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Managing Water in the West

Extending Flood Frequency Curves Beyond Current Consensus Limits

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Introduction

- This project provides information the NRC can use to develop guidance for extending frequency analysis methods beyond current consensus limits for both rainfall and riverine flooding applications.
- The focus is describing methods used by Reclamation to estimate flood loadings, which have been developed over the past 20 years. Case studies exemplifying these approaches are also included.
- Uncertainty characterization and quantification is also a focus of this project.

Flood Loadings to Support Reclamation Dam Safety Risk Activities

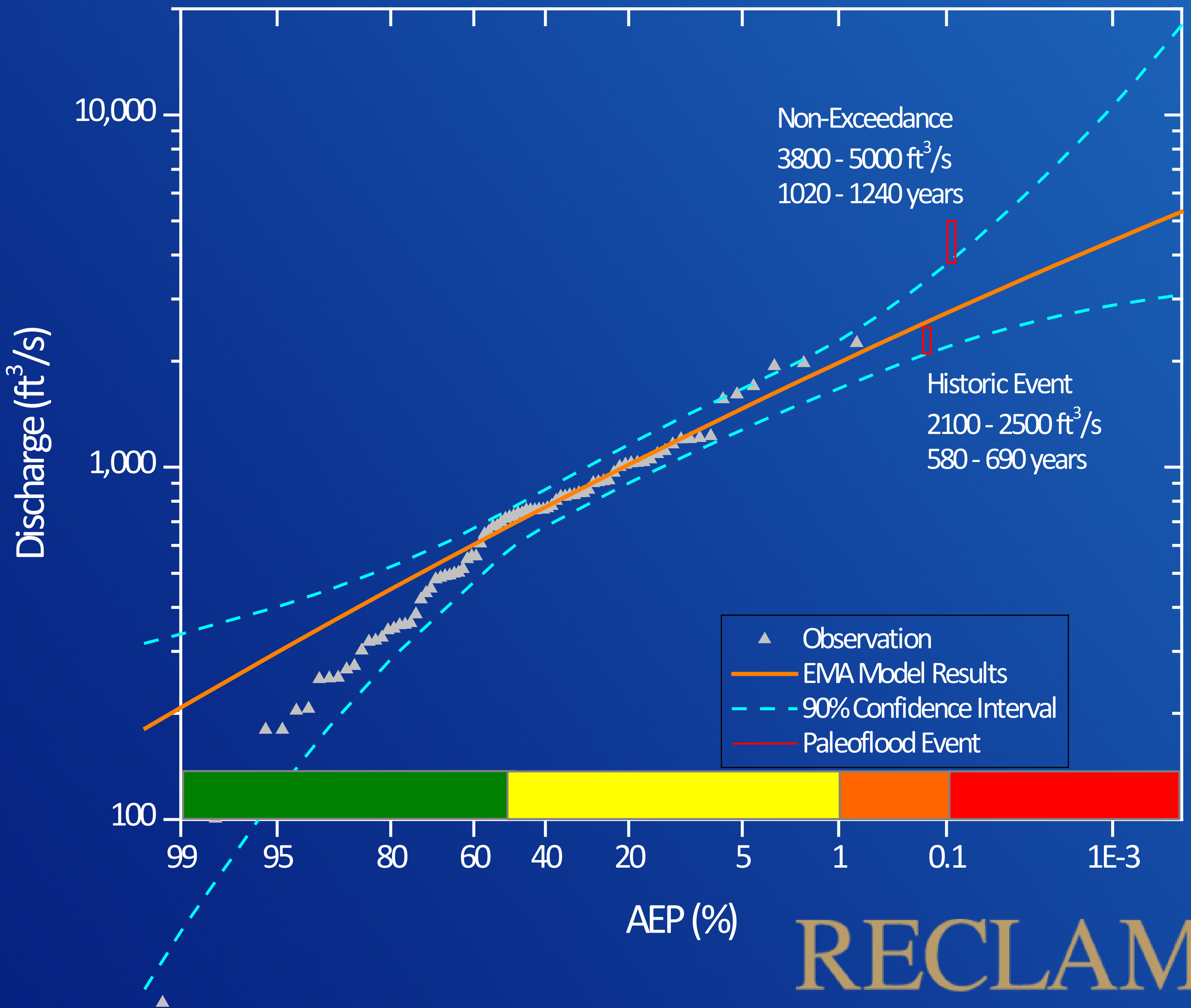
From a hydrologic perspective, risk estimates require an evaluation of a full range of hydrologic loading conditions and possible failure mechanisms tied to consequences of failure.

Hydrologic hazard curves combine peak flow, water surface elevation, duration thresholds, and volume probability relationships plotted with respect to their AEPs.

Flood loadings and associated flow and stage frequency hydrographs are used to assess the risk of potential hydrologic-related failure modes.

Reclamation primarily focuses on medium to large catchments in the Western U.S.

Flood Frequency Extrapolation



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Credible Extrapolation

Type of Analysis	Typical Range	Range (Best)
At-Site Stream Gage	1 in 100	1 in 200
Regional Stream Gages	1 in 500	1 in 1,000
At-Site Stream Gage combined with 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 Datasets and Extrapolation	1 in 40,000	1 in 100,000

Reclamation & Utah State University (1999), Reclamation (2006)

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Level of Effort

The goal of any hydrologic analysis is to provide hydrologic information to the necessary level to make effective dam safety decisions. The available data, possible analysis techniques, resources available, and needs of the decision influence the selection of method(s) used.

Method	Level of Effort	Benefits	Limitations
Graphical Flood Frequency	Low (CR, IE, CAS, FD)	Conservative, incorporates paleoflood information	Estimates far beyond credible extrapolation, conservative
EMA/FLDFRQ3	Low (CR, IE, CAS, FD)	Better estimate of uncertainty, incorporates paleoflood information	Estimates often extended beyond credible extrapolation
Australian Rainfall-Runoff	Low (CR, IE)	Rarer events, very conservative (pragmatic)	Primarily intended for largely deterministic design use, very conservative
GRADEX	Moderate (CR, IE)	Rarer events, conservative	Assumption of all rainfall to runoff, little physically-based modeling
Regional Precipitation Frequency	Moderate (IE, CAS, FD)	Better estimated of uncertainty, still conservative	Improved estimate of precipitation frequency, limited by AEP neutrality
Stochastic Rainfall-Runoff Modeling	High (IE, CAS, FD)	Currently the best estimate of uncertainty, uses information from statistical frequency methods, physical understanding of driving factors/ processes	Extremely rare extrapolation is still uncertain and full range of aleatory variability and epistemic uncertainty is not understood, difficulties calibrating to extreme events

Data Sources

The sources of information used for flood hazard analyses include streamflow, precipitation, and paleoflood data.

Data Source	Level of Effort (Cost)	Analyses
Public Data Sources - Precipitation (e.g. NOAA, PRISM, NCEI)	Low (generally free)	Precipitation frequency (L-moments, Bayesian); storm templates
Public Data Sources – Gaging Stations (e.g USGS, Reclamation)	Low (generally free)	EMA, FLDFRQ3, rainfall-runoff modeling, graphical approach
Public Data Sources – GIS (e.g USGS, NRCS, states)	Low (generally free)	Rainfall runoff-modeling
Regional Paleoflood Information	Moderate (generally free)	EMA, FLDFRQ3, graphical approach
Site-Specific Paleoflood Stratigraphy	Moderate (moderate)	EMA, FLDFRQ3, graphical approach
Detailed Paleoflood Information	High (high)	EMA, FLDFRQ3, graphical approach
LiDAR Collection	High (high)	Paleoflood information, H&H modeling

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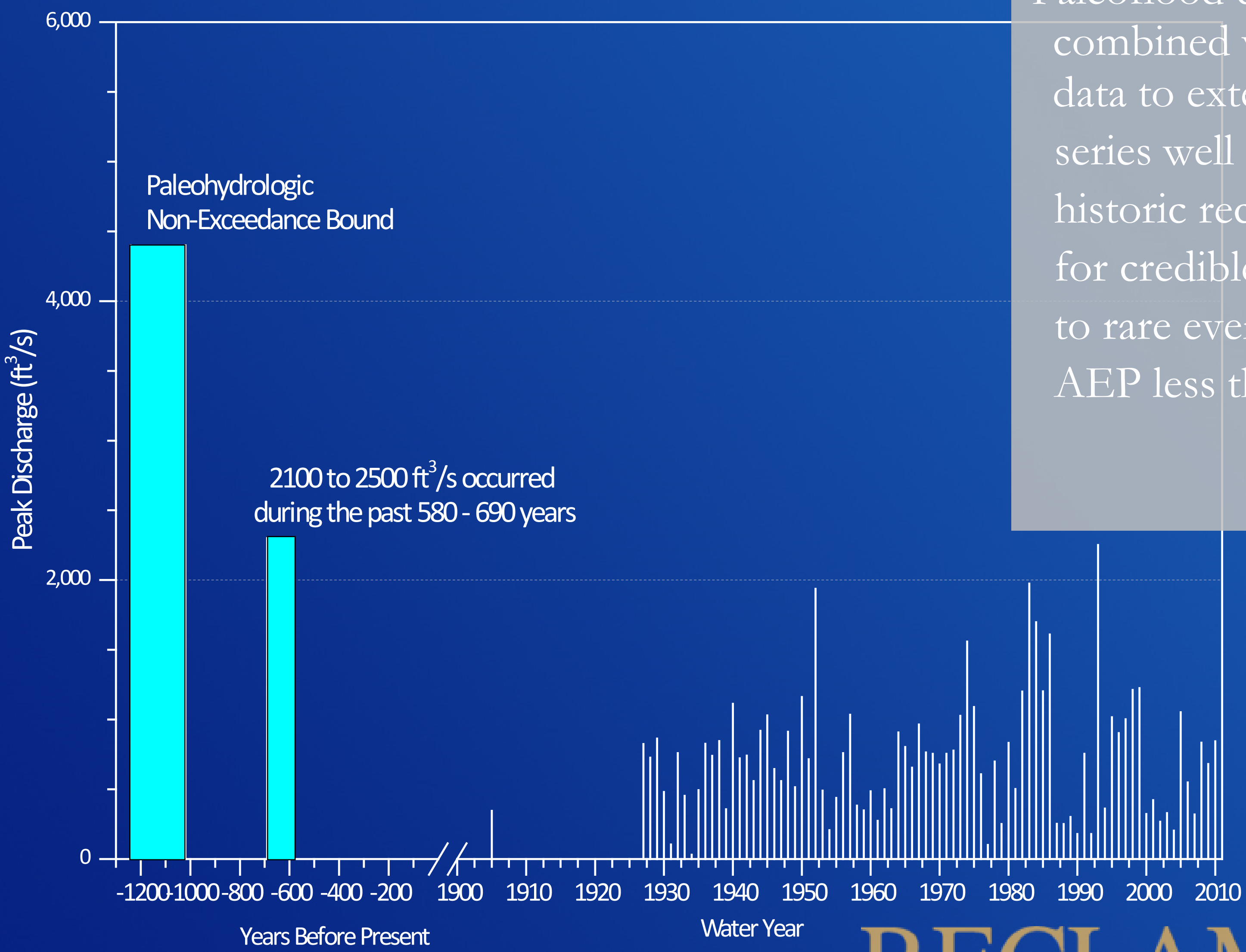
Incorporating Paleoflood Data



Paleoflood data can be combined with stream gage data to extend the time series well before the historic record. This allows for credible extrapolation to rare events having an AEP less than .01 %

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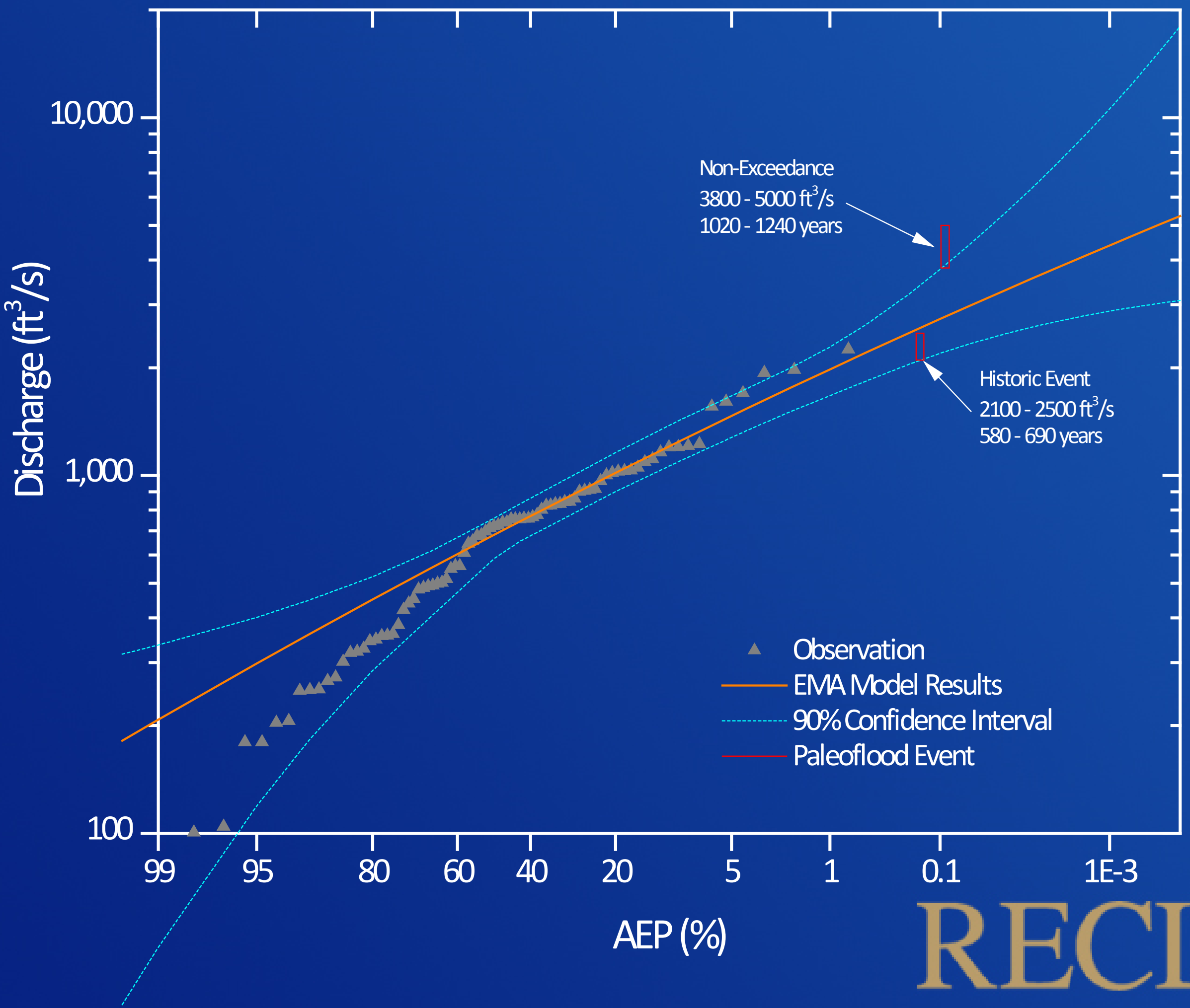
Low Level Analyses

Reclamation will typically spend 5-10 days for some preliminary analyses (CRs, feasibility level, etc). This often includes EMA with regional paleoflood information. ARR (frequency PMF) is often used to deal conservatively estimate beyond credible extrapolation.



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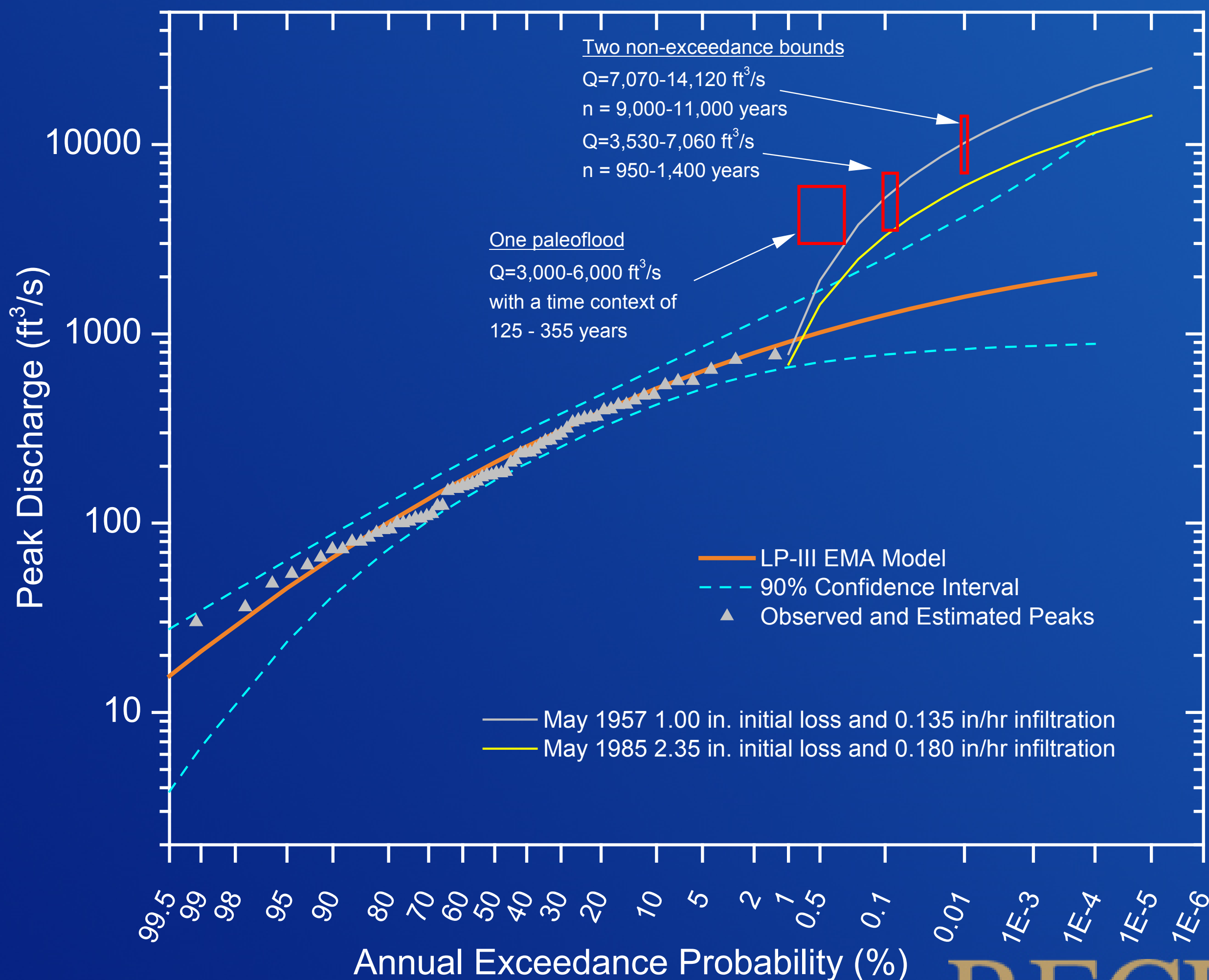
Moderate Level Analyses

15-45 day efforts are often applied to Issue Evaluation, Corrective Action, and Final Design studies (and some high level Comprehensive Reviews).



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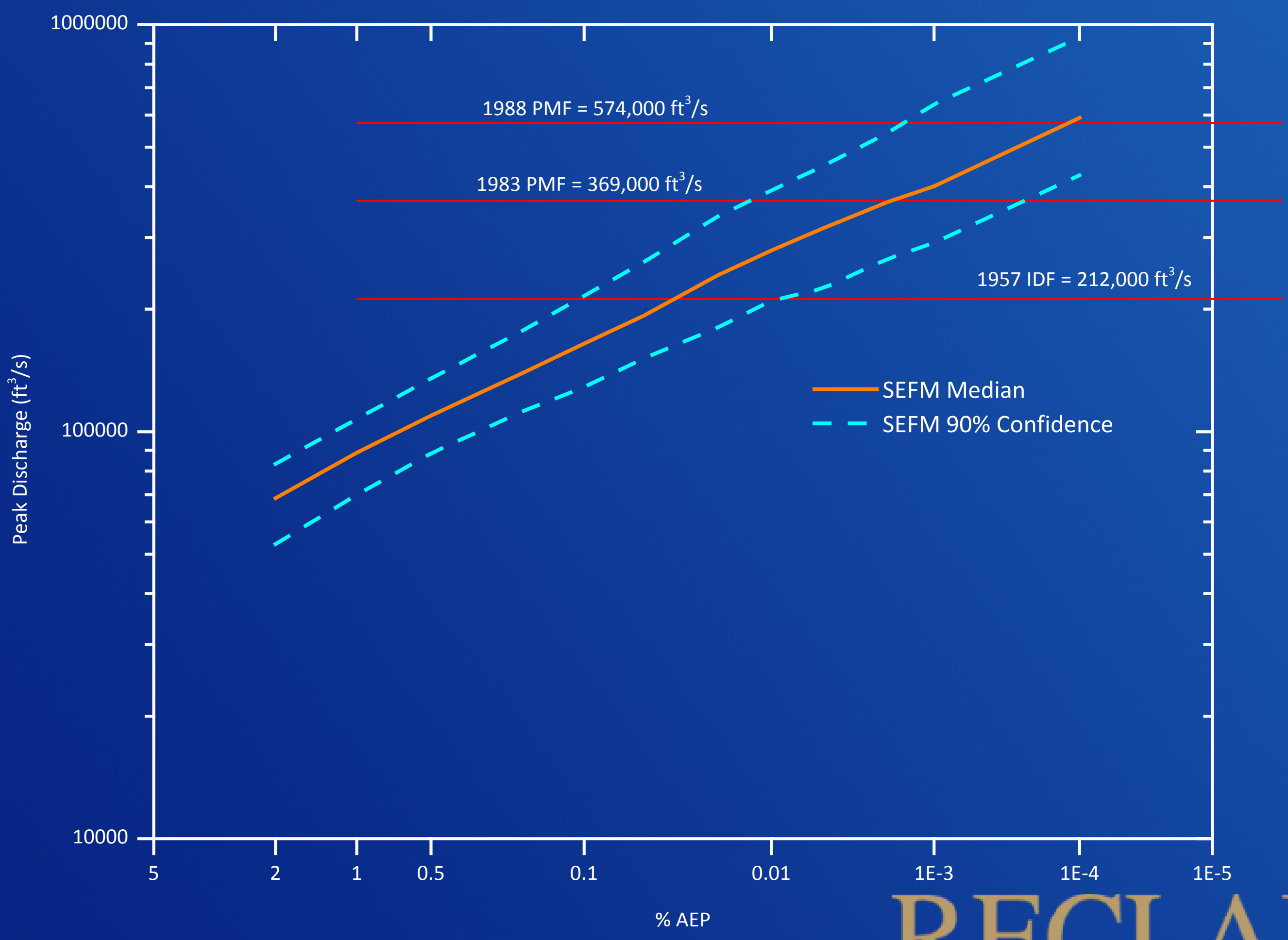
High Level Analyses

When the hydrologic risk at a facility may require expensive mitigation (i.e. operations, mechanical, construction risk reduction measure alternatives), studies often require extensive time, effort, and cost to produce flood estimates.



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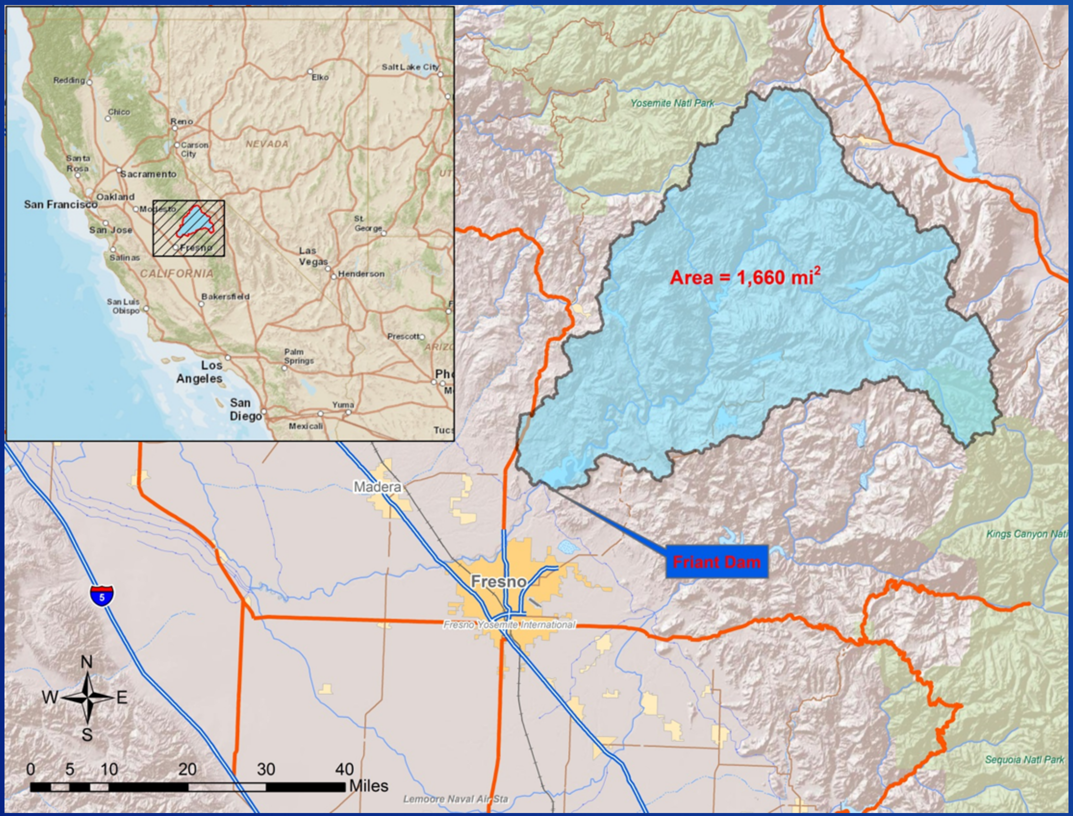
Case Study – Friant Dam HHA

This study provided a detailed probabilistic flood loading analysis used to quantify risks associated with various failure modes. This was accomplished by developing flood frequency hydrographs using a stochastic rainfall-runoff model (SEFM).



- Structural Height of 319 feet
- One 100x18 ft Drum Gate
- Two 100x18 ft Obermeyer Gates
- Spillway Capacity is 83,000 ft^3/s
- Combined Outlet Work Capacity is 17,000 ft^3/s
- Controls 1,660 ft^3
- 11 Upstream facilities (six of which are large dams)

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Stochastic Rainfall-Runoff Model

1. Develop physical based 1-dimensional rainfall-runoff using hydrologic runoff units (HRU's)
2. Estimate a precipitation frequency curve using the L-Moments method of regional statistics
3. Randomly sample the frequency precipitation curve as well as a storm pattern to determine an annual maximum storm event
4. Randomly determine the initial model conditions
5. Repeat steps 3 and 4 to develop a simulate time-series of maximum flood events
6. Fit a statistical distribution to the time series of annual maximum events

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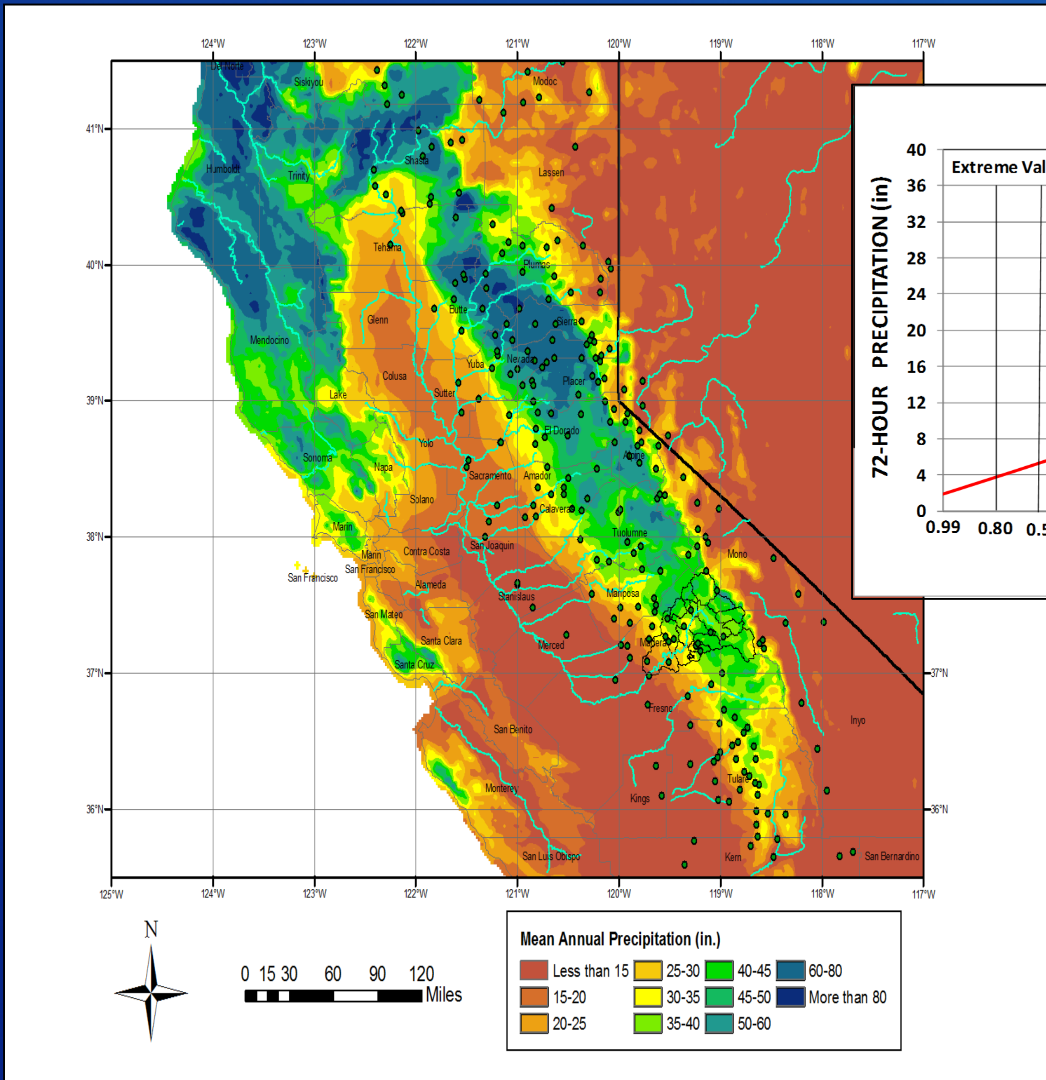
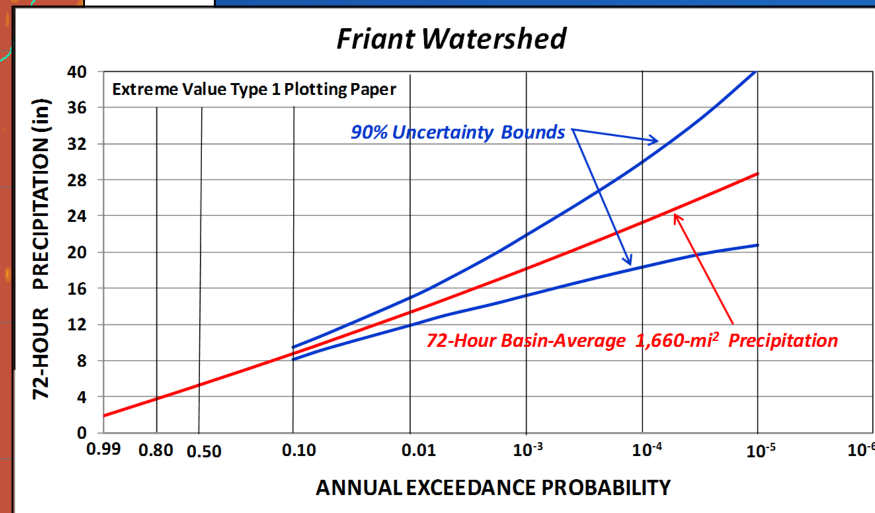
Regional Precipitation Analysis





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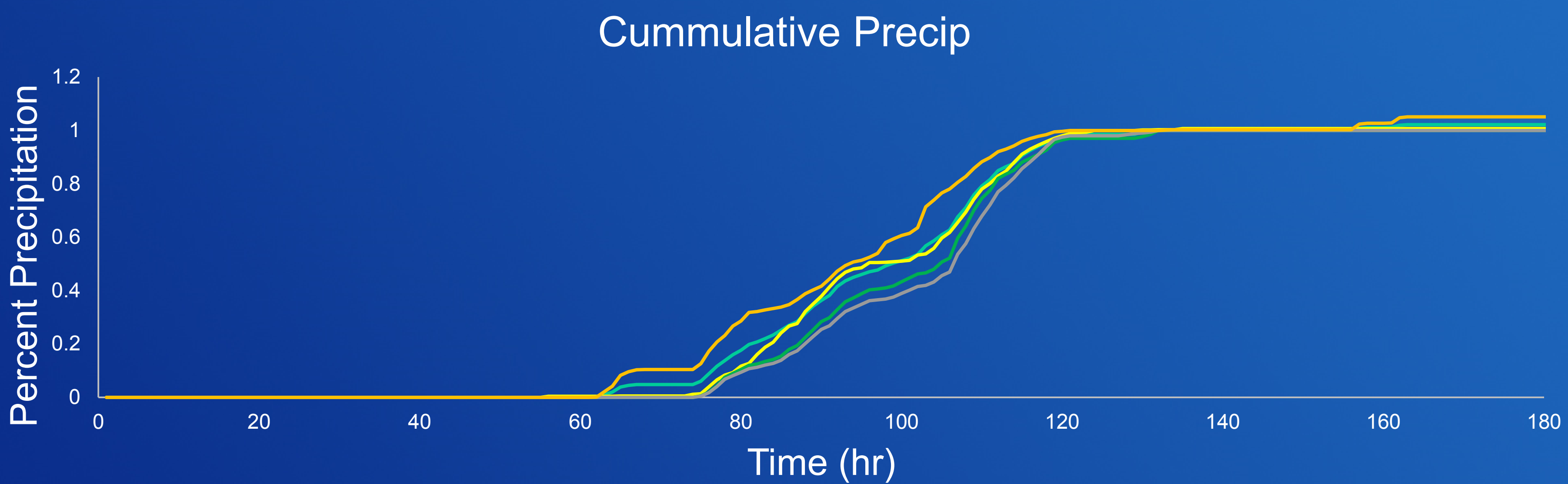
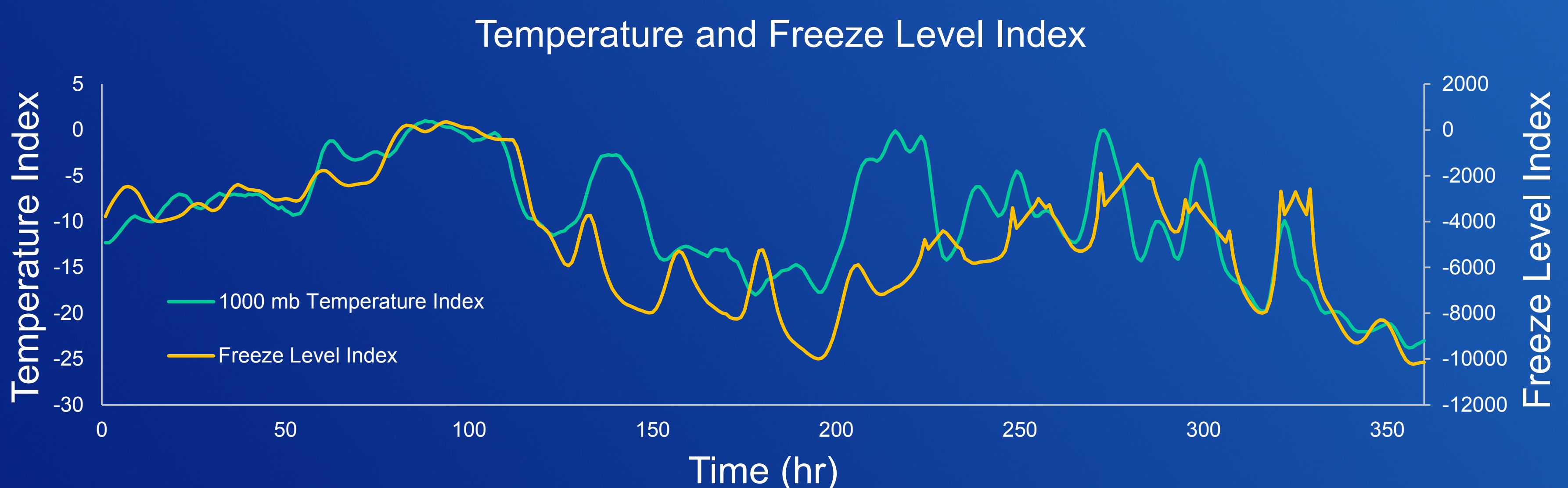
Spatial and Temporal Storm Patterns

Storm	72-hr Precipitation	Use
November 13-22, 1950	10.58	Calibration/Production
December 18-27, 1955	15.09	Calibration/Production
February 3-17, 1962	9.56	Production
January 29 - February 7, 1963	14.91	Calibration/Production
December 17-31, 1964	5.69	Production
December 1-11, 1966	9.56	Production
January 18-22, 1969	10.86	Production
January 23-29, 1969	7.56	Production
September 1-10, 1972	1.67	Calibration
September 1-10, 1978	3.63	Calibration/Production
January 9-19, 1980	8.97	Production
Sepetember 23 - October 2, 1982	4.28	Calibration/Production
February 12-21, 1986	8.78	Production
March 8-18, 1995	9.84	Production
Dec 29, 1996 - Jan 7, 1997	7.29	Calibration/Production
November 6-16, 2002	7.15	Calibration/Production
Dec 26, 2005 - Jan 9, 2006	7.88	Production
December 15-24, 2010	11.2	Production

Stochastic Storm Template





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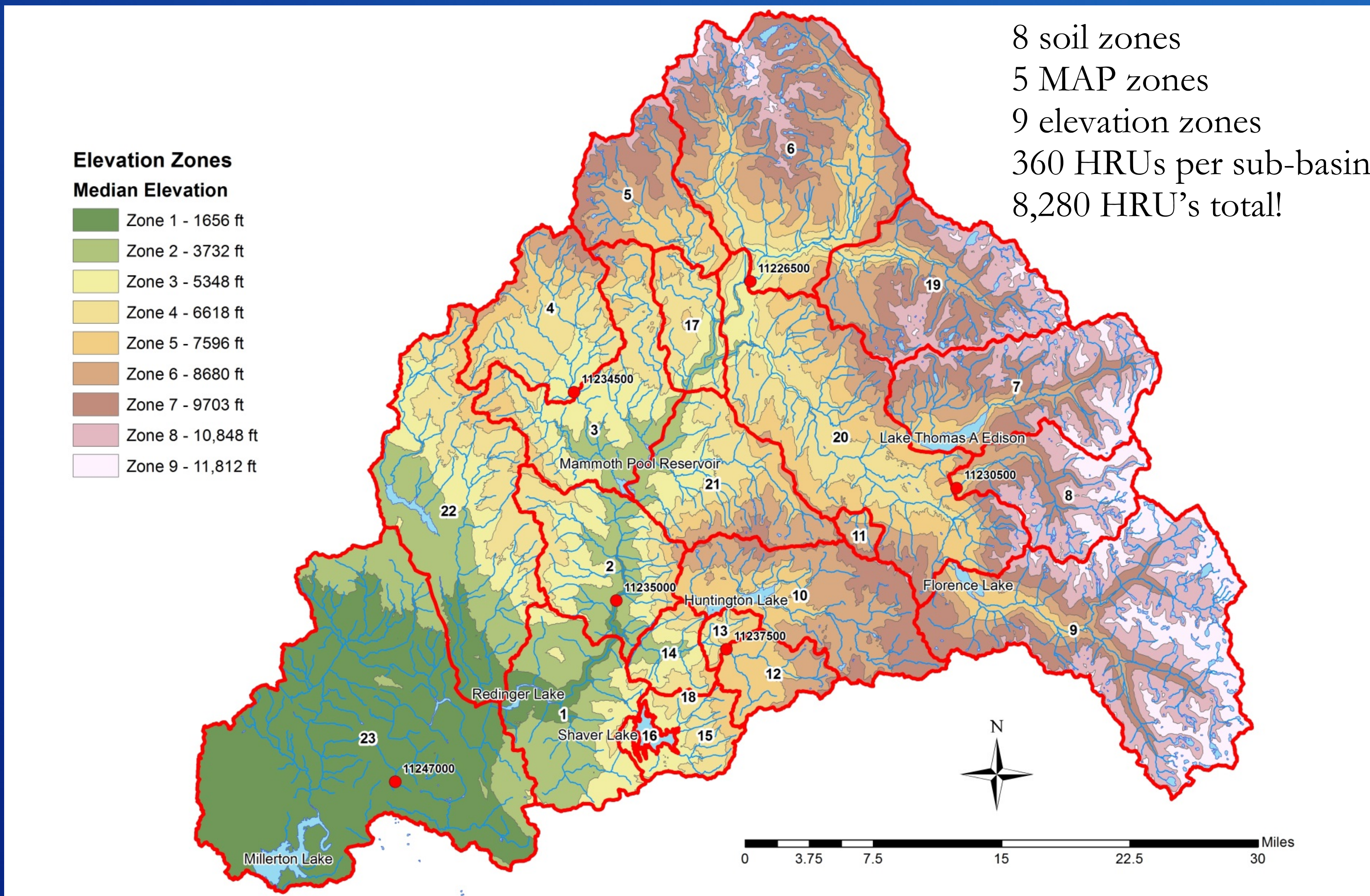
Physical Based Model



8 soil zones
5 MAP zones
9 elevation zones
360 HRUs per sub-basin
8,280 HRU's total!

Calibration

8 Historic Flood Events were used in Calibration

Friant is a mixed population (rain and snowmelt) system – the maximum annual rainfall didn't always yield the maximum annual flood

Fall events were used to calibrate high elevation basins because they represented snow-free ground

Runoff calibration was performed from the upstream basins to the downstream basins

Adjustments were made to the routing parameters and freeze level offsets to better fit the peak-discharge frequency

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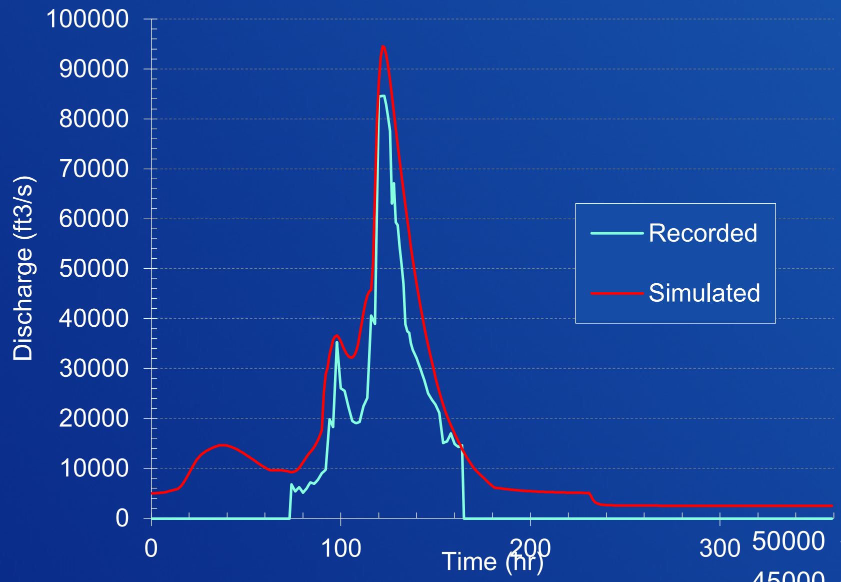
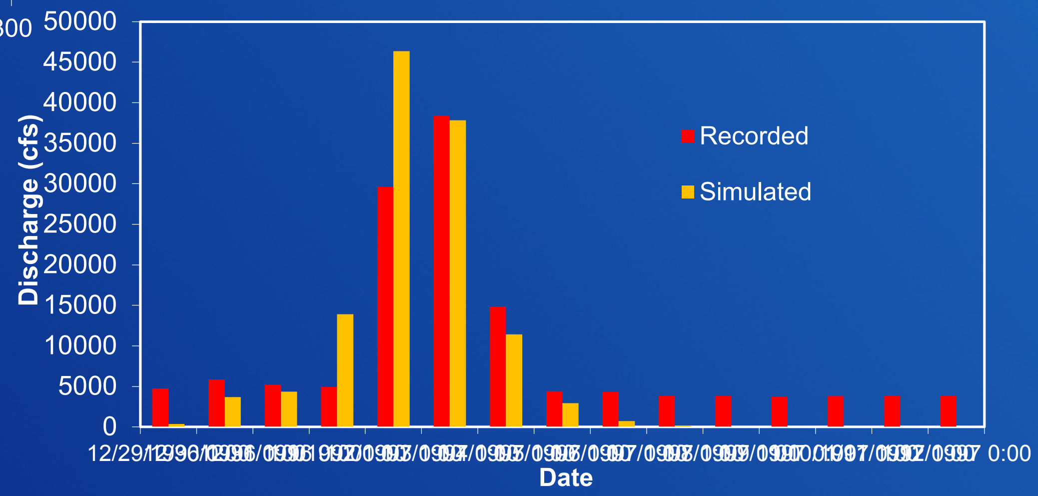
Calibration





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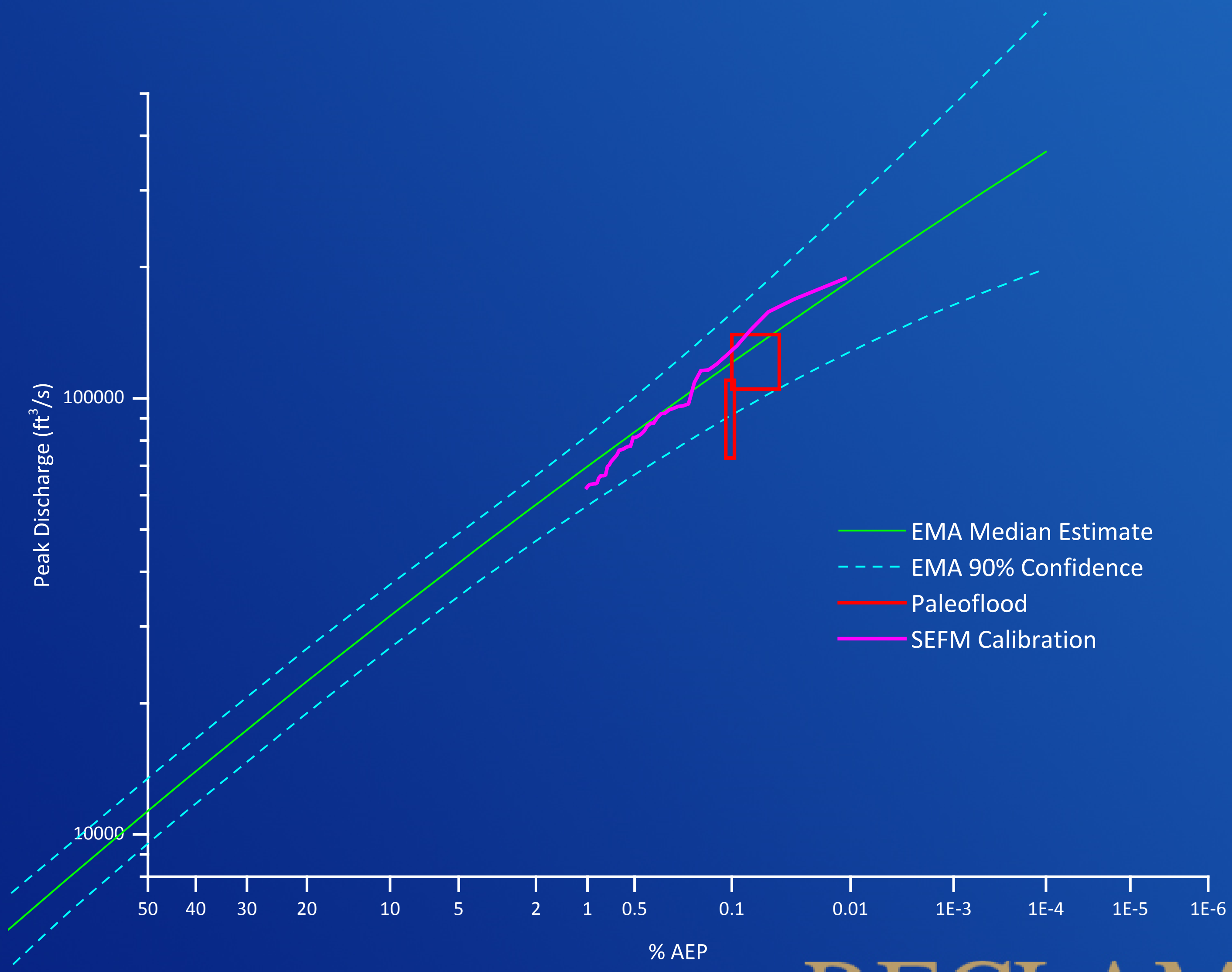
Peak-Discharge Frequency Calibration



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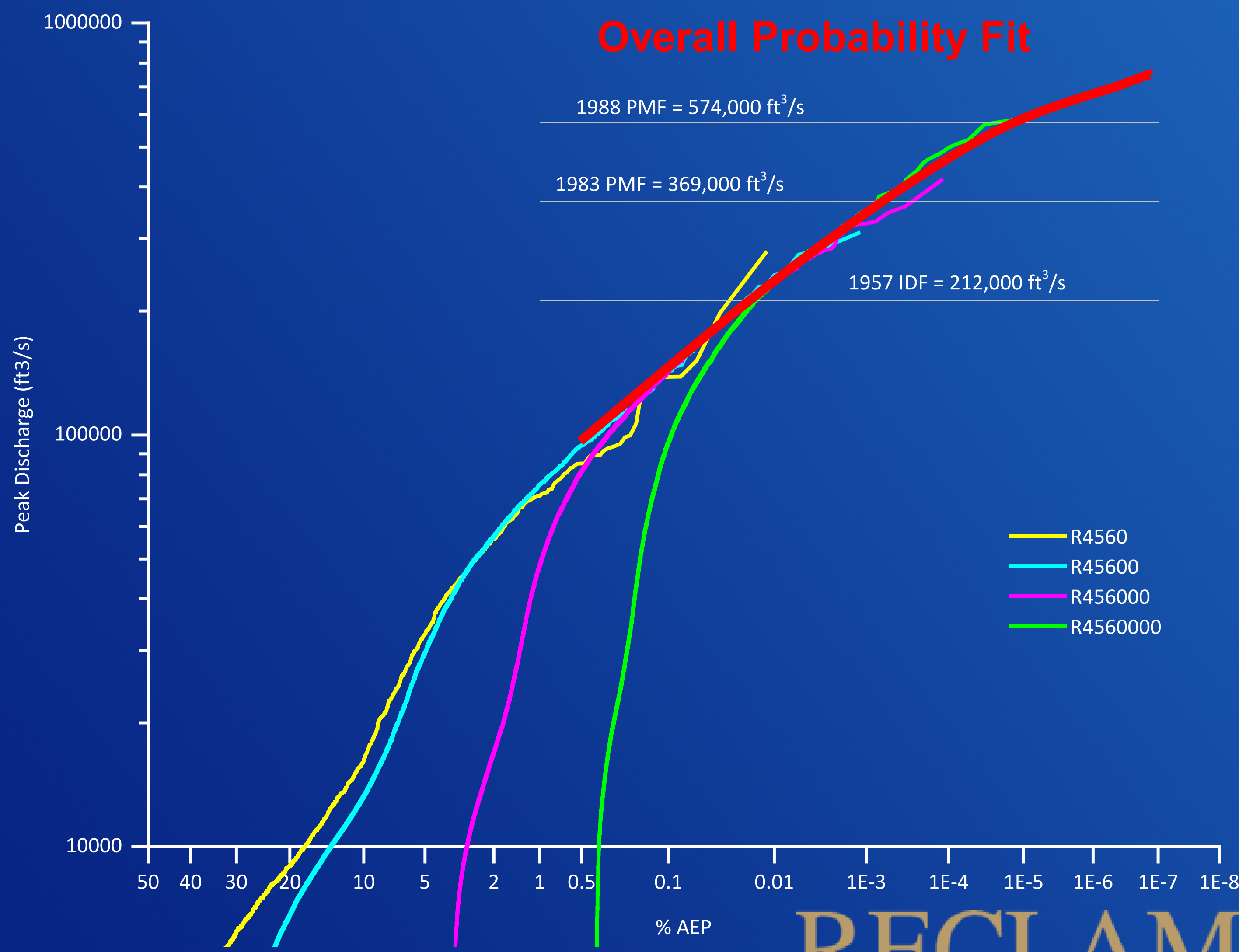
Peak-Discharge Frequency



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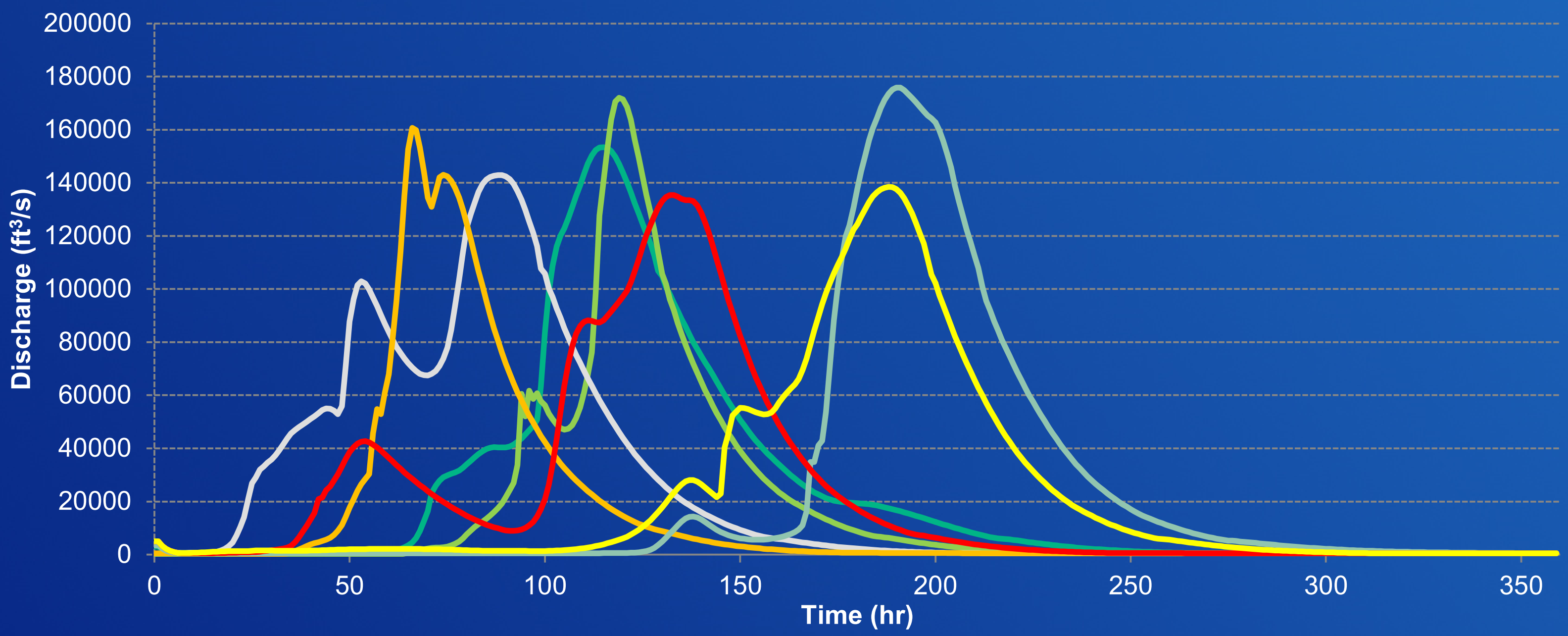
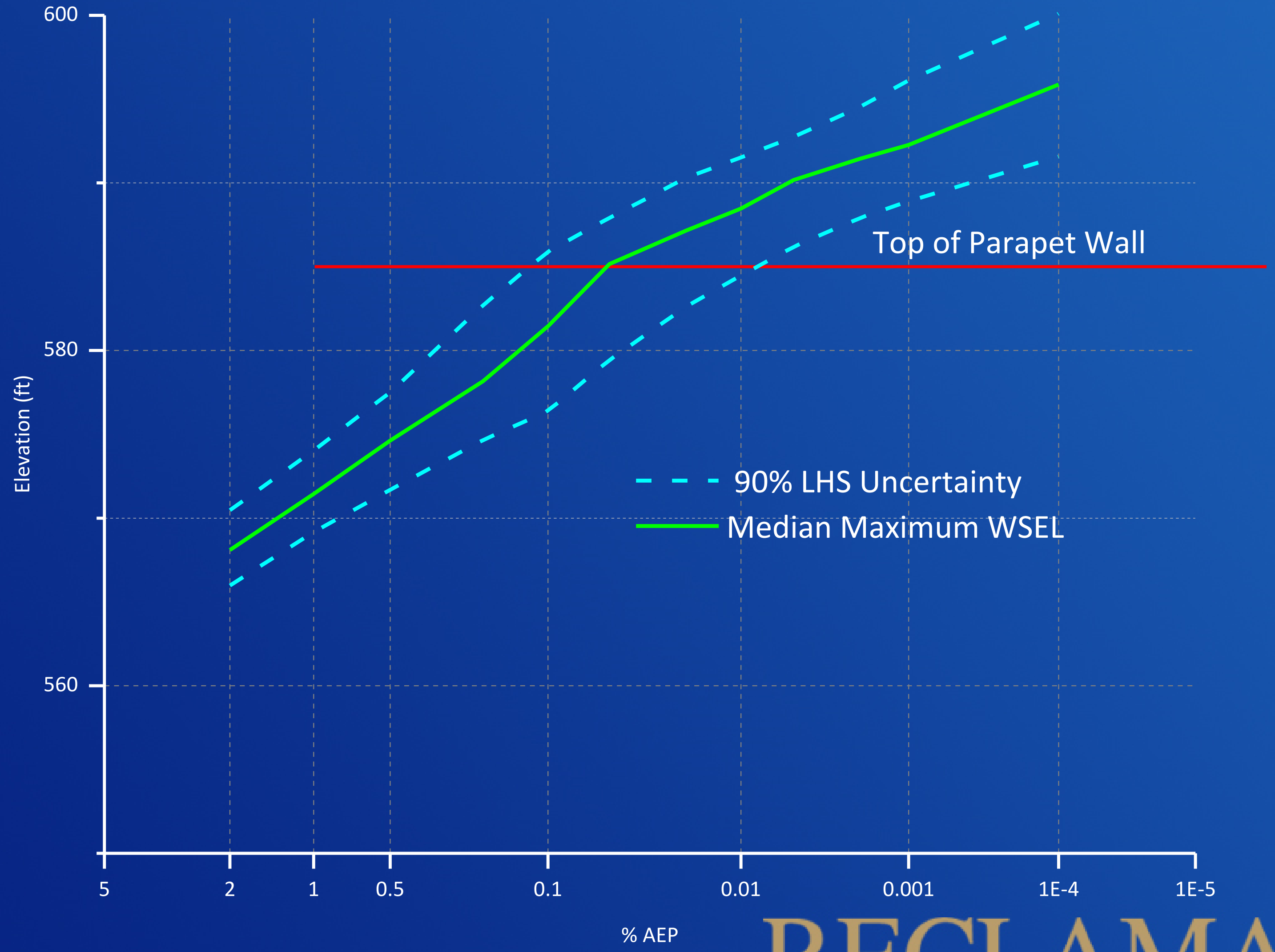
Friant Inflow Hydrographs that result in 1,000-yr RWSEL



Rank	AEP (%)	Simulation Number	Init WSEL (ft)	Peak Discharge (ft^3/s)	Total Volume (ac-ft)	Peak Discharge Rank	Total Volume Rank
454	0.0995	5735	531.2	153,396	684,560	644	399
455	0.0997	7021	550.4	172,089	502,242	424	1178
456	0.0999	2540	504.1	142,907	730,048	814	306
457	0.1001	659	563.3	160,704	460,092	540	1531
458	0.1003	3094	485.0	175,883	711,248	387	338
459	0.1006	5992	557.6	135,378	673,066	980	428
460	0.1008	10596	537.0	138,460	661,433	919	454

Friant Hydrologic Loading



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