Hydrologic Hazards

Best Practices in Dam and Levee Safety Risk Analysis

Part B - Hazards and Loading

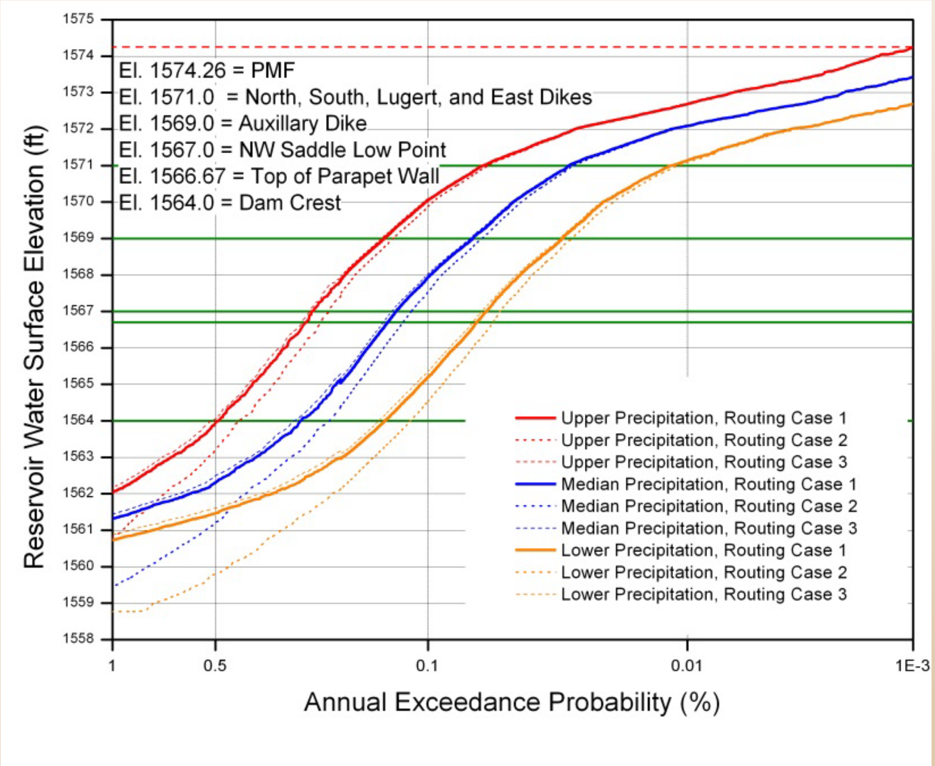
Chapter B-1

Last modified July 2018, presented July 2019

US Army Corps of Engineers

Objectives

- Understand the methods used to characterize hydrologic hazards
- Understand how hydrologic hazards are used to estimate risks



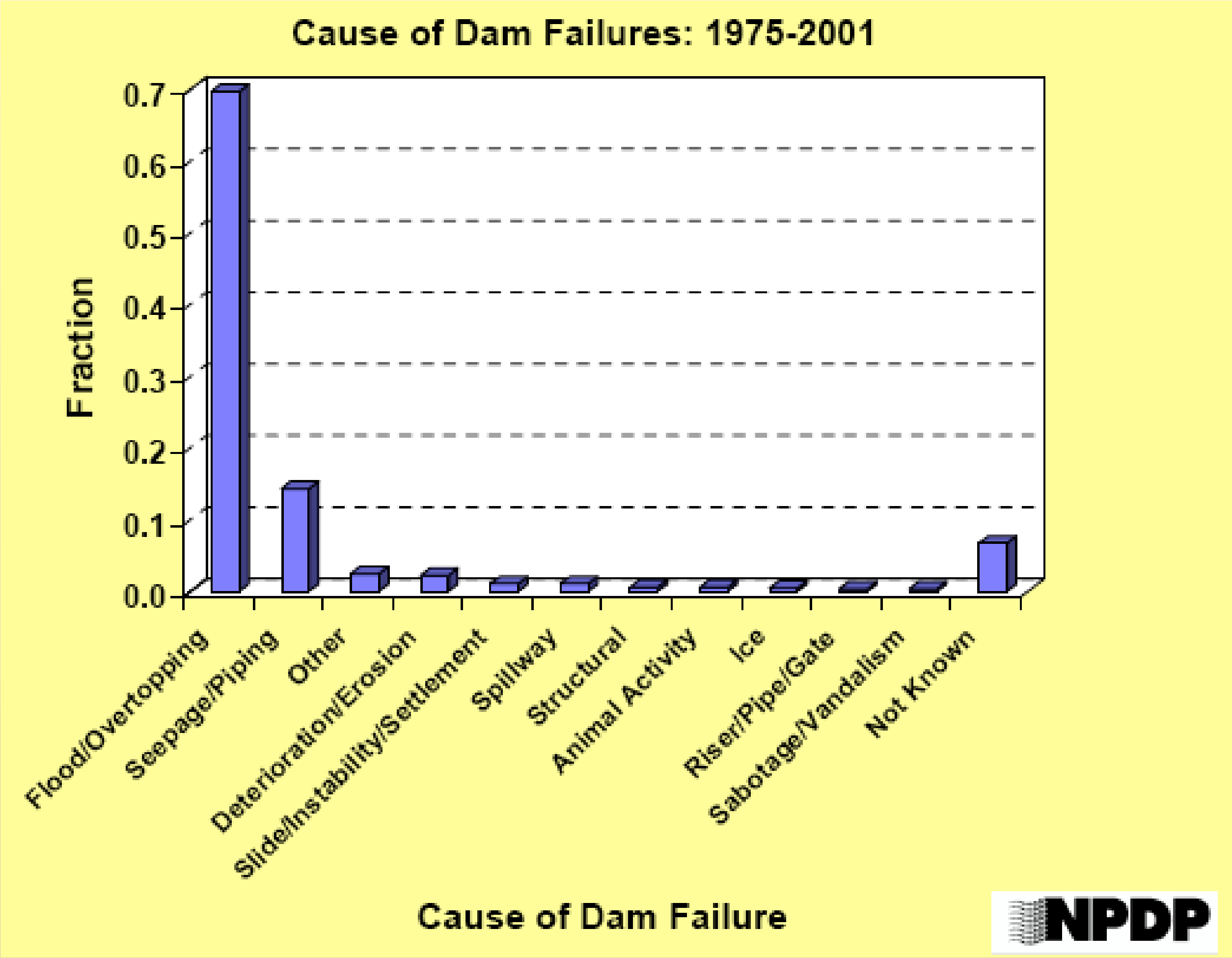
Key Concepts – Hydrologic Hazards

- Variables, magnitudes, and ranges of interest for risk estimate
  - Stage, discharge, volume, velocity, others
  - Peak, timing, duration
- Entire distribution shape matters
- Load partitioning important to develop a proper event tree
- Integration of hazard with failure modes and consequences
- Deterministic floods not easily mapped to hazard curves
- Quantify and understand uncertainty

Outline

- Why are hydrologic hazards important?
- Some Hydrologic-Related Potential Failure Modes
- What’s a Hydrologic Hazard Curve?
- Hydrologic Hazards - Current Guidance
- Hydrologic Hazard Curve Estimation – Key Principles and Methods
- Hydrologic Hazards and use in Risk Analysis

Why Flood Hazards are Important



Dam	Year	Fatalities
South Fork, PA	1889	2,209
Walnut Grove, AZ	1890	100
Buffalo Creek, WV	1905	125
Swift Dam, MT	1964	19
Canyon Lake, SD	1972	237
Laurel Run, PA	1977	40
Kelly Barnes, GA	1977	39
Rainbow Lake, MI	1986	3
Callaway, TX	2002	2
Ka Loko, HI	2006	7

Why Flood Hazards are Important

Levee Overtopping
Mississippi River
July 1993

Floodway Operation
Mississippi River
May 2011

Dam Overtopping
Iowa
July 2010

Refer to Case Histories for More Details and More Examples

Why are Flood Hazards Important

Annualized Failure Probability

$$f = P_l * P_{r|l}$$

Risk: Annualized Life Loss

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

P_l = Probability of Load – ***Hydrologic Hazard Curve***

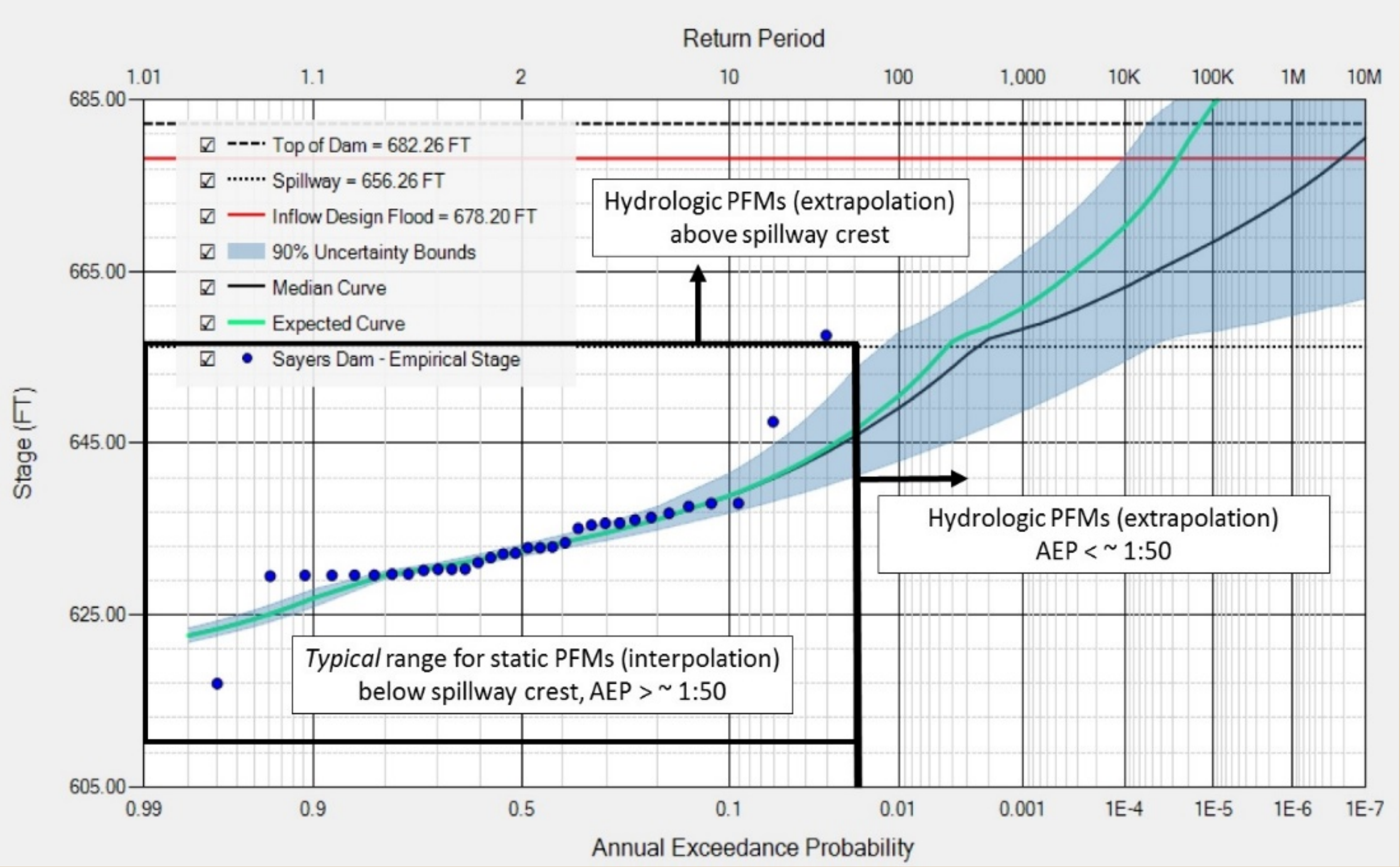
$P_{r|l}$ = Probability of Adverse Response Given Load
C = Consequences (or Loss of Life, N)

Potential Failure Modes

- Almost all of them
  - No water = No failure mode
- Overtopping of Dams and Levees
  - erosion of downstream toe, foundation, or dam crest
- High Reservoir Levels or River Stages
  - Internal erosion, instability, and many others
- Spillway and Stilling Basin
  - erosion, cavitation, wall overtopping
- Misoperation or malfunction
  - Gate electrical/mechanical, pump stations, closures

What is a Hydrologic Hazard Curve?

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



Hydrologic Hazard: Discharge and Volume

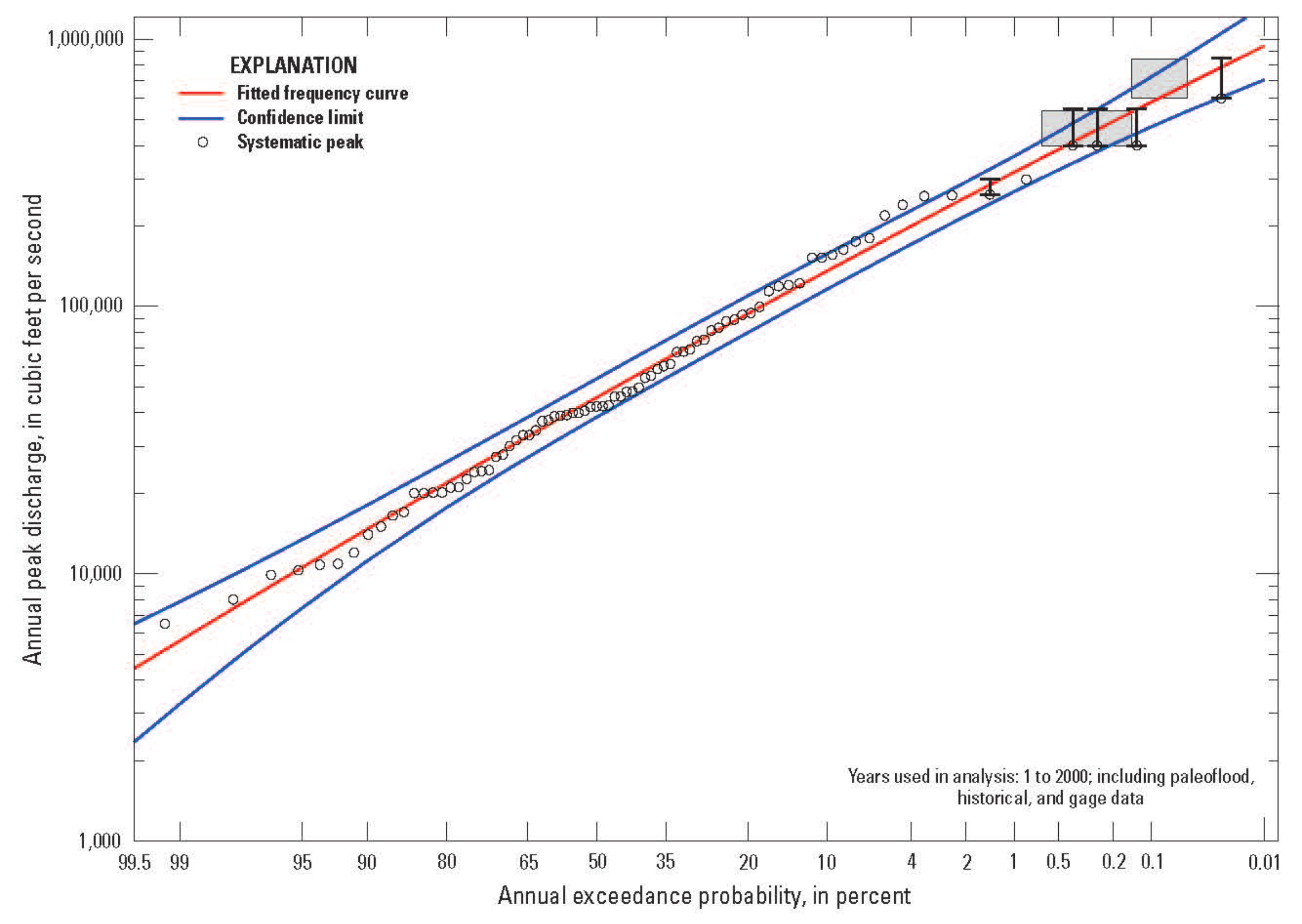
Leverage all available information
- Gage records
- Historic flood records
- Paleoflood studies

Use current methods
- Bulletin 17C

Do not anchor
- Do use an assigned AEP for the PMF to define the curve
- Ok to report the AEP for the PMF discharge or volume from the curve

Quantify uncertainty
- Typically large due to extrapolation

Identify key parameter
- Peak
- Volume (for the critical duration)



[Bulletin 17C Appendix 10 Example]

Hydrologic Hazard: Reservoir Pool or River Stage

Understand how physical characteristics influence the shape of the curve

- I – O = dS/dt
- Downstream controls
- Gate operations
- Spillway crest
- Overtopping flows
- Storage

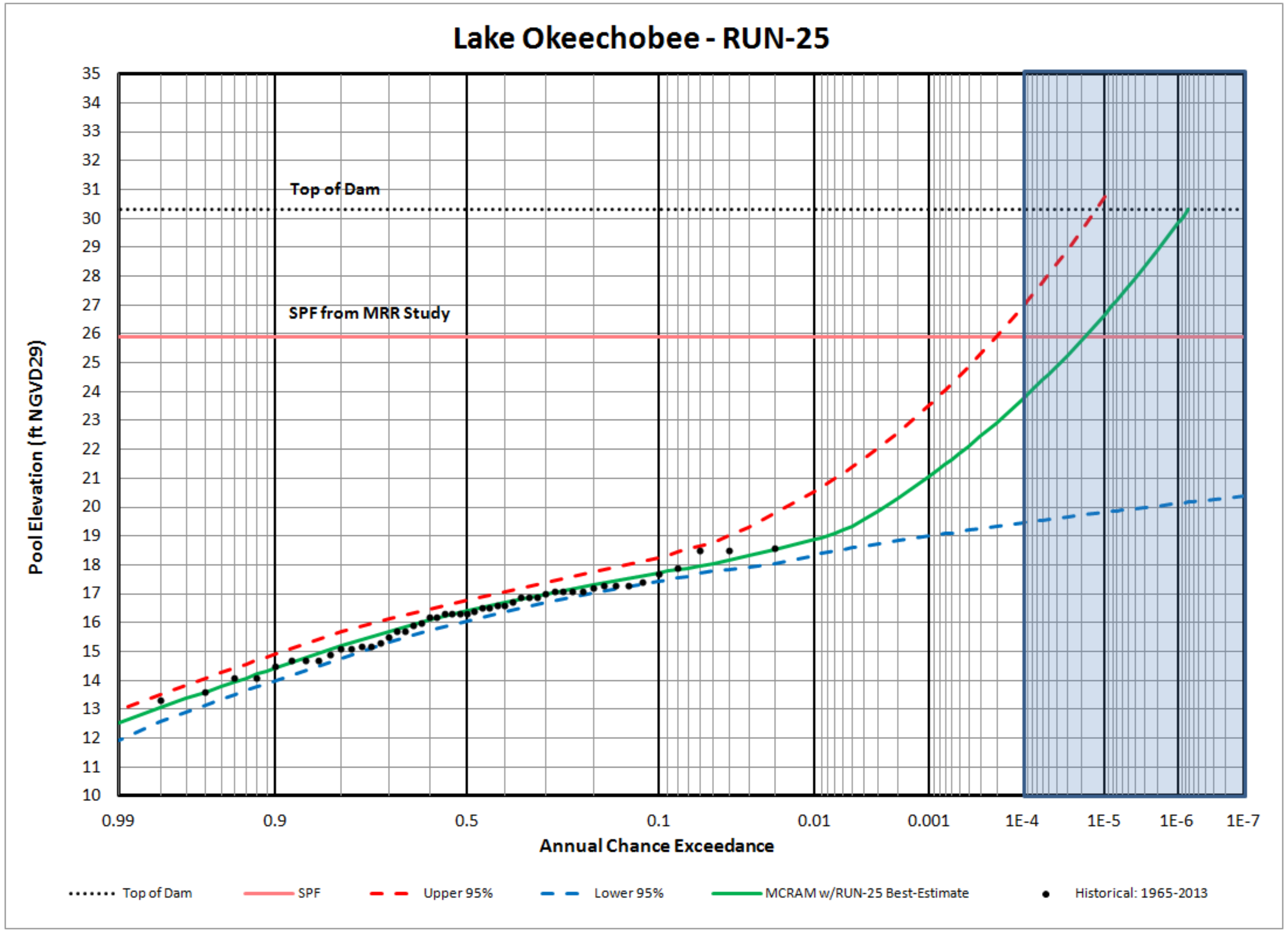
Leverage available data

- Observed stages
- Reconstruct historic events

No anchoring

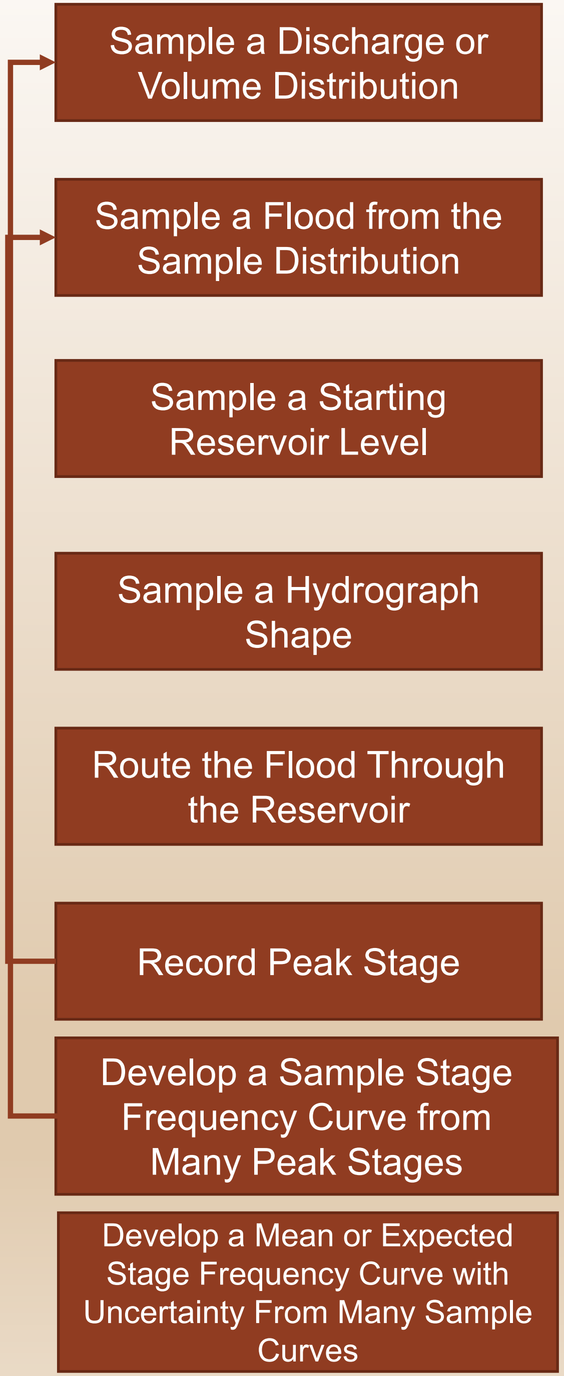
- Do not assign an AEP to the PMF to define the curve
- Ok to report the AEP of the PMF stage from the curve

Uncertainty



Stochastic Modeling

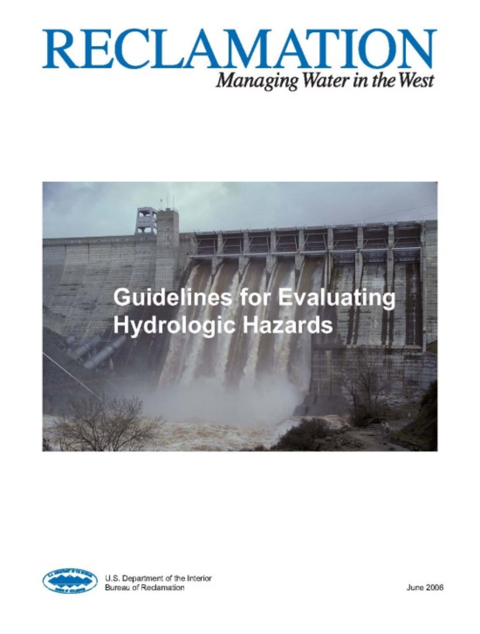
- Monte Carlo Simulation
- Used to combine uncertainties
  - Precipitation
  - Discharge or volume
  - Starting reservoir or river level
  - Hydrograph shape
  - Many others possible
- No single point estimates
- Some items are typically reserved for the event tree based on needs and preference
  - Gate reliability and debris blockage
  - Develop separate hazard curves for several assumed gate and debris scenarios
  - Address probabilities for the gates and debris scenarios in an event tree
  - Easier to attribute the contribution of gates and debris to project risk



Current Guidance on Hydrologic Hazard Estimation

Reclamation, USACE and FERC implementing and using similar methods for hydrologic hazards; some technical details on methods in these reports

Reclamation, 2006

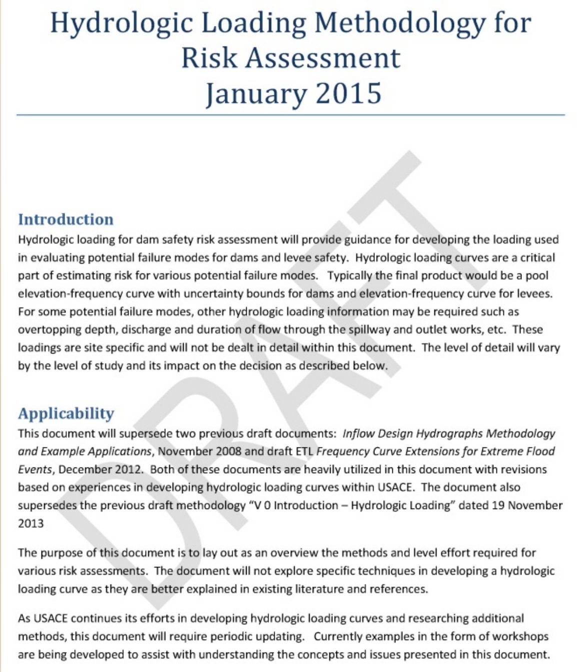

RECLAMATION
Managing Water in the West

Guidelines for Evaluating Hydrologic Hazards

U.S. Department of the Interior
Bureau of Reclamation

June 2006

USACE, 2015;
under development/revision


Hydrologic Loading Methodology for Risk Assessment
January 2015

DRAFT

Introduction

Hydrologic loading for dam safety risk assessment will provide guidance for developing the loading used in evaluating potential failure modes for dams and levee safety. Hydrologic loading curves are a critical part of estimating risk for various potential failure modes. Typically the final product would be a pool elevation-frequency curve with uncertainty bounds for dams and elevation-frequency curve for levees. For some potential failure modes, other hydrologic loading information may be required such as overtopping depth, discharge and duration of flow through the spillway and outlet works, etc. These loadings are site specific and will not be dealt in detail within this document. The level of detail will vary by the level of study and its impact on the decision as described below.

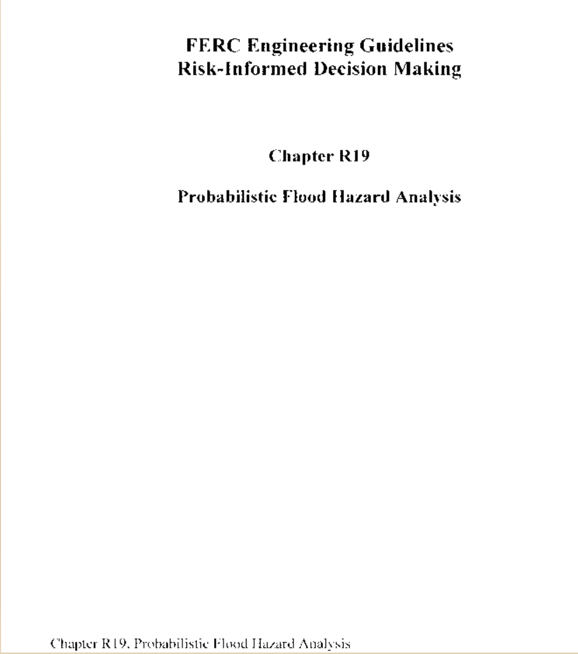
Applicability

This document will supersede two previous draft documents: *Inflow Design Hydrographs Methodology and Example Applications*, November 2008 and draft ETL *Frequency Curve Extensions for Extreme Flood Events*, December 2012. Both of these documents are heavily utilized in this document with revisions based on experiences in developing hydrologic loading curves within USACE. The document also supersedes the previous draft methodology "V 0 Introduction – Hydrologic Loading" dated 19 November 2013

The purpose of this document is to lay out as an overview the methods and level effort required for various risk assessments. The document will not explore specific techniques in developing a hydrologic loading curve as they are better explained in existing literature and references.

As USACE continues its efforts in developing hydrologic loading curves and researching additional methods, this document will require periodic updating. Currently examples in the form of workshops are being developed to assist with understanding the concepts and issues presented in this document.

FERC, 2014
draft for public

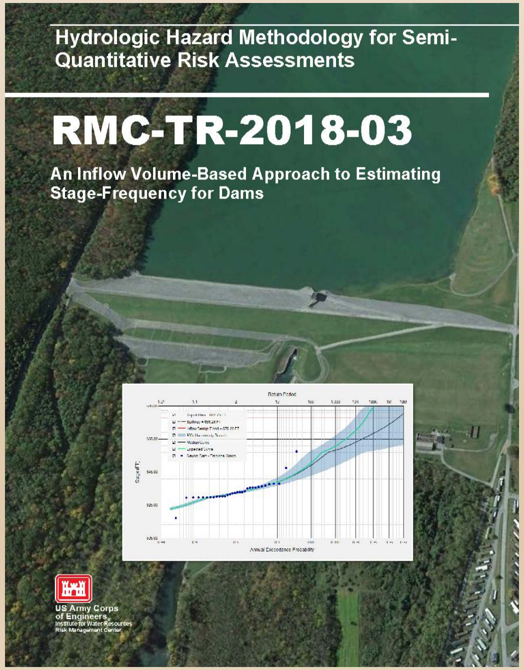

FERC Engineering Guidelines
Risk-Informed Decision Making

Chapter R19

Probabilistic Flood Hazard Analysis

Chapter R19. Probabilistic Flood Hazard Analysis

USACE, 2018;
SQRA


Hydrologic Hazard Methodology for Semi-Quantitative Risk Assessments

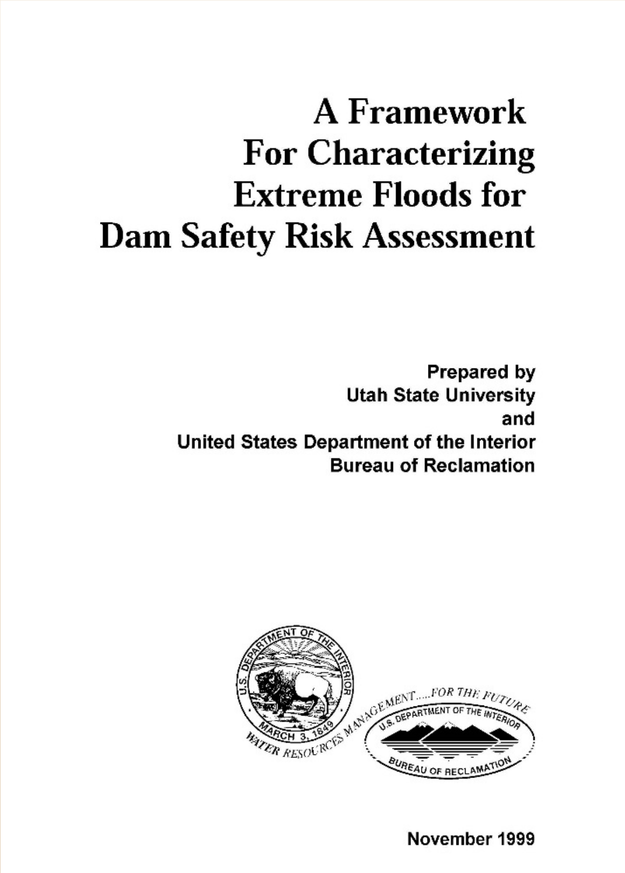
RMC-TR-2018-03

An Inflow Volume-Based Approach to Estimating Stage-Frequency for Dams

See Chapter References for links to documents

Hydrologic Hazard Guiding Principles

- No Single Approach Describes Flood Hazards Over the Range of AEPs Needed – *Multiple Methods: combine flow frequency curves and rainfall-runoff curves*
- Greatest Gains From Incorporating Regional Precipitation, Stream flow, Paleoflood Data – *Lots of Data*
- Honestly Represent Uncertainty – *Explicitly Quantify Uncertainty*
- Temporal Information: expand data in time
- Spatial Information: expand data in space
- Causal Information: utilize hydrological understanding of flood-producing processes
- Do Not Assign an AEP to the PMF

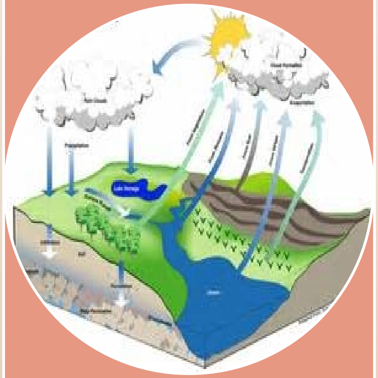

A Framework
For Characterizing
Extreme Floods for
Dam Safety Risk Assessment

Prepared by
Utah State University
and
United States Department of the Interior
Bureau of Reclamation

November 1999

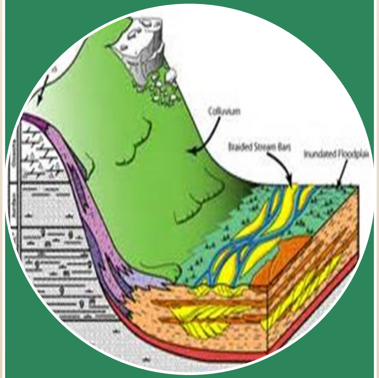
Expertise

Meteorology



Hydrology

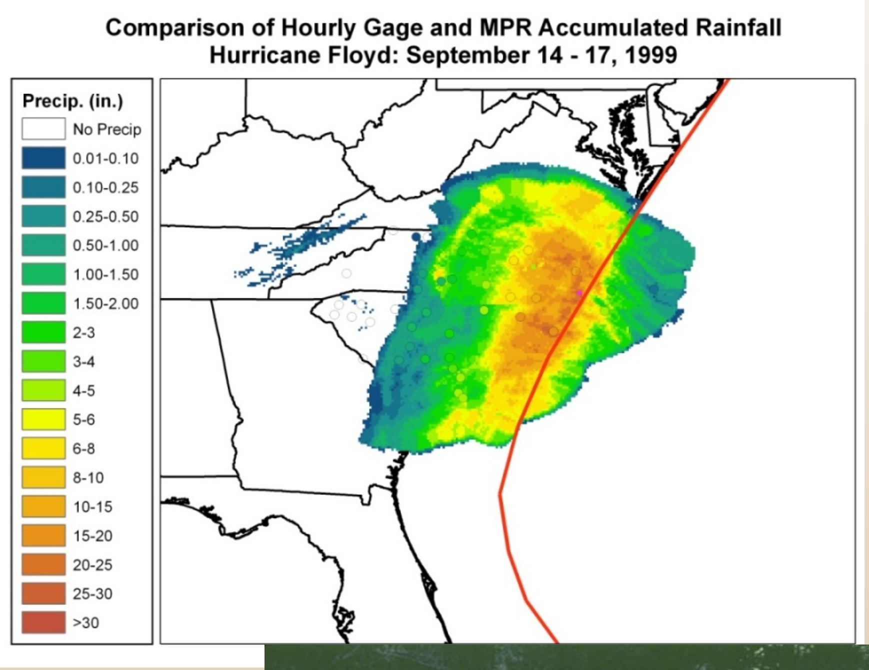
Statistics



Paleoflood

Interdisciplinary Skills Needed

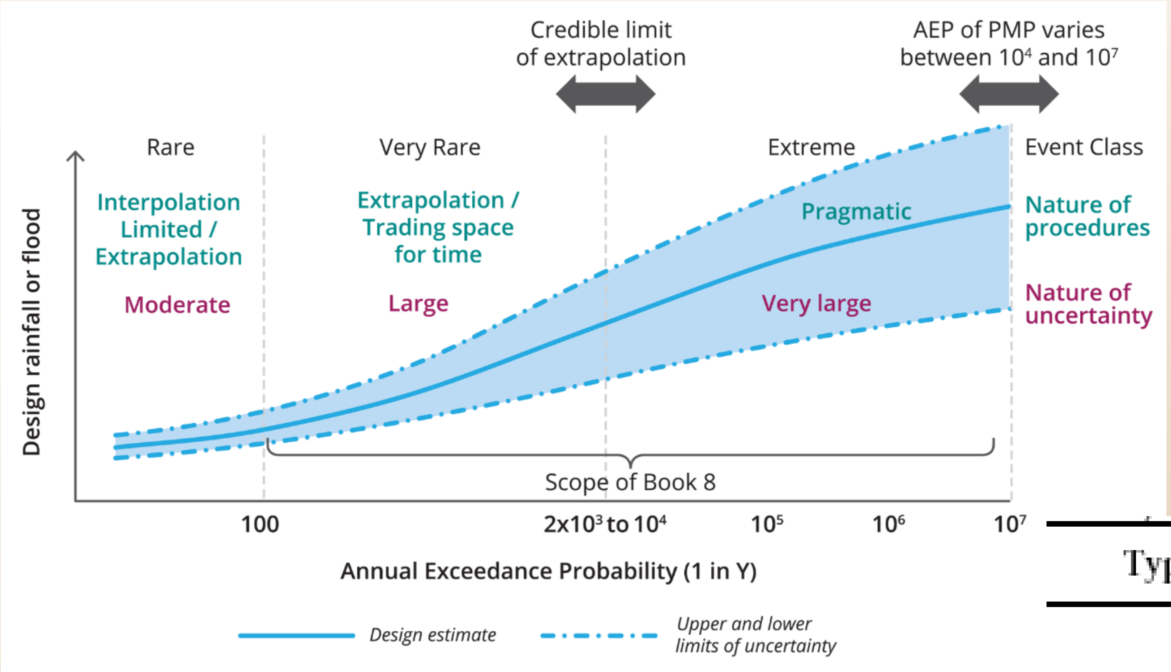
Storm Types and Processes



Brook, a small tributary of Connecticut River, at Suffield, Conn., the morning of August 19, 1955. Photograph by Roger C. Loomis.

Examples
Hurricanes and TCs – Eastern US
Convective Thunderstorms - Flash floods

Credible Extrapolation



USBR - USU (1999), Swain et al. (2006)

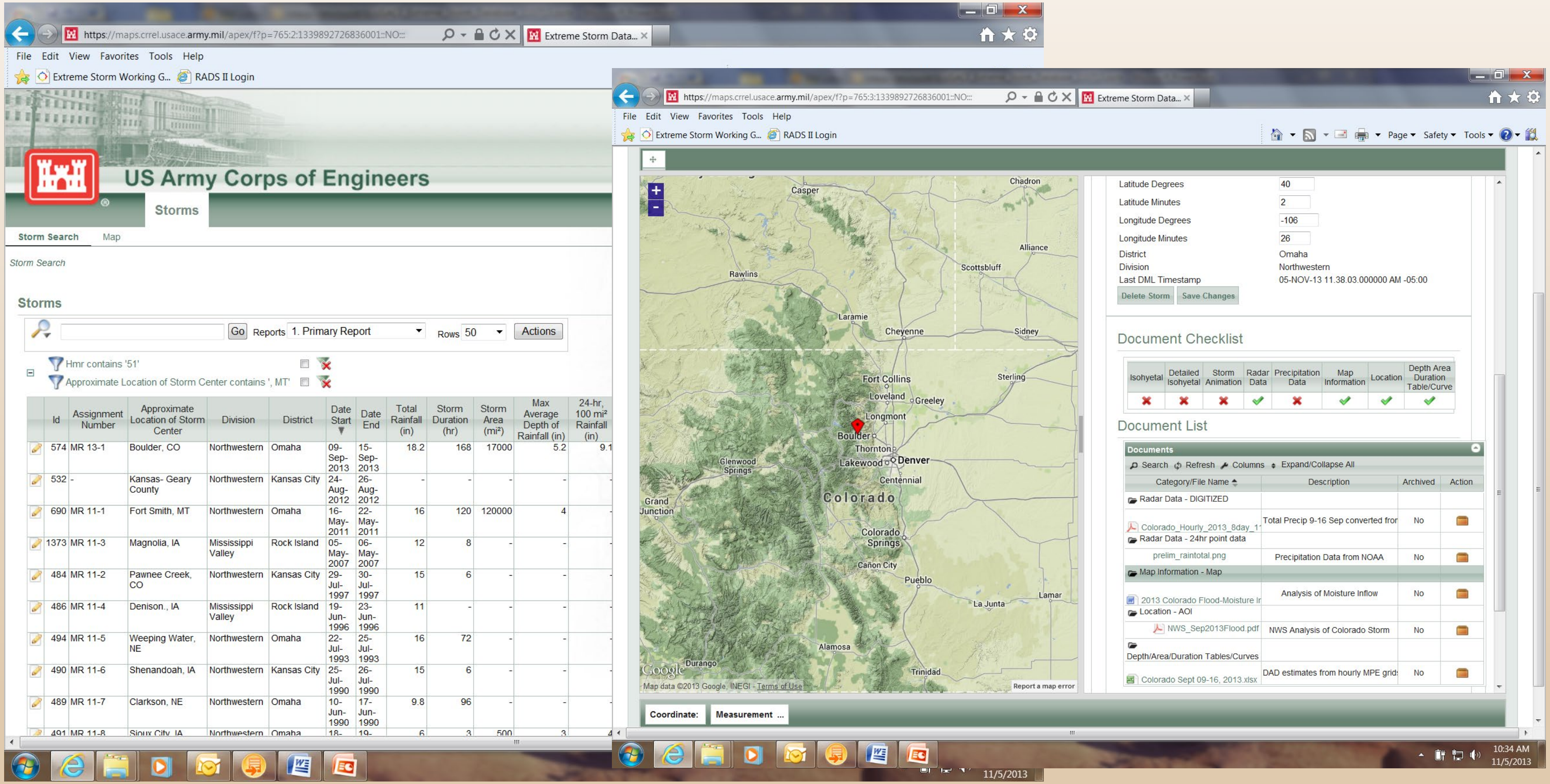
Also in: Australian Rainfall & Runoff (2016) Book 8 Estimation of Very Rare to Extreme Floods by Nathan and Weinmann
http://arr.ga.gov.au/

Type of data used for flood frequency analysis	Range of credible extrapolation for Annual Exceedance Probability	
	Typical	Optimal
At-site streamflow data	1 in 100	1 in 200
Regional streamflow data	1 in 500	1 in 1,000
At-site streamflow and at-site paleoflood data	1 in 4,000	1 in 10,000
Regional precipitation data	1 in 2,000	1 in 10,000
Regional streamflow and regional paleoflood data	1 in 15,000	1 in 40,000
Combinations of regional data sets and extrapolation	1 in 40,000	1 in 100,000

Data Sources

- Extreme Rainfall Data
  - NCDC gages
  - Depth-Area Duration storm catalog from USACE, Reclamation, NWS
  - MPE and MPR gridded precip (NWS)
- Extreme Flood Data
  - USGS stream gages: peaks, hydrographs
  - Historical information (photos, eye witness accounts, newspapers, flood reports
  - Paleoflood data
- Snow Data
  - Snow Course, SNOTEL, SNODAS
- Climate Data
  - Projections and models
  - CMIP5 Downscaled archive

Hydrologic Hazard – Extreme Storm data



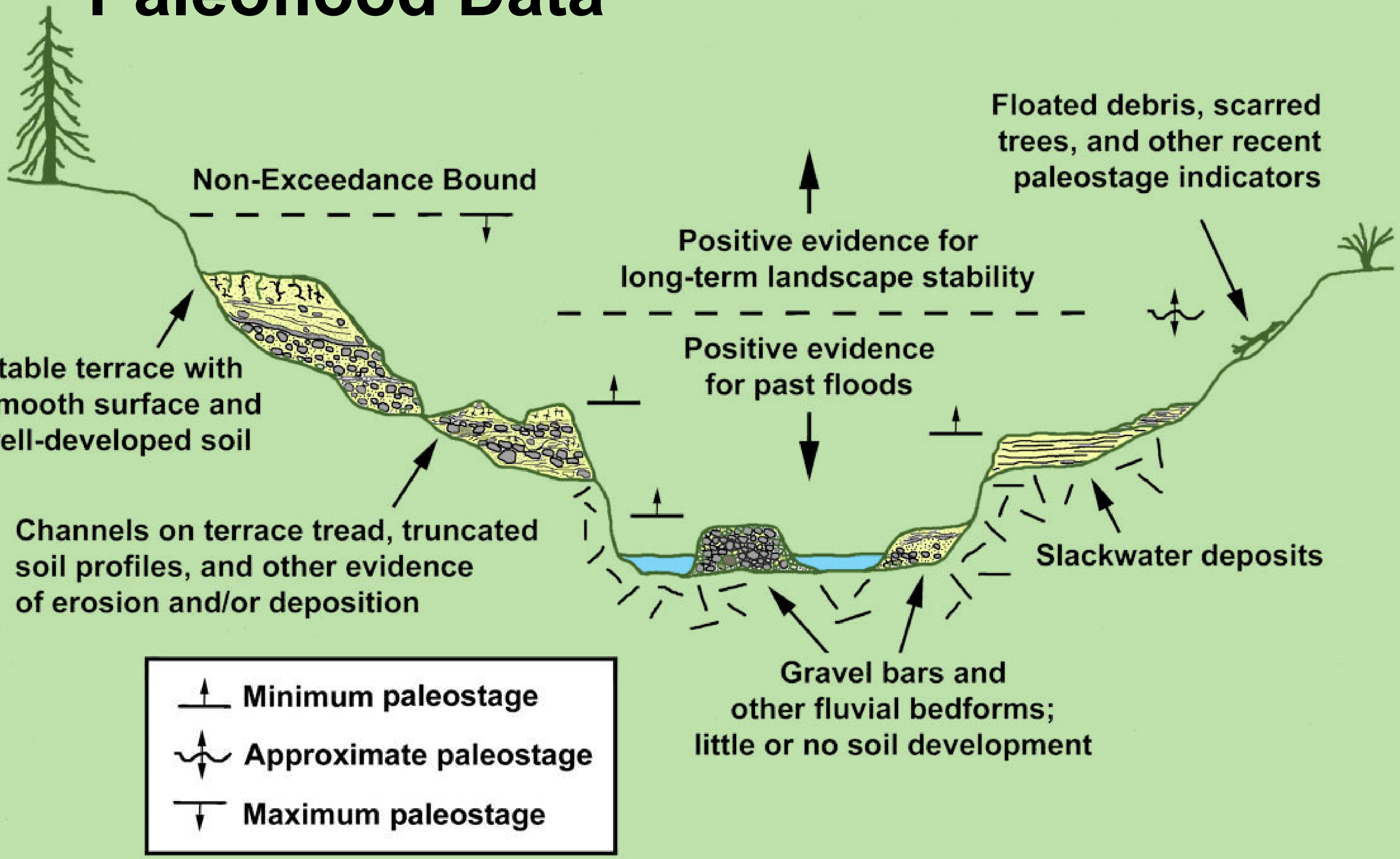
Hydrologic Hazard Data – Peak Flows

Battle Creek, Shasta County, CA: Dec. 22, 1964

Wind River near Crowheart, WY: Jul. 01, 2011

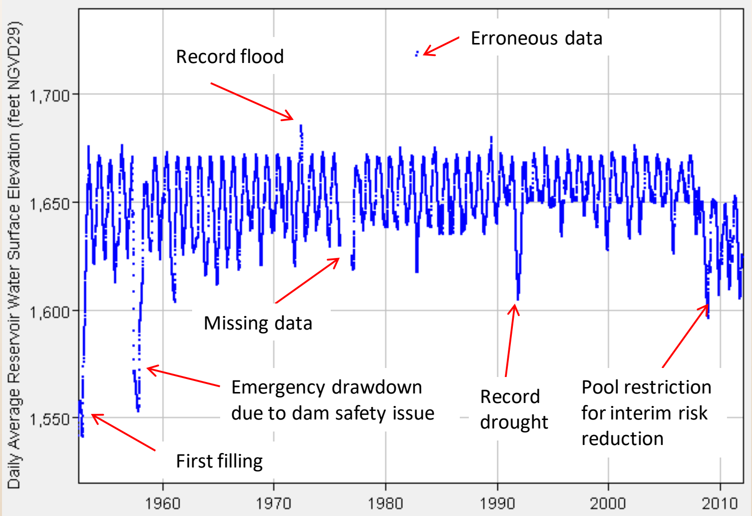
USGS National Water Information System and flood studies

Paleoflood Data



House et al. (2002) AGU Paleoflood Monograph

Data Acquisition and Evaluation



- Understand data source (collection interval, what is being measured)
  - Daily average, peak, something else
  - Recorded (stage) or calculated (computed from observed stage using a rating curve)
- Check for missing data, data shifts, and erroneous data
- Check that data is representative of conditions assumed for the risk analysis

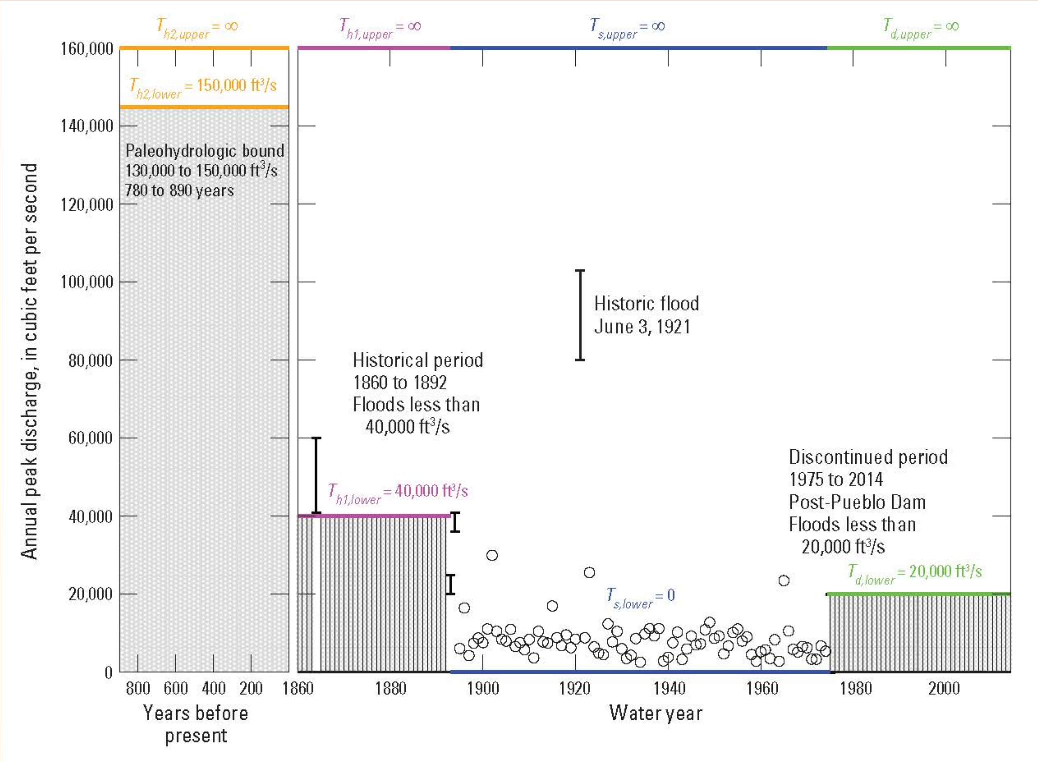
Hydrologic Hazard Methods- Stream flow

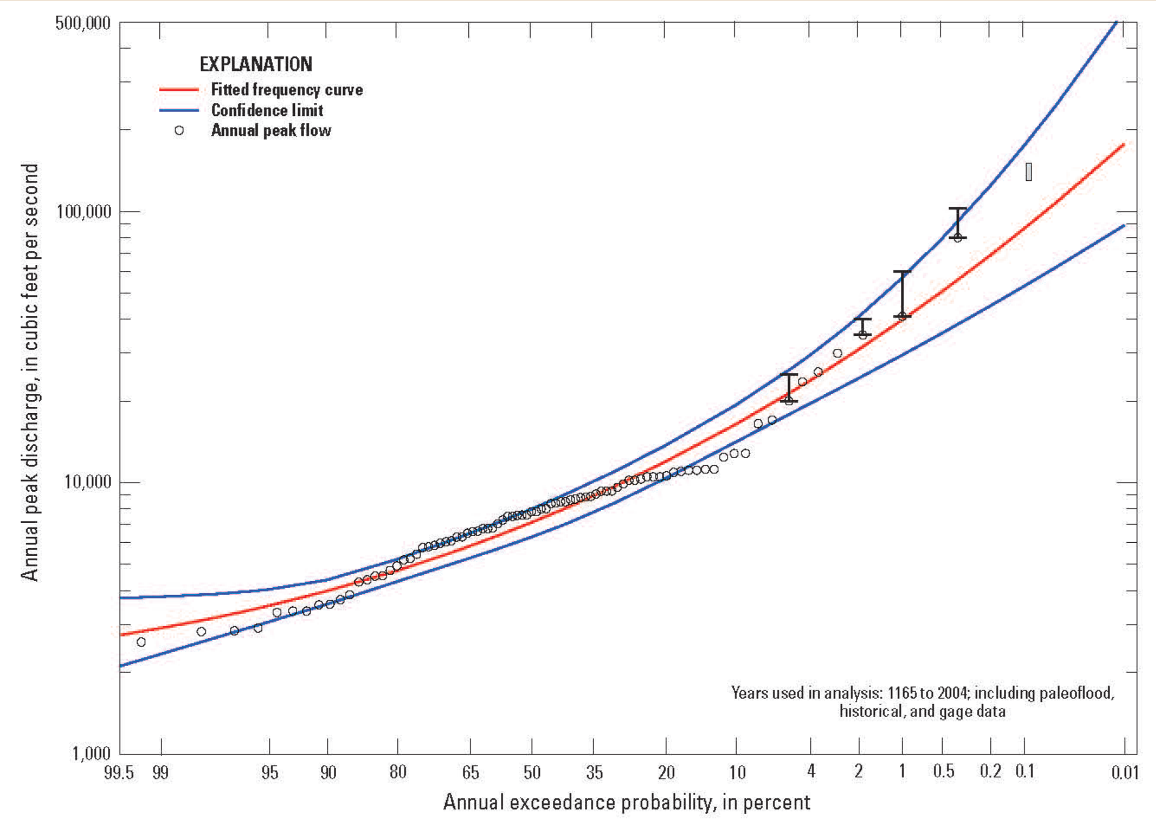
Method *(Agency)*	**Description *(reference)***	**Inputs**	**Assumptions**	**Hydrologic Hazard Curve**	**Why Choose**	**Level of Effort**
Bulletin 17C (EMA-LP-III) USGS PeakFQ; HEC-SSP *(USACE, USBR, FERC)*	Peak-flow and volume frequency analysis with historical/paleoflood data - EMA (*Cohn et al., 1997; England et al., 2018*)	Peak flow, historical data, paleoflood data, regional skews	LP-III flood frequency distribution with moments and regional skew	Peak flow frequency and confidence intervals; Volume Frequency	Federal guidelines for flood frequency; uses historical and paleoflood data when available	Low to moderate
FLDFRQ3 *(USBR)*	Bayesian Peak-flow frequency analysis with historical/paleoflood data - FLDFRQ3 (*O'Connell et al., 2002*)	Peak flow, detailed paleofloods	Various flood frequency distributions with likelihood	Peak flow frequency and confidence intervals	Detailed paleoflood data available; need FFA confidence intervals, choice of distribution	Low to moderate
Hydrograph Scaling *(USACE and USBR)*	Balanced Hydrographs and Pattern Scaling (*England, 2003, Smith et al., 2018*)	Hydrographs and volumes	Hydrographs represent extreme flood response; requires FFA for scaling	Hydrographs and volumes; based on peak flow and volume frequency	Ratios of the IDF hydrograph and statistically based balanced and patterned hydrographs	Low
Reservoir Frequency Analysis (RMC-RFA) *(USACE)*	Streamflow Volume Stochastic Modeling with reservoir routing *(Smith, 2018)*	Volume frequency, hydrographs, flood season, initial reservoir stage	Inputs defined by distributions, volume-frequency, observed hydrographs, and pool duration frequency	Reservoir elevation and confidence intervals	Monte-Carlo methods to sample inputs; combine inflows and routing, quantify uncertainty	Low to Moderate
Watershed Analysis Tool (HEC-WAT) *(USACE)*	Streamflow Volume Stochastic Modeling for Flood Risk Analysis with HEC-ResSim (within HEC-WAT)	Pool duration, volumes, and Hydrographs	Inputs defined by distributions, volume-frequency observed hydrographs, and pool duration frequency	Reservoir elevation and confidence intervals	Monte-Carlo methods to sample inputs; quantify uncertainty; system/downstream effects with coincident frequency	High

Bulletin 17C Streamflow - Example

Arkansas River at Pueblo, CO – record flood (1921), historical and paleoflood data, reservoir records

- 1,000 years of at-site flood information; additional data at 3 upstream sites spanning several thousand years





Hydrologic Hazard Methods: Rainfall-Runoff

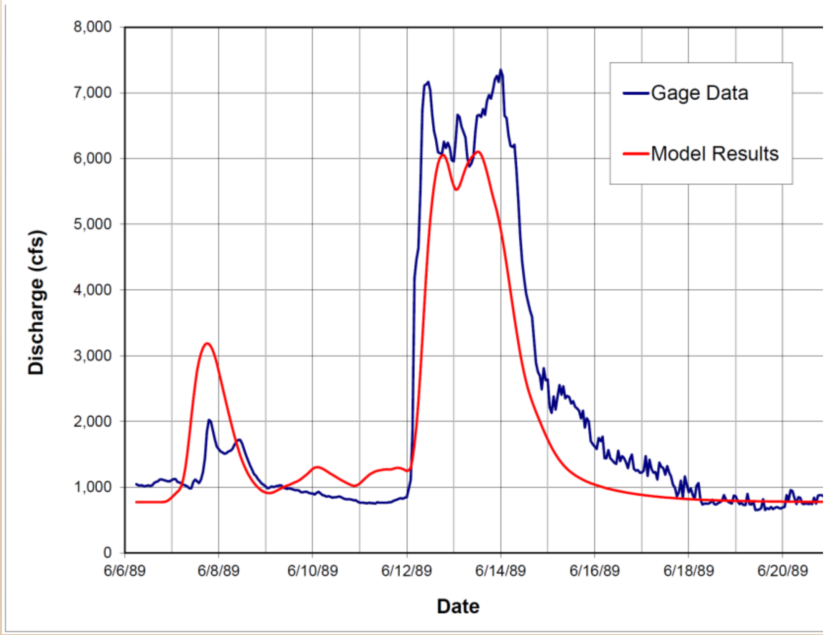
Method *(Agency)*	**Description (*reference*)**	**Data Inputs**	**Assumptions**	**Hydrologic Hazard Curve Product**	**Why Choose**	**Level of Effort**
Australian Rainfall-Runoff *(USBR, FERC)*	Australian Rainfall-Runoff Method (*Nathan and Weinmann, 1999*)	PMP design storm; rainfall frequency; watershed parameters	Exceedance Probability of PMP; average watershed parameter values; runoff frequency same as rainfall frequency	Peak flow and hydrographs; based on rainfall frequency and PMP	Similar runoff model as PMP/PMF; familiar design concepts	Moderate to High
SEFM *(USBR, FERC)*	Stochastic Event-Based Precipitation Runoff Modeling with SEFM (*MGS,2005, MGS, 2009; Schaefer and Barker, 2002*)	Rainfall gages/ detailed regional rainfall frequency, watershed parameters, snowpack, reservoir data	Main inputs defined by distributions; unit hydrograph; rainfall frequency using GEV/L-moments	Peak flow frequency; hydrographs; volume frequency; reservoir elevation frequency	Monte-Carlo methods to sample input distributions	High
HEC-WAT *(USACE and USBR)*	Watershed analysis tool coupling rainfall-runoff model (HEC-HMS), river routing (RAS), and reservoir operations for system-wide basin flood studies	Can be Regional extreme storm DAD data or meteorlogic extreme storm data, watershed parameters, snowpack	Main inputs defined by distributions; unit hydrograph; rainfall frequency using GEV/L-moments or weather generator	Monte Carlo inputs and resampling; Reservoir elevation (pool) frequency curves, flood volumes, and hydrographs	Flexible framework for system-wide flood modeling with coupled components	High

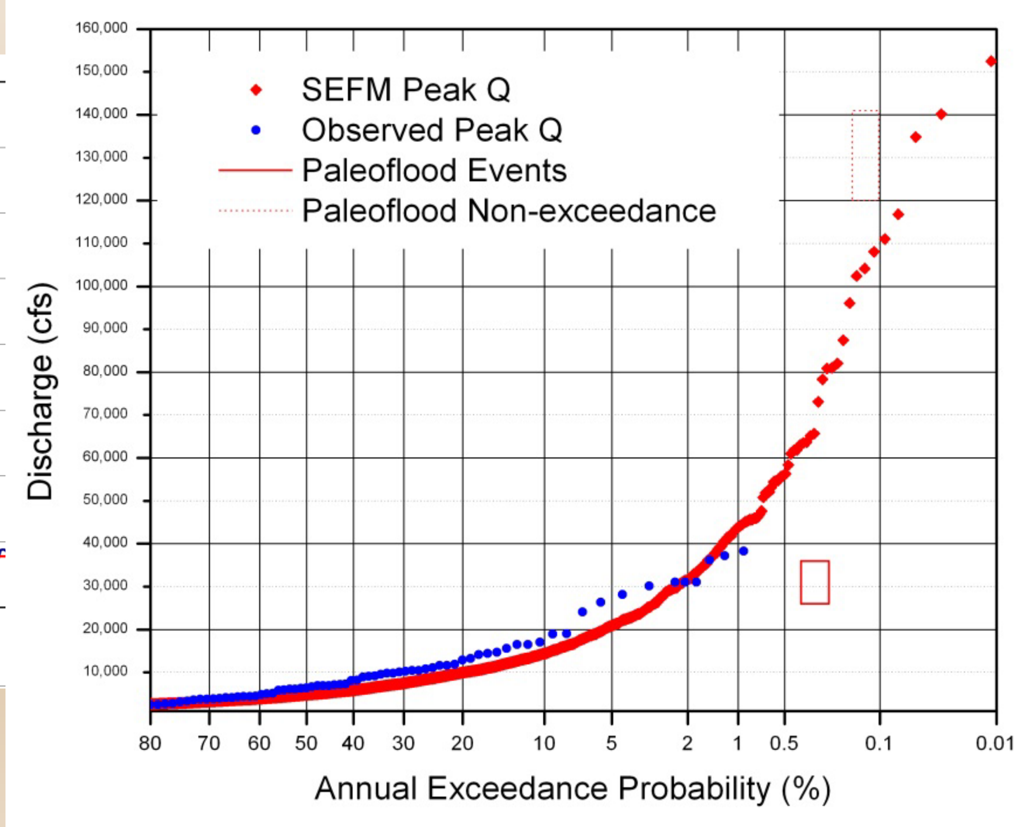
Hydrologic Hazard Methods
Rainfall-Runoff after NRC (1988)

- Construct a space-time extreme *rainfall* model
  - ***rainfall probability distribution biggest factor***
  - *Stochastic Storm Transposition*
  - *Regional Extreme Precipitation Frequency Analysis*
- Generate several large storms from model
- Model "deterministic" rainfall-runoff transformation
- Monte-Carlo Simulation
  - Hazard curves for flood peaks, volumes, reservoir stages and Uncertainty

Rainfall-Runoff Calibration and Weighting

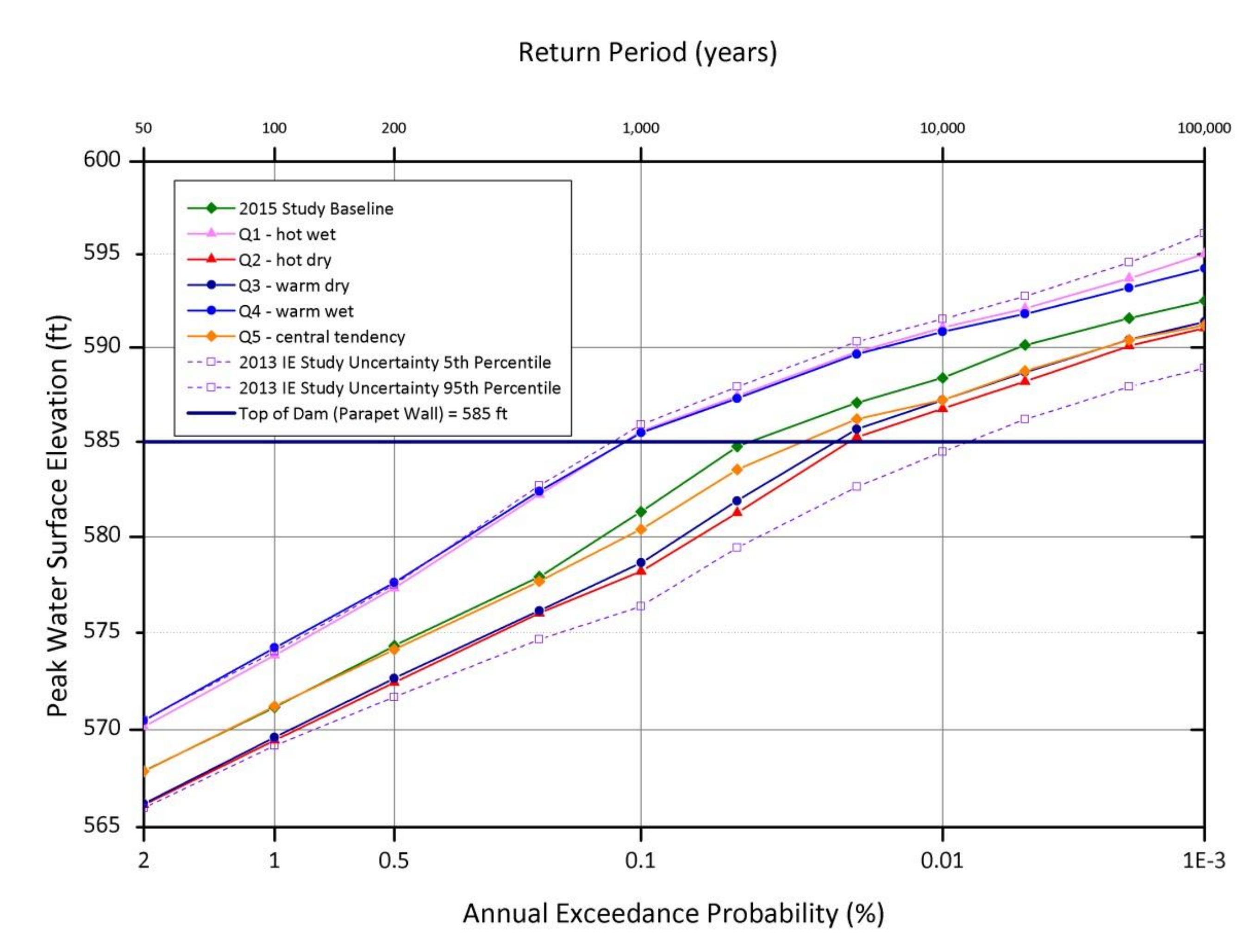
Calibrate model results to observed hydrographs and estimated frequency curves (peak/volume) to determine best model input parameters and distributions



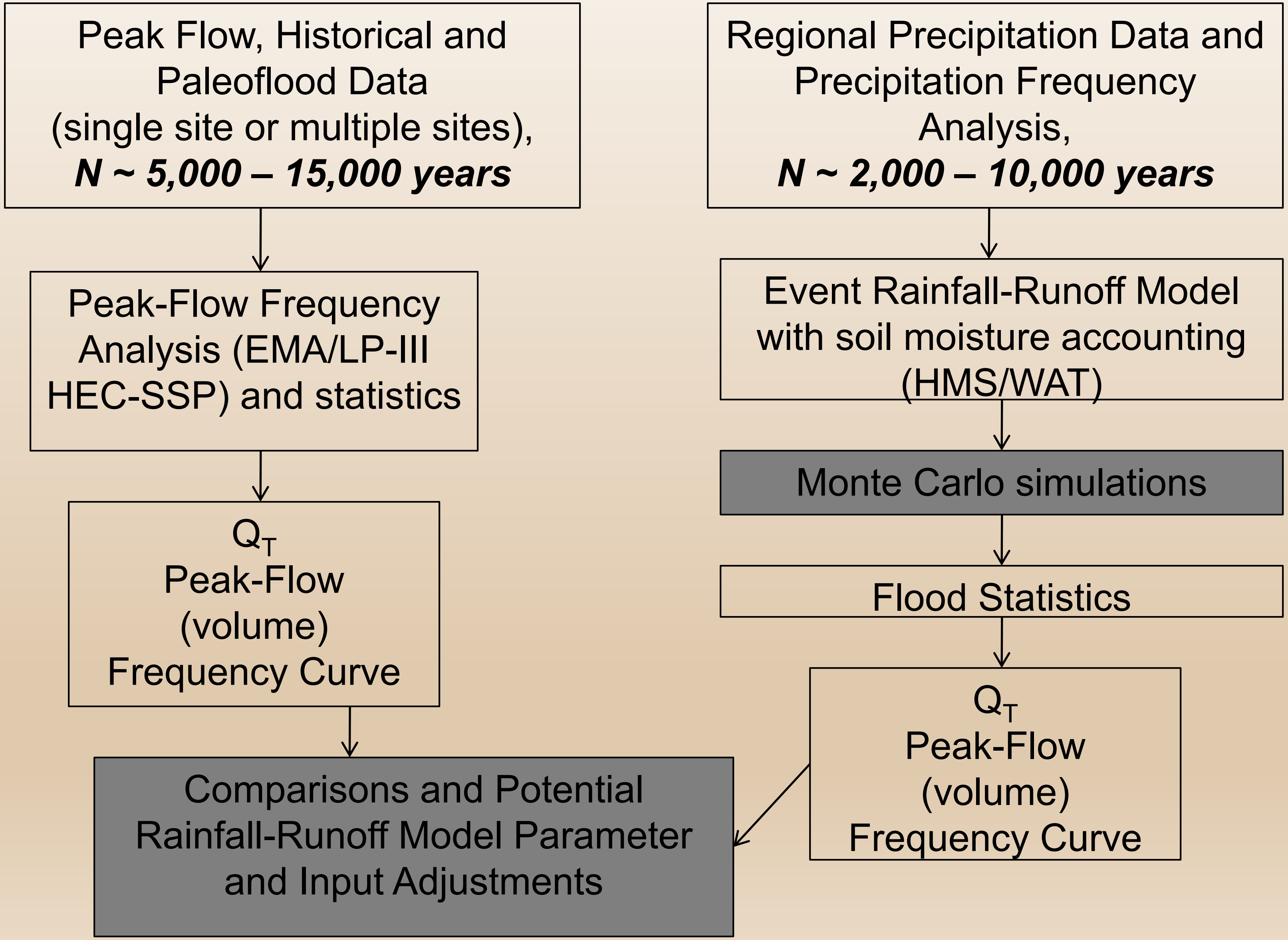


Represent Uncertainty

- Uncertainty of peak flow frequency with paleofloods
- Uncertainty of basin-average rainfall frequency
- Variation in rainfall-runoff parameters and inputs
- Include future Climate projections



Hydrologic Hazard
Multiple Methods, Data and Extrapolations

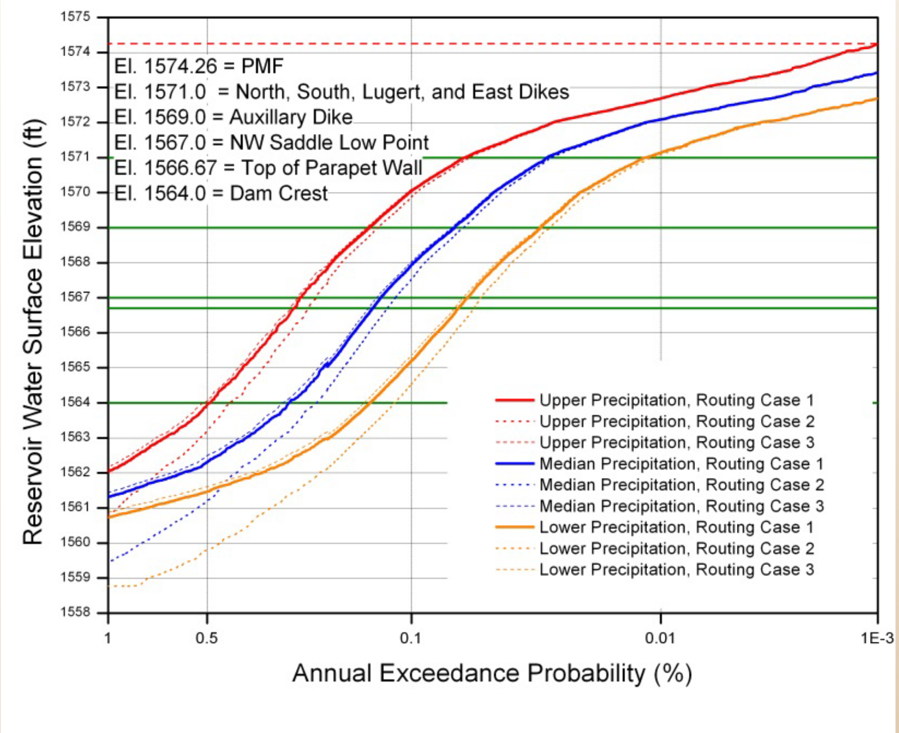


Hydrologic Hazard Methods
Scalable Effort

Hydrologic Hazard estimates are typically made for three levels of risk informed decisions. Data and methods depend on type of study:

- Periodic Assessments/Comprehensive Reviews
  - Screening-level/qualitative information used
- Issue Evaluation Studies
  - Increased regional data collection and level of detail
- Corrective Action/Dam Safety Modification Studies
  - additional site-specific data collection
  - advanced modelling efforts
  - Monte-Carlo rainfall-runoff modelling
  - expert elicitation

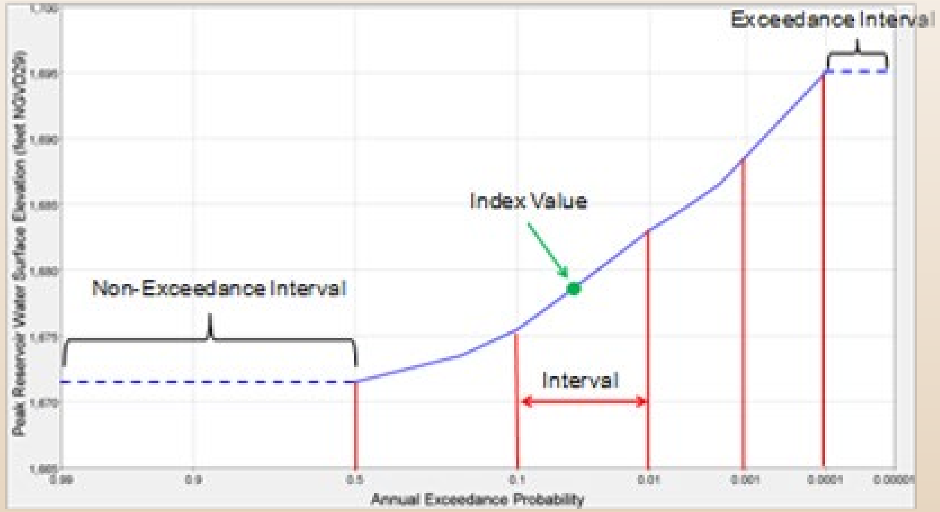
Hydrologic Hazards for Risk Analysis - Inputs

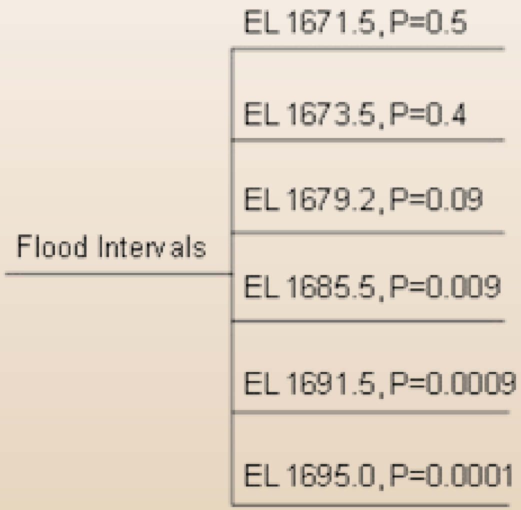


P_l = Probability of Load –
Hydrologic Hazard Curve (Reservoir Elevation)

$P_{r|l}$ = Probability of Response Given Load (Depth above Dam Crest)

Flood Event Tree Partitions





Elevation			Probability		
Lower Bound	Upper Bound	Index Value	Lower Bound	Upper Bound	Probability
n/a	1671.5	1671.5	1	0.5	0.5
1671.5	1675.5	1673.5	0.5	0.1	0.4
1675.5	1683.0	1679.2	0.1	0.01	0.09
1683.0	1688.0	1685.5	0.01	0.001	0.009
1688.0	1695.0	1691.5	0.001	0.0001	0.0009
1695.0	n/a	1695.0	0.0001	0	0.0001

Questions?

Folsom
Joint Federal Project
Sacramento, CA

Reclamation and USACE Partnership

New spillway for improved flood control