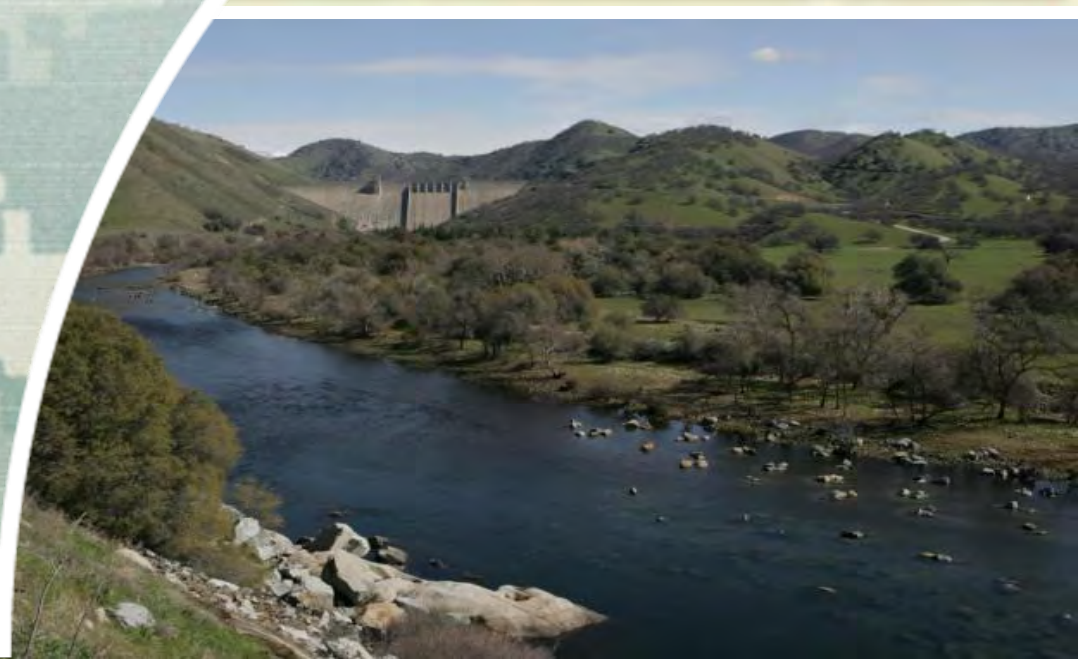
Probable Maximum Flood
Annual Exceedance Probability

California Extreme Precipitation Symposium

University of California, Davis

June 28, 2011



Jeff Harris

USACE, Hydrologic Engineering Center

US Army Corps of Engineers

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Topics

- Background
- Curve Extension Methods
- Regional PMP Method
- AEP Estimation
- Samples

Background

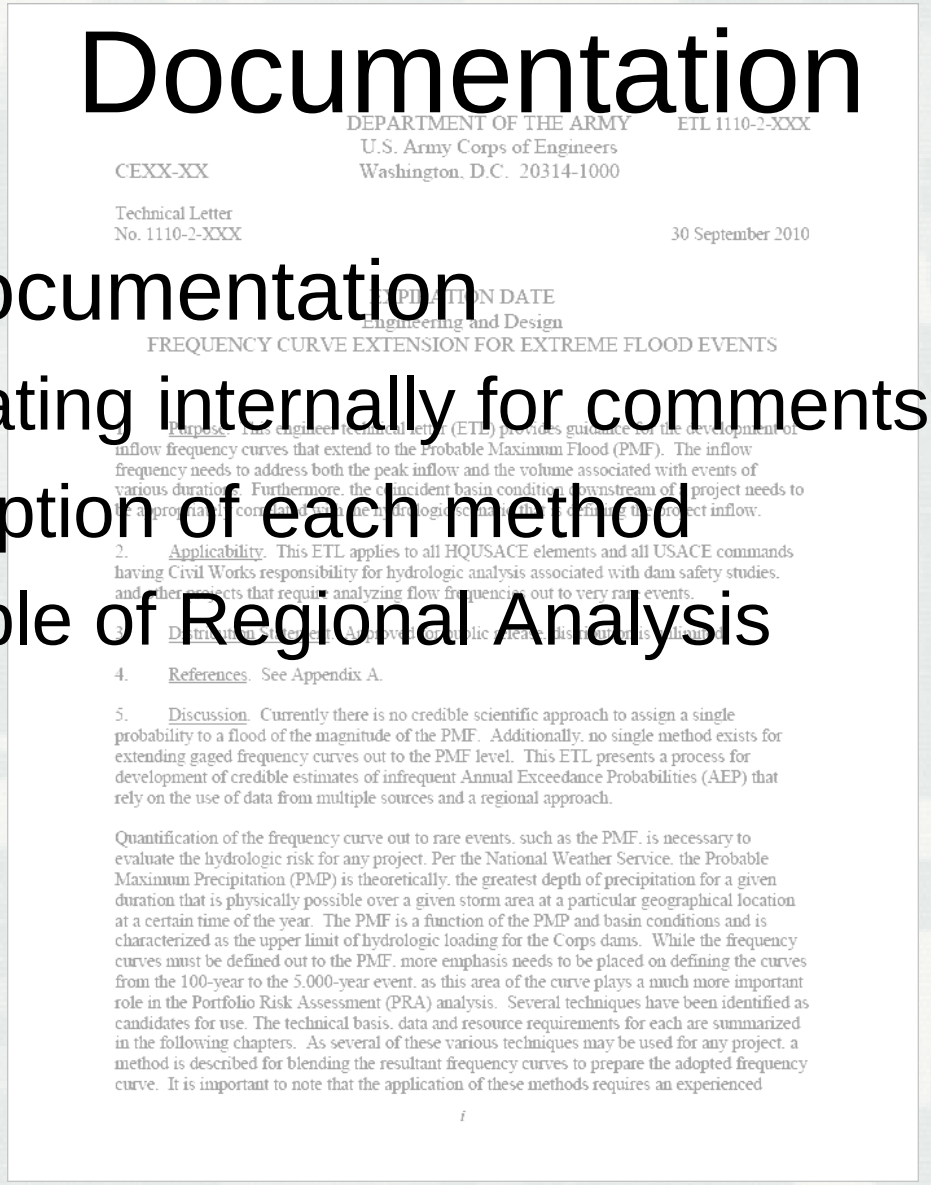
- USACE Portfolio Risk Assessment, 2005
- Develop inflow frequency curves for USACE Dams
- Challenge
  - No single accepted approach for curve extension methodology
  - No single accepted approach for AEP of PMF
  - Develop a simplified method

Proposal for Simplified Curve Combination and Extension

- Combine Techniques
  - 17B Analysis
  - Hydrologic Modeling using Frequency Based Storms
  - Stochastic Event Flood Model (SEFM)
  - Regional Probability Method
  - Extension of Gaged Freq-Curves with Historic/Paleoflood
  - GRADEX

Documentation

- Draft Documentation
  - Circulating internally for comments
  - Description of each method
  - Example of Regional Analysis



DEPARTMENT OF THE ARMY ETL 1110-2-XXX
U.S. Army Corps of Engineers
CEXX-XX Washington, D.C. 20314-1000

Technical Letter
No. 1110-2-XXX 30 September 2010

[illegible] DATE
Engineering and Design
FREQUENCY CURVE EXTENSION FOR EXTREME FLOOD EVENTS

[illegible] (ETL) provides guidance for the development of inflow frequency curves that extend to the Probable Maximum Flood (PMF). The inflow frequency needs to address both the peak inflow and the volume associated with events of various durations. Furthermore, the coincident basin conditions downstream of a project needs to be appropriately considered. [illegible] project inflow.

2. Applicability. This ETL applies to all HQUSACE elements and all USACE commands having Civil Works responsibility for hydrologic analysis associated with dam safety studies, and other projects that require analyzing flow frequencies out to very rare events.

3. [illegible]

4. References. See Appendix A.

5. Discussion. Currently there is no credible scientific approach to assign a single probability to a flood of the magnitude of the PMF. Additionally, no single method exists for extending gaged frequency curves out to the PMF level. This ETL presents a process for development of credible estimates of infrequent Annual Exceedance Probabilities (AEP) that rely on the use of data from multiple sources and a regional approach.

Quantification of the frequency curve out to rare events, such as the PMF, is necessary to evaluate the hydrologic risk for any project. Per the National Weather Service, the Probable Maximum Precipitation (PMP) is theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographical location at a certain time of the year. The PMF is a function of the PMP and basin conditions and is characterized as the upper limit of hydrologic loading for the Corps dams. While the frequency curves must be defined out to the PMF, more emphasis needs to be placed on defining the curves from the 100-year to the 5,000-year event, as this area of the curve plays a much more important role in the Portfolio Risk Assessment (PRA) analysis. Several techniques have been identified as candidates for use. The technical basis, data and resource requirements for each are summarized in the following chapters. As several of these various techniques may be used for any project, a method is described for blending the resultant frequency curves to prepare the adopted frequency curve. It is important to note that the application of these methods requires an experienced

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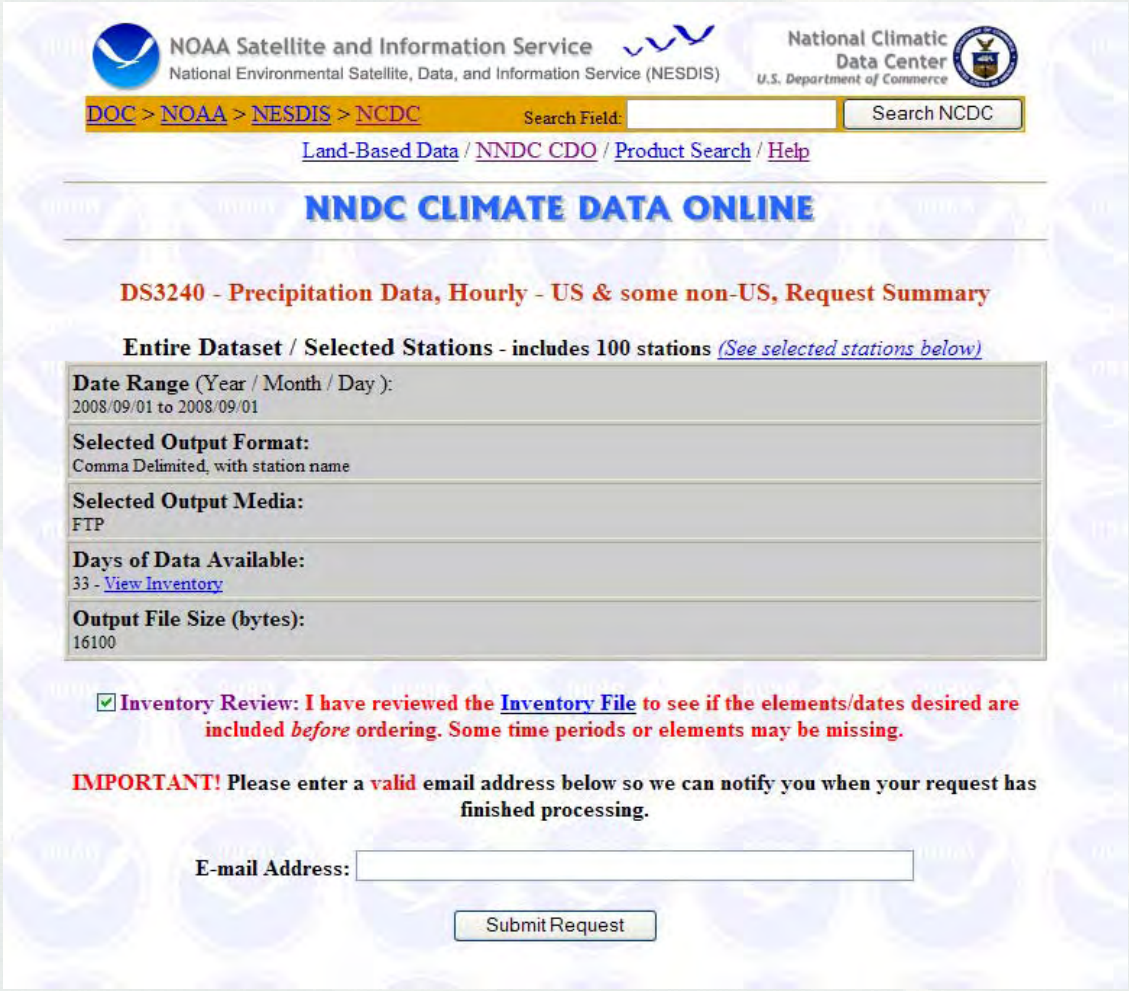
Regional Probability Method

- AEP Estimate of PMF from regional precipitation
  - Attempt to regionalize the AEP based on historic, regional rainfall
  - Ratio Historic Precipitation vs PMP
  - Include effects of
    - Regional weather patterns
    - Distance from moisture source
    - Orographic impacts
  - Result is an *ESTIMATED AEP*

NCDC Precipitation Archive



NOAA Satellite and Information Service
National Environmental Satellite, Data, and Information Service (NESDIS)

National Climatic Data Center
U.S. Department of Commerce

DOC > NOAA > NESDIS > NCDC Search Field: Search NCDC

Land-Based Data / NNDC CDO / Product Search / Help

NNDC CLIMATE DATA ONLINE

DS3240 - Precipitation Data, Hourly - US & some non-US, Request Summary

Entire Dataset / Selected Stations - includes 100 stations *(See selected stations below)*

Date Range (Year / Month / Day):
2008/09/01 to 2008/09/01

Selected Output Format:
Comma Delimited, with station name

Selected Output Media:
FTP

Days of Data Available:
33 - View Inventory

Output File Size (bytes):
16100

☑ **Inventory Review: I have reviewed the Inventory File to see if the elements/dates desired are included *before* ordering. Some time periods or elements may be missing.**

IMPORTANT! Please enter a valid email address below so we can notify you when your request has finished processing.

E-mail Address:

Submit Request

Create Shapefile

6256461766673stn_edit.txt

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STATIONNAME,LATITUDE,LONGITUDE
WILKESBARREWSOAP,41.33889,-75.72667
BEARCREEK,41.18333,-75.76667
FRANCISEWALTERDAM,41.11667,-75.73333
BENEZETTE4ENE,41.33333,-78.31667
BIGCOVETANNERY,39.81667,-78.08333
BLUEKNOB2S,40.33333,-78.56667
BLUEMARSHLAKE,40.38444,-76.03389
BUCKSTOWN1SE,40.06306,-78.84222
CARTERCAMP2W,41.61667,-77.75
CLERMONT,41.68333,-78.5
COALPORT,40.75,-78.53333
CRESSON1ESUMMIT,40.46667,-78.56667
CRESSON1SE,40.45,-78.56667
CURWENSVILLELAKE,40.95833,-78.52944
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DUBOIS7E,41.1,-78.63333
DUNLO,40.28722,-78.72417
DUSHORE3NE,41.55,-76.35
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KANE5SE,41.6,-78.76667
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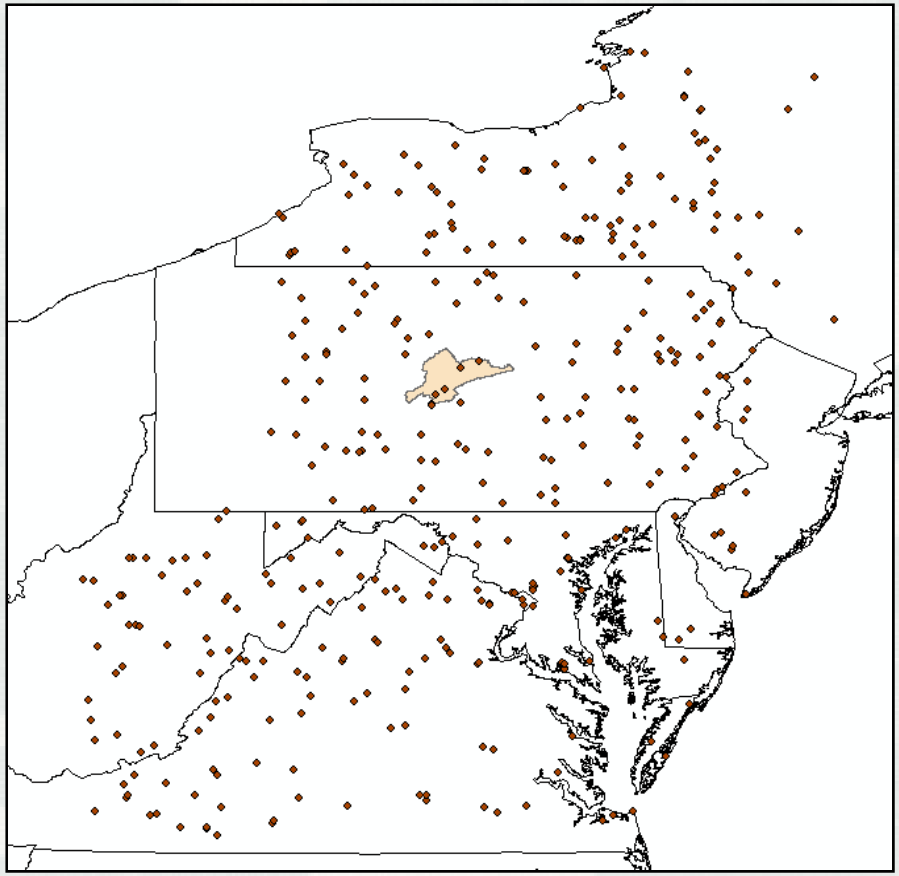
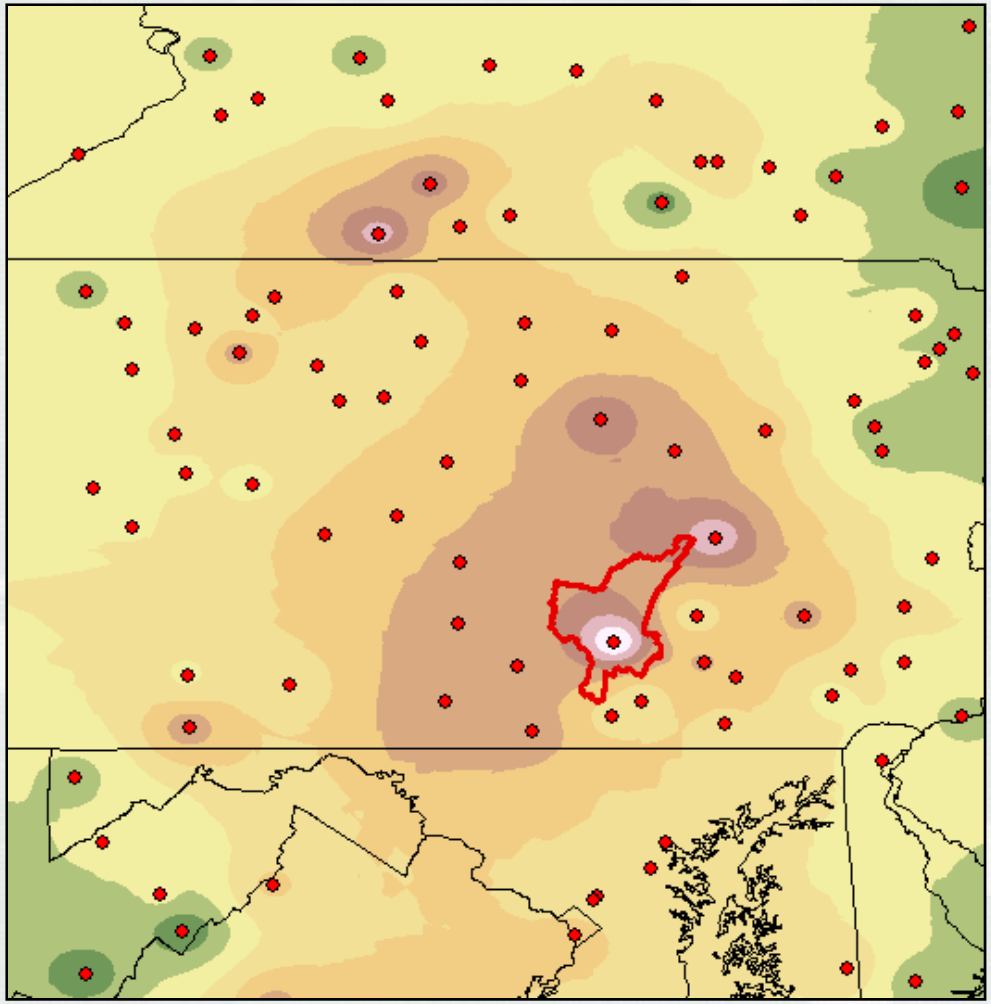
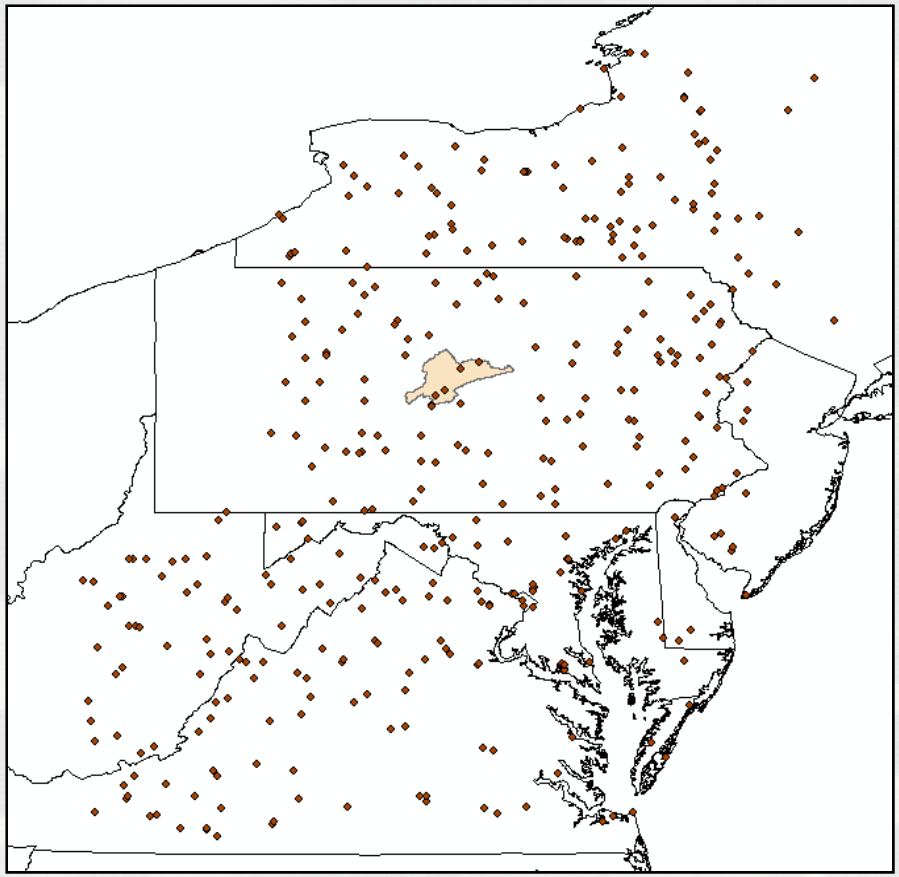
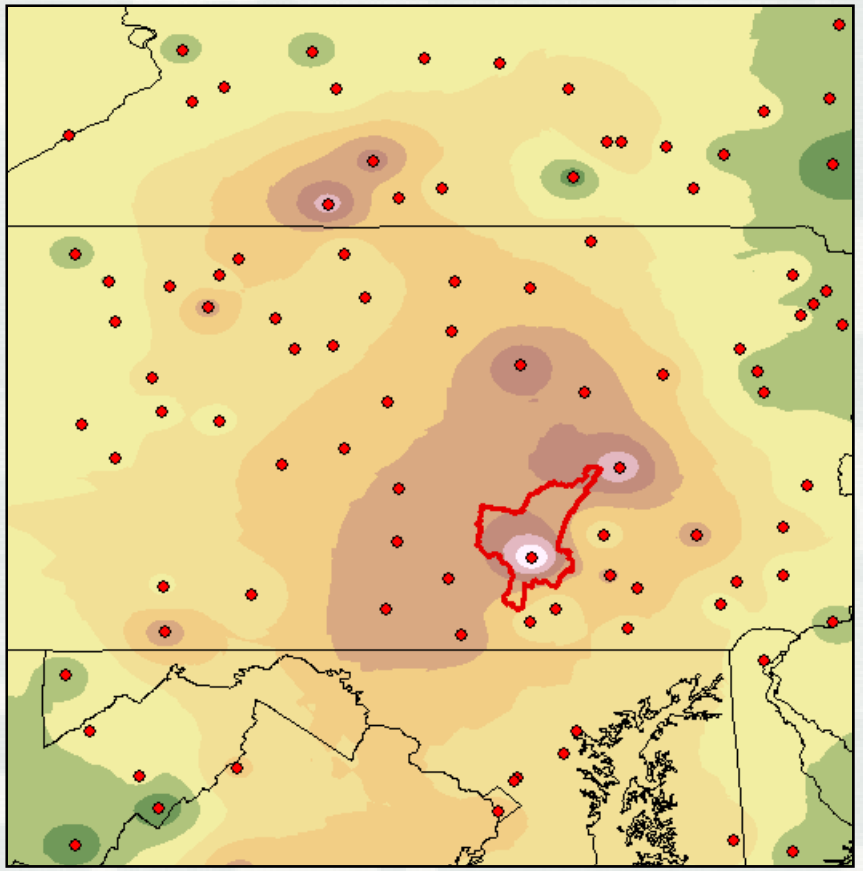


Contour Rainfall



Basin Translation



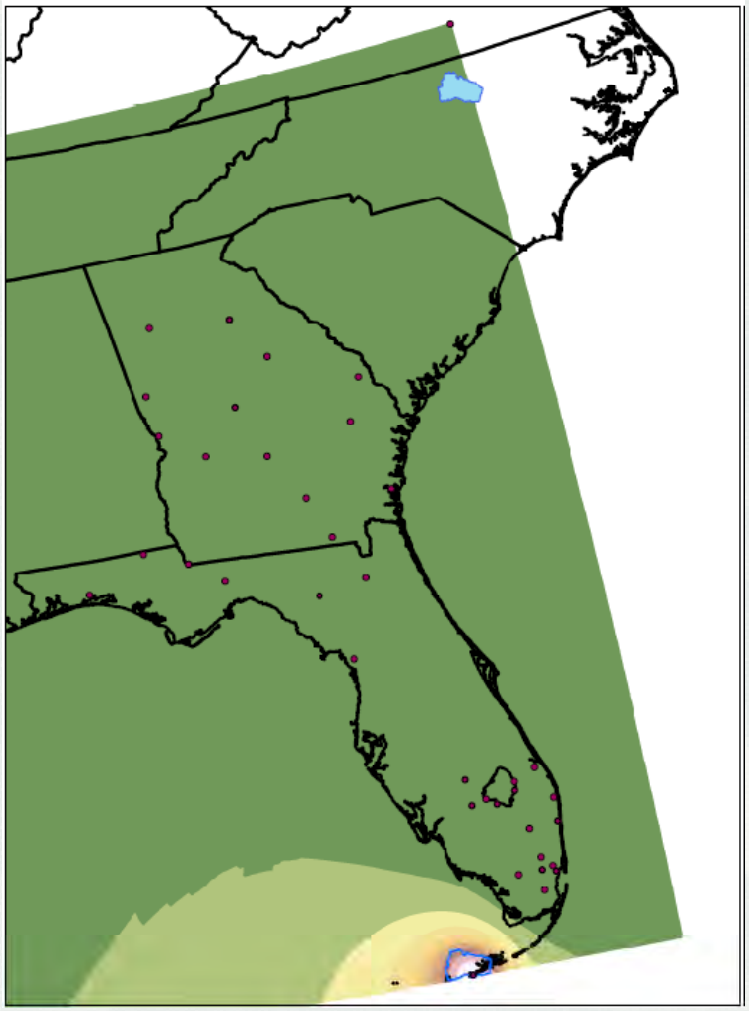


Intersect basin and rainfall to get average precipitation

Regional Probability – Historic Precipitation

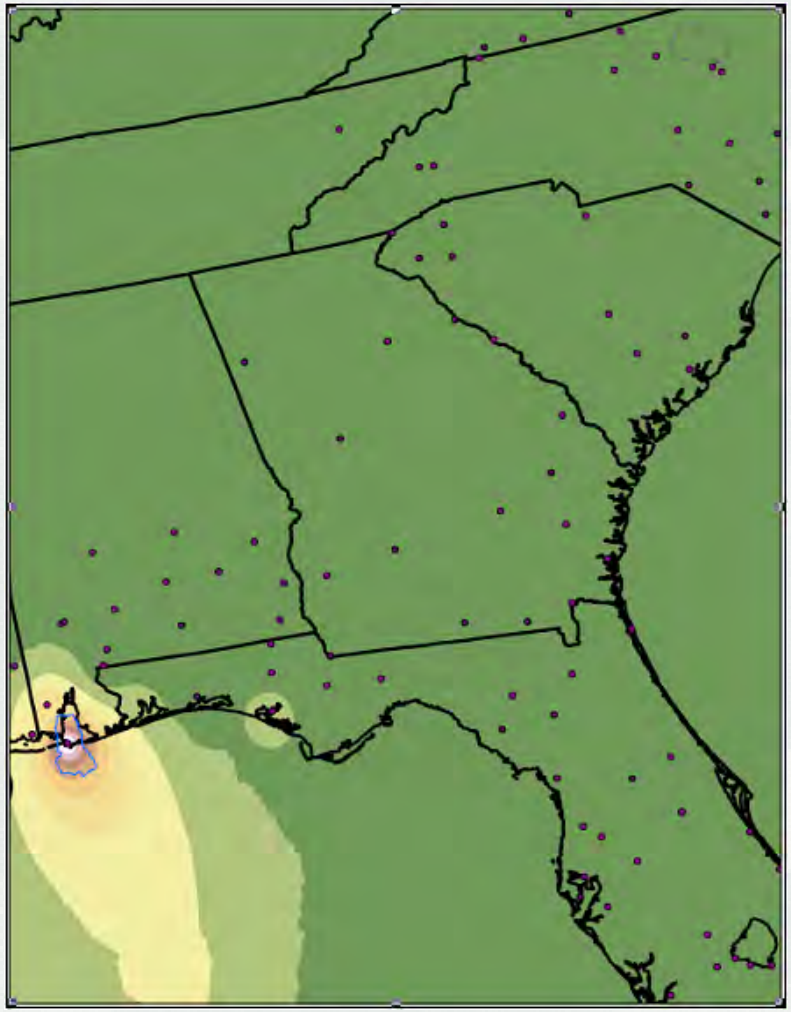
- Falls Lake, NC
  - Collect regional rainfall
  - Select large events
    - Sept. 1999
    - July 1997
    - Nov 1980
  - Select largest Historic Event
  - Develop isohyets
  - Center over basin
  - GIS Tools to compute average rainfall

Falls Lake - November 1980



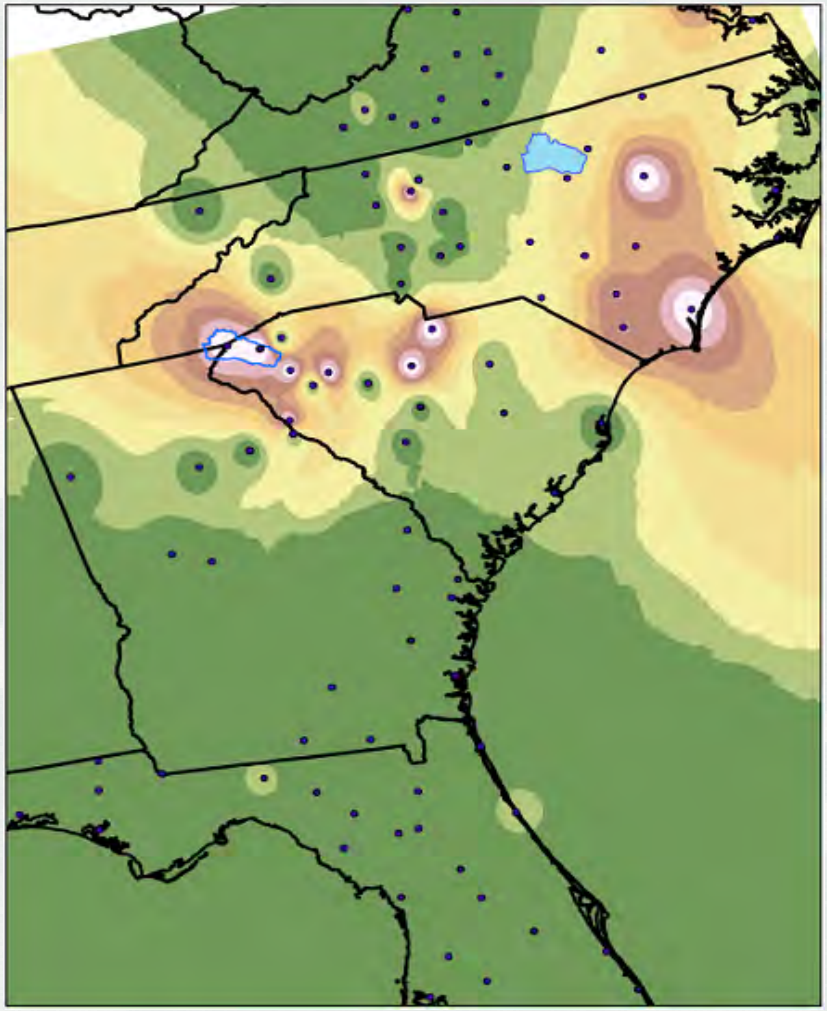
- Small # of stations
- Move to location far away
- 3-day mean, 20.71”

Falls Lake - July 1997



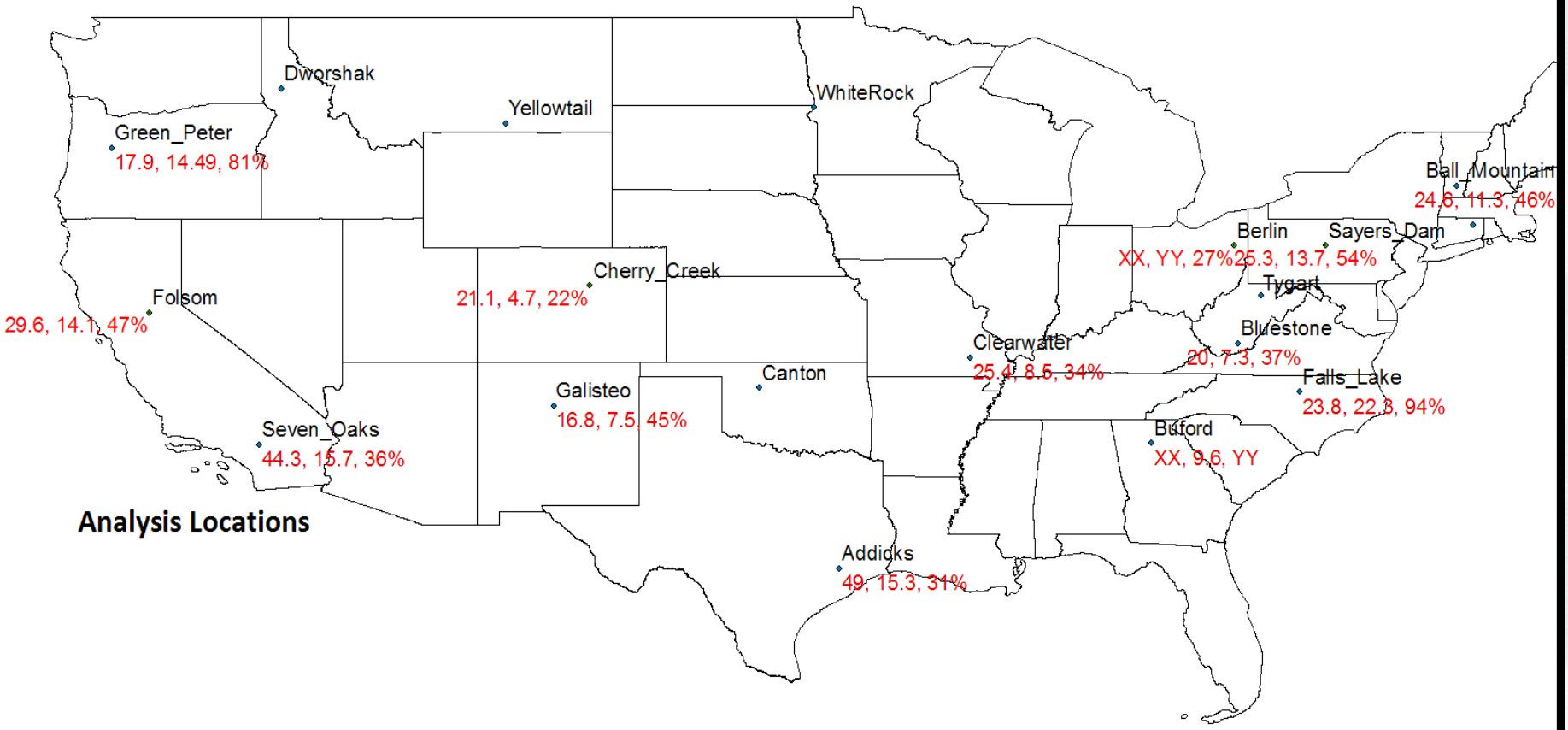
- More stations
- Move to location far away
- 3-day mean, 22.75”

Falls Lake - September 1999



- Same # stations as 1997
- Move to location nearby
- 3-day mean, 22.34”
- Historic/PMP Ratio= .938

The red numbers represent PMP, Regional Precipitation, Ratio



AEP of PMF Range

Location	PMP	Regional	Date	Percentage	Range			
					10^{-3} to 10^{-4}	**10^{-3} to 10^{-5}**	**10^{-3} to 10^{-6}**	10^{-3} to 10^{-7}
Addicks	49	15.3	Jun-01	31%	4,873	**23,742**	**115,682**	563,664
Bald Eagle	25.3	11.1	1972	44%	3,641	**13,260**	**48,283**	175,816
Ball Mountain	24.6	11.3	Aug-55	46%	3,473	**12,059**	**41,875**	145,412
Berlin (1-Day)				27%	5,370	**28,840**	**154,882**	831,764
Bluestone	20	7.34	Sep-04	37%	4,295	**18,450**	**79,250**	340,408
Cherry Creek (1-Day)	21.1	13.5	June-65	64%	2,292	**5,253**	**12,038**	27,590
Clearwater	25.4	8.5	Mar-77	33%	4,628	**21,415**	**99,102**	458,608
Falls Lake (No Curve)	23.8	22.3	Sep-99	94%	1,156	**1,337**	**1,546**	1,787
Folsom	29.6	14.1	Jan-97	47%	3,355	**11,254**	**37,755**	126,658
Galisteo	16.8	7.5	Jun-65	45%	3,577	**12,798**	**45,784**	163,789
Green Peter	17.9	14.5	Nov-06	81%	1,549	**2,398**	**3,714**	5,751
Seven Oaks (No Curve)	44.3	15.8	Jan-69	36%	4,399	**19,350**	**85,118**	374,424

Equation

$$AEP = 10^{-[(1-Ratio)\times Range + Min.Value]}$$

Ratio = Max historic storm precipitation divided by PMP for region of interest.
Range = Selected institutional range for probability of the PMF
Min Val = Minimum value of institutional range.

As ratio approaches 1 = More frequent AEP
As ratio approaches 0 = Less frequent AEP

Falls Lake Sample Computation

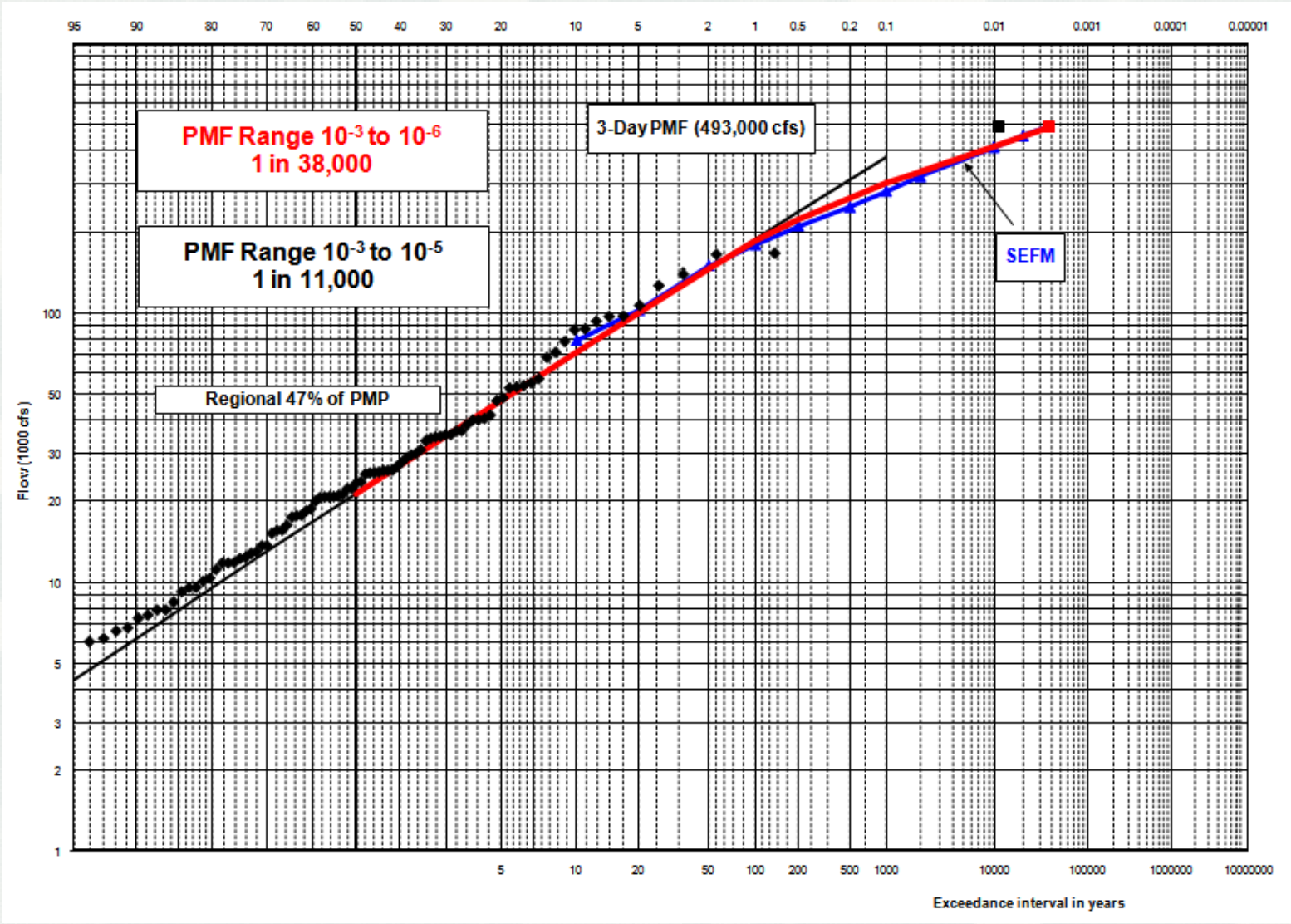
- 72-Hour Historic Precip = 22.3 inches
- 72-Hour PMP = 23.8 inches
- Ratio = 22.3/23.8=.94

- Range = 3 (10^{-3} to 10^{-6})
- Min Value = 3

- AEP = $10^{-(0.06*3+3)} = 10^{-3.18} = 0.0007$ (1 in 1,546)

$$AEP = 10^{-[(1-Ratio)\times Range + Min.Value]}$$

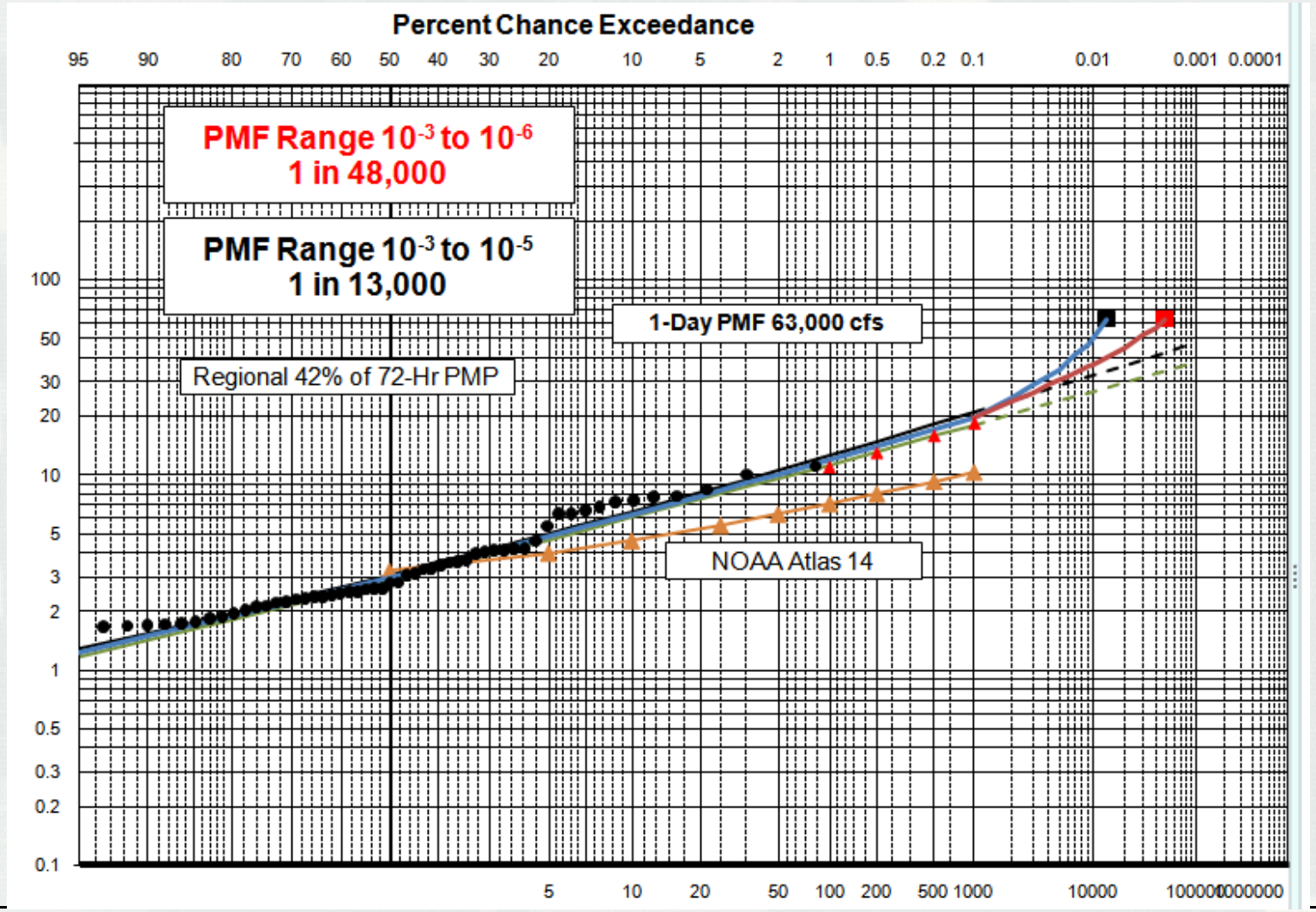
Folsom


PMF Range 10-3 to 10-6
1 in 38,000
PMF Range 10-3 to 10-5
1 in 11,000
3-Day PMF (493,000 cfs)
SEFM
Regional 47% of PMP
Flow (1000 cfs)
Exceedance interval in years
95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.01 0.001 0.0001 0.00001
100 50 30 20 10 5 3 2 1
5 10 20 50 100 200 500 1000 10000 100000 1000000 10000000

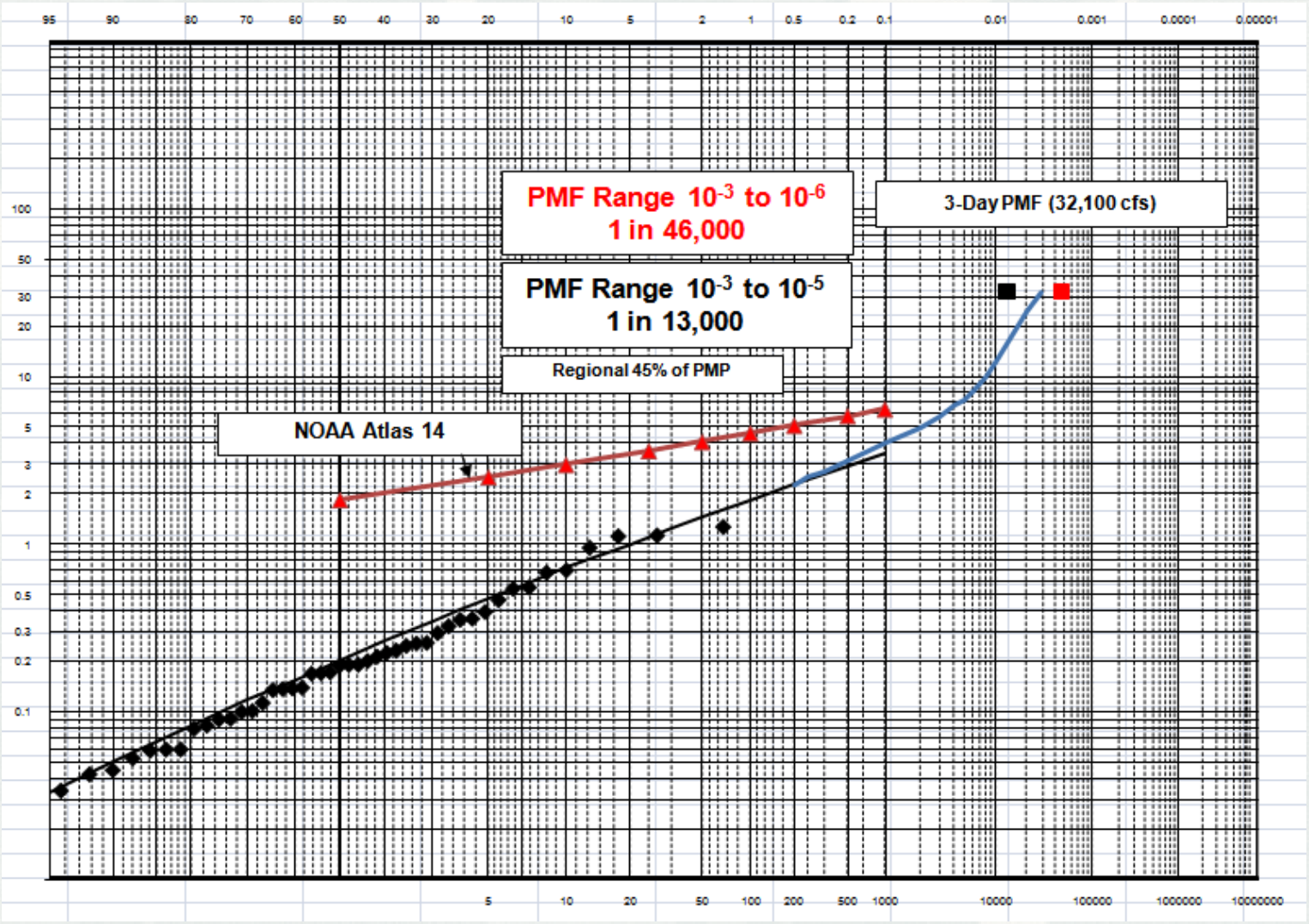
Curve Combination

Frequency	Observed Record		Rainfall-Runoff		SEFM		GRADEX		Paleo		Adopted Values (cfs)
	Value	Weight	Value	Weight	Value	Weight	Value	Weight	Value	Weight	
0.5	21,000	1									21,000
0.2	47,000	1									47,000
0.1	72,000	1									72,000
0.04	100,000	1									100,000
0.02	147,000	1			146,000						147,000
0.01	188,000	0.5			180,000	0.50					184,000
0.005	237,000	0.5			210,000	0.50					223,000
0.002	312,000	0.25			250,000	0.75					265,428
0.001	378,000	0.25			280,000	0.75					304,448
0.0002					375,000	1.0					375,000
0.0001					415,000	1.0					415,000
0.00001											
0.000001											
0.0000001											

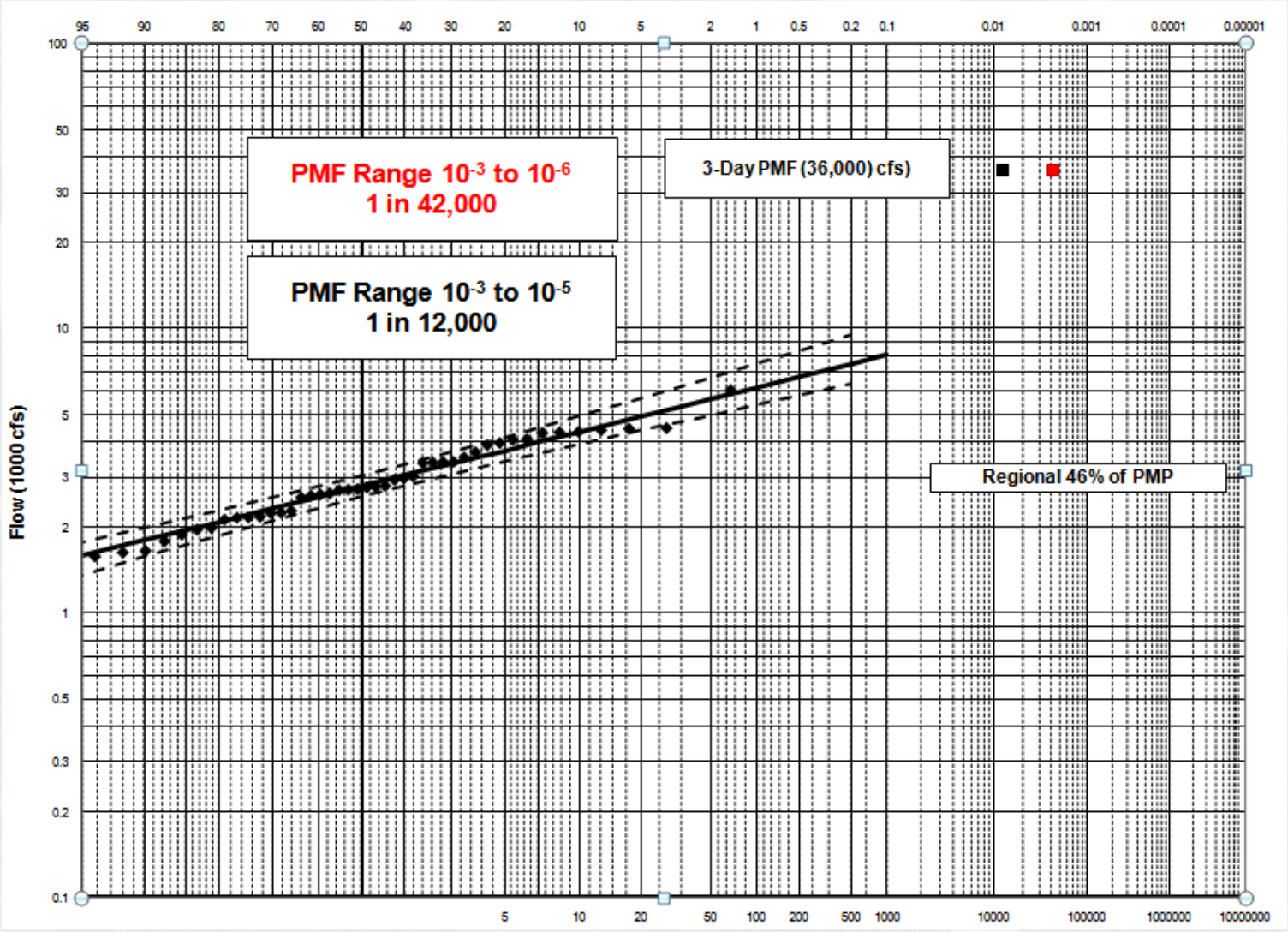
Bald Eagle


Percent Chance Exceedance
95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.01 0.001 0.0001
PMF Range 10-3 to 10-6
1 in 48,000
PMF Range 10-3 to 10-5
1 in 13,000
1-Day PMF 63,000 cfs
Regional 42% of 72-Hr PMP
NOAA Atlas 14
100 50 30 20 10 5 3 2 1 0.5 0.3 0.2 0.1
5 10 20 50 100 200 500 1000 10000 100000 1000000

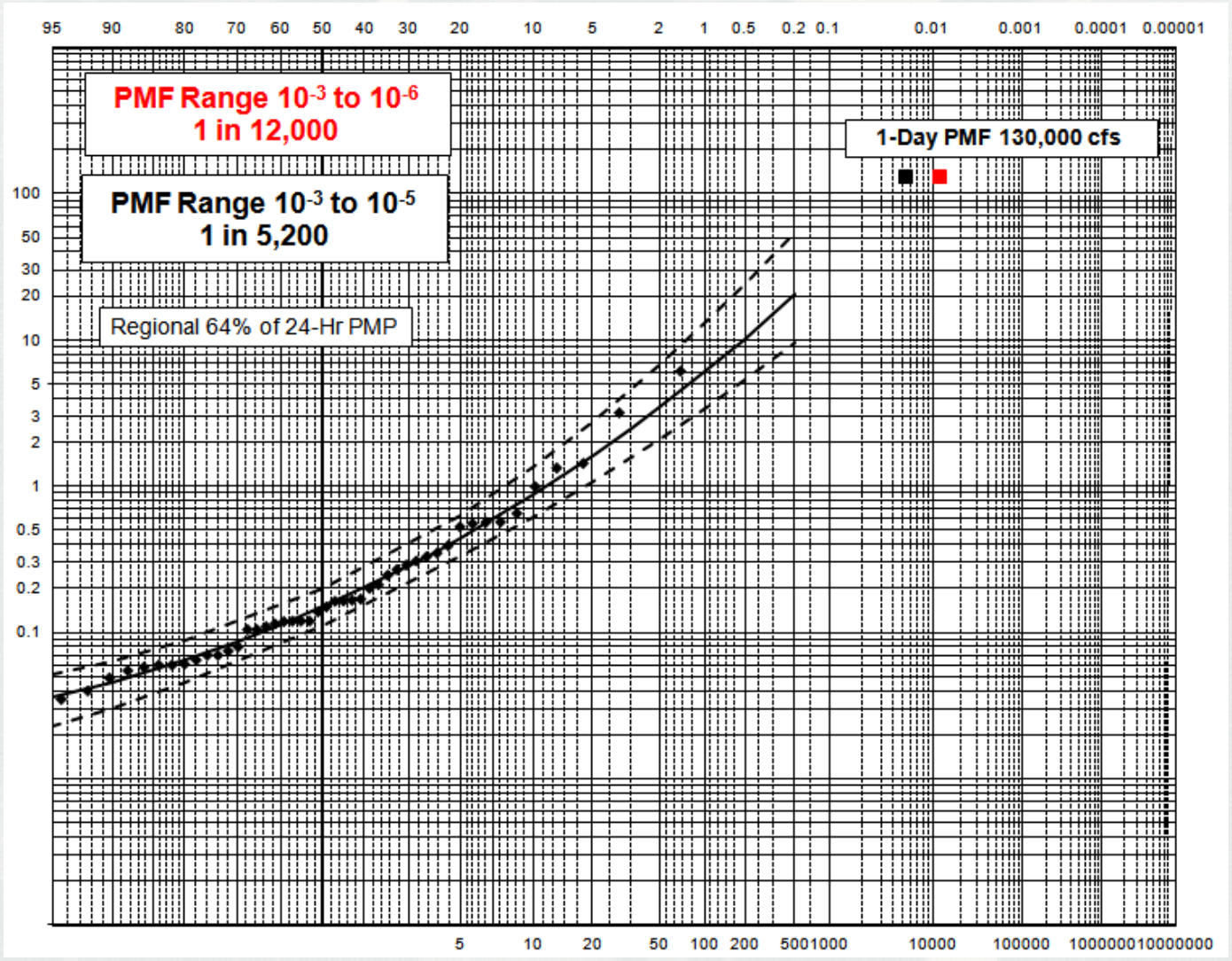
Galisteo


PMF Range 10-3 to 10-6
1 in 46,000
PMF Range 10-3 to 10-5
1 in 13,000
Regional 45% of PMP
NOAA Atlas 14
3-Day PMF (32,100 cfs)

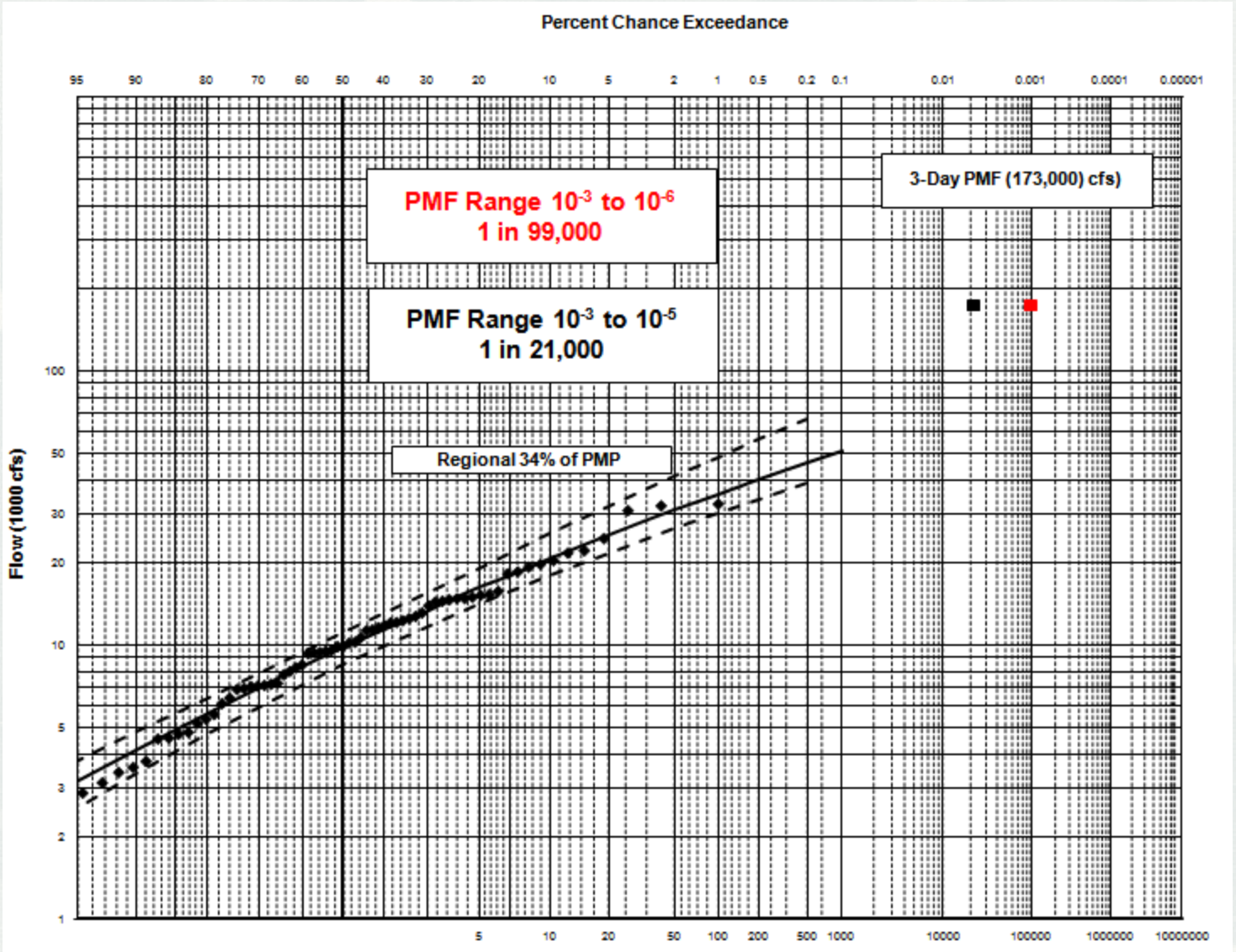
Ball Mountain



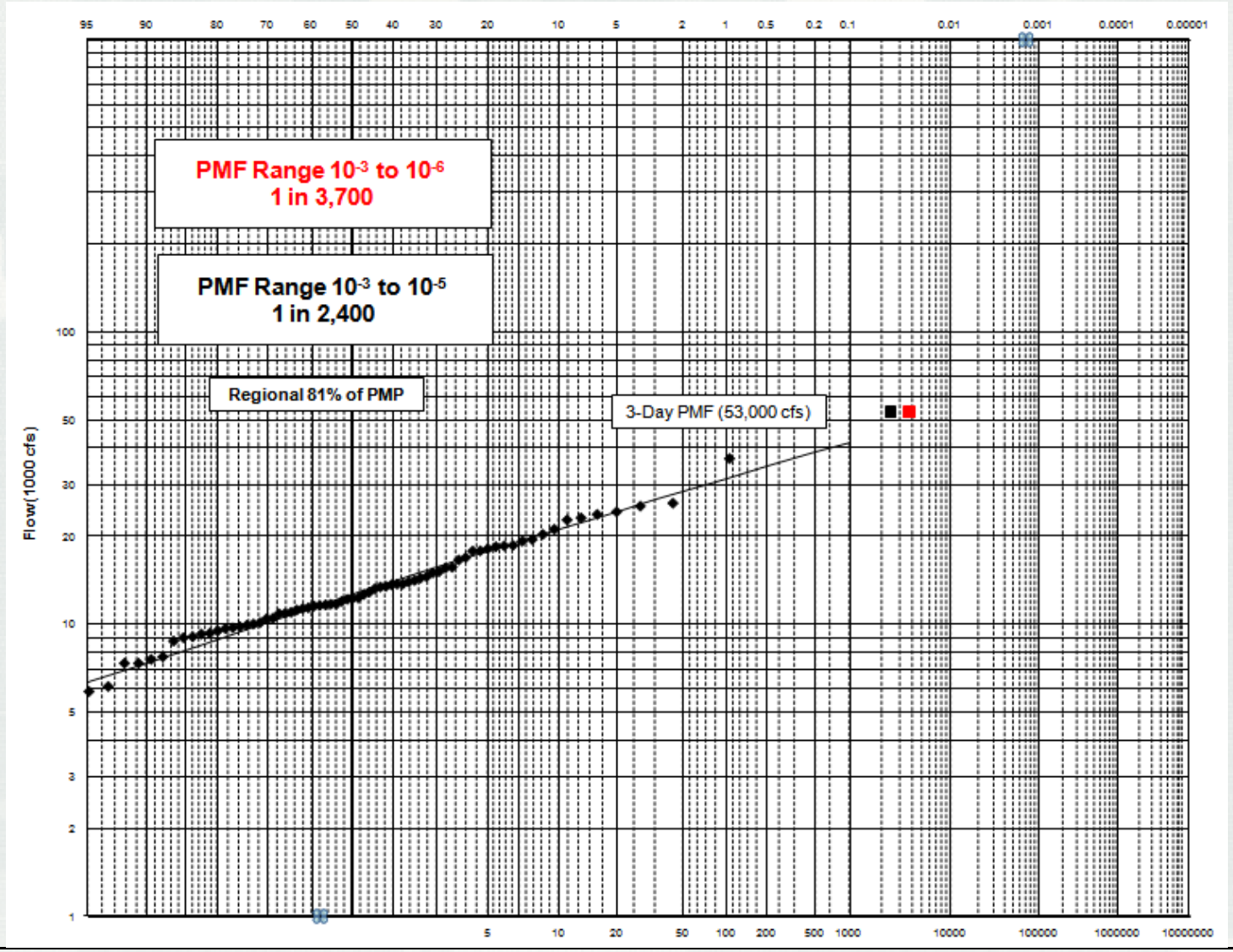
Cherry Creek



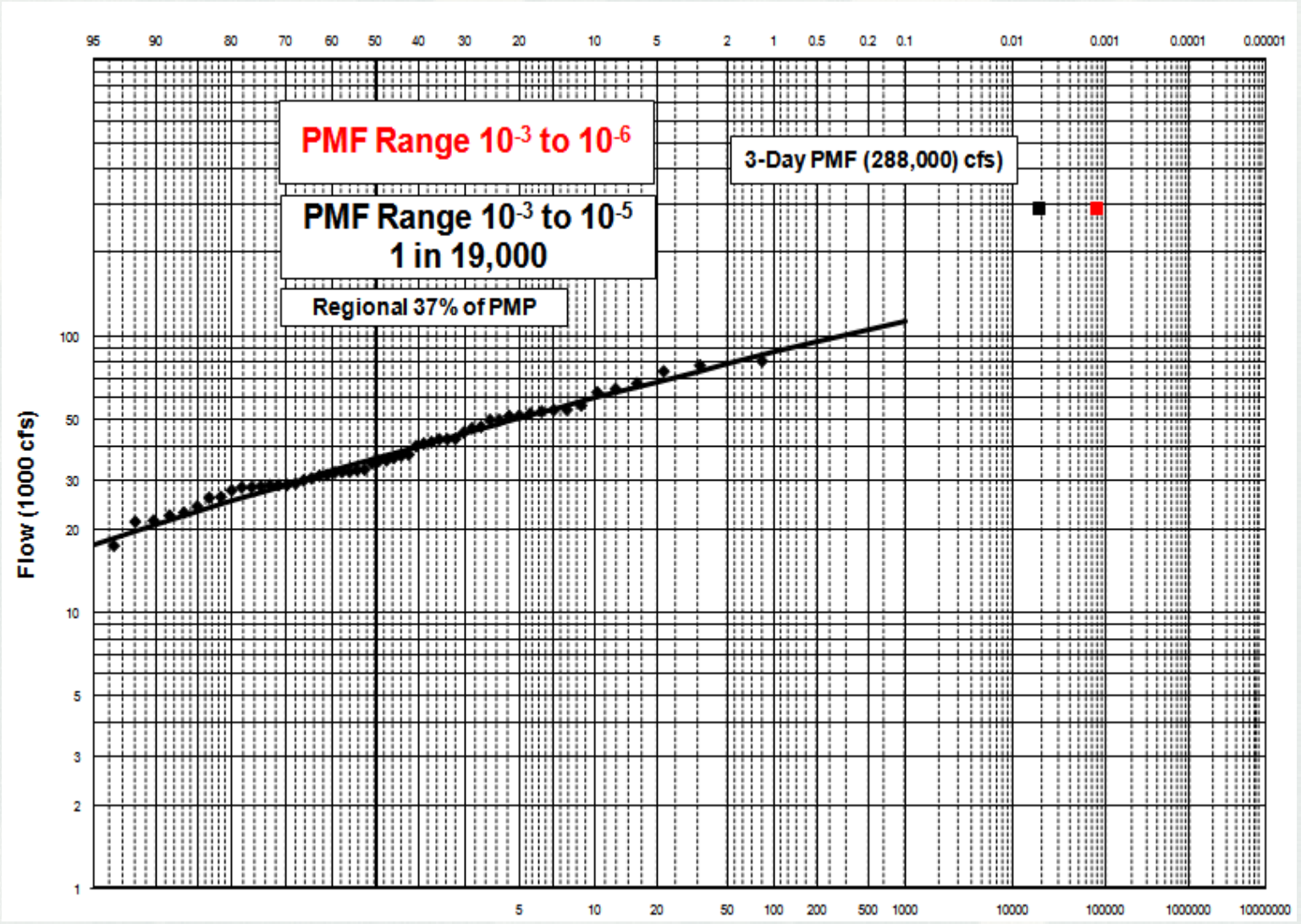
Clearwater


Percent Chance Exceedance
95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.01 0.001 0.0001 0.00001
PMF Range 10-3 to 10-6
1 in 99,000
PMF Range 10-3 to 10-5
1 in 21,000
3-Day PMF (173,000) cfs)
Regional 34% of PMP
Flow (1000 cfs)
100 50 30 20 10 5 3 2 1
5 10 20 50 100 200 500 1000 10000 100000 1000000 10000000

Green Peter


PMF Range 10-3 to 10-6
1 in 3,700
PMF Range 10-3 to 10-5
1 in 2,400
Regional 81% of PMP
3-Day PMF (53,000 cfs)
Flow(1000 cfs)
95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.01 0.001 0.0001 0.00001
100 50 30 20 10 5 3 2 1
5 10 20 50 100 200 500 1000 10000 100000 1000000 10000000

Bluestone


PMF Range 10-3 to 10-6
3-Day PMF (288,000) cfs)
PMF Range 10-3 to 10-5
1 in 19,000
Regional 37% of PMP
Flow (1000 cfs)
95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.01 0.001 0.0001 0.00001
100 50 30 20 10 5 3 2 1
5 10 20 50 100 200 500 1000 10000 100000 1000000 10000000

Summary

- Collect as much rainfall as possible for applicable duration from available sources.
- Use all data available to generate Combined Curve
- All methods have challenges.
- AEP of PMF is an ESTIMATE
- PMF magnitude needs flow and exceedance error bands