On the impact, identification and treatment of extraordinary floods in the systematic record

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A taste of extremes in water science:

Preparing for July 2021 Summer School

Zoom Meeting

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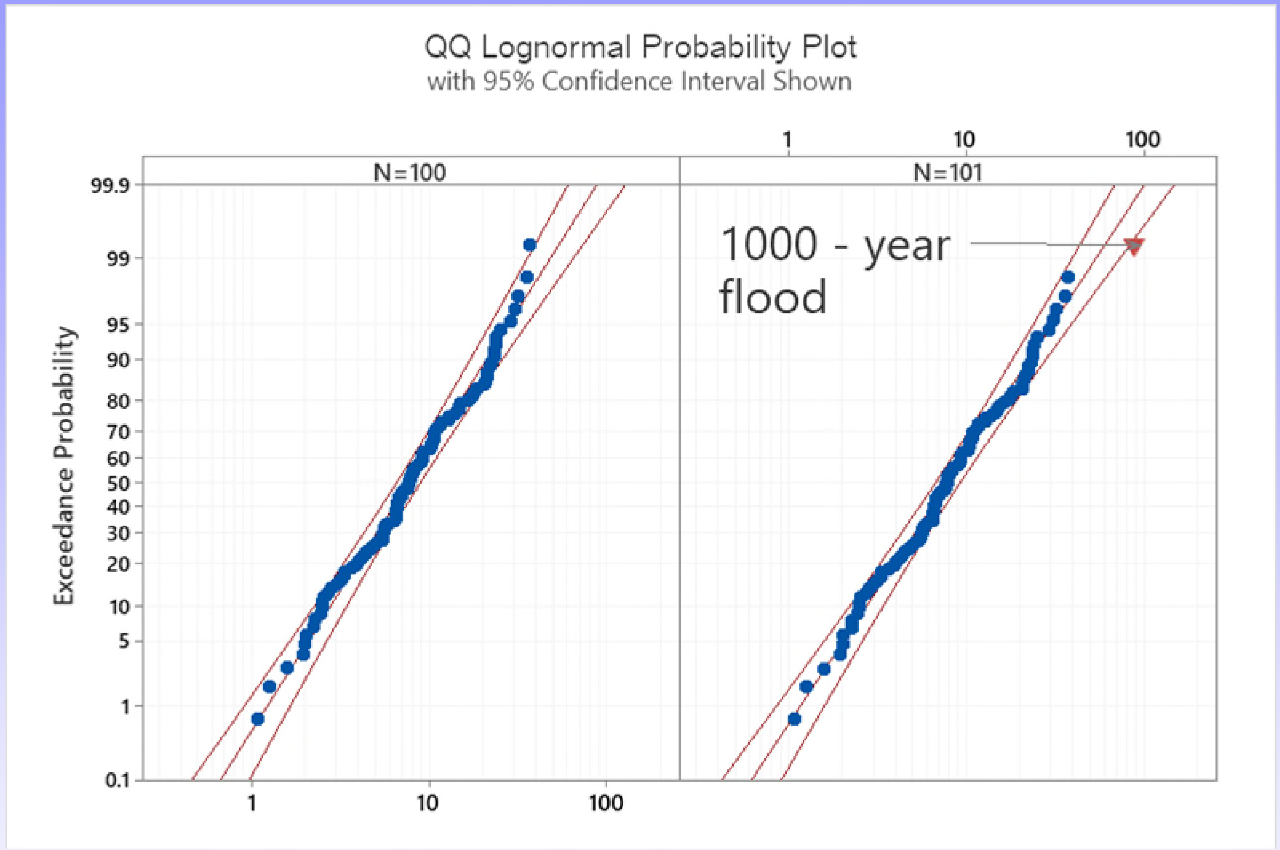
A Synthetic Lognormal Flood Record, μ = 10, σ = 10 cms



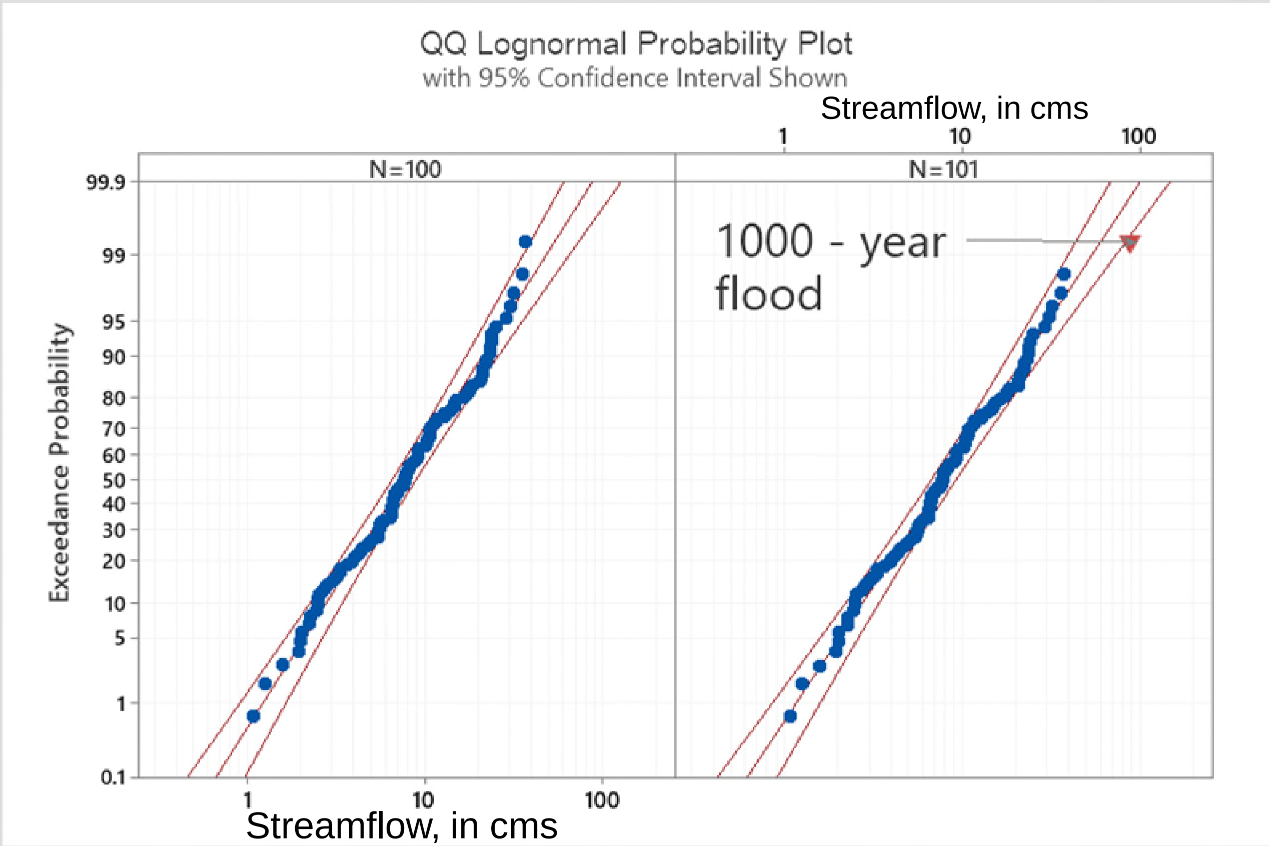
Lognormal n=100

Lognormal n=101 with 1000 yr flood

The 1000-year flood would be called the flood of record

It is the largest flood in n=101 years of systematic gaging

Background: Setting the Stage



Lognormal n=100 n=101 with 1000 year flood

How do we deal with situation on right?

Probability of at least one T=1000 year flood in 100 years = $1 - (1 - 0.001)^{100} = 0.095$

Probability of at least one T=100 year flood in 100 years = $1 - (1 - 0.001)^{100} = 0.634$

Theoretical Treatment of the Flood of Record

CHAPTER 12

Hydrologic Record Events

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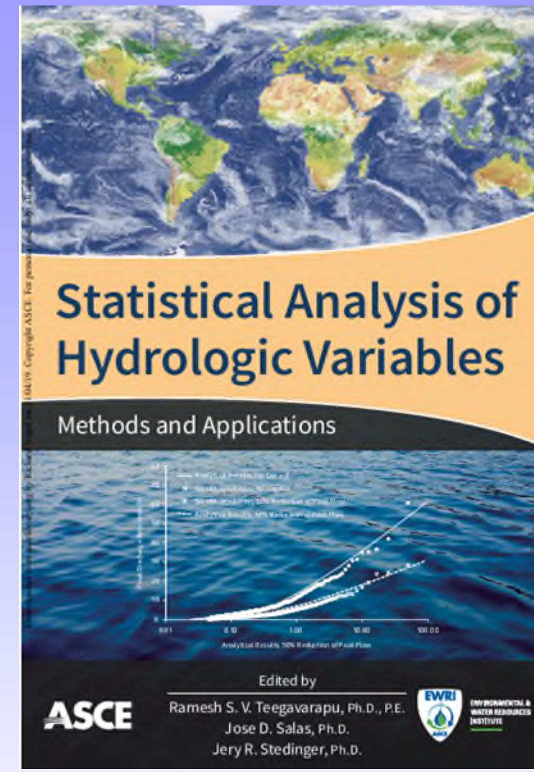

Citation:
Vogel, R.M., N.C. Matalas, A. Castellarin and J.F. England, Hydrologic Record Events, Chapter 12 in Manual on Applications of Statistical Distributions in the Hydrologic Sciences, ASCE, 2019.

This chapter is a theoretical treatment of the behavior of the flood of record

As with all my papers, it can be downloaded from my website:

https://sites.tufts.edu/richardvogel/research/publications/

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Nomenclature: Types of Flood Observations

- **Systematic Record**: Discharge and Stage (elevation) data collected at regular intervals, typically at gaging station.
- **Historic Record:** Flood events directly observed by nonhydrologists, in a nonsystematic manner. Usually occurred prior to the systematic record.

Figure 2. Photograph of historic flood high-water marks and flood of March 13–15, 2010, Potomac River at Great Falls Park, Virginia, upstream of U.S. Geological Survey streamflow-gaging station 01646500, Potomac River near Washington, D.C.

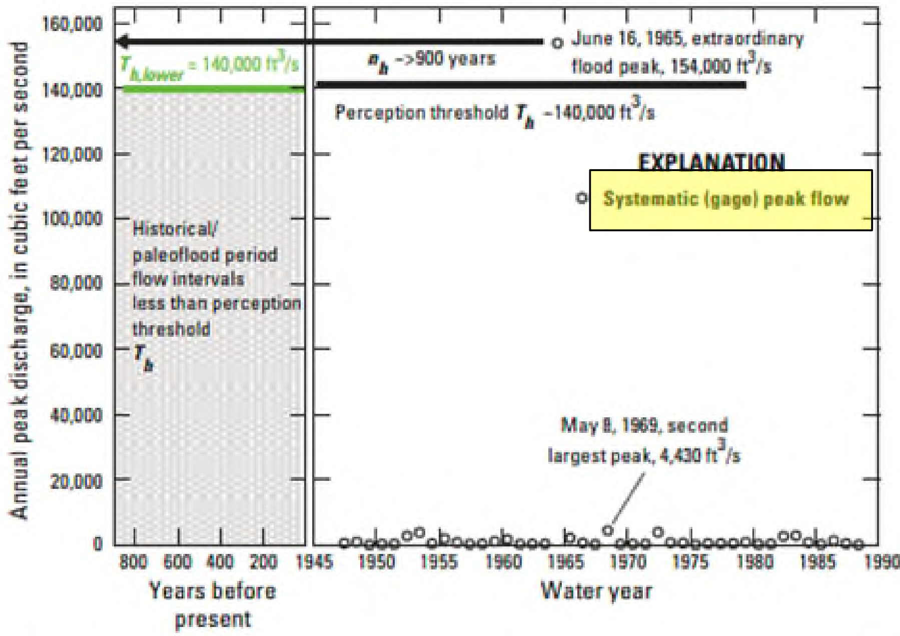
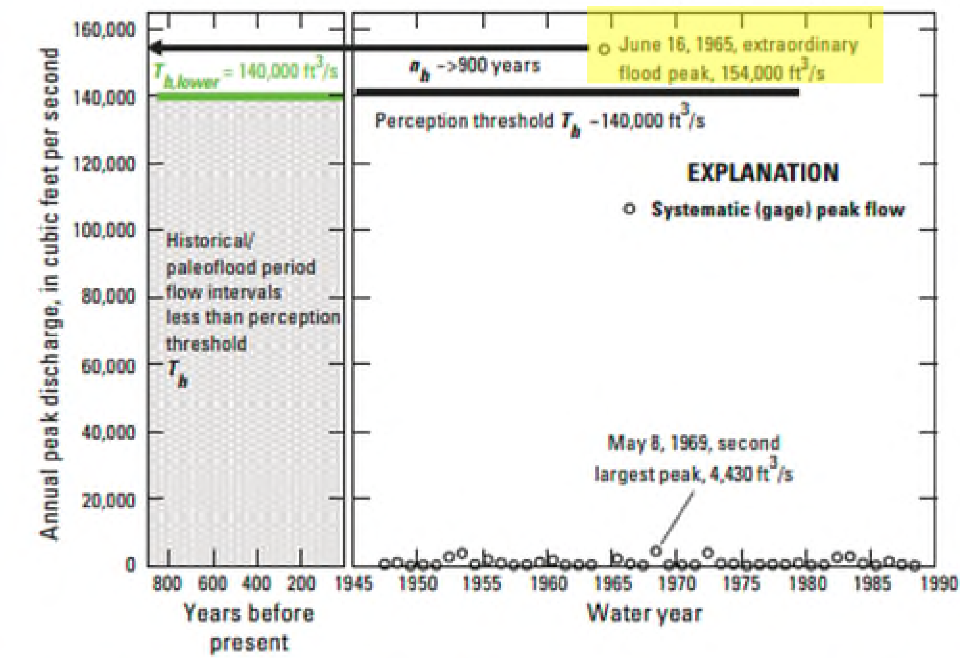


Figure 5. Graph showing an example site with an extraordinary flood peak that represents a longer time frame, Plum Creek near Louviers, Colorado, U.S. Geological Survey streamflow-gaging station 06709500. A scale break is used to separate the gaging station data from the longer historical/paleoflood period. Horizontal lines indicate the approximate historical period n_h and the perception threshold T_h.

Outliers and Spurious Observations

- **What is a Spurious Observation?**
  - Result from spurious error such as: measurement error, typographical error, etc.
- **What is a Flood Outlier?**
  - Outliers are potentially influential floods (PIF) that are exceedingly low or high compared to the distributional properties of the vast majority of the data (England et al. 2018)



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Example: Hamdi et al. 2018, NHESS.

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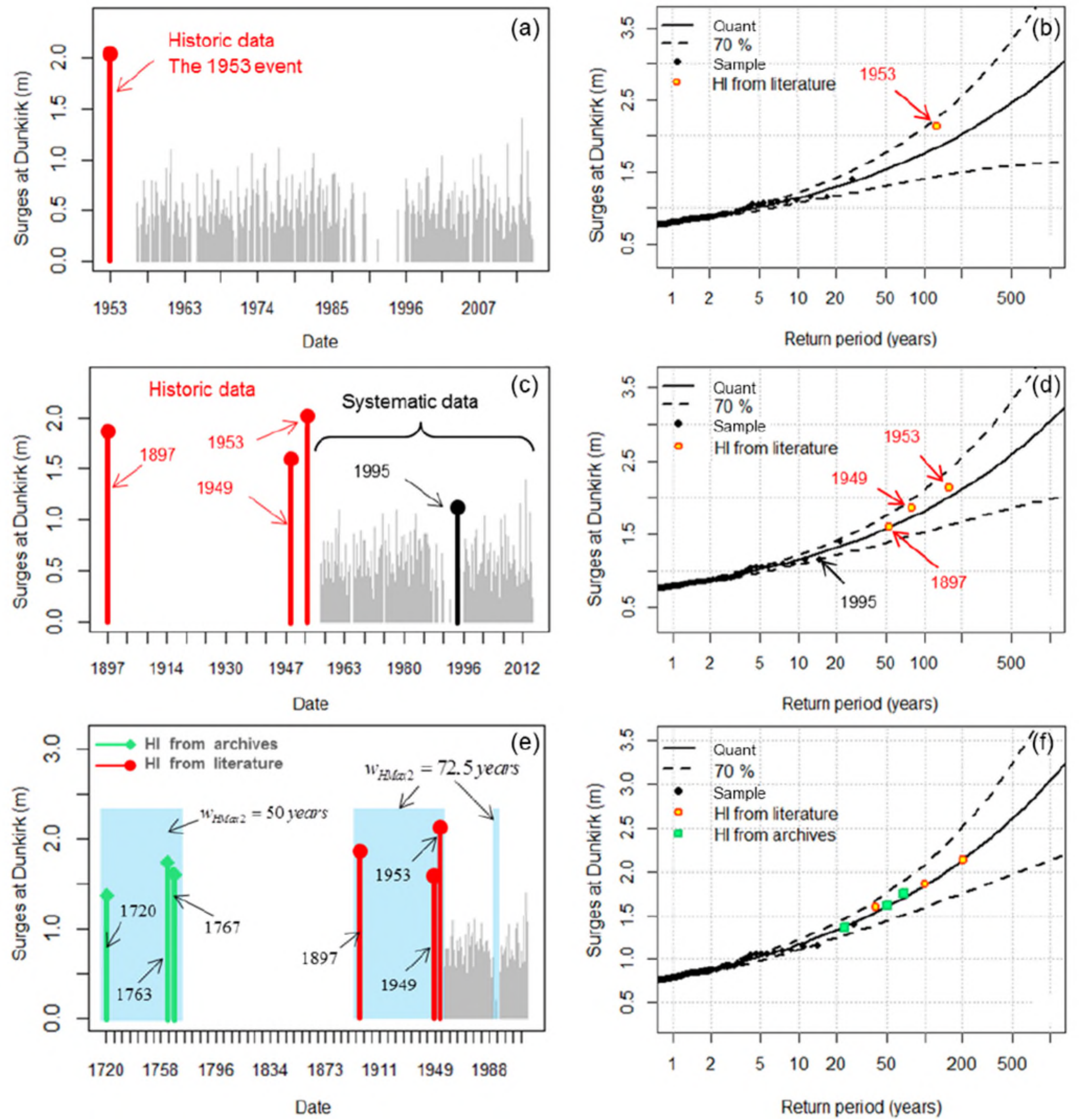
Generalized Pareto fit to POT series of storm surges, Dunkirk, France

(a, b) the 1953 event as historical data;

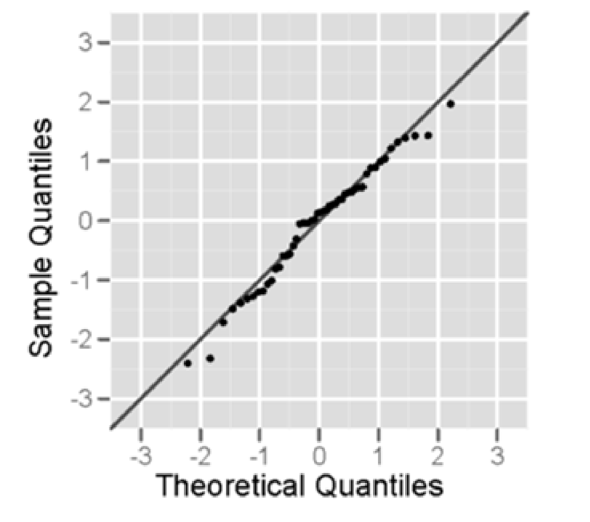
(c, d) historical data from literature;

(e, f) data from literature and archives.



Extraordinary Events Can Dominate Flood and Drought Frequency Analysis

- QQ Probability plots can assess goodness of fit of a theoretical probability distribution
- (QQ = Quantile-Quantile)
- Probability Plot Correlation Coefficient (PPCC) is a common goodness of fit statistic
- PPCC= correlation between ordered observations and estimate of ordered observations



Consider 200 USGS sites with 85-127 years of annual maximum floods

Dataset used by Hirsch and Ryberg (HSJ, 2012)

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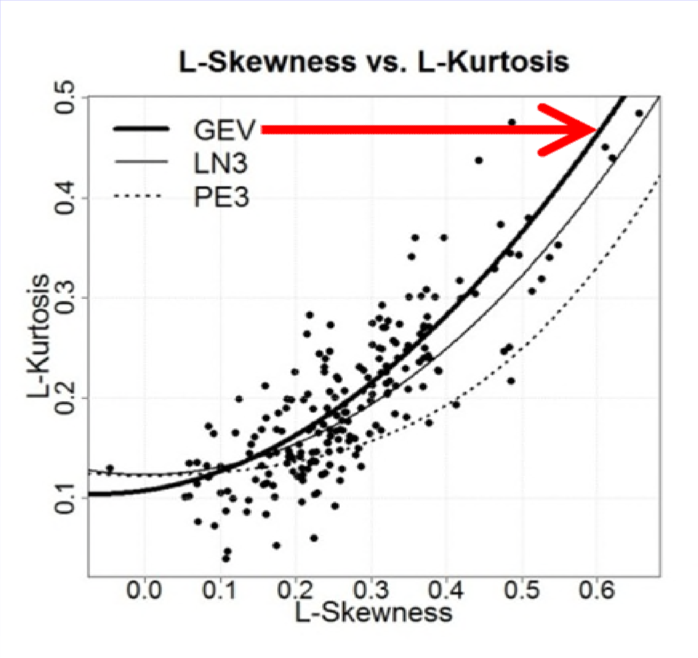
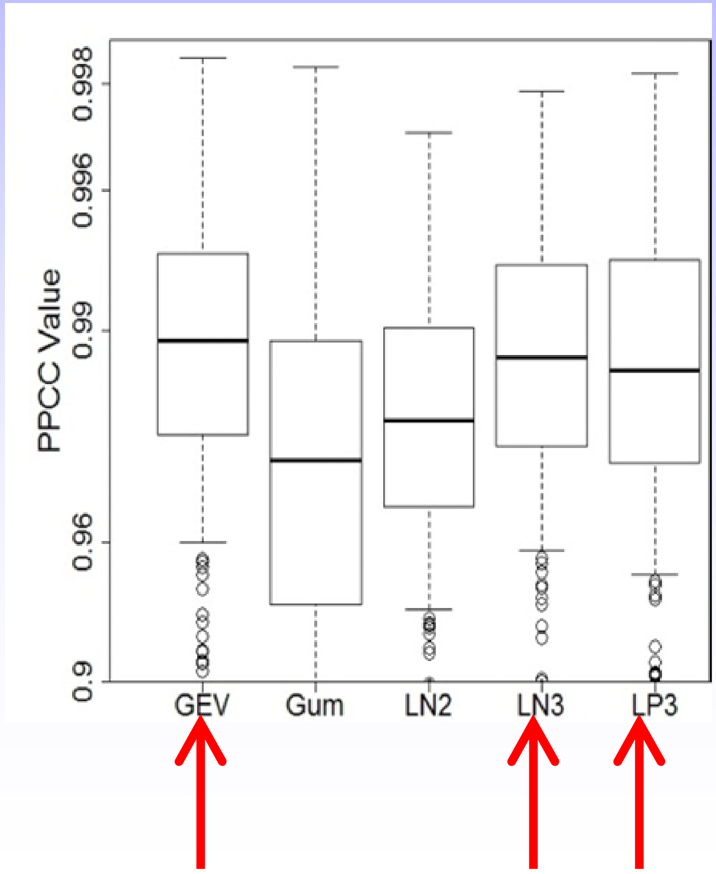
Goodness of Fit of Various Probability Distributions

- **Lmoment Diagram indicates GEV provides a good fit**



- **PPCC Values for GEV, LN3 and LP3 indicate excellent fits**



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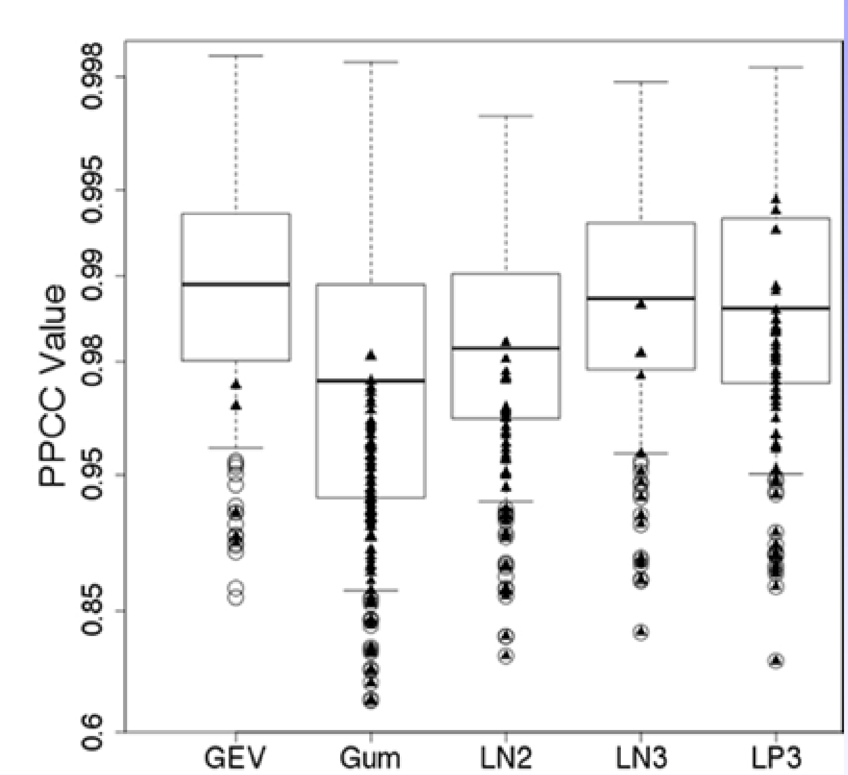
Samples With Important Floods Always Lead to Poor Goodness of Fit!

- **Hirsch and Ryberg (2012)**
  - **200 Sites (85 < n < 127 years)**
- **Open Circles:**
  - **Outliers based on Grubbs (1969)**
- **Solid Triangles:**
  - **Observations > 1000 yr flood**
- **Regardless of the model considered, samples with observations larger than 1000-yr flood (solid triangles) had the LOWEST VALUES OF PPCC**



Example from: Boehlert, PhD Dissertation, Tufts Univ., 2015.

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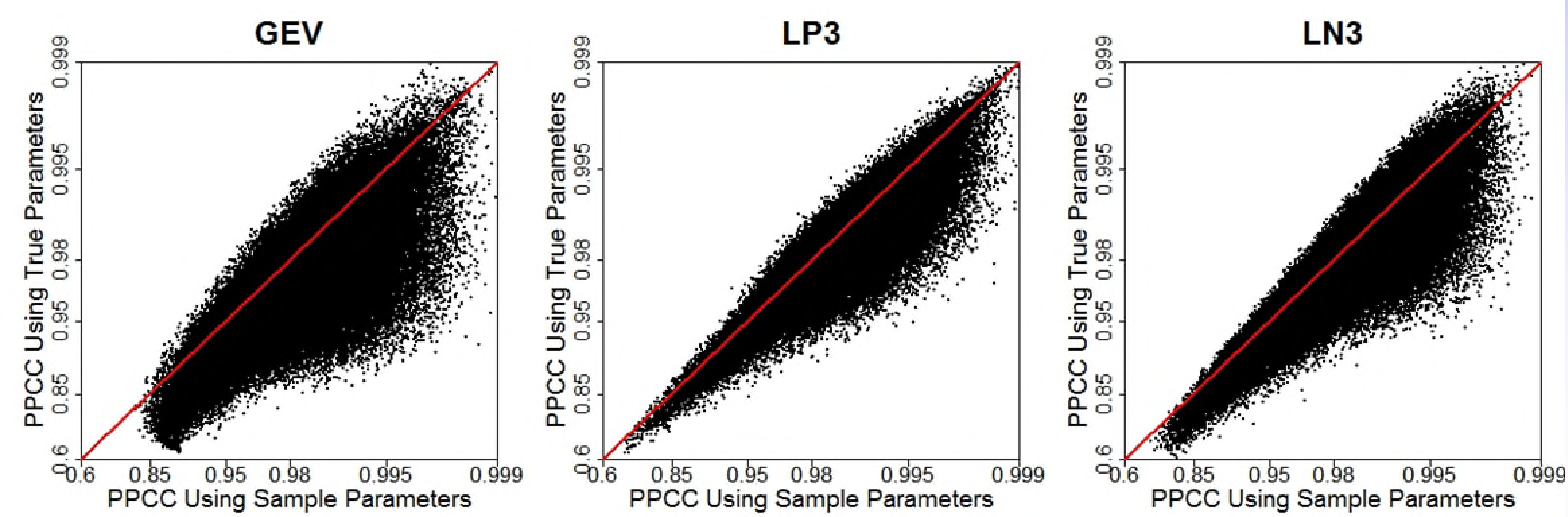
Goodness-of-Fit Can Be VERY misleading!

- **Experiment:**

  Generate 10,000 samples each of length 100 from GEV, LP3 and LN3 distributions.

  Compare goodness-of-fit using 'known' or 'true' parameters with goodness-of-fit using at-site sample estimates.

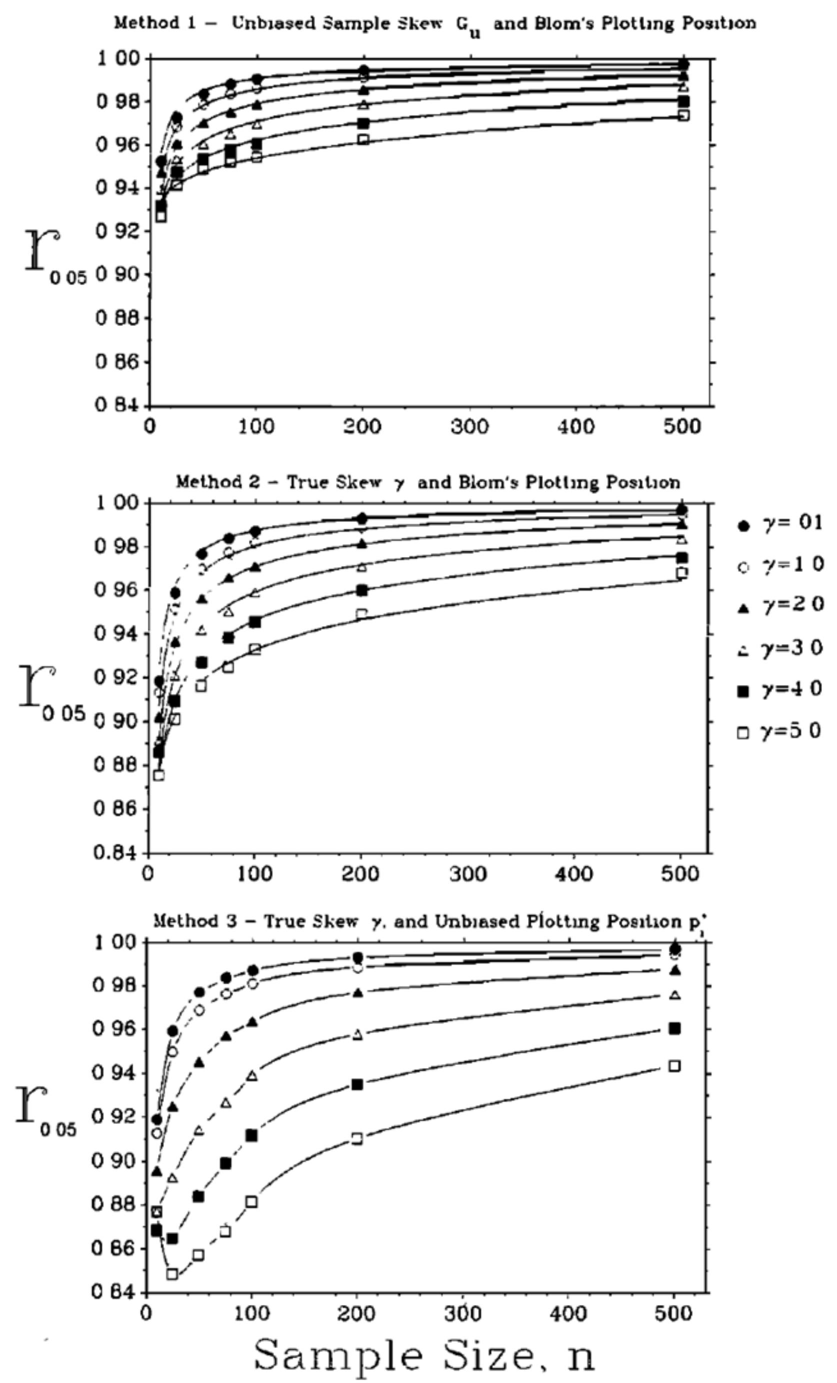
Result: Fitting true model degrades goodness-of-fit!



Example from: Boehlert, PhD Dissertation, Tufts Univ., 2015.

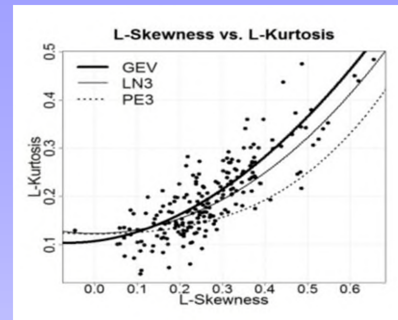
PPCC Test for Log Pearson type 3 (LP3)

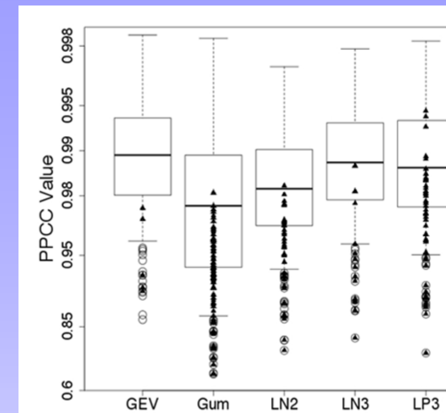
- $r_{0.05}$ is value of PPCC for LP3 at 5% significance level
- Note how goodness-of-fit is inflated when true skew must be estimated
- Goodness of fit can be misleading



From: Vogel, R. and McMartin, D. 1991. Probability plot goodness-of-fit and skewness estimation procedures for the Pearson type 3 distribution. *Water Resour. Res.* 27: 3149–3158.

Downward Bias in GEV Quantile Estimates





- Hirsch and Ryberg 200 Sites with (85 < n < 127)
  - In the **19,000** observations, we expect **19 - 1000-yr** floods (95% confidence interval: 12-26)
  - Yet only **6 – 1000-year** floods were obtained from GEV at-site models, (6/19) = 30%
  - Suggests that GEV exhibits downward bias
  - Why?

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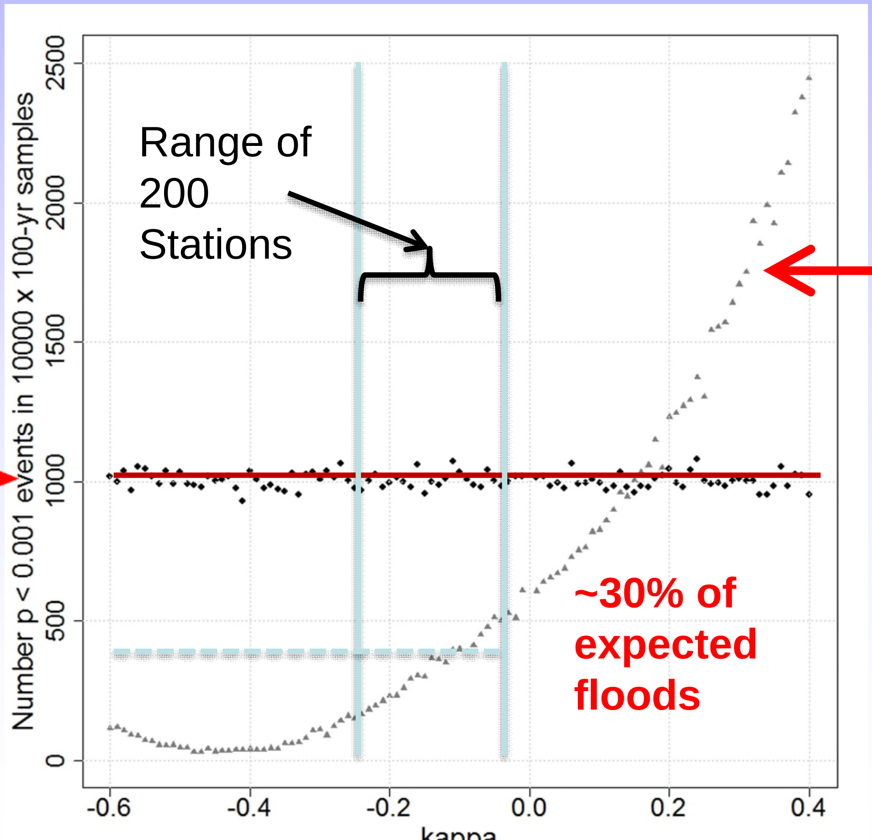
Downward Bias Associated with Extraordinary Floods – WHY? – Its all about GEV shape parameter kappa κ

Experiment:

Generate 10,000 samples of length 100 years and count the number of 1000 year floods

Kappa κ, known (black– NO bias

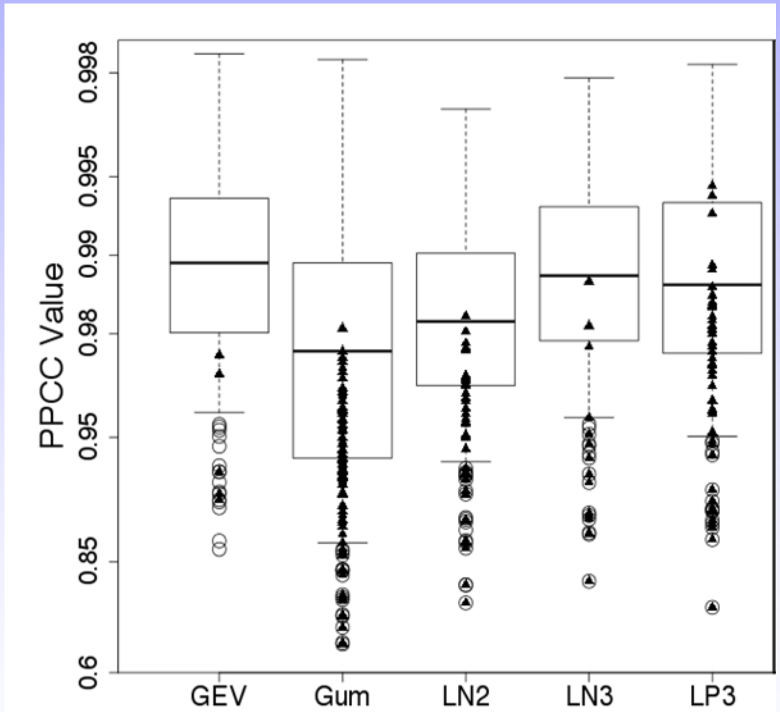


Kappa κ, unknown (gray) – downward bias

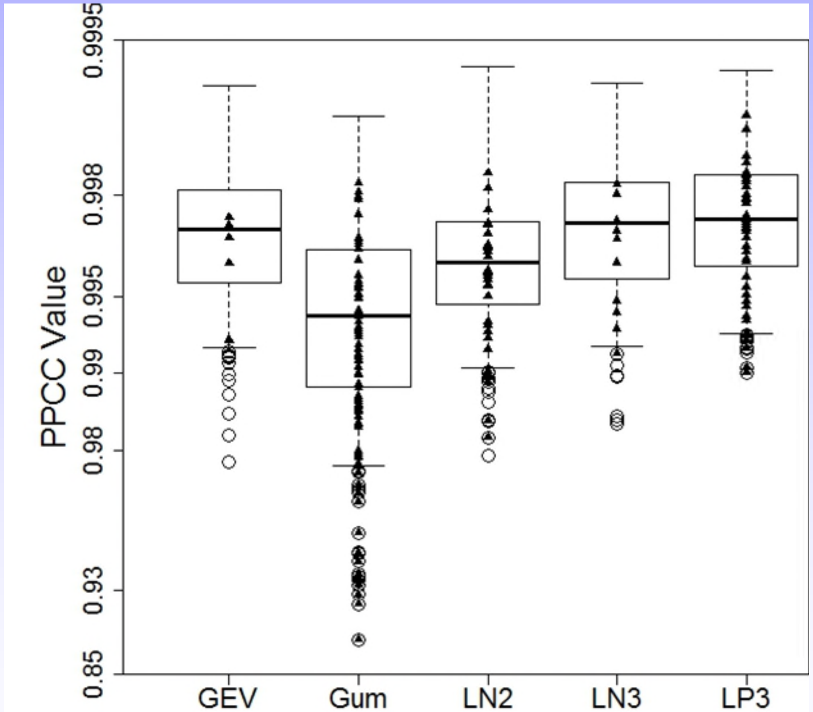
Example from: Boehlert, PhD Dissertation, Tufts Univ., 2015.

Recommendation use P-P plots rather than Q-Q plots

PPCC using Q-Q plot



PPCC using P-P plot



Example from: Boehlert, PhD Dissertation, Tufts Univ., 2015.

Summary

- **Goodness of fit can be misleading:**
  - Fitted models tend to ‘look’ better than correct/true model.
  - Do not base decisions on ‘goodness of fit’ alone unless P-P plots are used instead of Q-Q plot

- **Reliable shape parameter(s) are critical for design flood/drought estimation**

- **Treatment of high outliers is critical for design flood/drought estimation**

Possible Paper Titles

- On the impact, identification and treatment of extraordinary floods in the systematic record
- P-P Probability Plots and Hypothesis Tests
- Goodness-of-fit is Misleading
- Improvements in Estimation of Shape Parameter for Flood Frequency Analysis

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Other Possible Paper Titles

- Accounting for stochastic persistence and deterministic trends when updating a flood and drought frequency analysis

- On the recurrence interval of the ‘drought of record’

- Methods for generation of stochastic ensembles of extreme events using deterministic simulation models.

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