How to Extrapolate Frequency Curves—with No Regrets!!

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BIOGRAPHICAL SKETCH

Mr. Countryman worked for the U.S. Army Corps of Engineers from 1966 through 1988 (22 years). His duties included flood control hydrology, hydraulic design, water resources planning, and design of hydraulic structures. In addition, he was involved in the operation of flood control reservoirs in California, and Colorado. In 1988, he joined MBK Engineers and in 1992 became a partner in the firm and is currently the president of MBK Engineers. While at MBK he has worked on a diverse array of flood control projects ranging from reservoir reoperation to the design of flood control facilities. He has also served as an expert witness in numerous flood litigation cases.

EDUCATION:
California State University, San Jose
BS in Civil Engineering, 1966

PROFESSIONAL LICENSES, SOCIETIES AND HONORS:
Registered Civil Engineer, California, 20486
Registered Civil Engineer, Nevada, 8086
Member, American Society of Civil Engineers
Award of Distinction, San Jose State University, College of Engineering

ABSTRACT

Joseph D. Countryman, PE, M. ASCE, D.WRE and Ben Tustison, PE, M. ASCE

The design of flood control facilities is based on the utilization of design floods that (in most cases) are larger than any historic flood. Much effort has been expended in the estimation of 100-year, 200-year and now 500-year floods. Since many localities only have 50 to 100 years of record and that record has been subject to changing conditions (climate, reservoirs, levees, urban development, etc) it is problematic to assume that recorded data provide a clear indication of the magnitude of an extreme flood suitable for the use in design of flood protection works for an urban area. Although underestimation of the flood has obvious ramifications (high risk of failure of the structure), overestimation of the flood has significant consequences also (project feasibility, misallocation of public resources, environmental impacts, etc).

This paper provides information on how not to extrapolate statistically derived frequency curves. In particular, careful evaluation of the federally approved methods described in the Bulletin 17B guidelines is given. A new/old method that considers the physical limitations of a watershed to produce runoff was utilized. A new Monte Carlo method of establishing uncertainty around the derived curve was employed. Specifically, an example of integrating the Probable Maximum Flood (PMF) into the process of frequency curve development and extrapolation is described.

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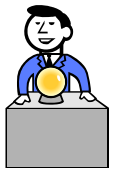

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Dictionary.com Unabridged (v 1.1)
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ex·trap·o·late

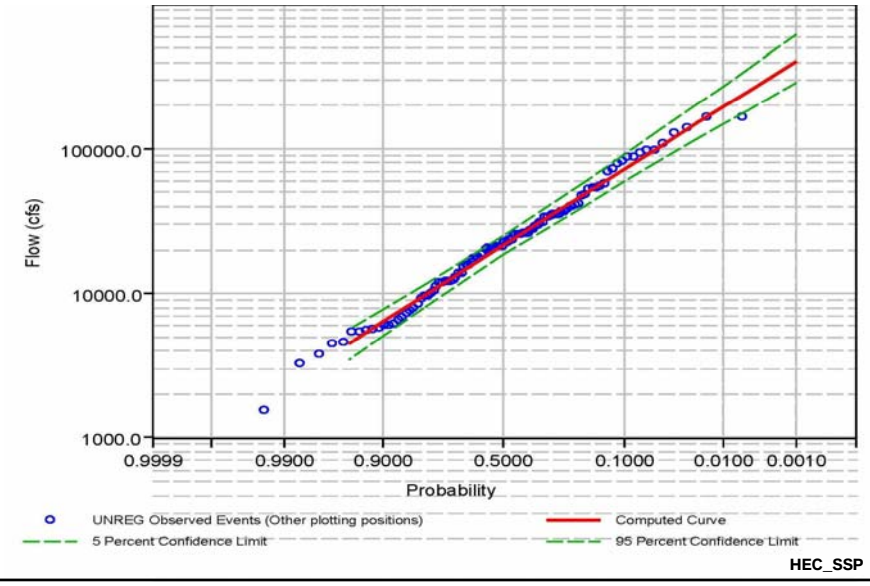
1. to infer (an unknown) from something that is known; conjecture.

2. Statistics. to estimate (the value of a variable) outside the tabulated or observed range.

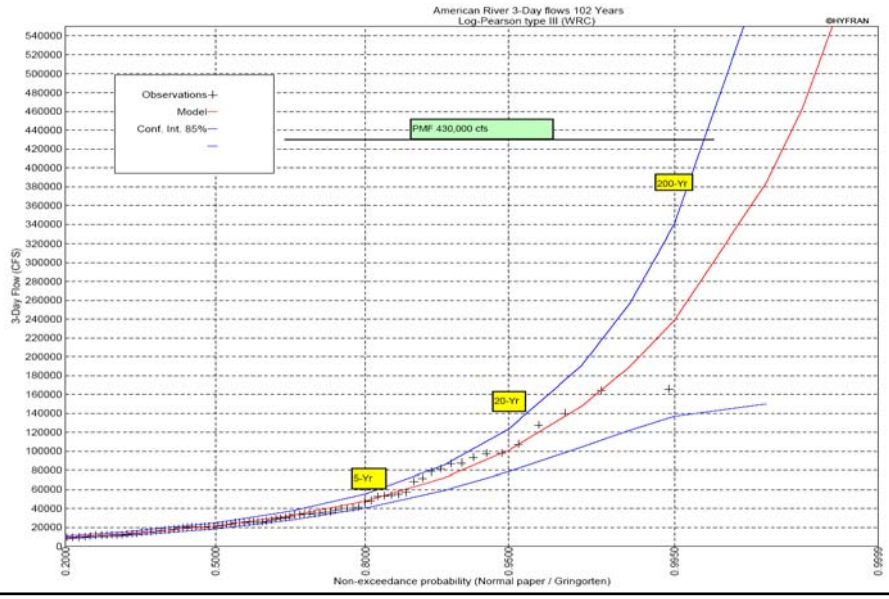
Some Bad Examples

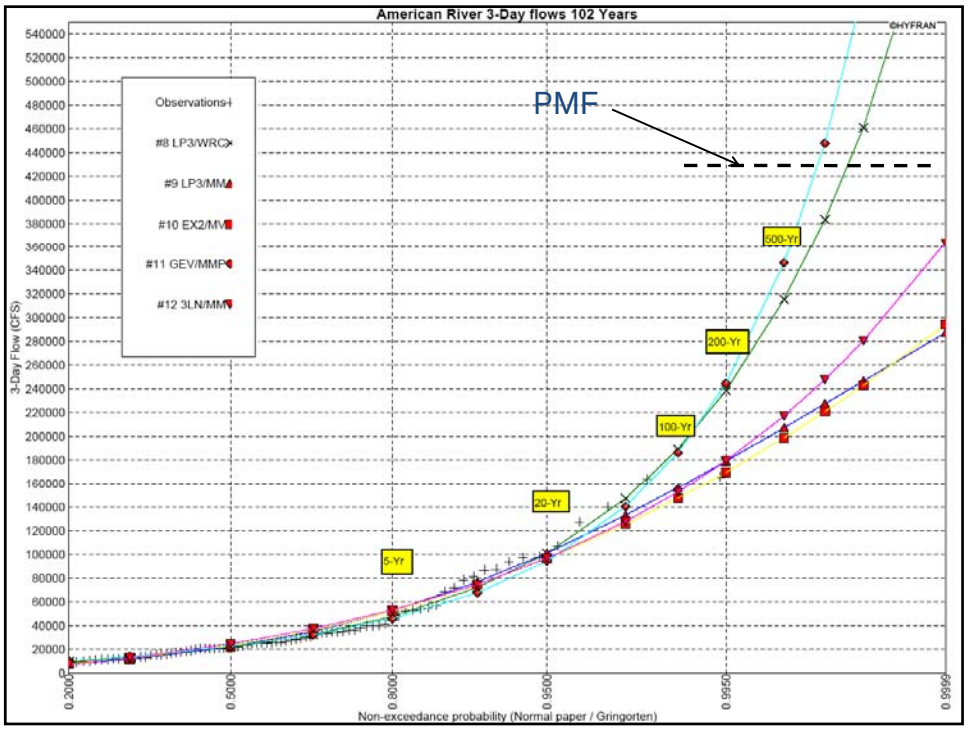
Using PDFs Without Understanding

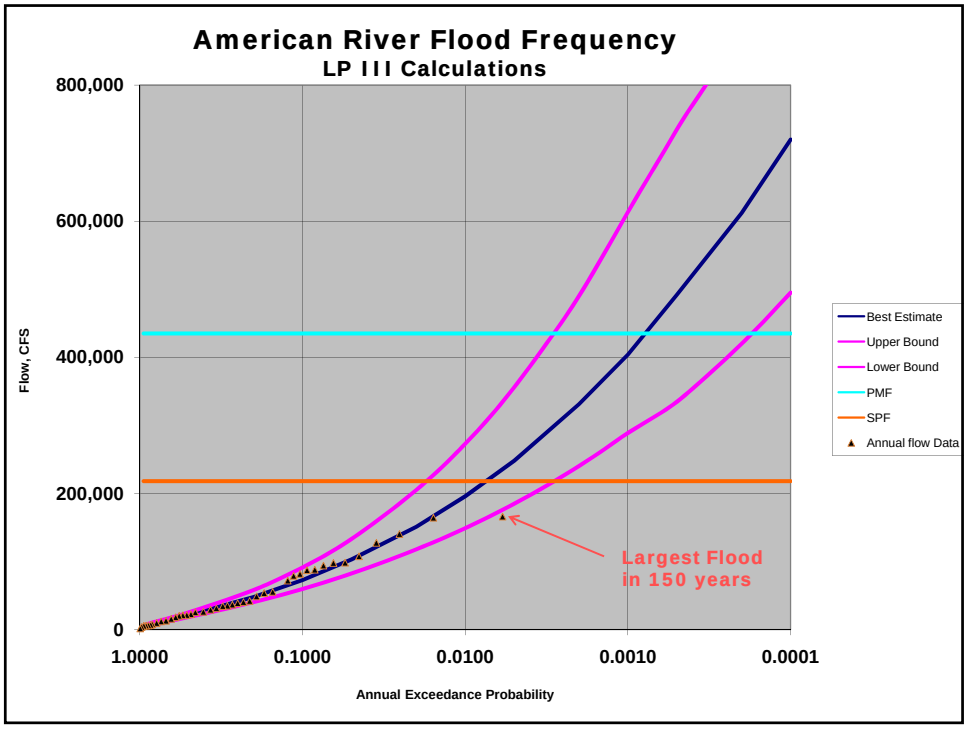
American River LP III
(Log Scale)

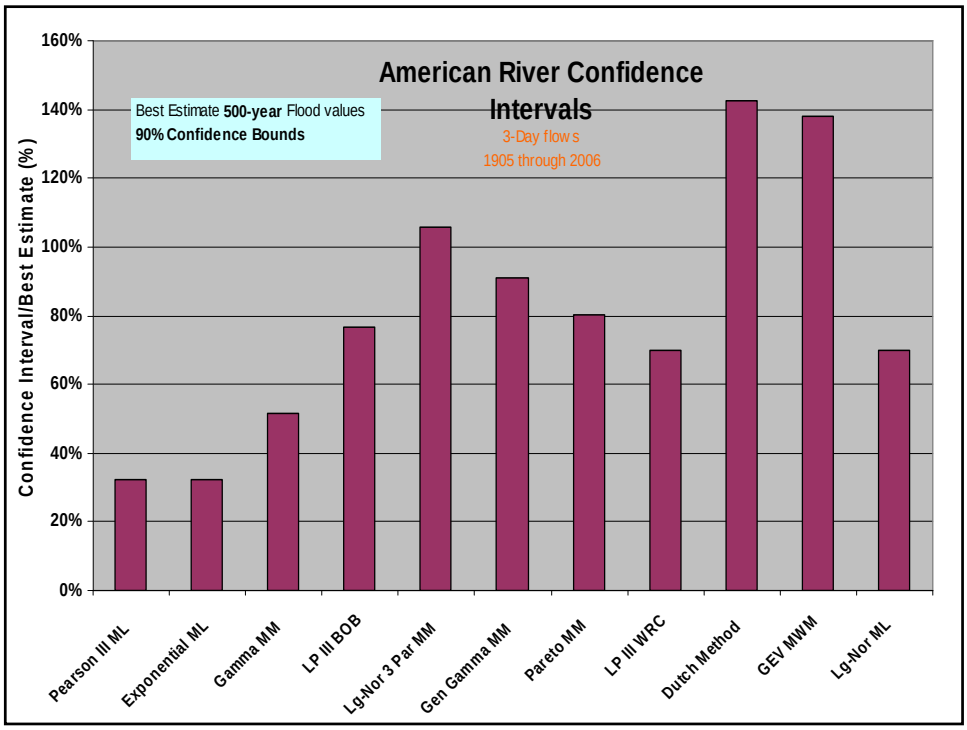


American River LP III WRC
(Linear Scale)





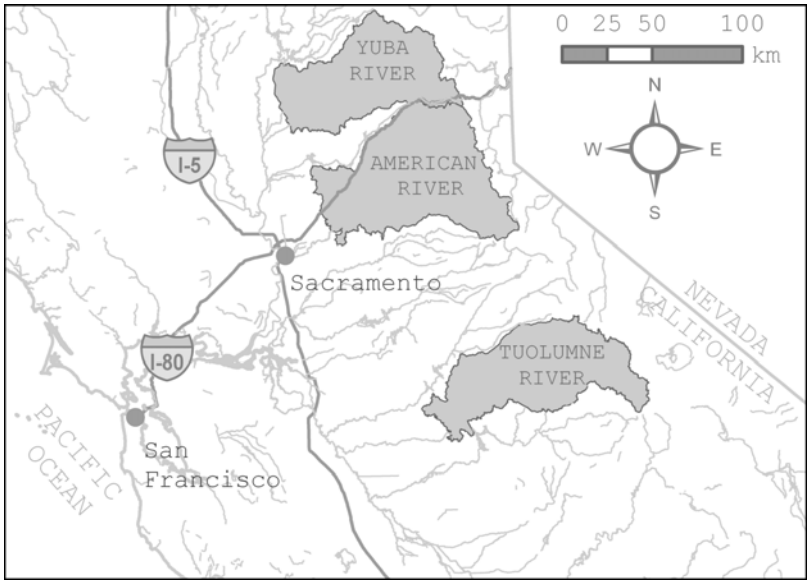

American River Flood Frequency
LP III Calculations
800,000
600,000
400,000
200,000
0
Flow, CFS
1.0000
0.1000
0.0100
0.0010
0.0001
Annual Exceedance Probability
Largest Flood in 150 years
Best Estimate
Upper Bound
Lower Bound
PMF
SPF
Annual flow Data


American River Confidence Intervals
3-Day flows
1905 through 2006
Best Estimate 500-year Flood values
90% Confidence Bounds
Confidence Interval/Best Estimate (%)
160%
140%
120%
100%
80%
60%
40%
20%
0%
Pearson III ML
Exponential ML
Gamma MM
LP III BOB
Lg-Nor 3 Par MM
Gen Gamma MM
Pareto MM
LP III WRC
Dutch Method
GEV MWM
Lg-Nor ML

A Test

- Create a graphically derived flood flow Exceedance Frequency Curve (Mother Curve) based on:
  - Recorded Data (over 100 years of annual max)
  - Extrapolation of Frequency Curves based on evaluation of PMF as a near Absolute Maximum
  - SPF (50% PMF) as a Flood with a Exceedance Probability of between 1-in-200 and 1-in-500

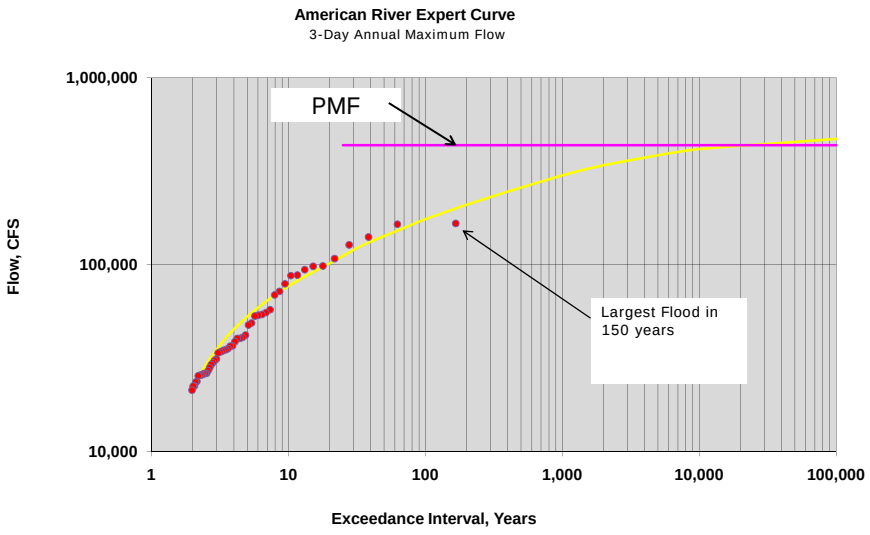
Study Basin

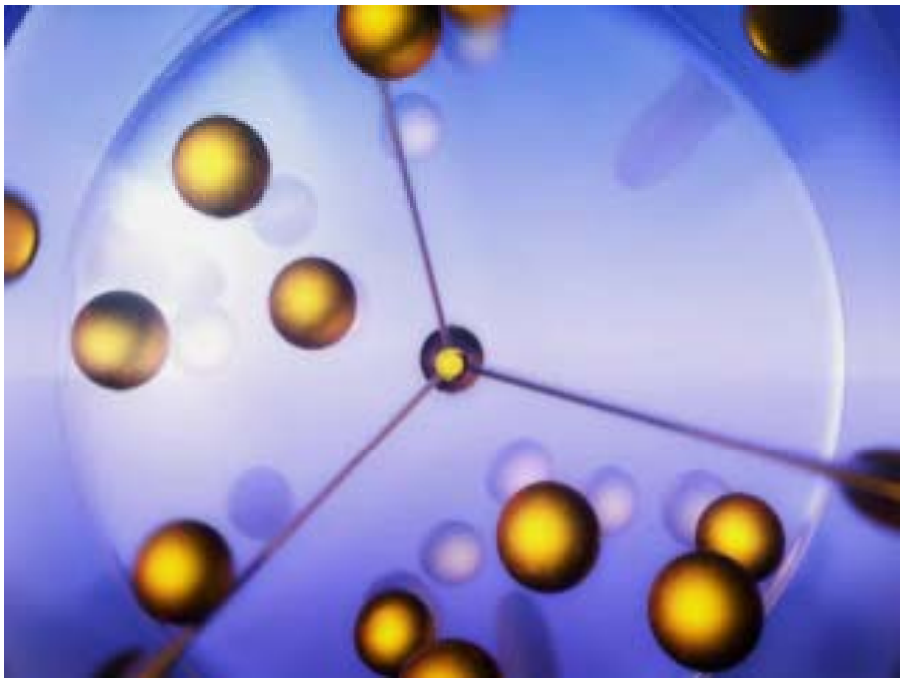


The Mother Curve

- The Mother Curve now Represents the "Real" values for each Exceedance Probability
- The Mother Curves Provide a Test Bed for the Performance of the PDF's
- The Mother Curve Development Provides a Possible Path Forward

Mother Curve (log scale)





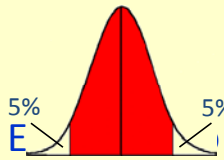
Create Data Records

- 100 sets of Record
- Each set with 100 years of annual Maximum Flood data

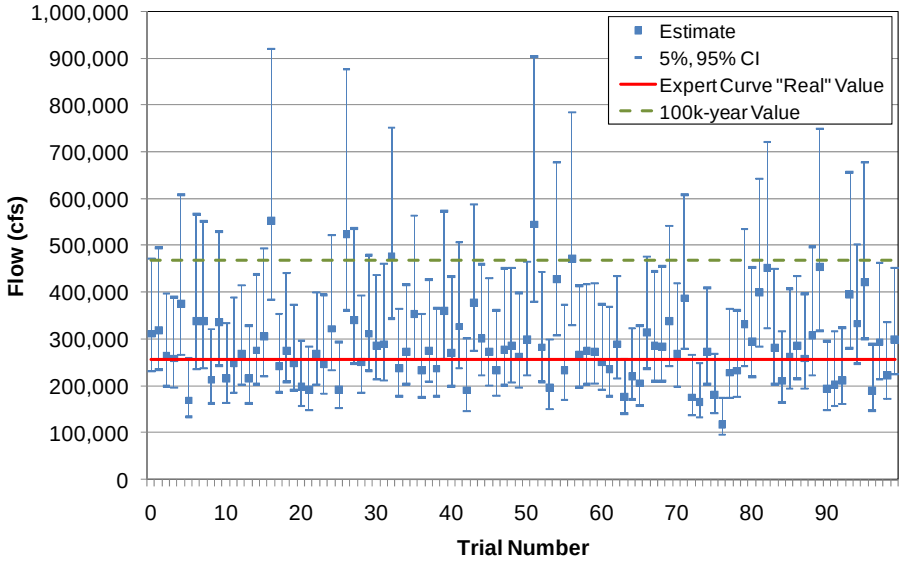
10,000 years of Record!!

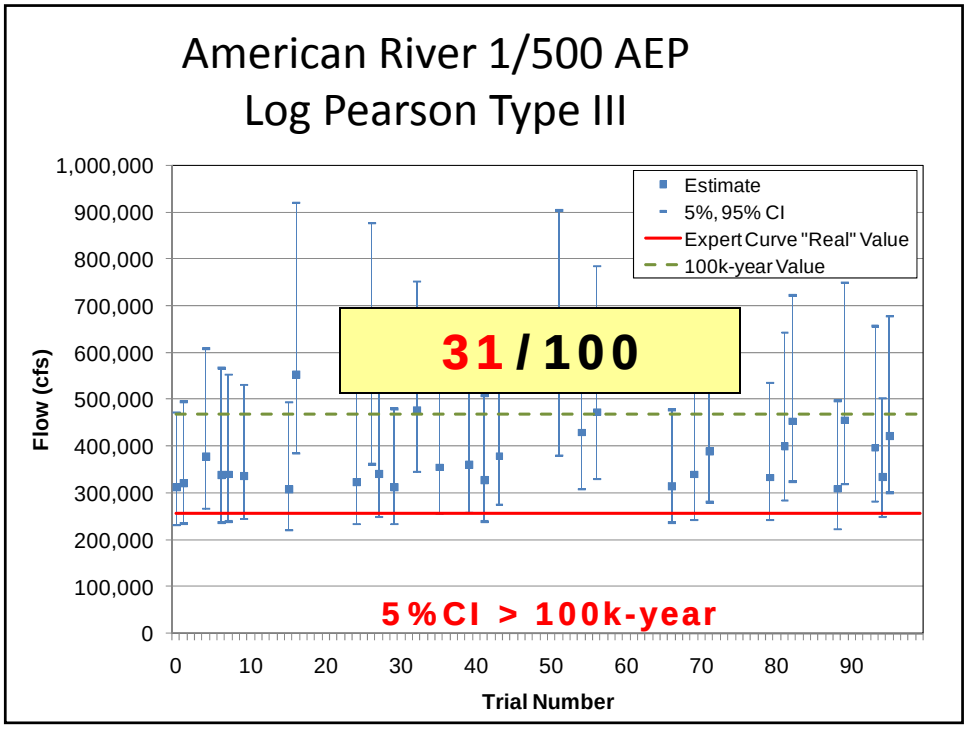
Use LP III PDF To Estimate

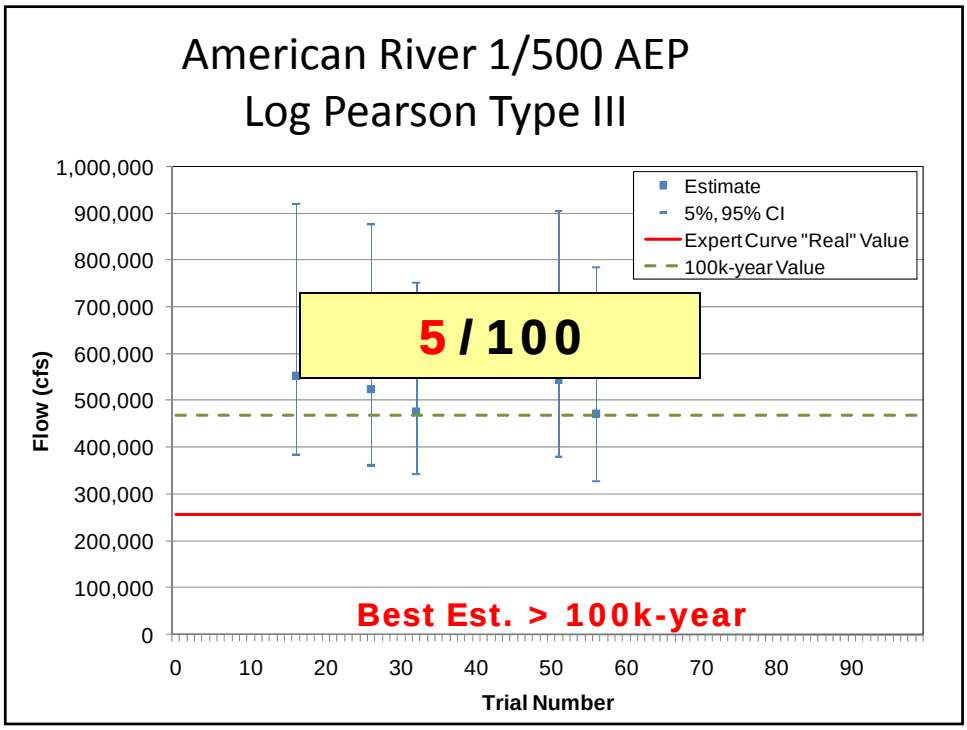
- 500-Year Exceedance Interval Floods
- 90% Confidence Intervals for Each Flood
- Compare E "Real" Values

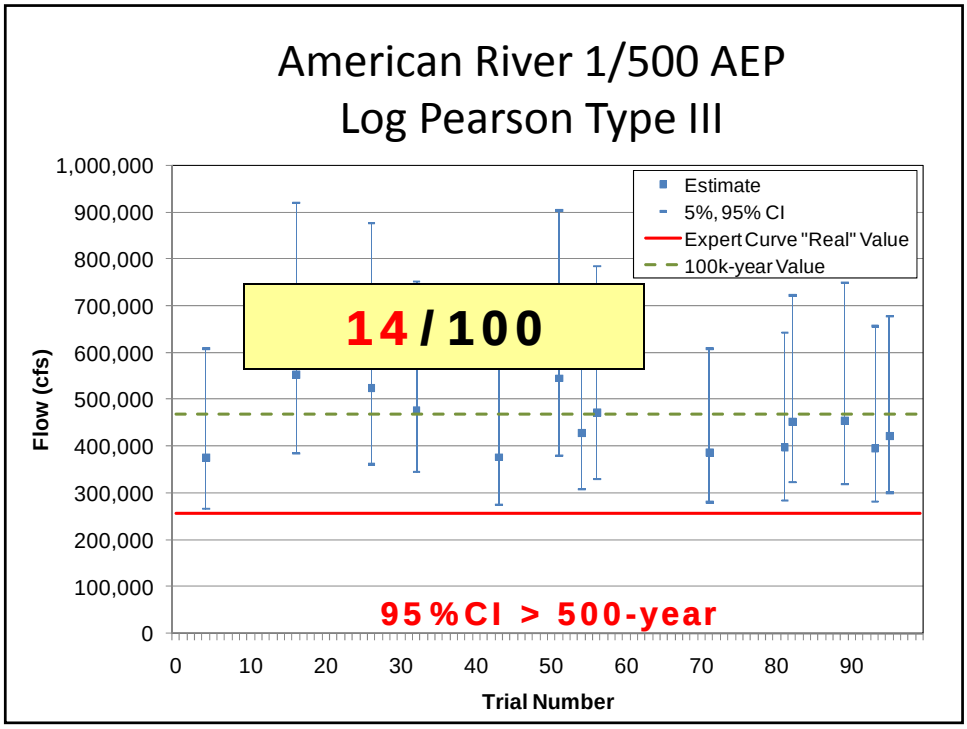


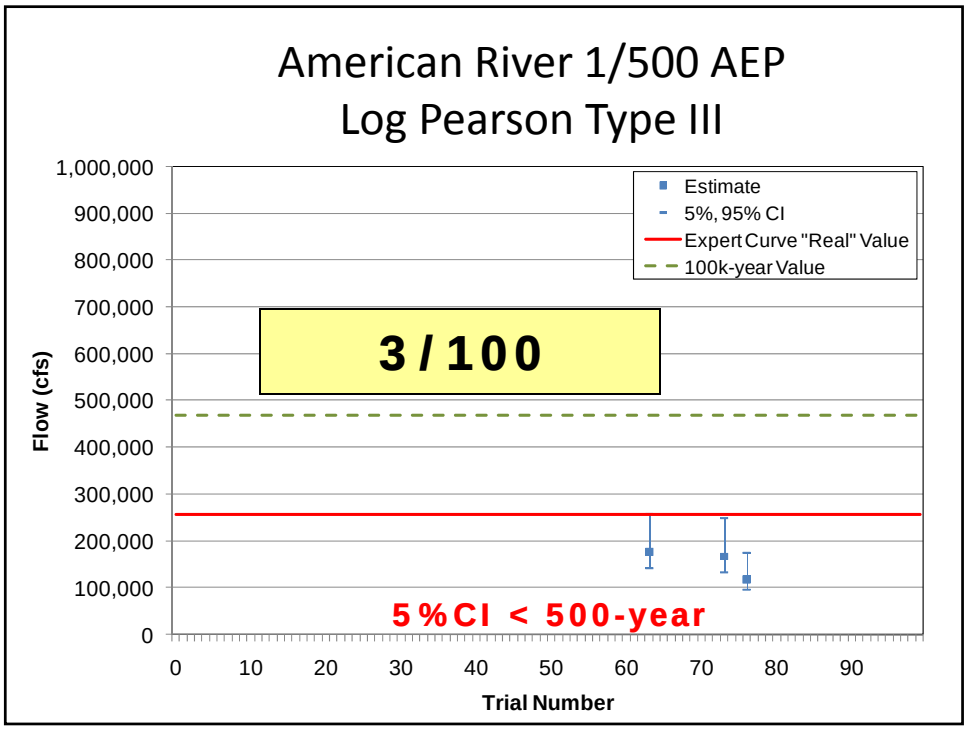
American River 1/500 AEP
Log Pearson Type III

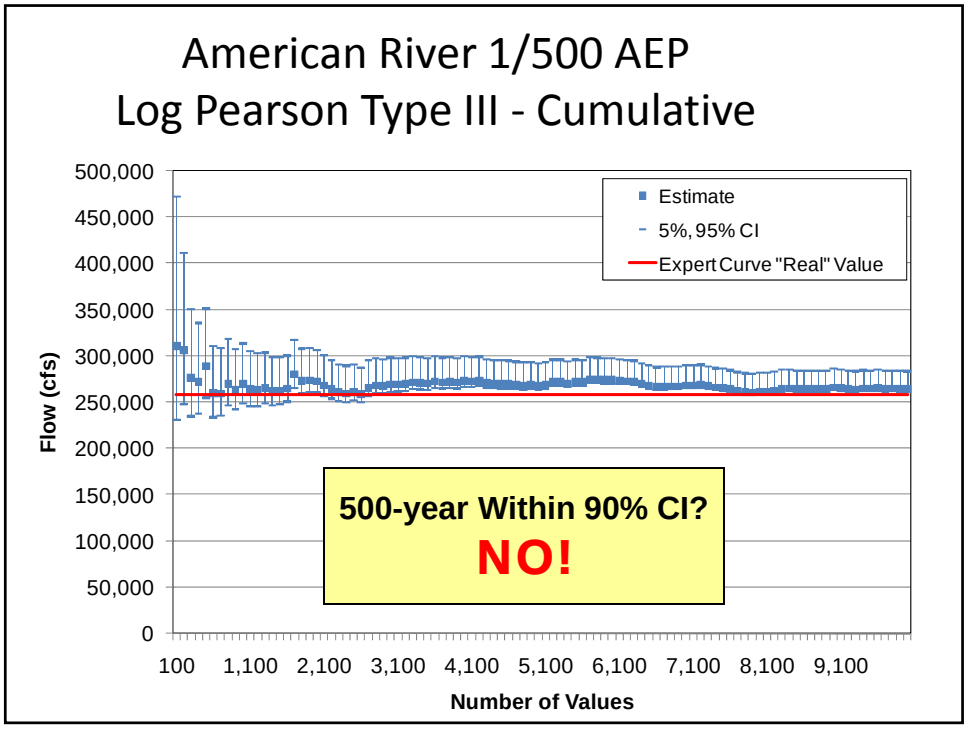


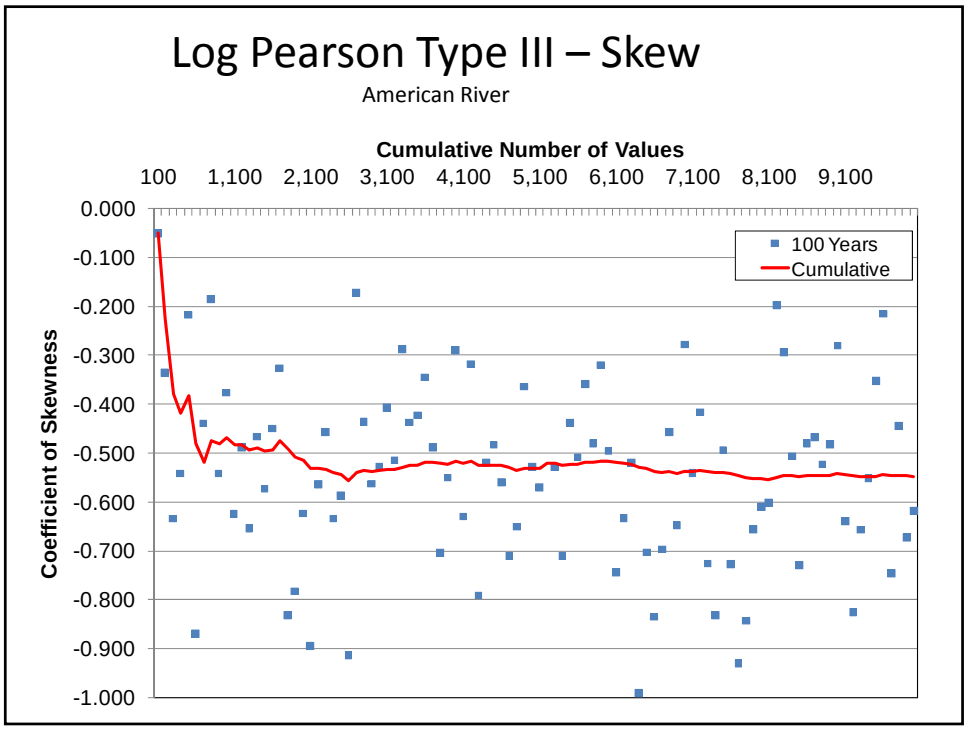

American River 1/500 AEP
Log Pearson Type III
Estimate
5%, 95% CI
Expert Curve "Real" Value
100k-year Value
31 / 100
5%CI > 100k-year
Flow (cfs)
Trial Number
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
0
10
20
30
40
50
60
70
80
90


American River 1/500 AEP
Log Pearson Type III
Estimate
5%, 95% CI
Expert Curve "Real" Value
100k-year Value
5 / 100
Best Est. > 100k-year
Flow (cfs)
Trial Number
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
0
10
20
30
40
50
60
70
80
90


American River 1/500 AEP
Log Pearson Type III
Estimate
5%, 95% CI
Expert Curve "Real" Value
100k-year Value
14 / 100
95%CI > 500-year
Flow (cfs)
Trial Number
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
0
10
20
30
40
50
60
70
80
90


American River 1/500 AEP
Log Pearson Type III
Estimate
5%, 95% CI
Expert Curve "Real" Value
100k-year Value
3 / 100
5%CI < 500-year
Flow (cfs)
Trial Number
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
0
10
20
30
40
50
60
70
80
90


American River 1/500 AEP
Log Pearson Type III - Cumulative
Flow (cfs)
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
100
1,100
2,100
3,100
4,100
5,100
6,100
7,100
8,100
9,100
Number of Values
Estimate
5%, 95% CI
Expert Curve "Real" Value
500-year Within 90% CI?
NO!


Log Pearson Type III – Skew
American River
Cumulative Number of Values
100
1,100
2,100
3,100
4,100
5,100
6,100
7,100
8,100
9,100
Coefficient of Skewness
0.000
-0.100
-0.200
-0.300
-0.400
-0.500
-0.600
-0.700
-0.800
-0.900
-1.000
100 Years
Cumulative

What's Next?

- Bulletin 17B is **Not** Doing the Job for Extreme Flood Events
- Incorporate PMF and SPF Analysis for Frequency Curve Extrapolation
- Fundamentally Change Uncertainty Calculations…Goodbye Confidence Bounds!

No Regrets Option

- **Fit pdf to the limit of data (100 years of data 100-year Exceedance Interval maximum extrapolation)**
- **Graphically extend Frequency curve to 100k-Year Exceedance Interval using PMF**

No Regrets Option

- Use Monte Carlo Sampling to develop uncertainty Information Concerning the Next 50 Years
- Utilize Atmospheric Models to Estimate Climate Change (No Stationarity)