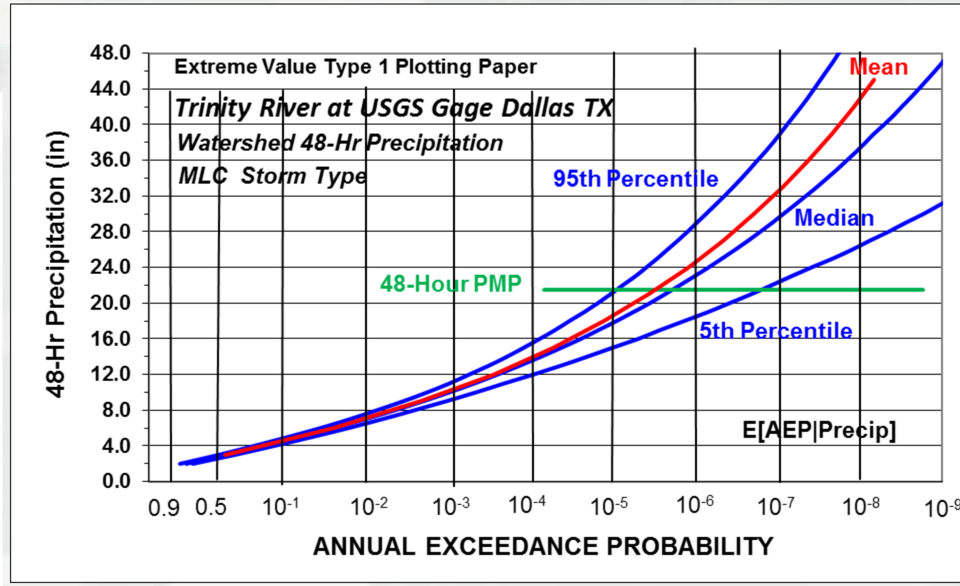
Storm Types that Cause Extreme Rainfall and Flooding

Example: Trinity Basin, TX (Grapevine Dam)
Tropical Storm Remnants (*TSRs*) (2 day duration)
Mesoscale Embedded Convection (*MEC*) (6 hr)
Mesoscale Local Convection (*MLC*) (2 day)



Classify rain days by storm type (March 27, 1977 *MLC* example)

Trinity Basin-Average Precipitation Frequency for MLC Storm Type

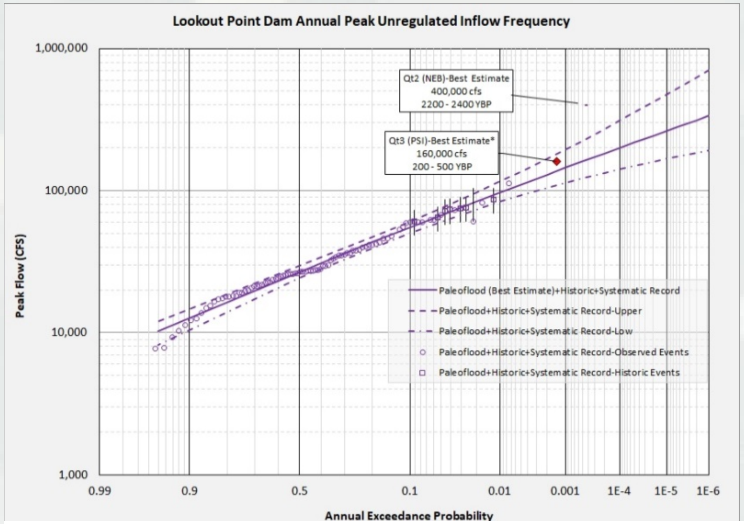


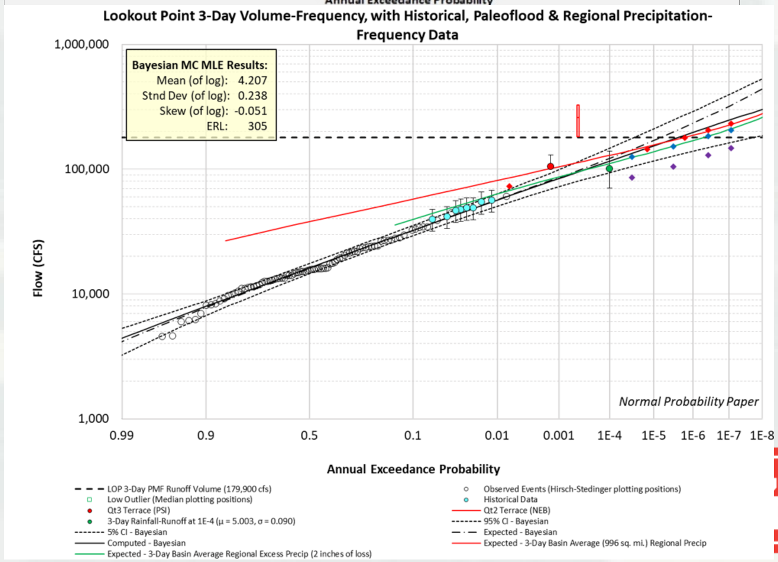
Improved inputs for IES risk analysis (spillways, overtopping PFMs)

Collaboration with HEC, SWF, MetStat Inc.

Combining Flood Hazard Curves

1. Hydrologic hazard curve from streamflow, historical, paleoflood data [Temporal]
2. Hydrologic hazard curve based on precipitation frequency and rainfall-runoff relations [Spatial and Causal]





Example concepts – draft work in progress

Methods to Weight and Combine Hazard Curves

- Qualitative, Expert Elicitation
- Weighting of Independent Estimates (Bulletin 17C Appendix 9)
- Formal Bayesian Methods

Viglione et al. (2013) WRR https://doi.org/10.1029/2011WR010782

Skahill et al. (2016) ERDC https://apps.dtic.mil/dtic/tr/fulltext/u2/1002919.pdf

Qualitative, Expert Elicitation

- A.R. Bowman Dam, OR (USBR, 1995-2006)
  - Regional precipitation frequency and stochastic rainfall-runoff modeling
  - Streamflow with paleoflood data
  - Cadre weighted curves based on data, record lengths, uncertainty

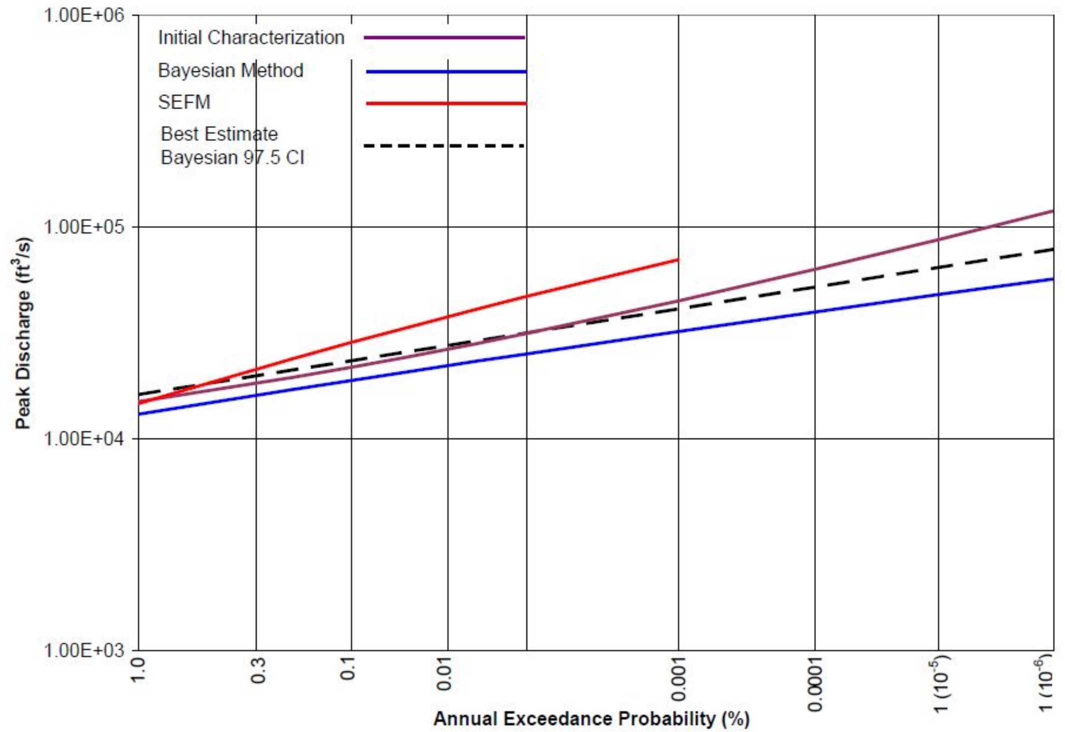


Figure 6-8.—Best estimate (Bayesian 97.5 percent) weighted peak-discharge frequency curve for A.R. Bowman Dam, Oregon.

See Swain et al. (2006)

Weighting of Independent Estimates [Bulletin 17C]

Bulletin 17C [p. 33, Appendix 9]

- Weights are based on quantile variance and are assumed to be unbiased and independent.
- Weight given to each estimate is inversely proportional to its variance.
- Weighting is done when reliable estimates of quantiles and variances are available.
- Evaluate estimates prior to weighting

$$X_{weighted,i} = \frac{X_{site,i} \times V_{reg,i} + X_{reg,i} \times V_{site,i}}{V_{site,i} + V_{reg,i}}$$

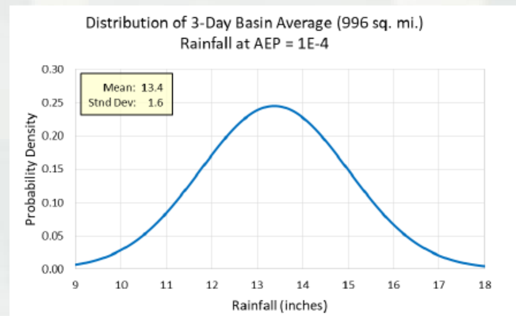
Rainfall-runoff quantile variance is a challenge
Can be represented by the Effective Record Length (ERL) based on flow frequency and precipitation frequency.

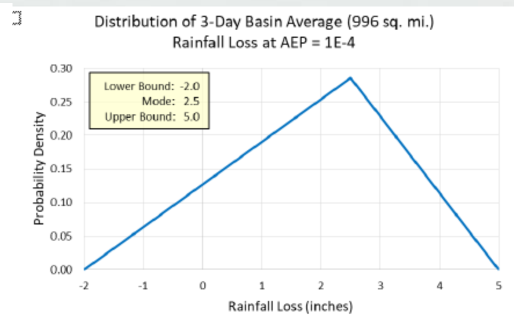
Formal Bayesian Methods

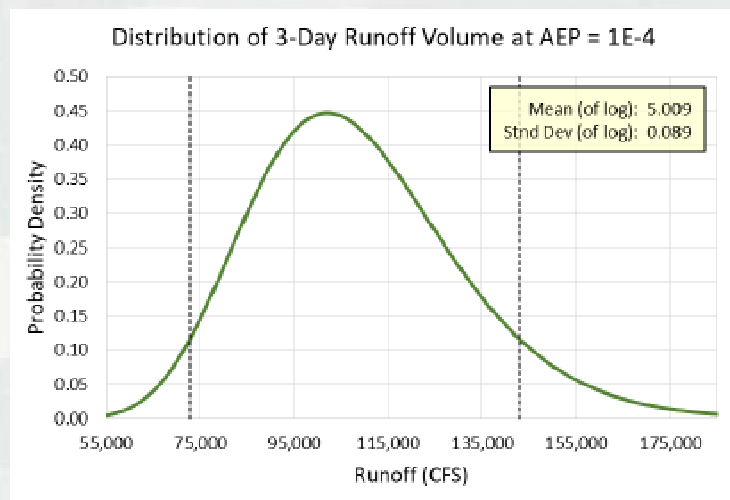
- Utilize Bayesian inference to combine four types of information
  - Streamflow gage records
  - Historical/Paleoflood data (discrete interval floods)
  - Non-exceedance information (right-censored)
  - Rainfall-runoff quantile at 10^{-4} [causal prior from spatial rainfall, loss distribution]

Prior on Rainfall-Runoff

$$h(Q_T) = N(\mu_{Q_T}, \sigma_{Q_T})$$





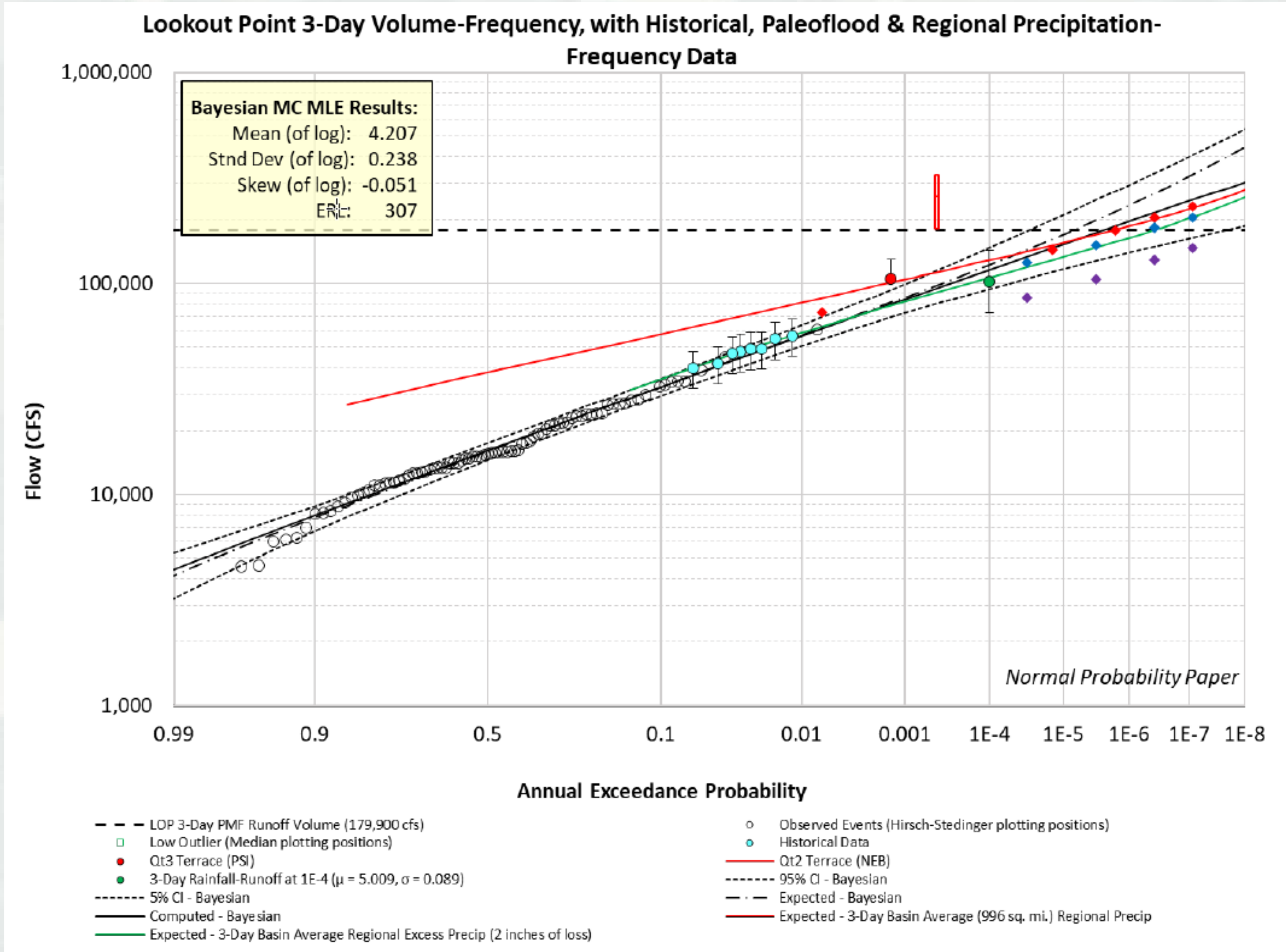


Formal Bayesian Methods

Preliminary Results

- Systematic, historical and paleoflood data
- Regional precipitation frequency
- Rainfall-runoff model discrete events
- Runoff distribution [loss-adjusted precip]

Bayesian Markov Chain Monte Carlo sampler with informative priors [accounts for parameter uncertainty; provides full posterior distribution]



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Formal Bayesian Methods

Ongoing Work and Potential Next Steps

- Software development (ERDC-RMC), testing, and application on numerous hydrologic hazard studies for dam safety
  - Comparisons and testing flood frequency portion with existing codes (EMA, FLDFRQ3, FLIKE)
- Documentation of key concepts, complete treatment of priors, inputs, assumptions, applications, etc.
- Exploring generalization to model selection and models
  - Weight and combine multiple parents GEV, LP3, GPA
- Advancement on additional Spatial and Causal information and its value
  - Snow water equivalent (SWE) [max stable estimates]
  - Spatial rainfall constraints, runoff processes, routing, etc.

Questions/Comments/Discussion?

Spencer Dam,
Niobrara River, NE
(upstream of Gavins Point Dam)
March 16, 2019

john.f.england@usace.army.mil
https://sites.google.com/a/alumni.colostate.edu/jengland/research

Extras for Discussion

Physical Limits to Rainfall and Floods and Upper-Bounded Frequency Distributions – Are They Useful?

Is there a physical limit? Is it increasing in the presence of climate variability/change? Should upper-bounded distributions be used? What processes and physics are included?

Examples: EV4, LN4, TDF (transformed extreme value) Or 5 parameter Wakeby*?

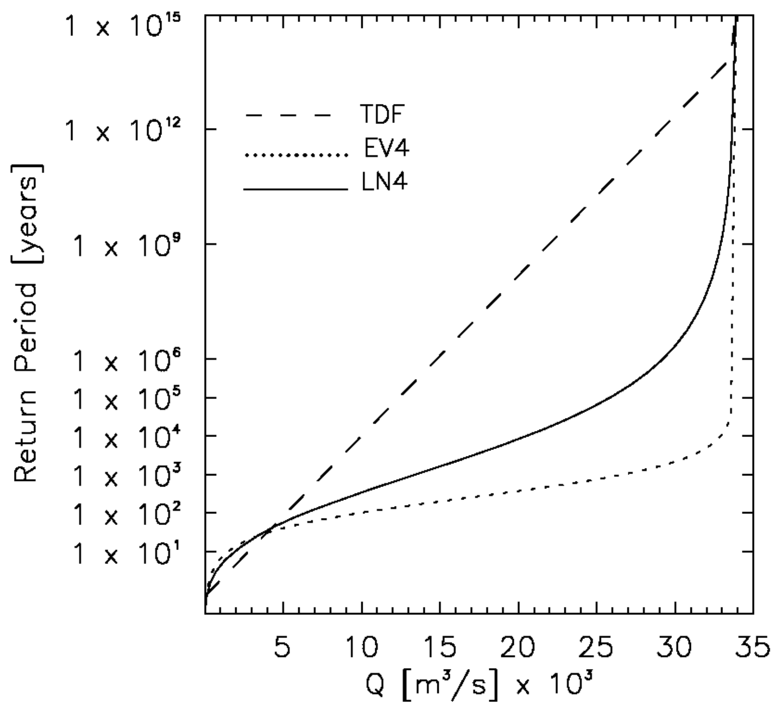
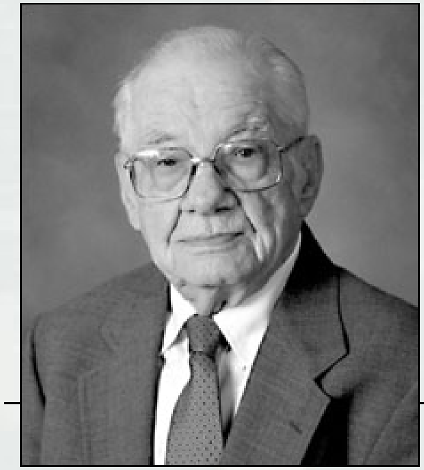


Fig. 3. TDF, EV4 and LN4 different behaviour approaching the same upper limit. Parameters for each distribution function are the same than in Fig. 2 (central): the case study data with the ML-PG estimation method.



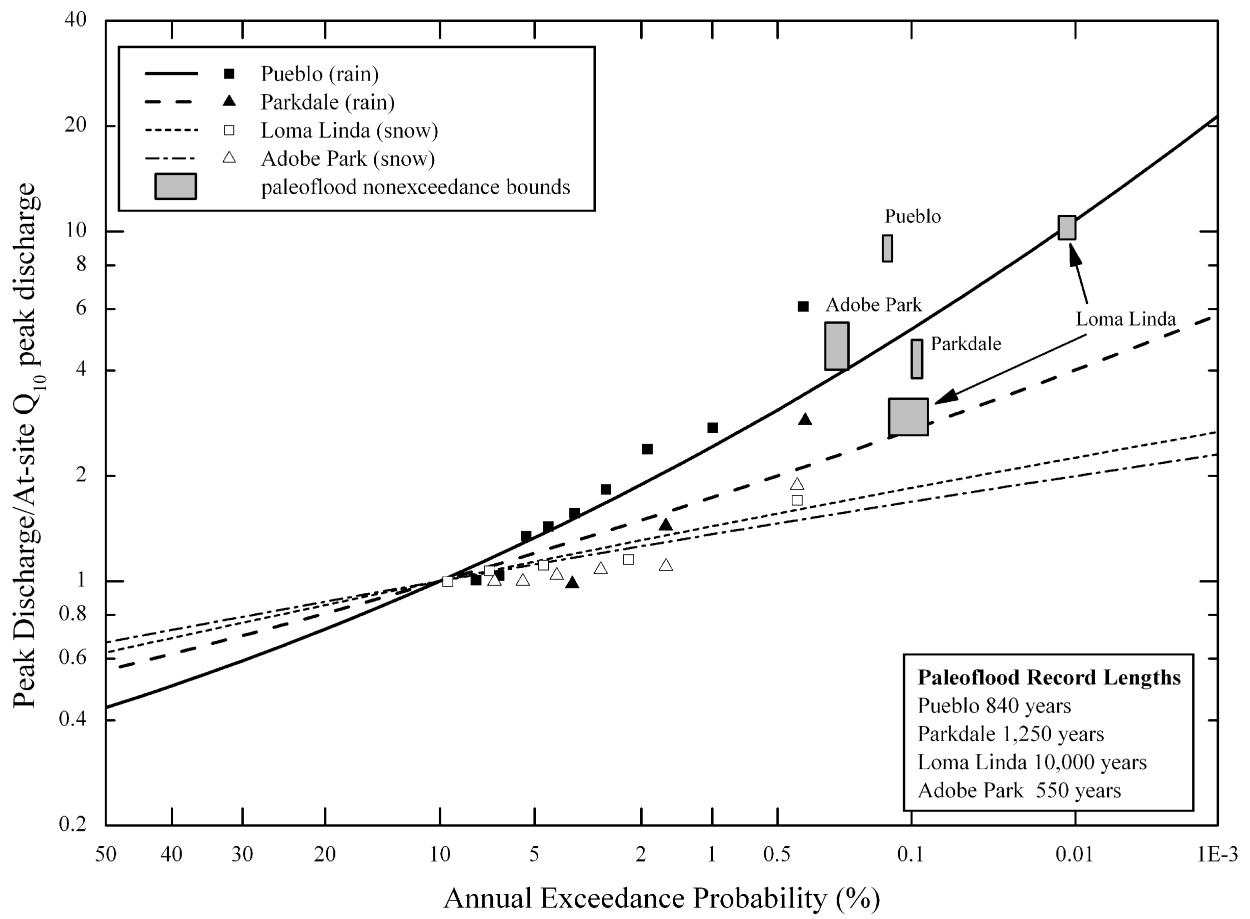
* Harold A. Thomas, Harvard U. (Wakeby distribution)

Hydrologic Hazard Principles – Causal Information

Causal Information: utilize hydrological understanding of flood-producing factors.

Example – transition from snowmelt runoff to rainfall runoff within a large watershed

England et al. (2010) Geomorphology



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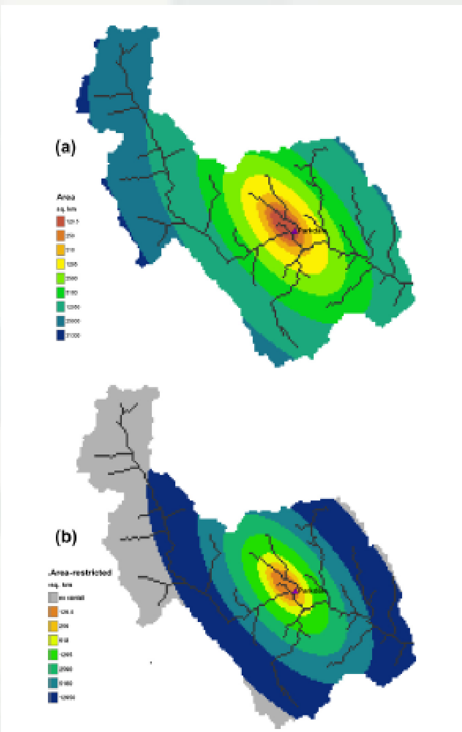
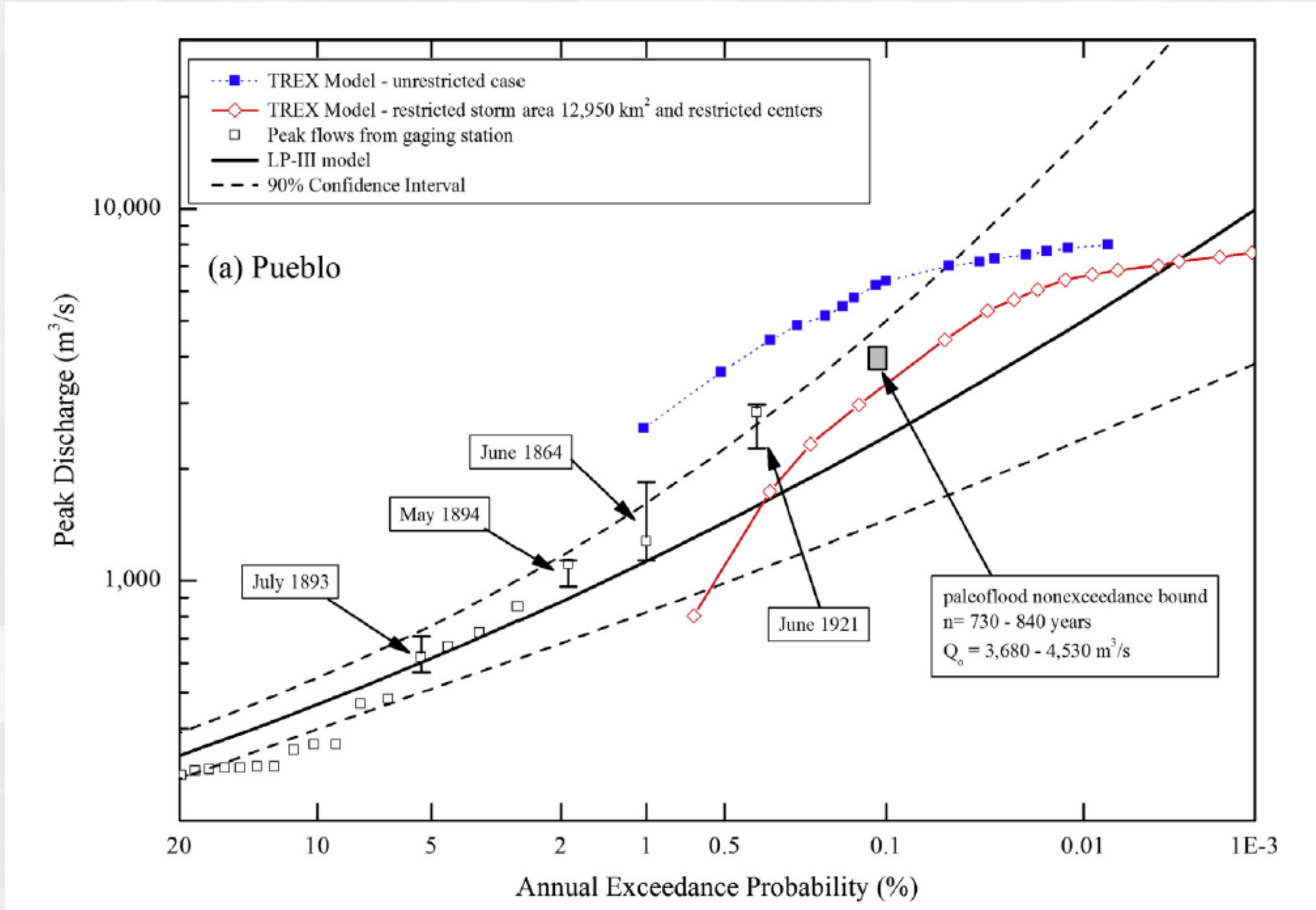
Qualitative, Expert Elicitation

- Paleoflood data/flow frequency
- 2D Rainfall-Runoff model
- Spatially-varying rainfall

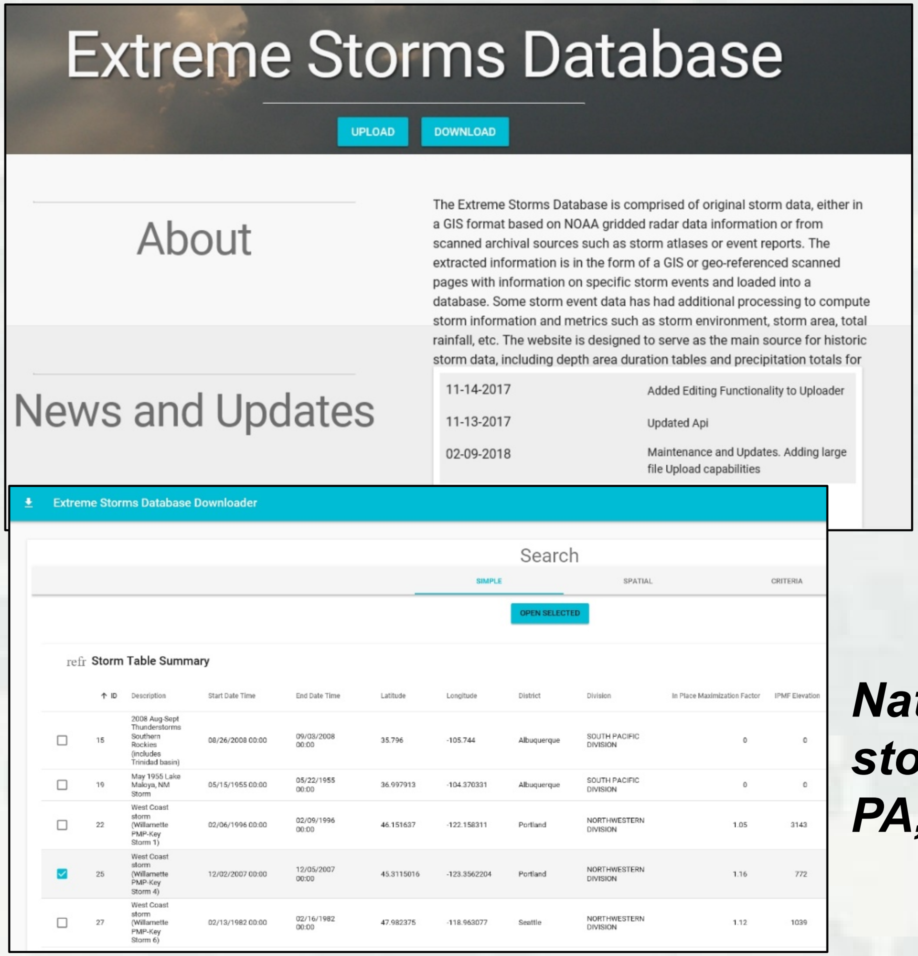


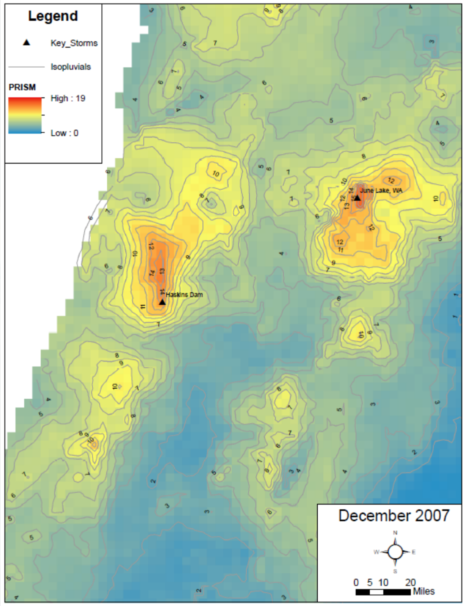


13,000 sq km Arkansas River, CO

England et al. (2010) Geomorphology; (2014) J. Hydrology

Extreme Storm Data

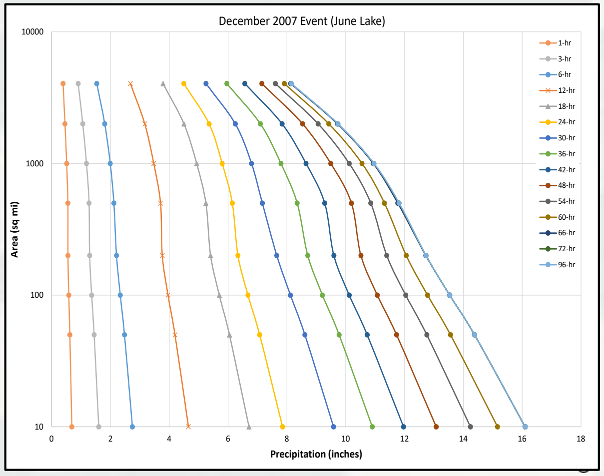




December, 2007 storm

Updated space-time precipitation estimates for Willamette basin: Lookout Point, Hills Creek, Green Peter, Foster Dams (and others)
Lead: Angela Duren (NWD)

National extreme storm data for PA, SQRA, IES

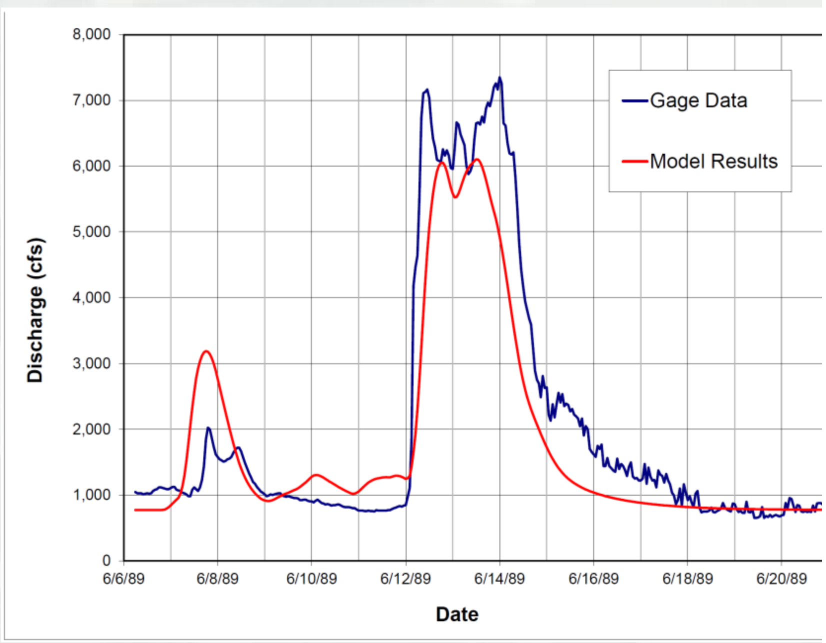


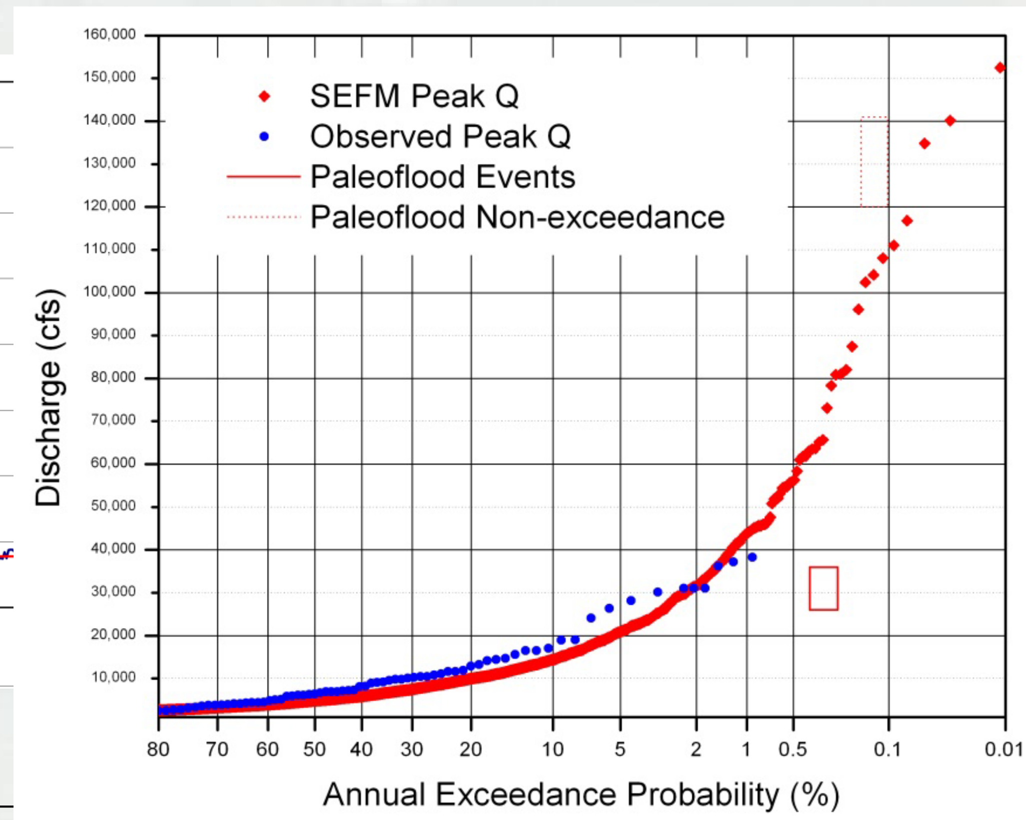
https://maps.mmc.usace.army.mil/esd/
Lead: Charles McWilliams (NWO)

Rainfall-Runoff Calibration and Weighting with Paleofloods

2-stage Model Calibration: (1) observed flood hydrographs; (2) estimated frequency curves (peak/volume).

Determine best inputs, parameters, and their distributions





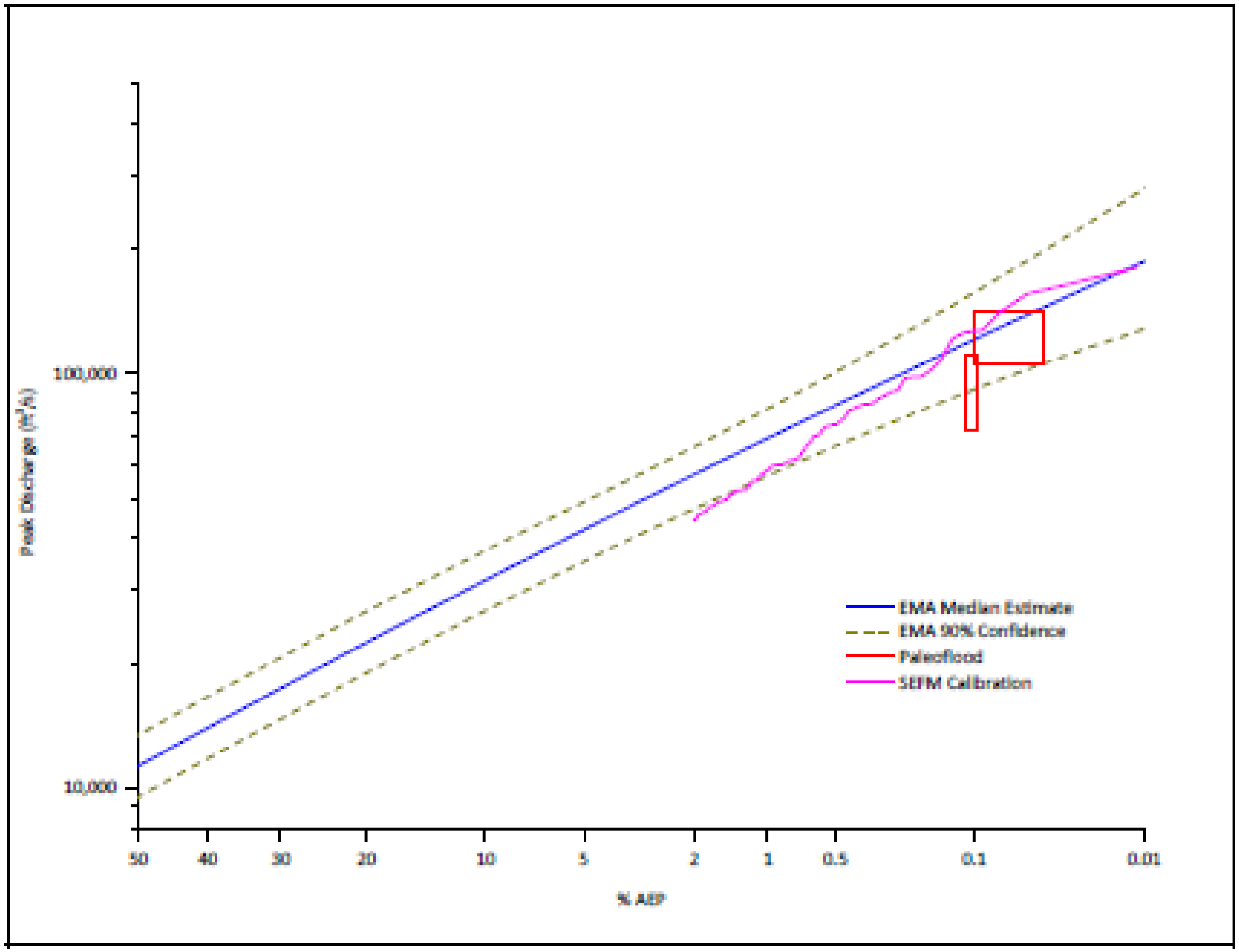
Altus Dam, OK - Reclamation

Rainfall-Runoff Calibration and Weighting with Paleofloods

Friant Dam, CA (USBR)

Stochastic Event Flood Model

(Wright et al, 2013)



https://sites.google.com/a/alumni.colostate.edu/jengland/file-upload/Friant_Report_final_compress.pdf

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