Lecture 3.1

Update of Bulletin 17B to 17C
Expected Moments Algorithm, etc

Flood Frequency Analysis

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Goals

- Understand why we have Federal guidance on flood frequency analysis, and how its development has progressed
- Be aware of the differences between Bulletins 17B and 17C, and improvements Bulletin 17C can offer

Outline

- Why a Bulletin? History
- Bulletin 17B / 17C elements
  - Generalized Data description
  - Missing values, zero flows, low outliers (PILFs)
  - Historical information, high outliers
  - EMA Computation
  - Weighted skew
  - Confidence intervals

Why Flood Frequency Analysis Guidance?

- Late 1960s: many agencies were performing flood frequency analysis for many reasons
  - economic analysis, standards & permitting, project design
- National Flood Insurance Program (NFIP) defined "100-year" flow (and floodplain) as the regulatory threshold
  - a lot of **significance** to the 100-year flow estimate!
- Needed a consistent, objective, reproducible method to estimate that 100-year flow
  - *So any entity doing the analysis with the same data will get the same result (flood frequency curve, 1% exc. estimate)*
- There is often a trade-off between consistency for all sites and the best analysis for a given site…

Evolution of Guidance

1967 Bulletin 15 *brief testing*

fit LogPearson type III (**LP3**) to at-site gage data using Method of Moments

1976 Bulletin 17 *more extensive testing*

LP3, weighting with a regional skew coefficient, low-outlier censoring, use of historical information

1977 Bulletin 17A

Improved low-outlier identification and adjustment

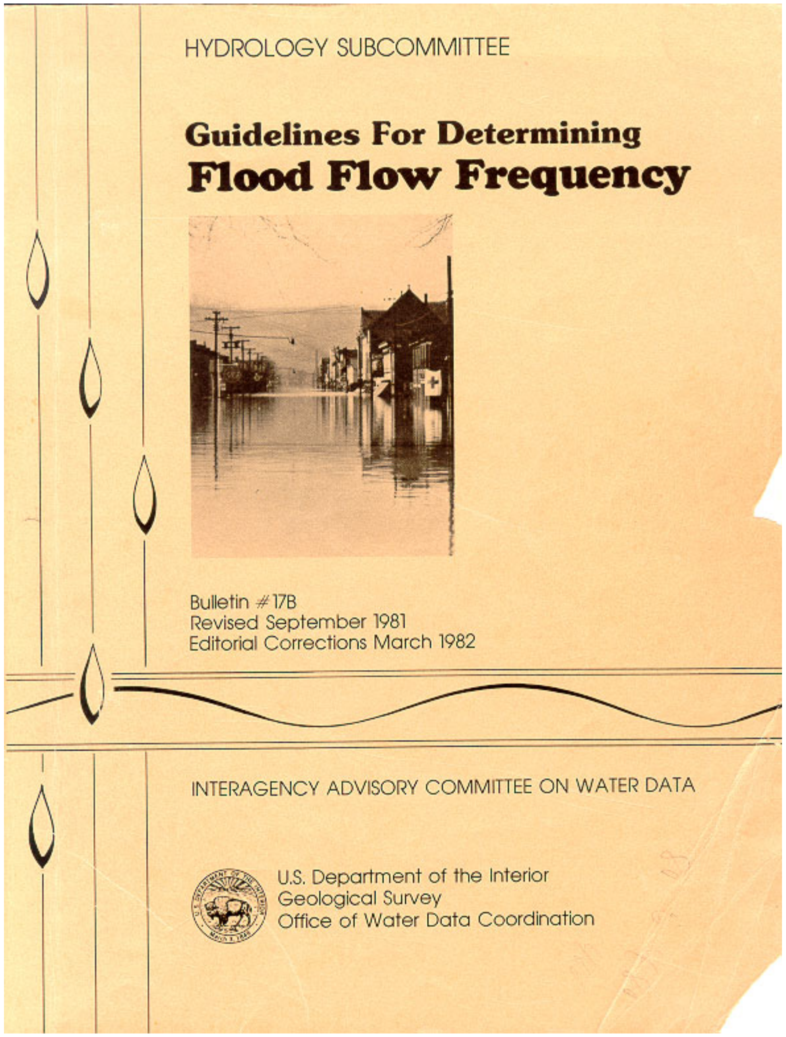
1982 Bulletin 17B

Improved use of historical information

1983 ***Water Resources Council abolished***

2018 Bulletin 17C

Fitting **LP3** by Expected Moments Algorithm (EMA), better confidence intervals, updated low outlier identification, improved regional skews



Bulletin 17B

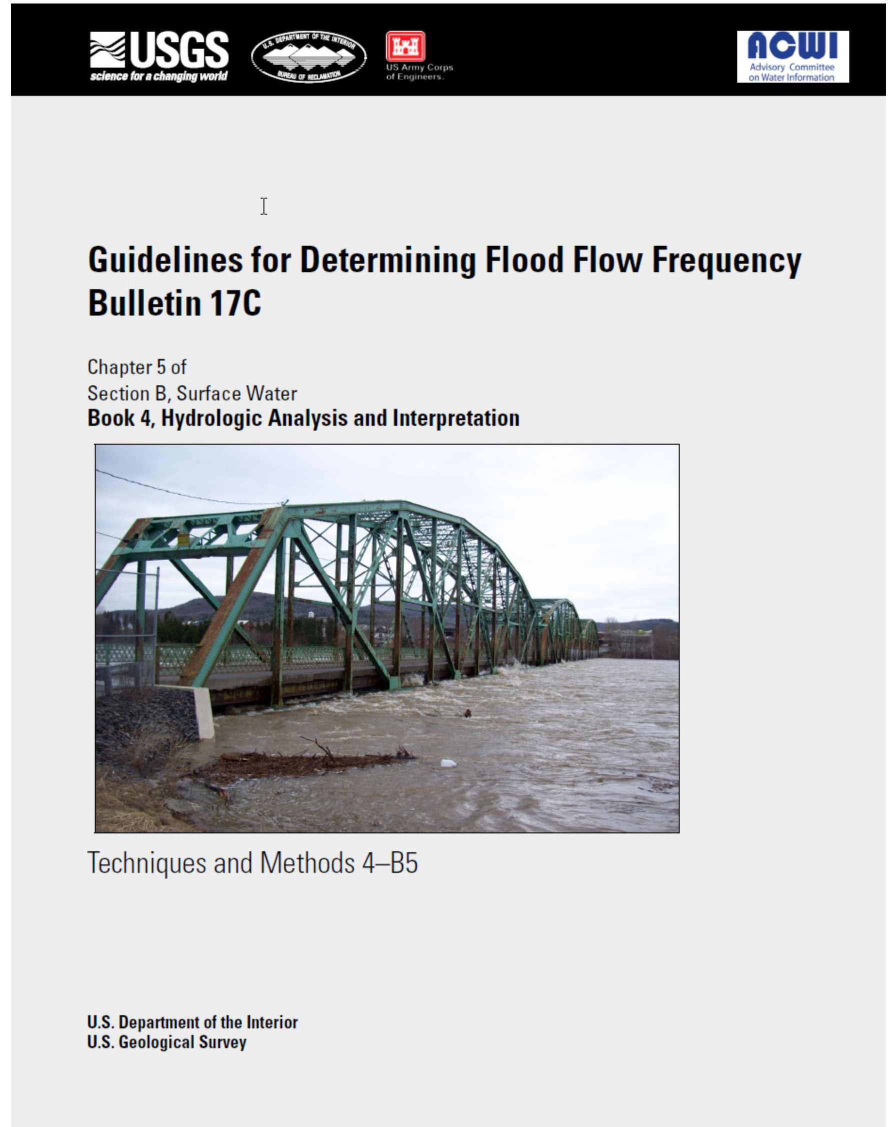
dated March 1982

←

Bulletin 17C

dated Feb 2018

→



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Bulletin 17B/C: Gaged Frequency Analysis

When a gage is present, and flows are unregulated, Bulletin 17B/C procedures must be applied

- Data set is each year's annual maximum streamflow
- Distribution fitted is **Log-Pearson III**, using MOM with $\log_{10}$flow
- Assumptions **IID**
  - annual peak flows are statistically independent **I-**
  - watershed characteristics are unchanged for the entire record (i.e., all floods from same probability distribution) **-ID**
  - sufficient record length to describe the "population" of floods

USGS's
National
Water
Information
System

http://waterdata.usgs.gov/usa/nwis/sw

USGS
science for a changing world

USGS Home
Contact USGS
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National Water Information System: Web Interface

USGS Water Resources (Cooperator Access)

Data Category: Surface Water
Geographic Area: United States
GO

Peak Streamflow for the Nation

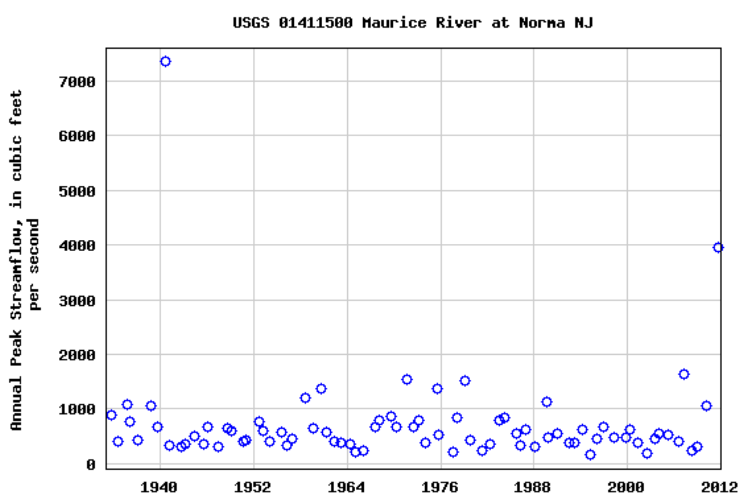
USGS 01411500 Maurice River at Norma NJ

Available data for this site: Surface-water: Peak streamflow GO

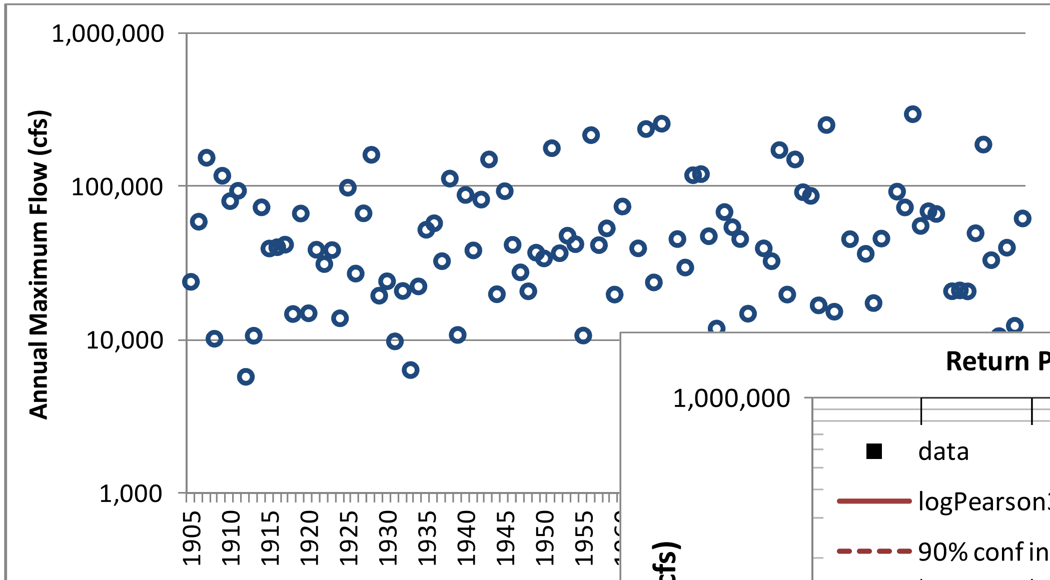
Salem County, New Jersey
Hydrologic Unit Code 02040206
Latitude 39°29'44", Longitude 75°04'37" NAD83
Drainage area 112 square miles
Gage datum 46.94 feet above NGVD29

Output formats

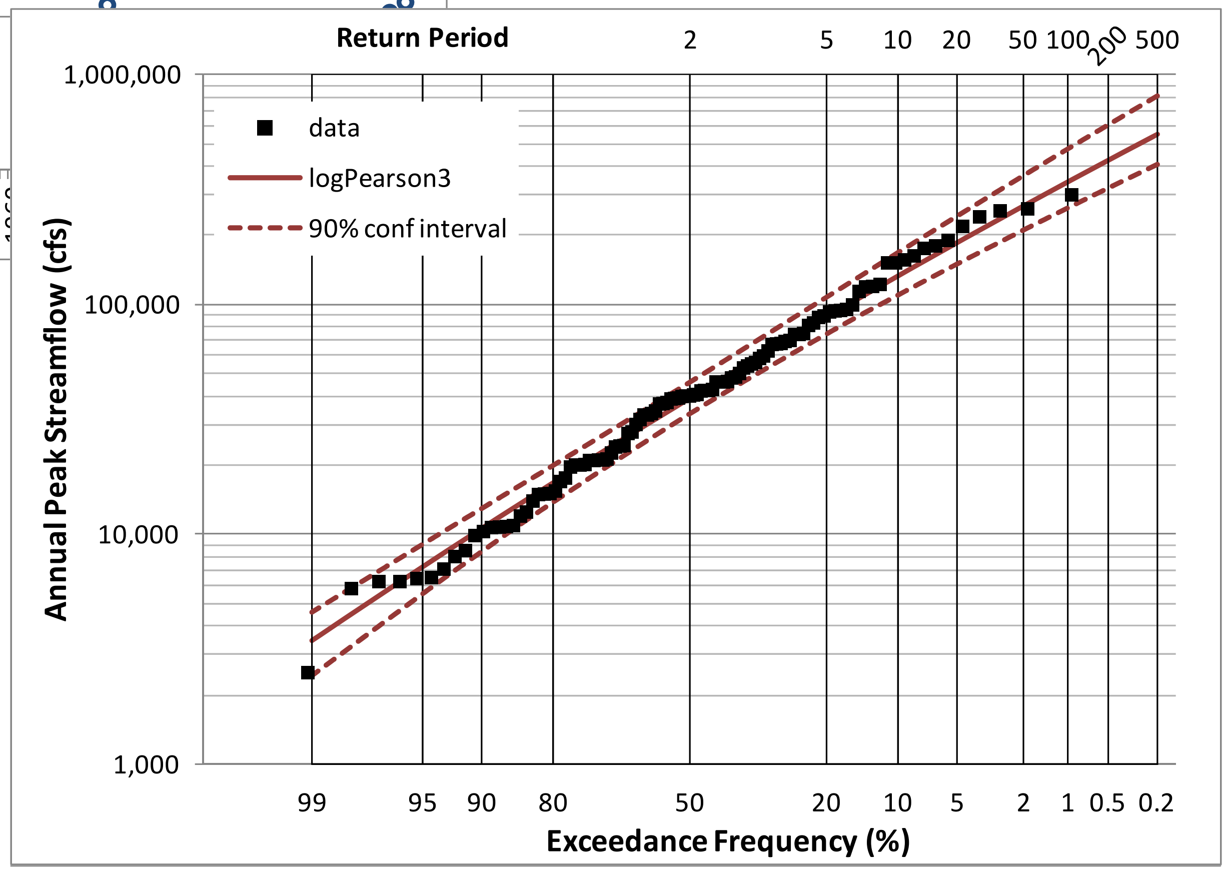
- Table
- Graph
- Tab-separated file
- peakfq (watstore) format
- Reselect output format



Download a presentation-quality graph



1,000,000
100,000
10,000
1,000
Annual Maximum Flow (cfs)
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955



Return Period
2
5
10
20
50
100
200
500
1,000,000
100,000
10,000
1,000
data
logPearson3
90% conf interval
Annual Peak Streamflow (cfs)
99
95
90
80
50
20
10
5
2
1
0.5
0.2
Exceedance Frequency (%)

Selection of Log Pearson Type III (LP3) for Annual Peak Flows

- Water Resources Council tests showed LP3 with regional info was best for estimating **100-year event**

  others: LogNormal, Gumbel, LogGumbel, 2-, 3-Gamma, but not GEV

  see Bulletin 17B, Appendix 14

- Greater flexibility than LogNormal – has a variable skew coefficient

  Normal has zero skew, logNormal has constant skew, P3 = "skewed Normal"

- **Recommendation**

  Bulletin 17B guidelines recommends use of Log-Pearson III distribution, with regional info, *unless some other distribution explains the observed data much better (must be well supported)*

"Future Work" (p. 27, B17B)

1. Selection of distribution and **fitting procedures**.
2. Mixed Distributions
3. **Low Outliers** (identification and treatment)
4. Use of **Historical data**
5. Correct **Confidence Intervals**
6. Incorporating precipitation frequency analysis.
7. Ungaged watersheds, limited gaging records.
8. Urbanization and regulation.

USGS science for a changing world   US Army Corps of Engineers   ACWI Advisory Committee on Water Information

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

Bulletin 17C

Finalized 2018

Differences in Bulletin 17C

- Uses the Expected Moments Algorithm (**EMA**) to estimate the LogPearson III distribution parameters still Method of Moments
- Allows a more general description of flow data as intervals, and requires definition of perception thresholds
- Has a more aggressive "low outlier" test
- Provides more accurate *(usually larger)* confidence intervals
- Improved regional skew method being used by USGS across US

➢ *If there are no low outliers and no historical information, the results of 17C are identical to 17B*

Computation of EMA parameter estimates

- EMA estimates product moments from sample data
  - *mean, standard deviation, skew coefficient*
- Due to the iterative nature of the EMA computation, it is not a "by hand" procedure like Bulletin 17B
- Computer code has been developed, and is present within USGS and USACE software (PeakFq, and HEC-SSP)
  - Bulletin 17C recommends use of this code

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  - EMA (Expected Moments Algorithm) computation
  - Weighted skew
  - Confidence intervals

EMA: Estimating Moments from Point Data

Mean (M), Standard Deviation (S), and Skew (G)

$$M \equiv \frac{1}{N}\sum_{i=1}^{N} X_i$$

$$S \equiv \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(X_i - M)^2}$$

$$G \equiv \frac{N}{S^3(N-1)(N-2)}\sum_{i=1}^{N}(X_i - M)^3$$

Method of Moments

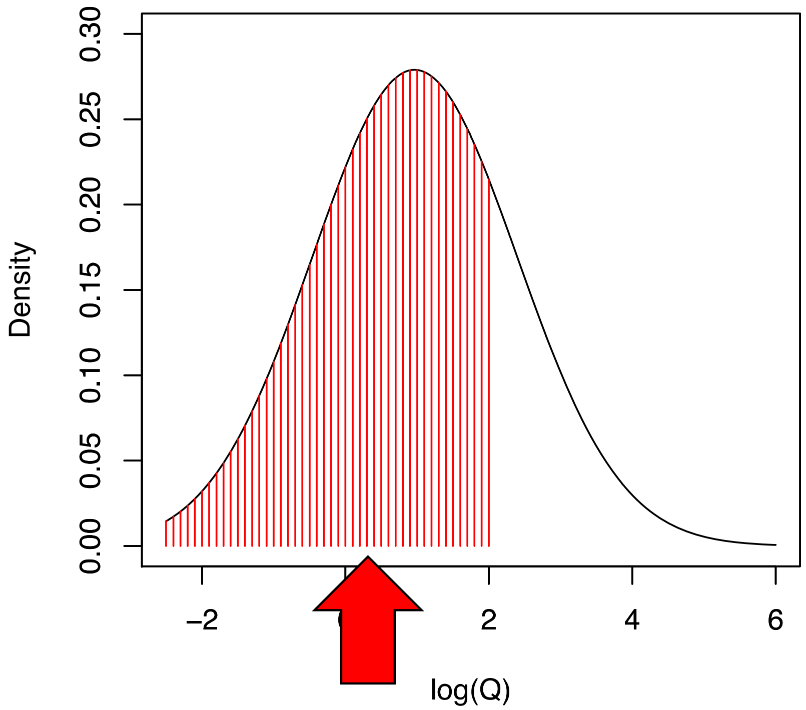
estimate population moments from sample moments

EMA: Estimating Moments from Interval Values

Moments are estimated with the assumption of **LP3**, so can use LP3 to define the likelihood of an interval

1. Given population moments
   – we can compute *expectation of mean*, *variance* and *skew* of interval observations

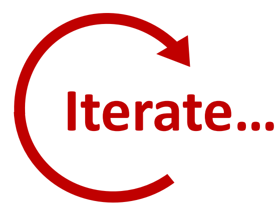
Computing Expected Moments



EMA: Estimating Moments from Interval Values

Moments are estimated with the assumption of **LP3**, so can use LP3 to define the likelihood of an interval

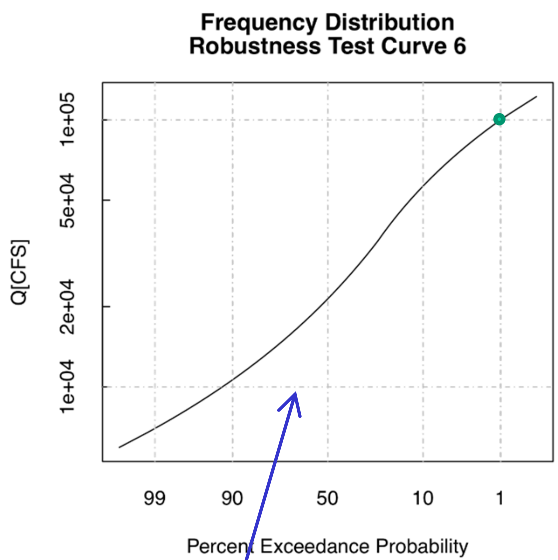
1. Given population moments
   – we can compute *expectation of mean*, *variance* and *skew* of interval observations
2. Given *expected mean, variance* and *skew* of interval observations,
   – we can estimate population moments



- Initial guess, and iterate…

Benefits of Expected Moments Algorithm (EMA)

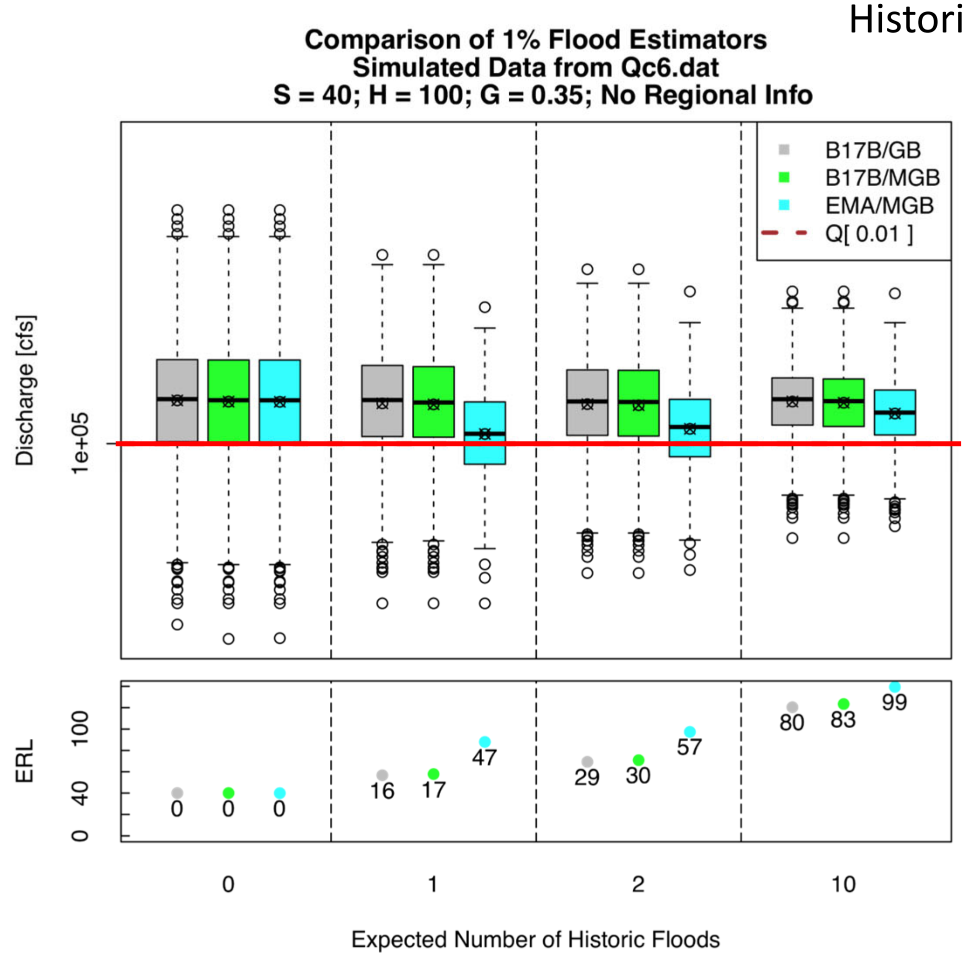
1. Consistent with Bulletin 17B *(LP3, MOM, etc)*
   - *Identical result if no historical info or low outliers*
2. Statistically efficient and robust



Not an LP3 distribution!

Estimating 1% event

Systematic = 40 years
Historical = 100 years



17B / GB
17B / MGB
17C / MGB

historical event threshold

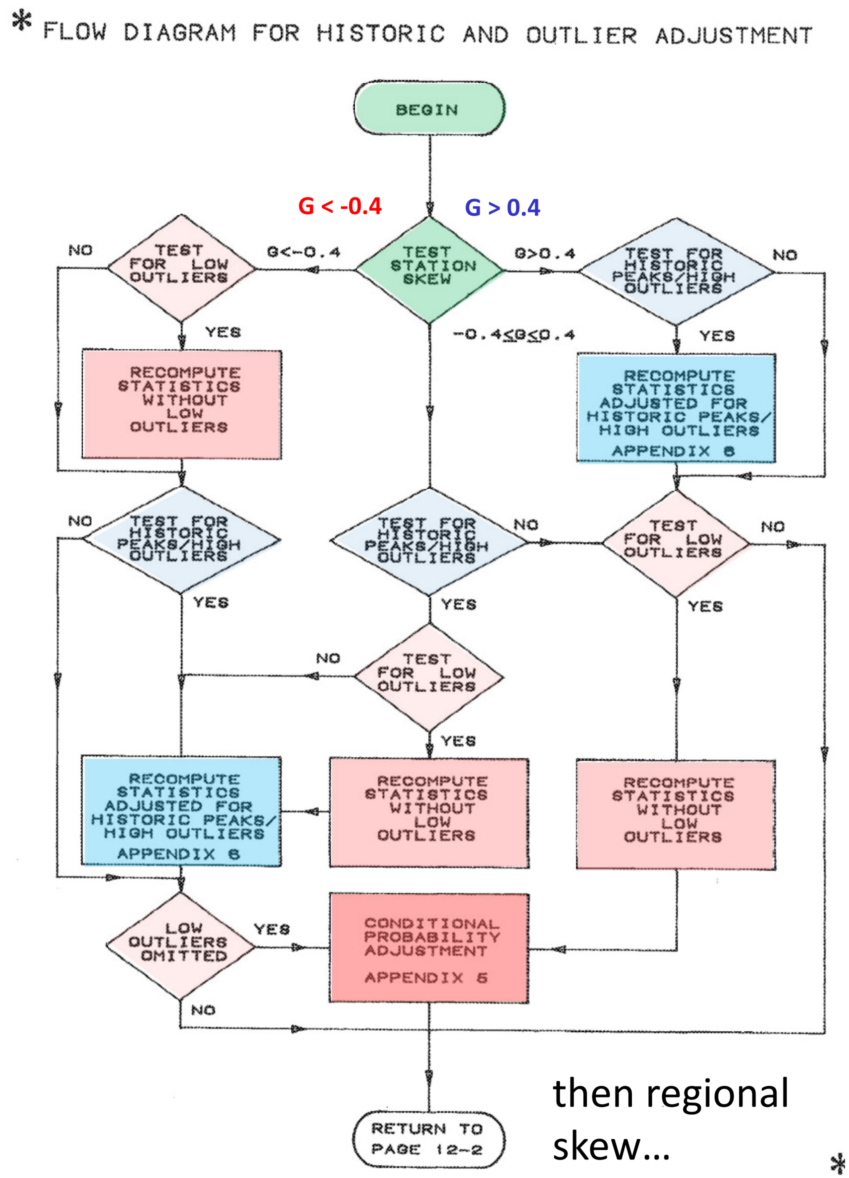
none 100-yr 50-yr 10-yr

Benefits of Expected Moments Algorithm (EMA)

1. Consistent with Bulletin 17B *(LP3, MOM, etc)*
   - *Identical result if no historical info or low outliers*
2. Statistically efficient and robust
3. Statistically tractable
4. <u>Simultaneous</u> consideration of low outliers, historical information and regional skew

Bulletin 17B: Complicated Flowcharts defining order of Computations

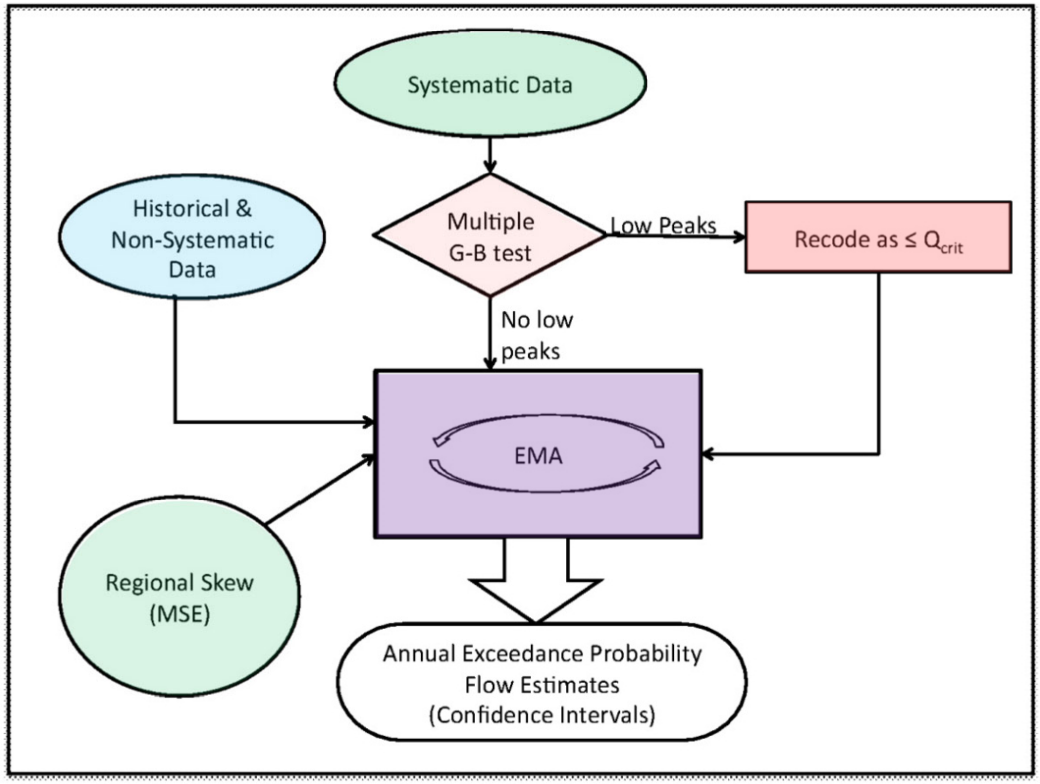
"Specialized" Procedures for Historic data and outlier adjustments



then regional skew…

*

EMA Flowchart for Bulletin 17C



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4. <u>Simultaneous</u> consideration of low outliers, historical information and regional skew
5. More accurate confidence intervals

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Weighted Skew, B17B

- Skew is very difficult to estimate well from a limited sample.
  G_s = station skew
- Improve the estimate with a regional skew, developed using many gages in the region ("trade space for time")
  G_r = regional skew
- Can weight the skew based on the relative error in the skew estimates **$G_w = W_r G_r + W_s G_s$** *where* $(W_r + W_s) = 1$

MSE = mean squared error

$$G_w = \frac{{}^{1}/_{MSE_{G_r}}\, \mathbf{G_r} + {}^{1}/_{MSE_{G_s}}\, \mathbf{G_s}}{{}^{1}/_{MSE_{G_r}} + {}^{1}/_{MSE_{G_s}}}$$

$$G_w = \frac{MSE_{G_s}\mathbf{G_r} + MSE_{G_r}\mathbf{G_s}}{MSE_{G_r} + MSE_{G_s}}$$

Weighted Skew, B17C

- In the Expected Moments Algorithm, additional information (historical info, regional skew, etc) is brought in **simultaneously** with the systematic record, not after
- The skew weighting equation is not at the end, as in 17B, but part of the skew estimation in each iteration. ***Uses N in place of 1/MSE***.

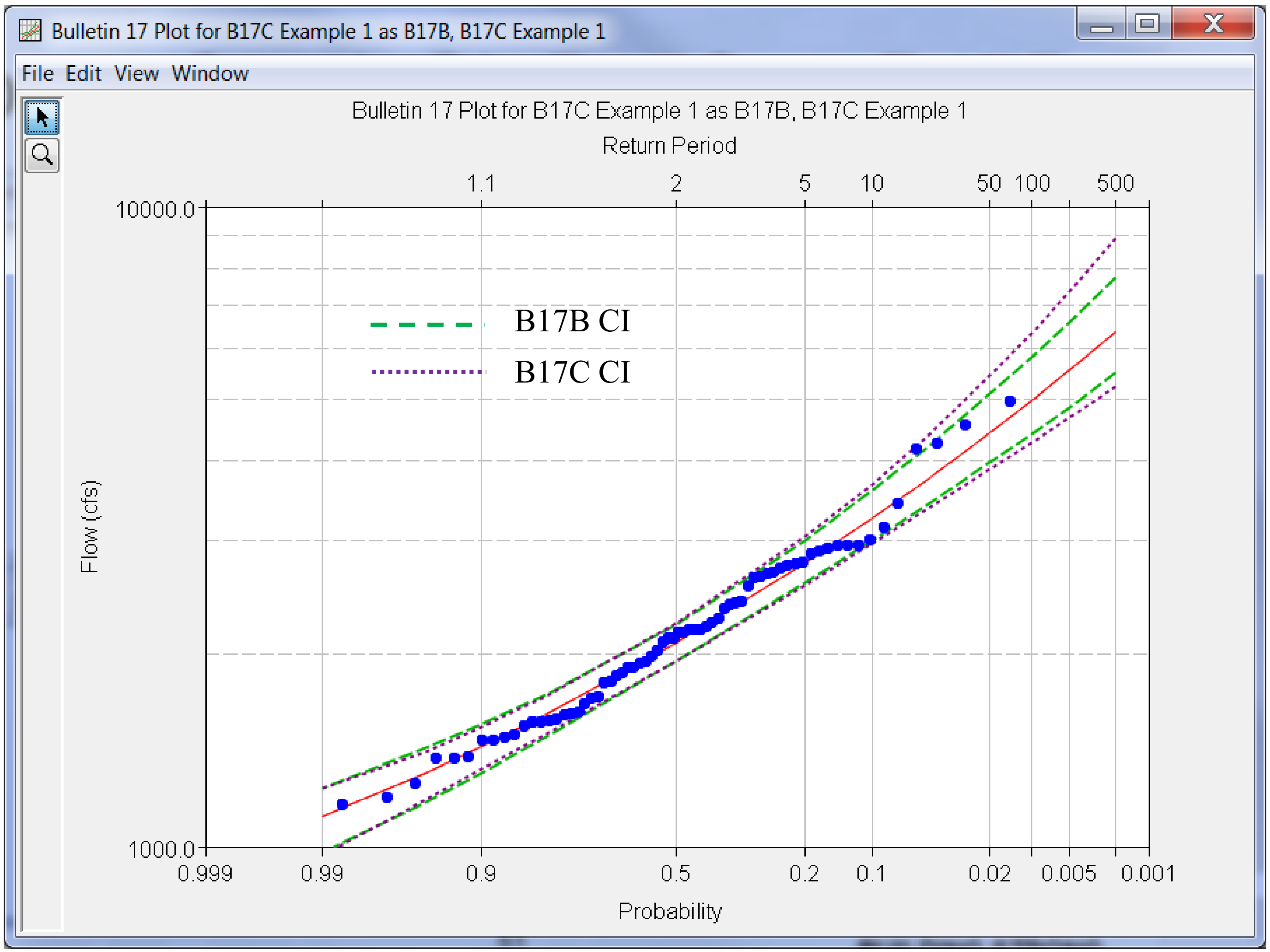
systematic censored regional

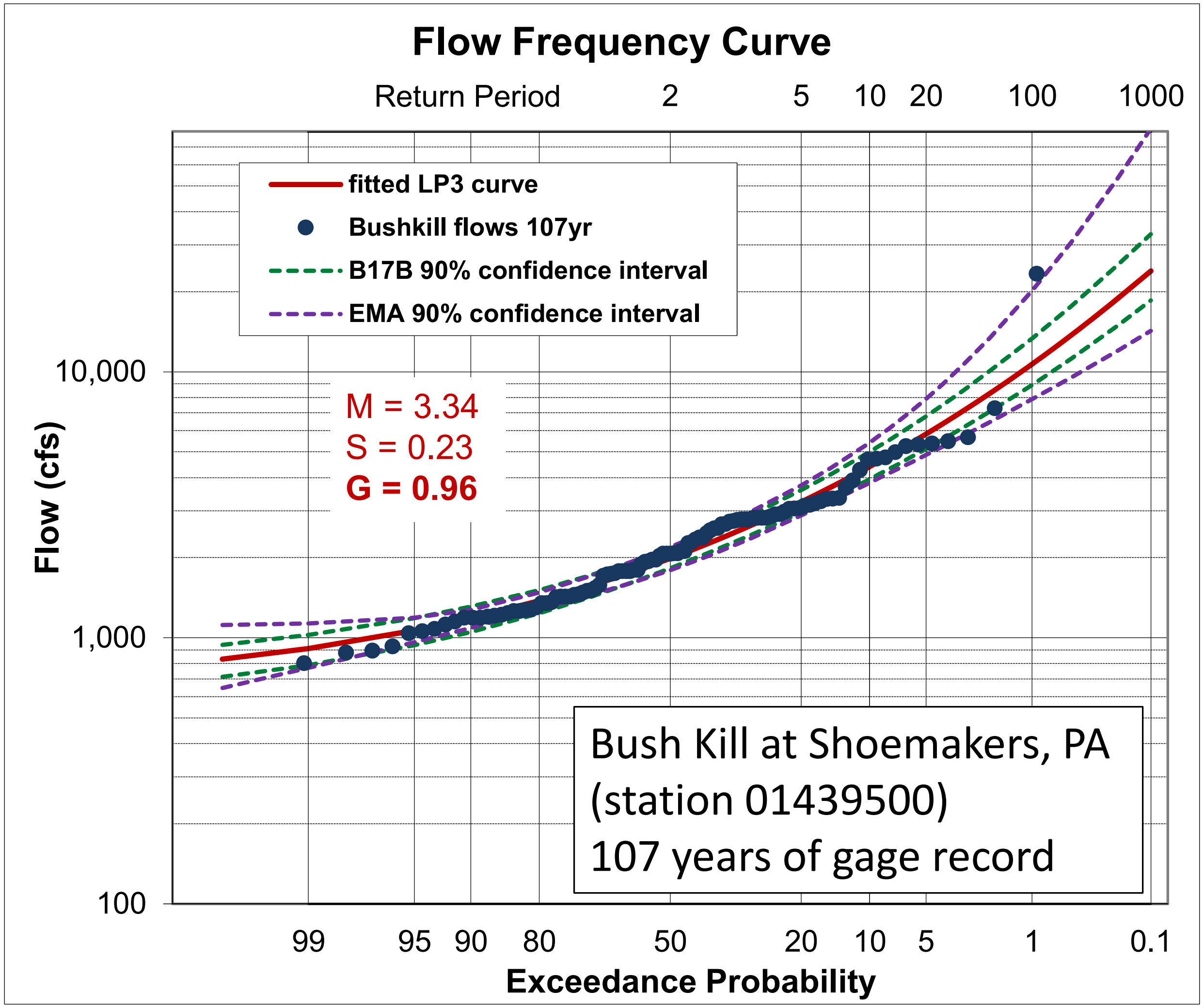
$$(7-10)\quad \hat{\gamma}_{j+1} = \frac{\sum_{i \in S}\left(\frac{X_i-\mu}{\sigma}\right)^3 + \sum_{i \in H} E\left[\left(\frac{X_i-\mu}{\sigma}\right)^3 \middle| T, \mu, \sigma, \hat{\gamma}_j\right] + N_R \hat{G}}{N_S + N_H + N_R}$$

More Correct Confidence Intervals

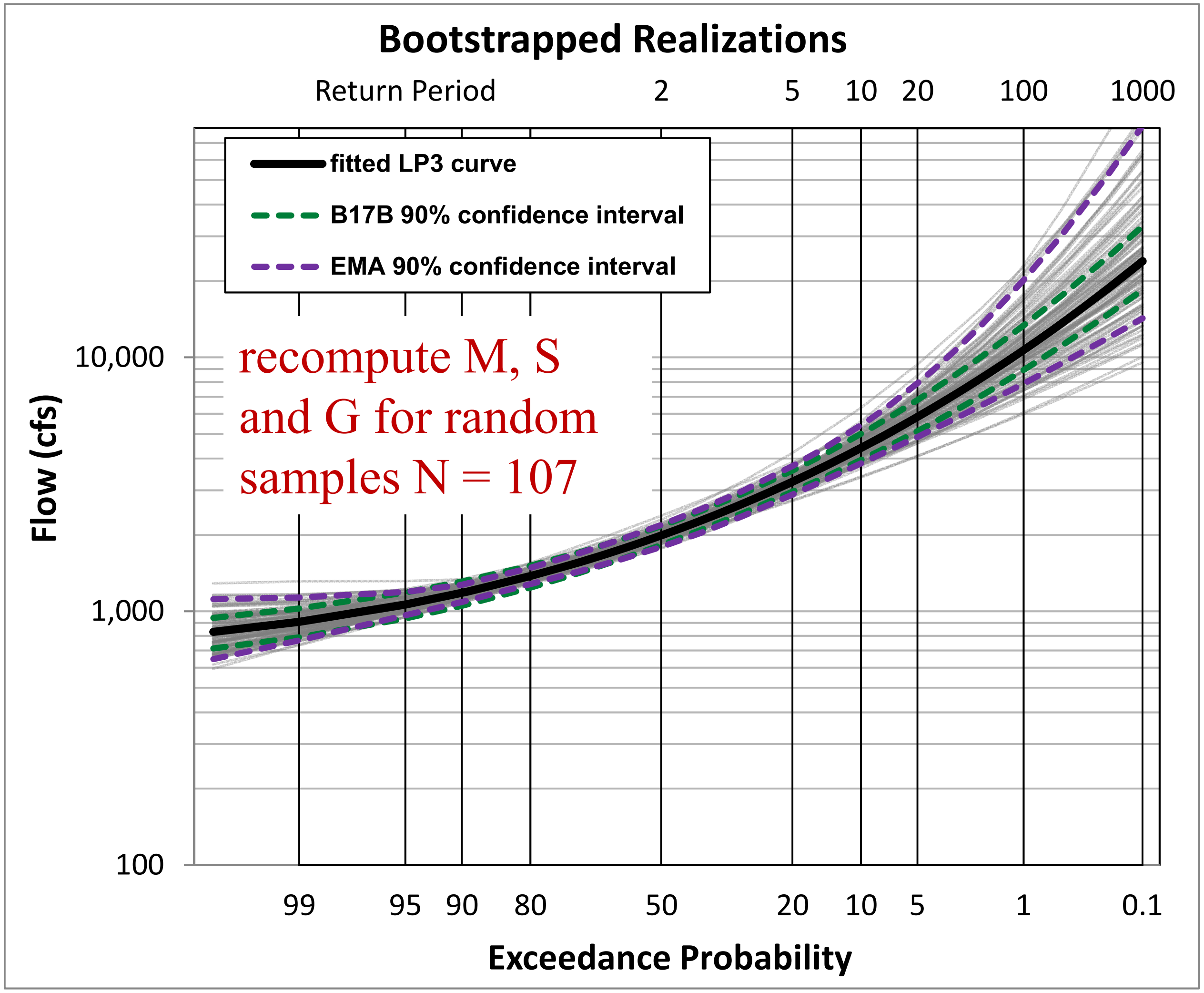
- We show confidence intervals around the estimated frequency curve to demonstrate our uncertainty
  - usually show 90% confidence interval
- The confidence interval formulas in B17B are based on log Normal – which has defined zero skew (can’t be changed)
  - intervals therefore <u>neglect</u> the uncertainty in the estimated <u>skew</u>
- EMA intervals **DO** include uncertainty in skew
- And also reflect <u>historical information</u> and <u>low outlier</u> adjustments

Moose Creek CI, B17C vs B17B

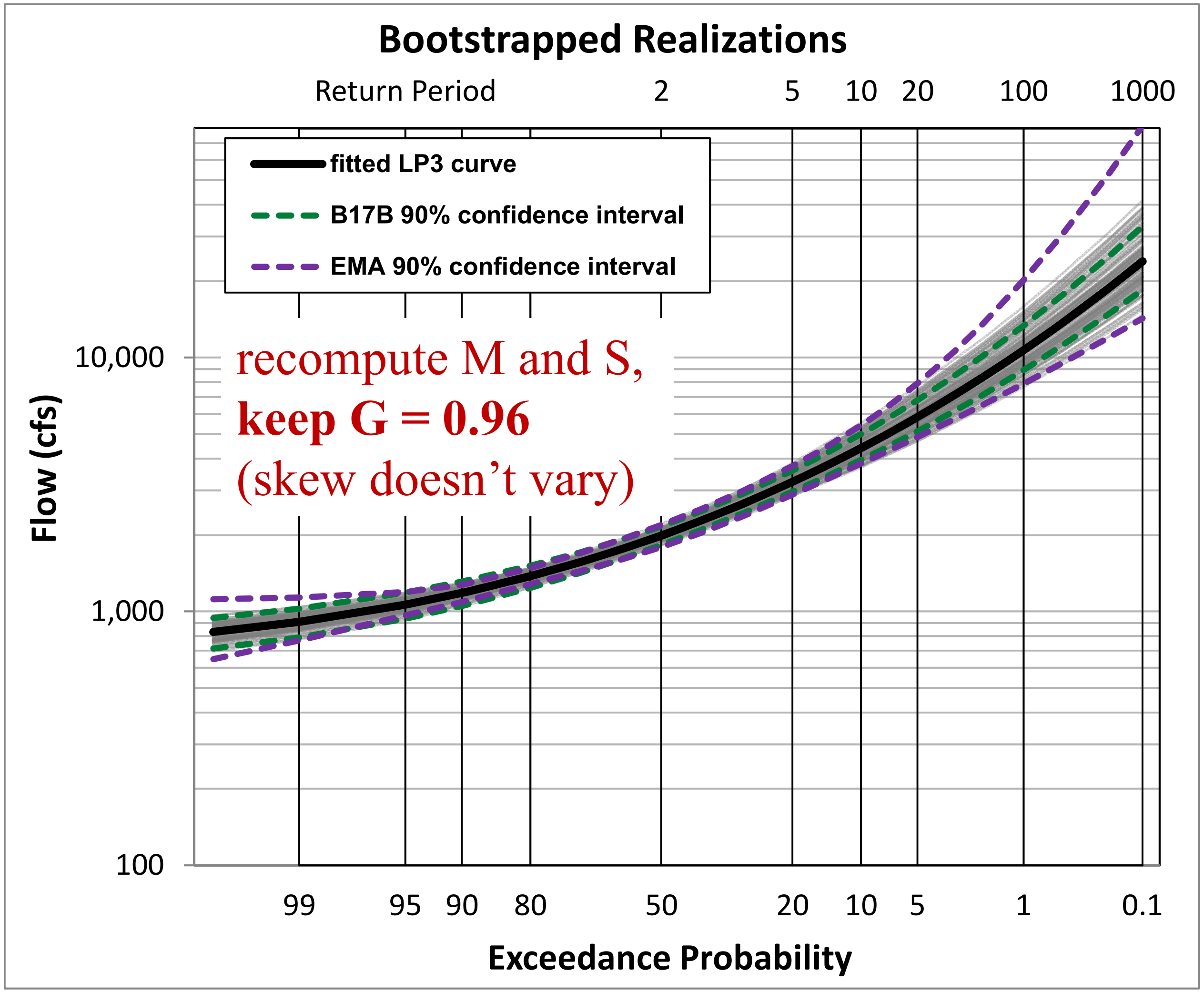




when estimated skew is far from zero, greater uncertainty and so greater difference in intervals



"parametric bootstrap"



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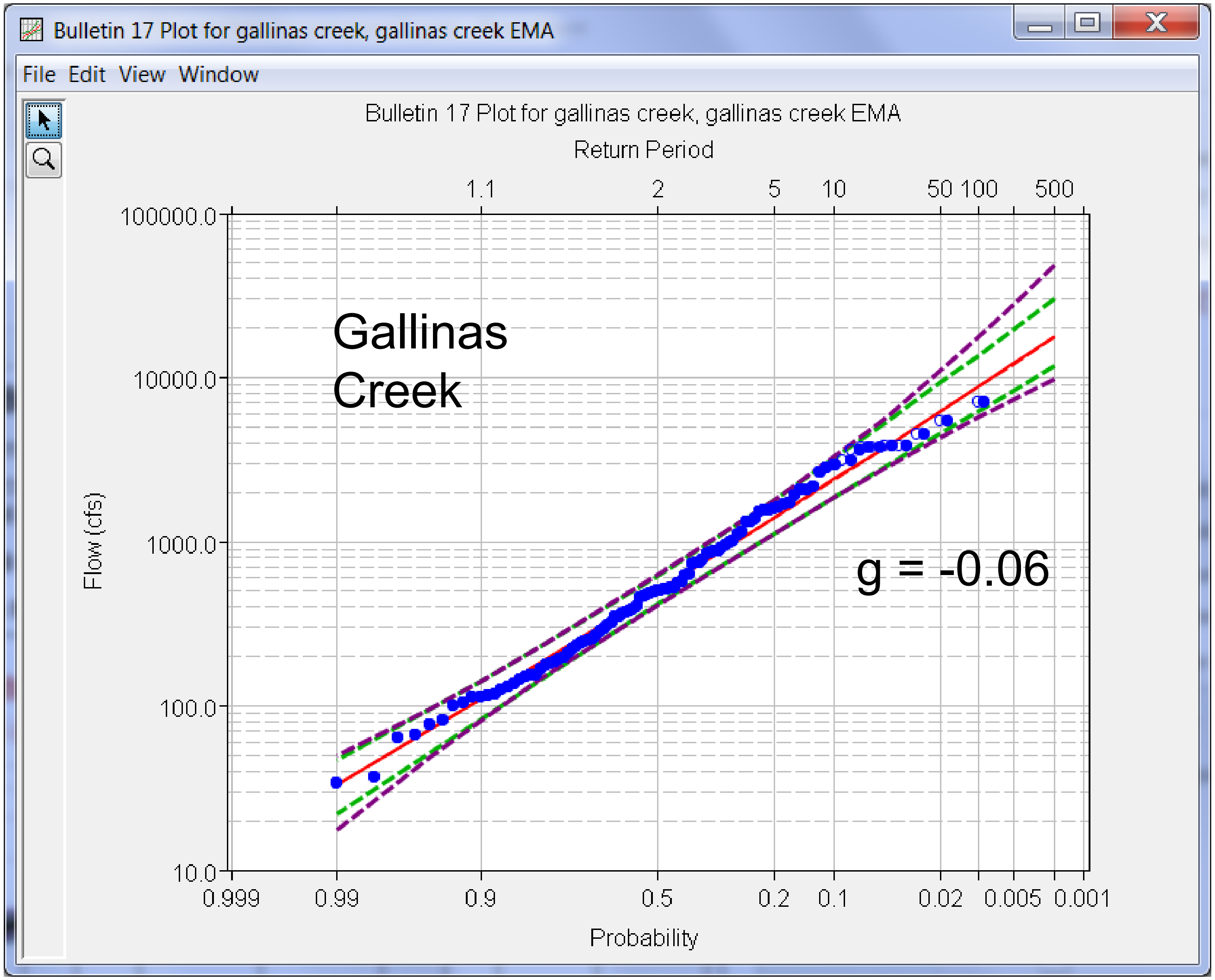

B17B and B17C confidence intervals more similar when estimated skew ≈ 0

Uncertainty Description

Bulletin 17B:

- The confidence intervals described in Bulletin 17B use the non-central t distribution
- They do not consider the uncertainty in the skew

Bulletin 17C:

- The confidence intervals in 17C do capture skew uncertainty, and so are more correct and generally wider than those from 17B

What 17B/C Does NOT Address

- Variables other than unregulated, instantaneous peak flow
  - max flow volume, channel stage, reservoir volume, precipitation, soil moisture, wave height, etc
- Flood frequency curves in un-gaged areas
- Regulated flows
- When the assumptions about **homogeneity**, reliability, randomness are challenged…
  - However, 17C recommends tests for trend and change
  - Allows for other methods, such as time-varying parameters

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