Extreme Flood Frequency Analysis:
Concepts, Philosophy and Strategies

Jery R. Stedinger

Cornell University and USGS

Member HFAWG

sabbaticals USGS, US ACE

with V. Griffis, A. Veilleux, E. Martins, T. Cohn

Challenge

Estimate frequency of rare floods (exceedance probabilities of 1 in 100,

or

1 in 10,000) using limited data provided by streamflow gauge at the site …

plus other sources of information.

What Data Do We Use?

Record at streamflow gauge at the site.

Historical data at the site

Paleoflood data at the site

Regional analysis of gaged data,
historical and paleoflood Information

Bulletin 17B

- Uniform flood frequency techniques used by US Federal agencies
- Bulletin not updated in 20+ years
  - despite significant amount of research
  - additional 30 years of data for skew map
  - better statistical procedures for censored data

Bulletin 17C

- Revision on the way
- Provides a tune up addressing
  - Use of historical information
  - Potentially Influential Low Floods (PILFs)
  - Censored & interval data
  - Confidence intervals & uncertainty analyses
- Also developing better regional skew

Regional Skew Estimation

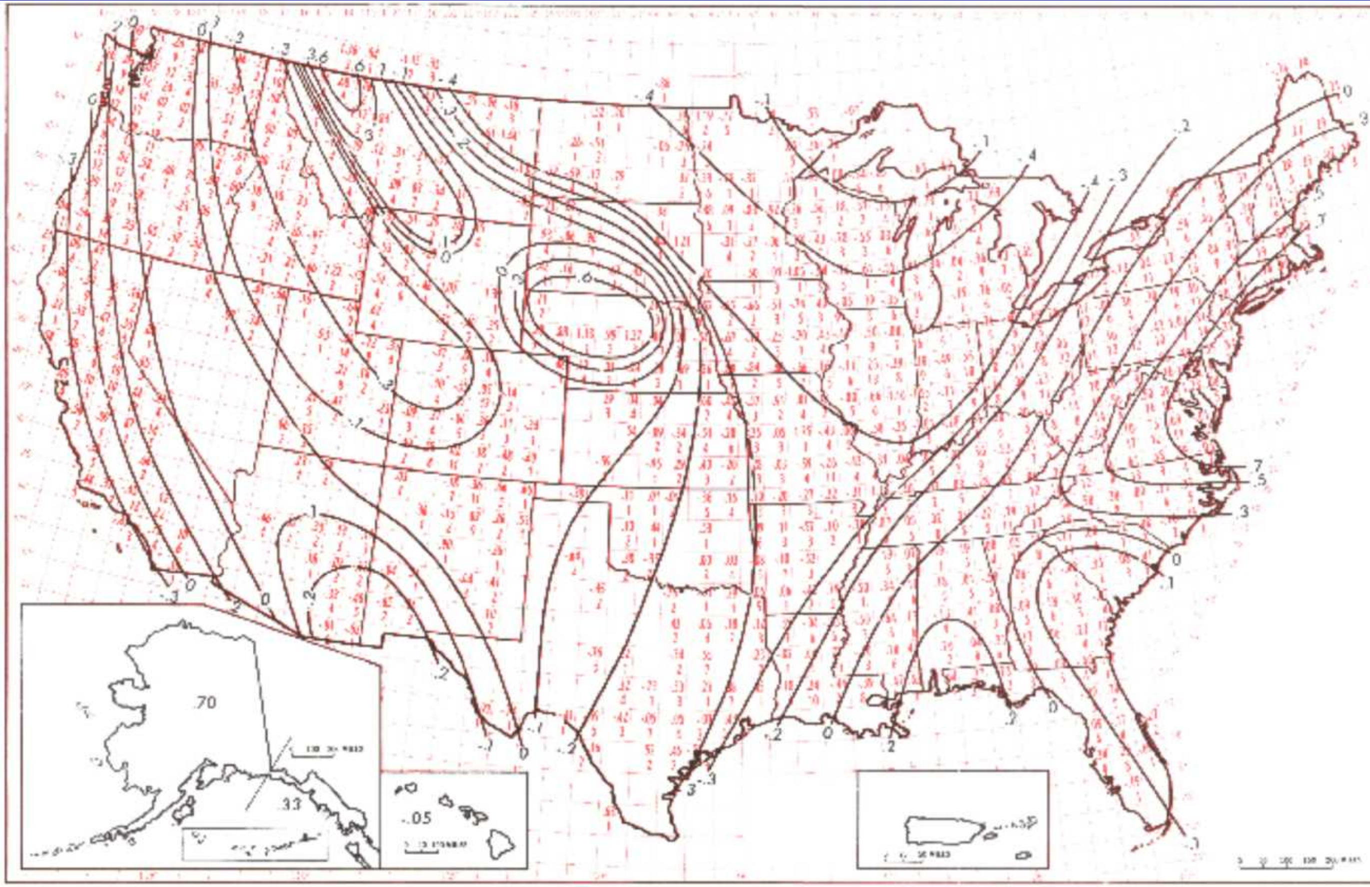
Regional skew G_g from B17 skew map

$-0.5 < G_g < +0.7$

Map SE = 0.55

→ $MSE[G_g] = 0.302$

Effective record length = 17 yrs



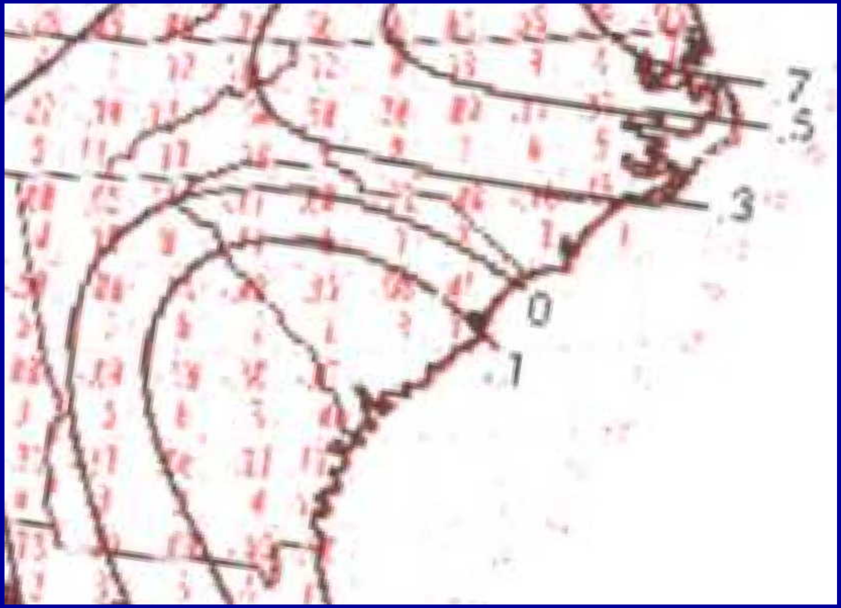
GENERALIZED SKEW COEFFICIENTS OF LOGARITHMS OF ANNUAL MAXIMUM STREAMFLOW

AVERAGE SKEW COEFFICIENT BY ONE DEGREE QUADRANGLES

Lower number in each quadrangle is number of stream gaging stations for which the average shown above it was computed

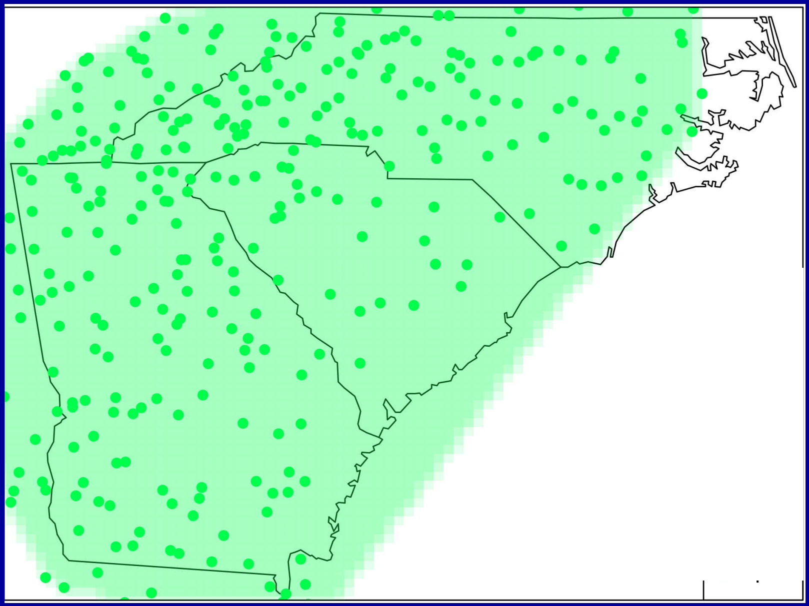
Regional Skew Southeast

1976 (MSE = 0.302)
2,972 sites nationally



Maps claims to be as good as 17 years

2009 (MSE = 0.14) revised 1/09
342 *independent* watersheds



γ = 0 as good as 40 years of record

Historial & Paleoflood data at a site:

Ways to extend the record.

Sources of Historical Information

Long-term Residences' Memory

Written accounts, markers, pictures

Geomorphologic evidence

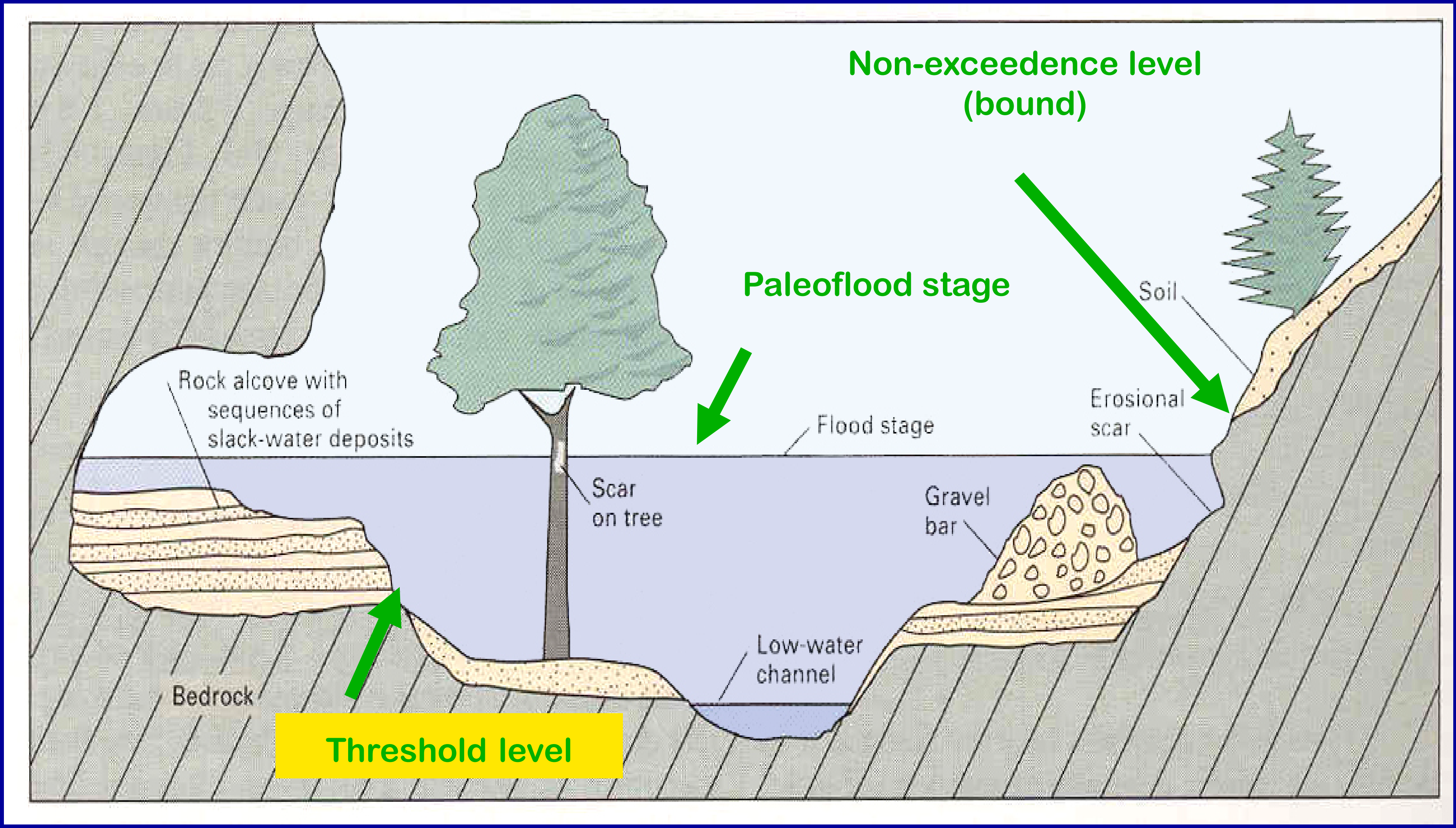
slack-water deposits

scour lines

high-water marks

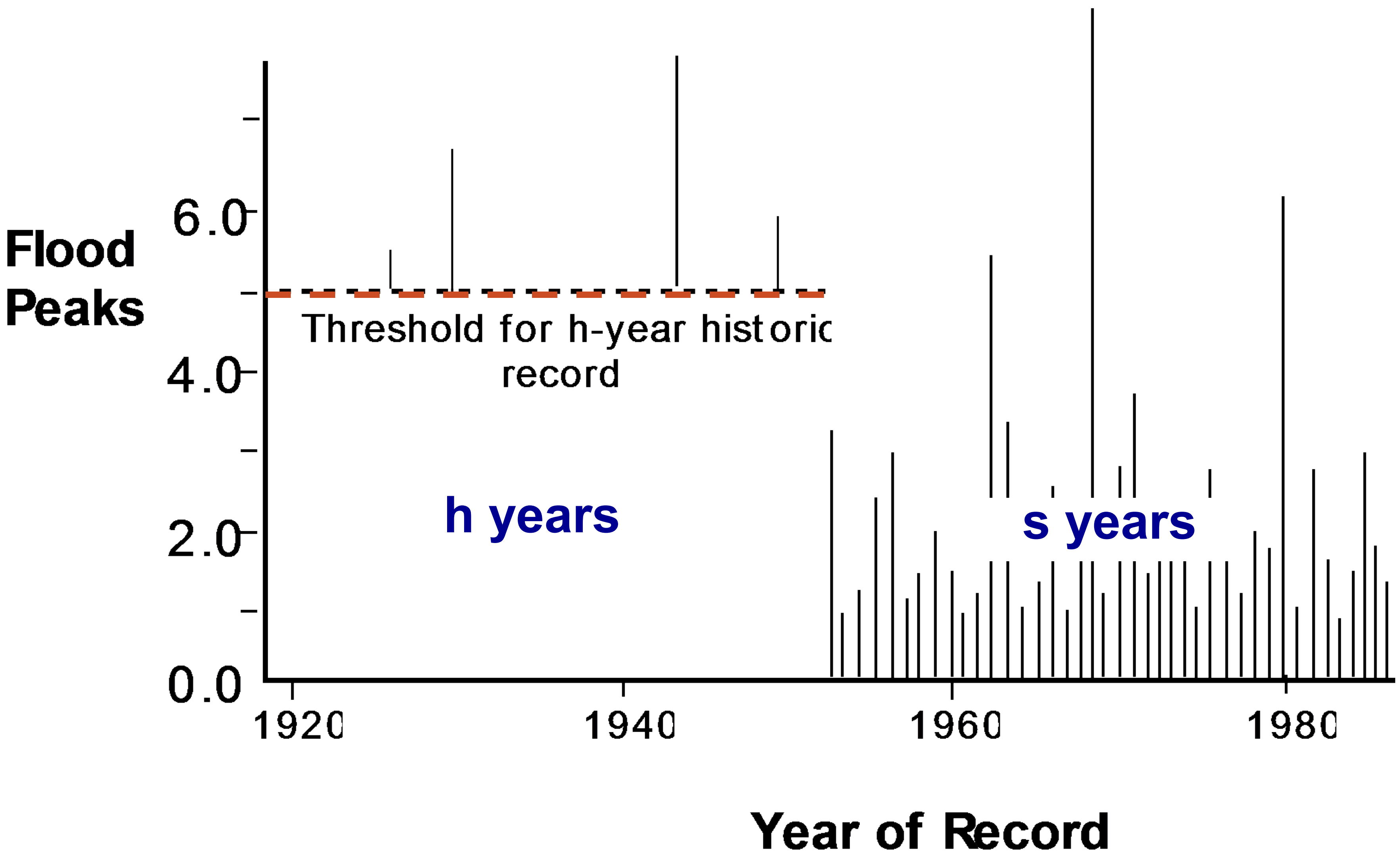
undisturbed areas

Paleoflood Data



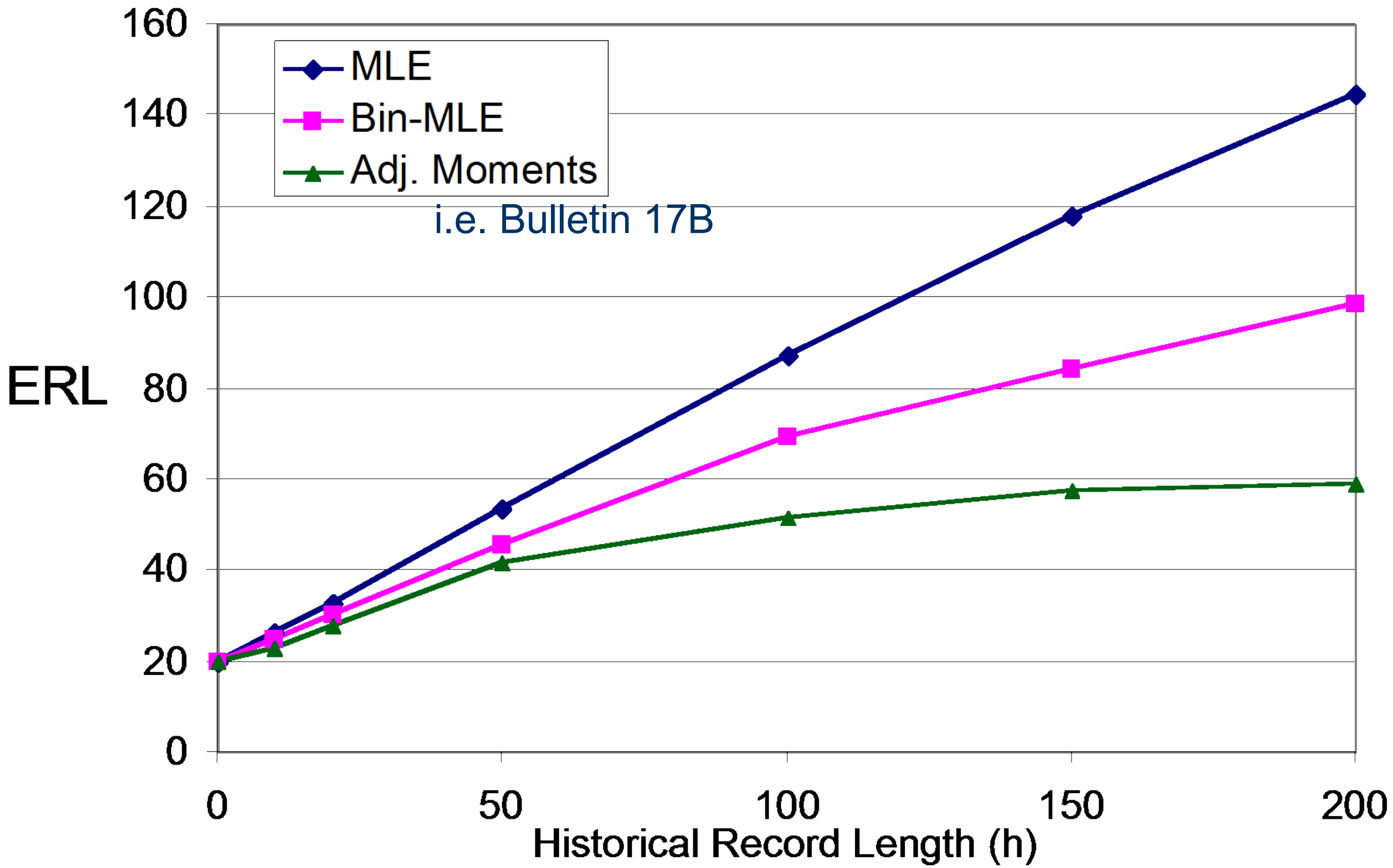
(Source: Jarrett 1991, modified from Baker 1987)

Historical and Gauged Record

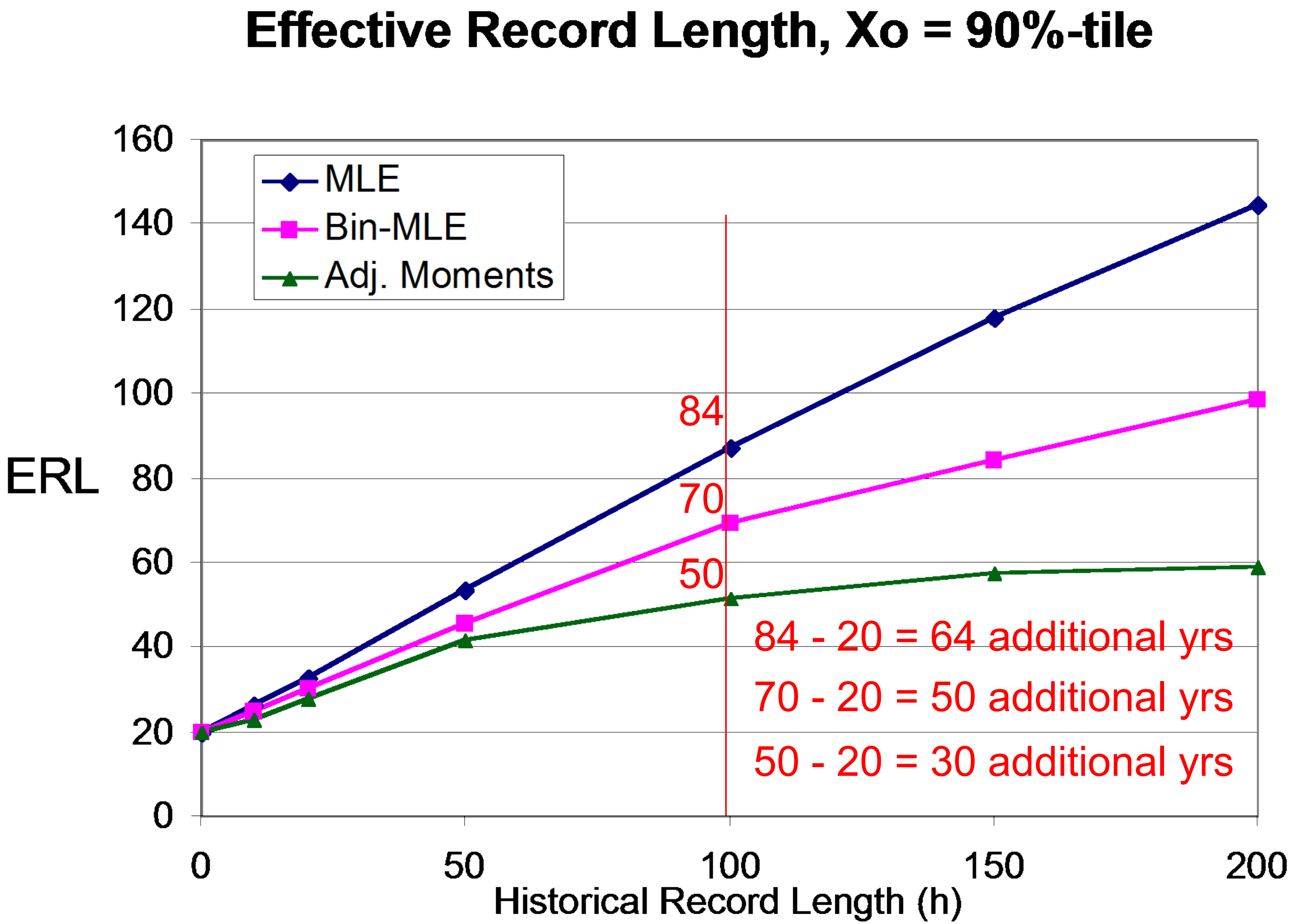


Value of Historical Information

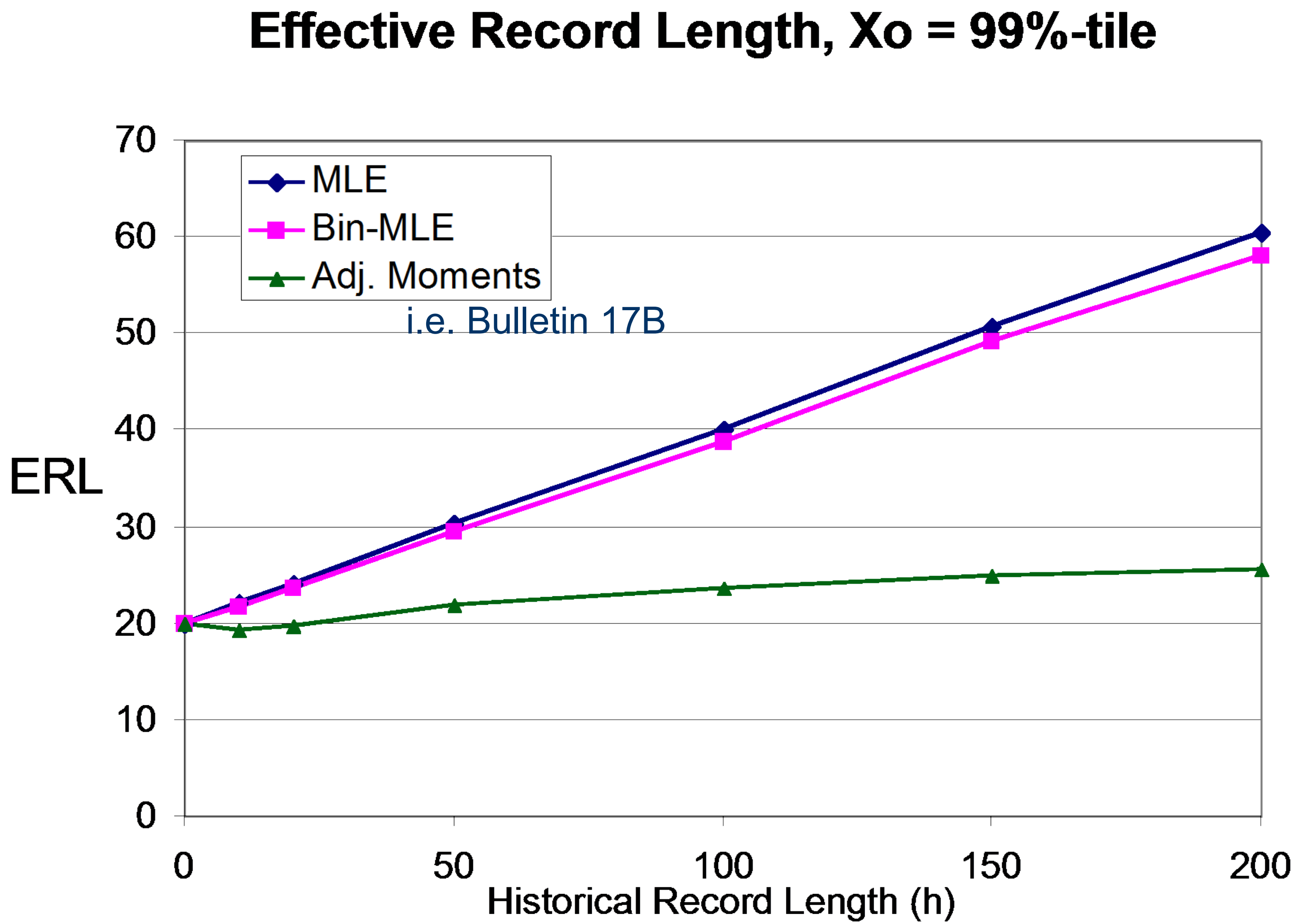
Effective Record Length, Xo = 90%-tile



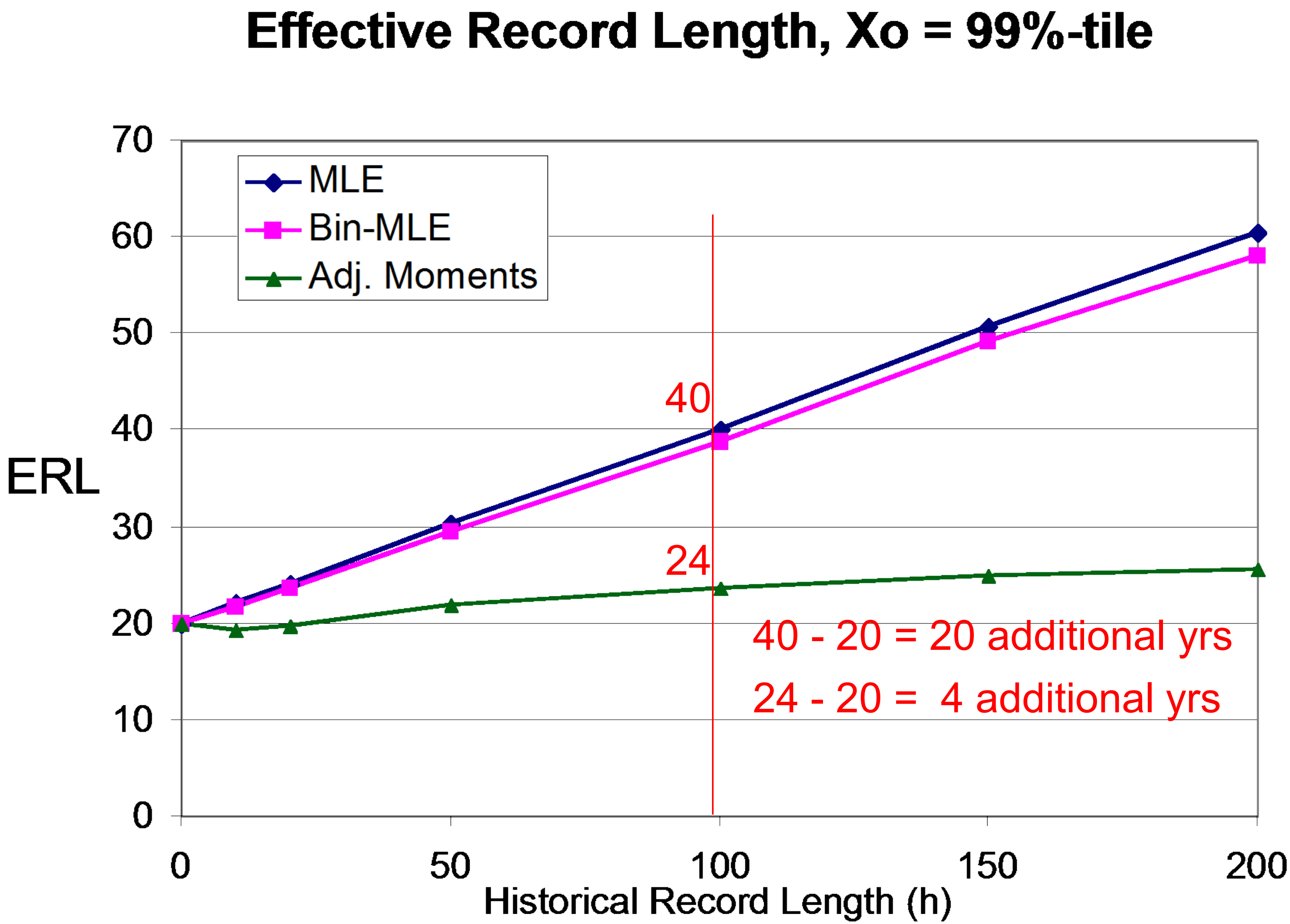
Value of Historical Information



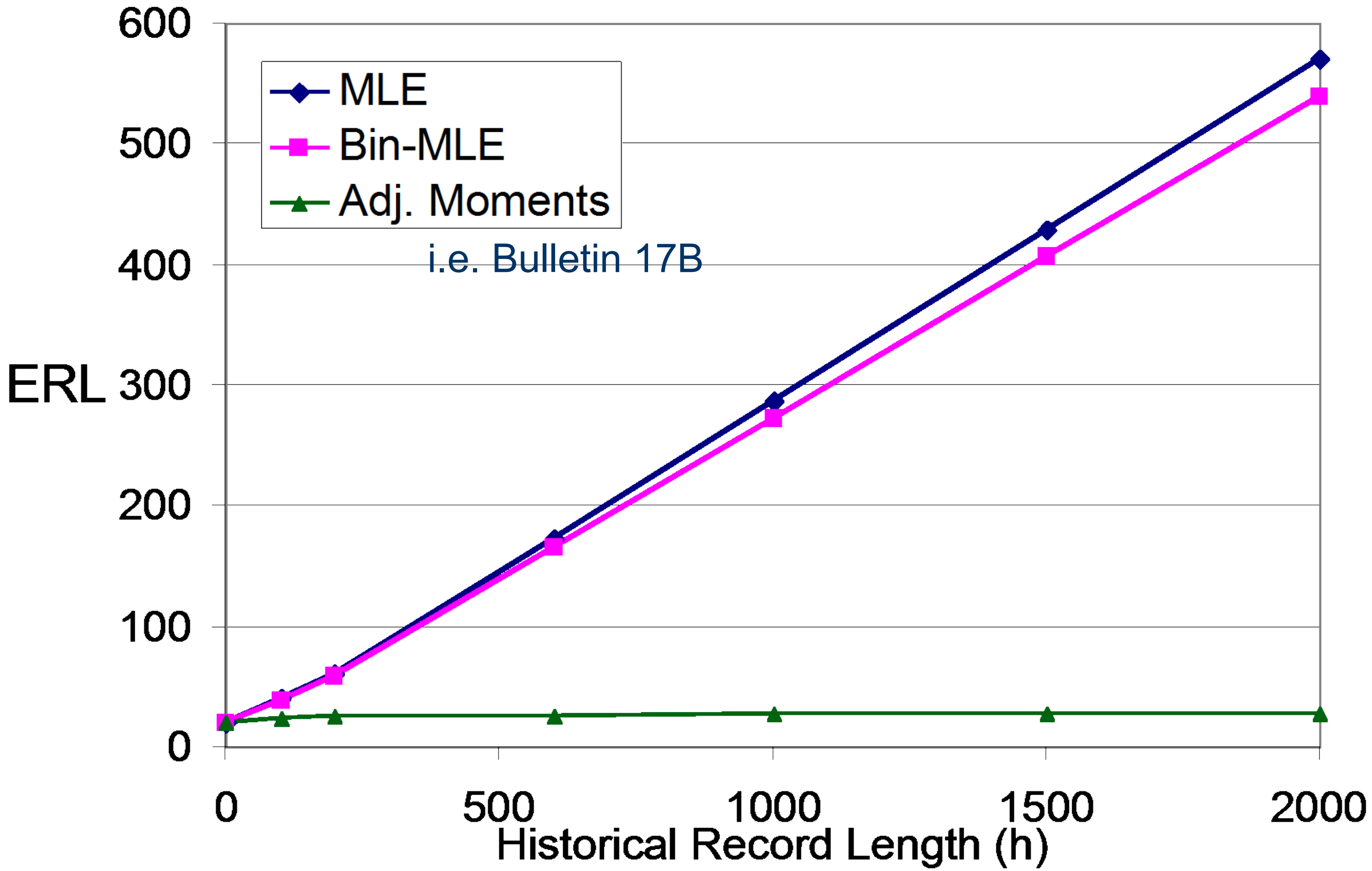
Value of Historical Information



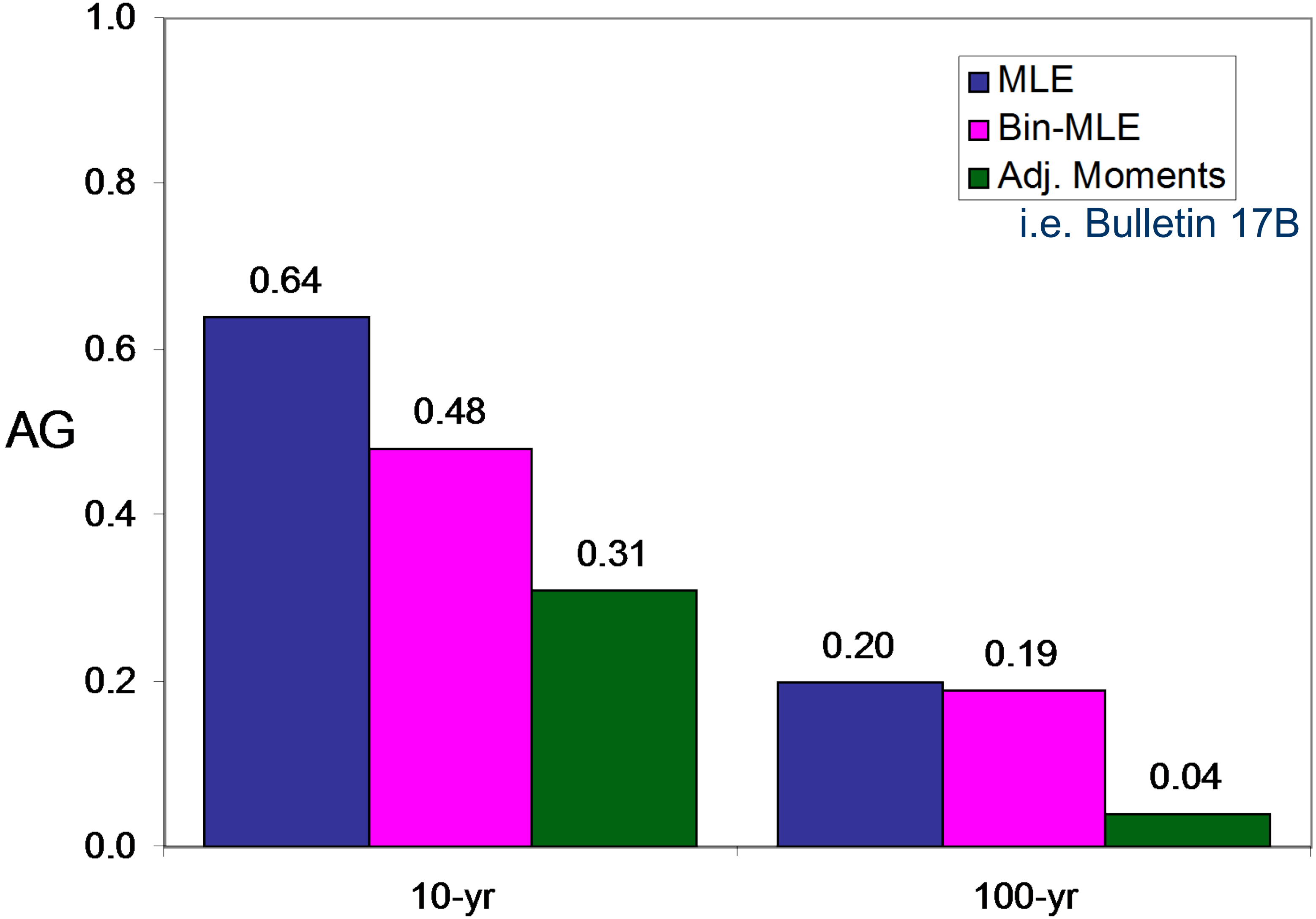
Value of Historical Information



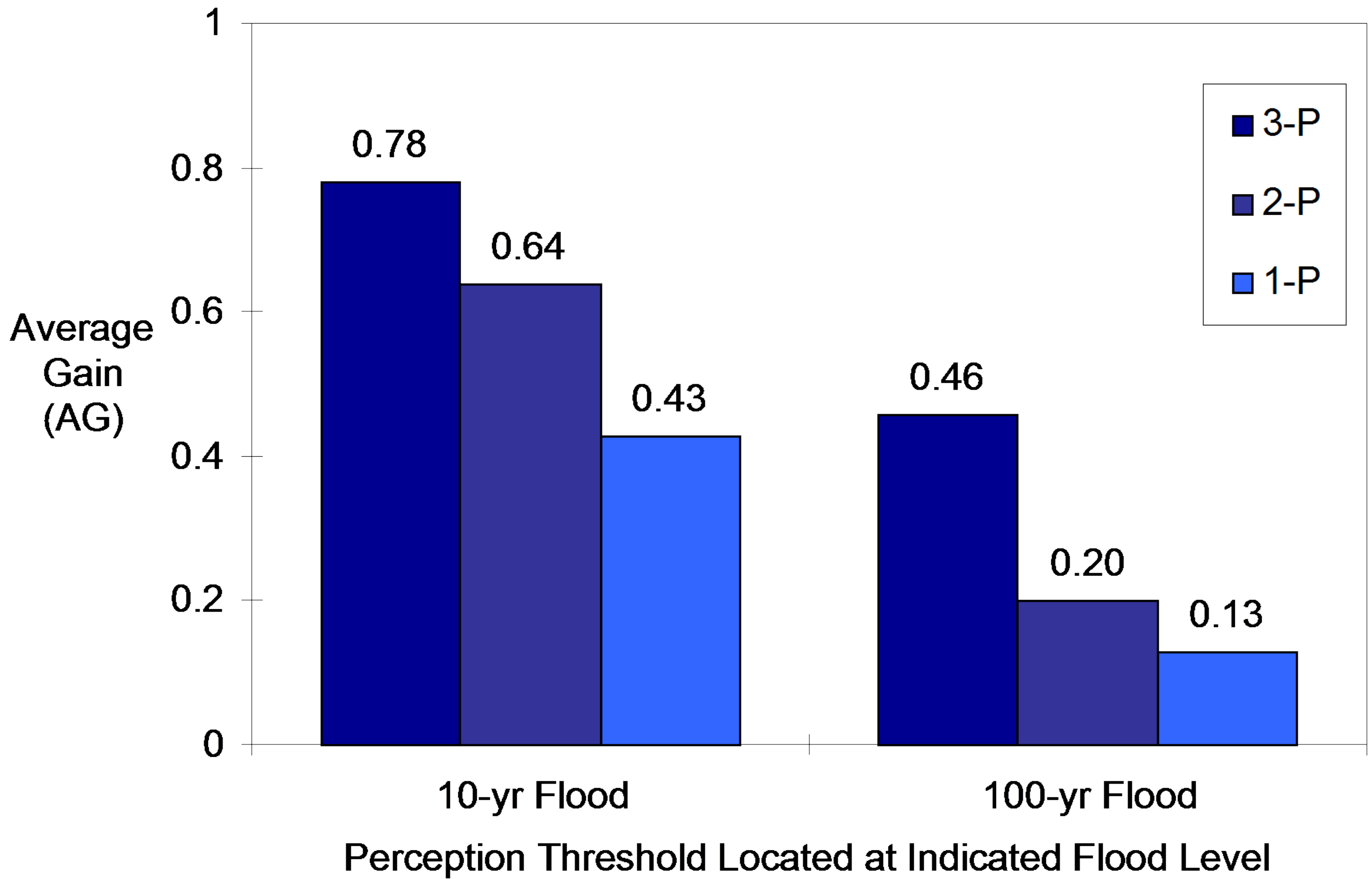
Effective Record Length, Xo = 99%-tile



Average Gains when Estimating 100-year Flood by fitting 2-Parameter Lognormal Distribution (s = 20 years; h = 100 years)



Average Gains when using MLE's to Estimate 1, 2, and 3 Lognormal Parameters

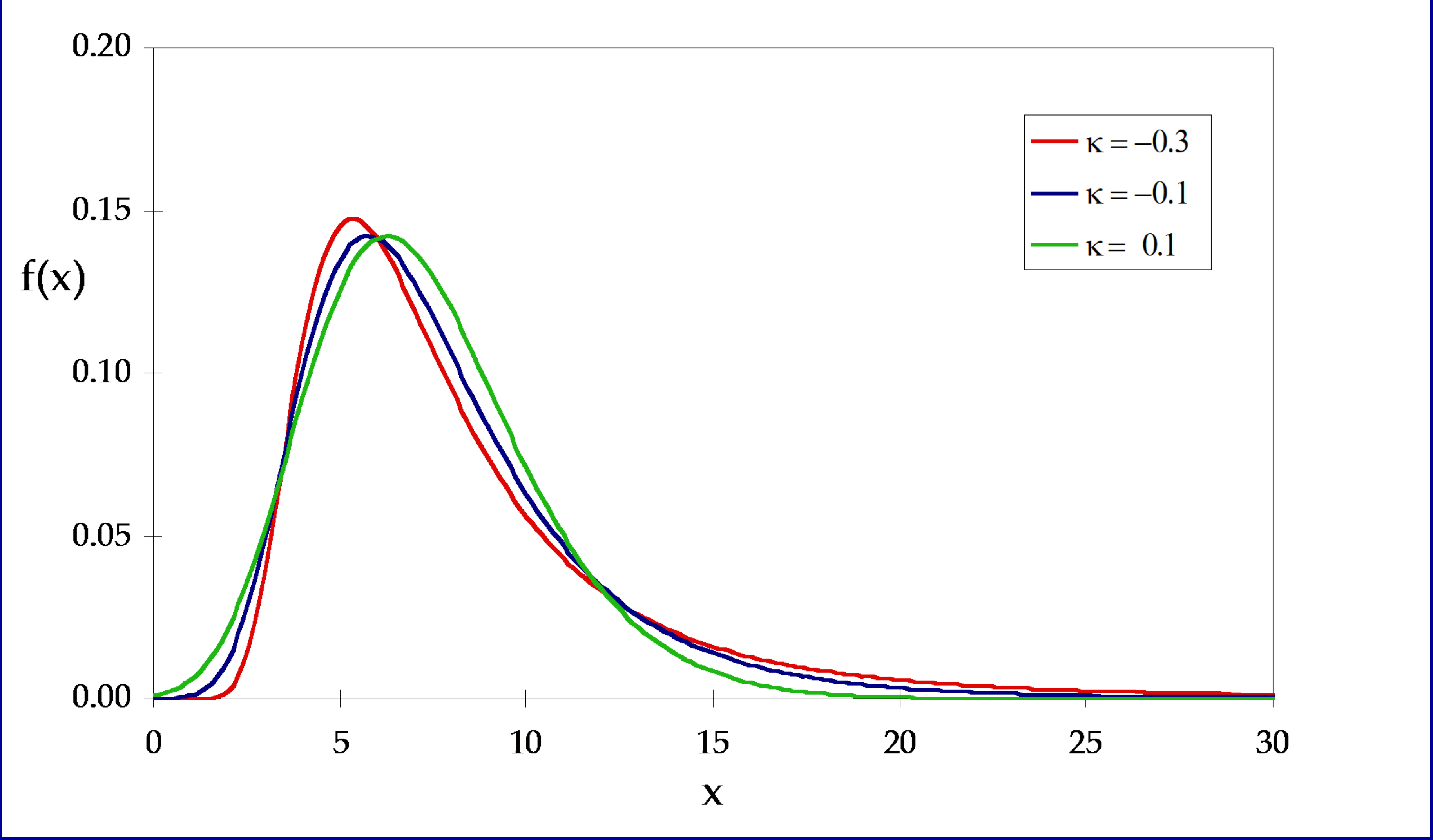


Observation:

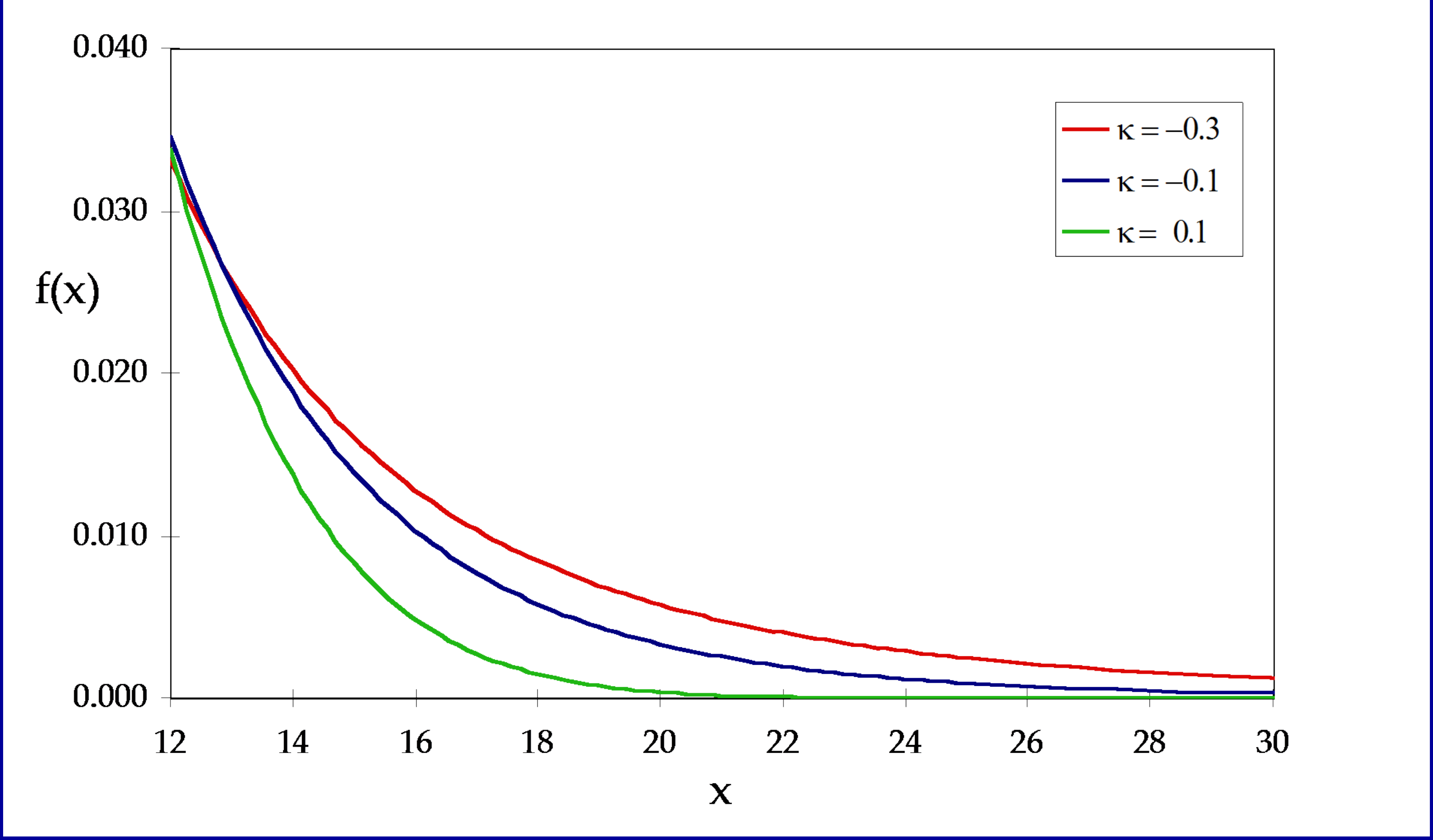
Much larger *Average Gains* when estimating 3 parameters.

Shape parameter is hard to pin down with short records, and their estimators are sensitive to extreme observations.

Generalized Extreme Value (GEV) distribution



GEV Prob. Density Function large x



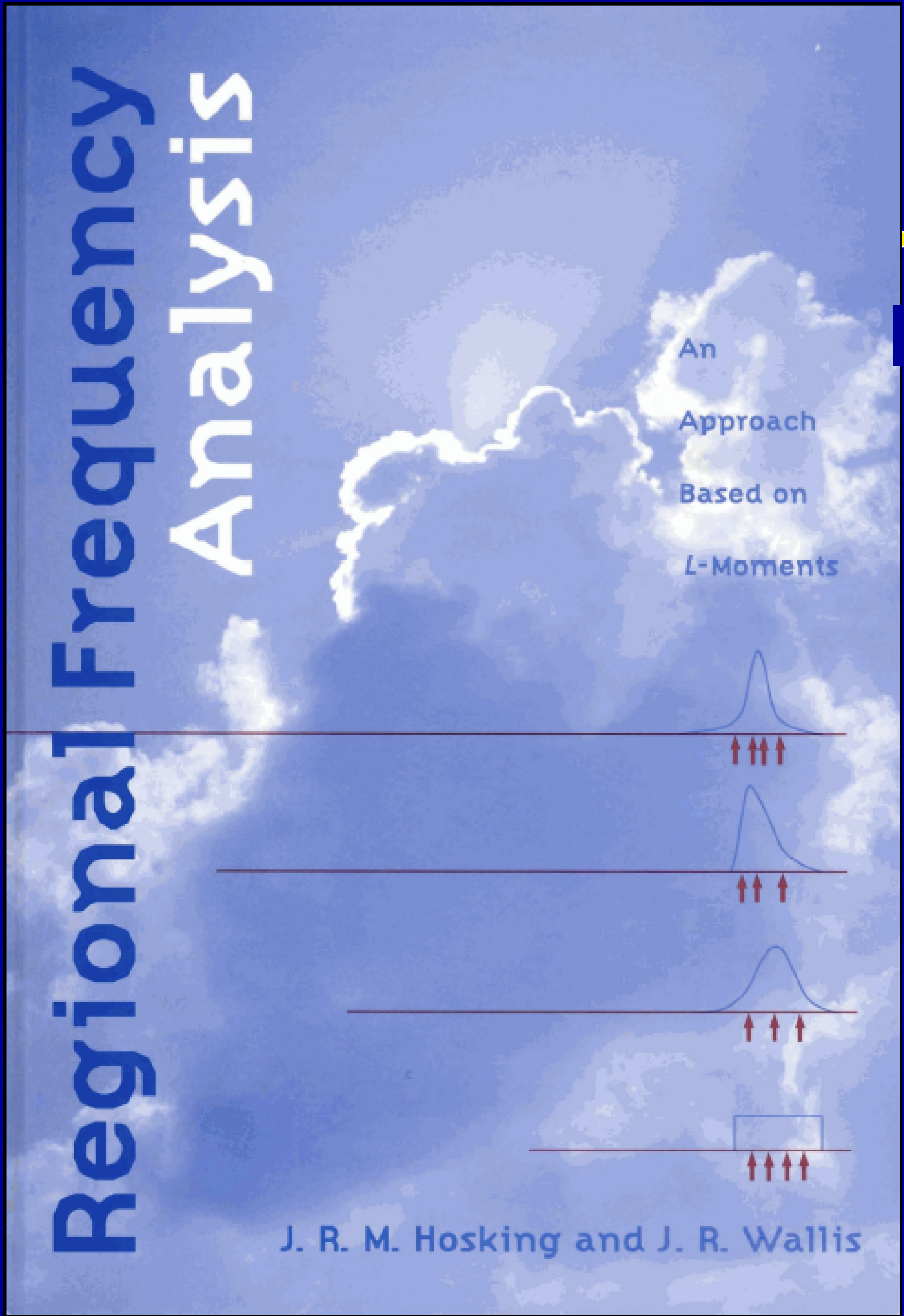
Index Flood & Regionalization

Substituting Space for Time.

Principles for better estimates of extreme flood probabilities

U.S. National Research Council report (1988)

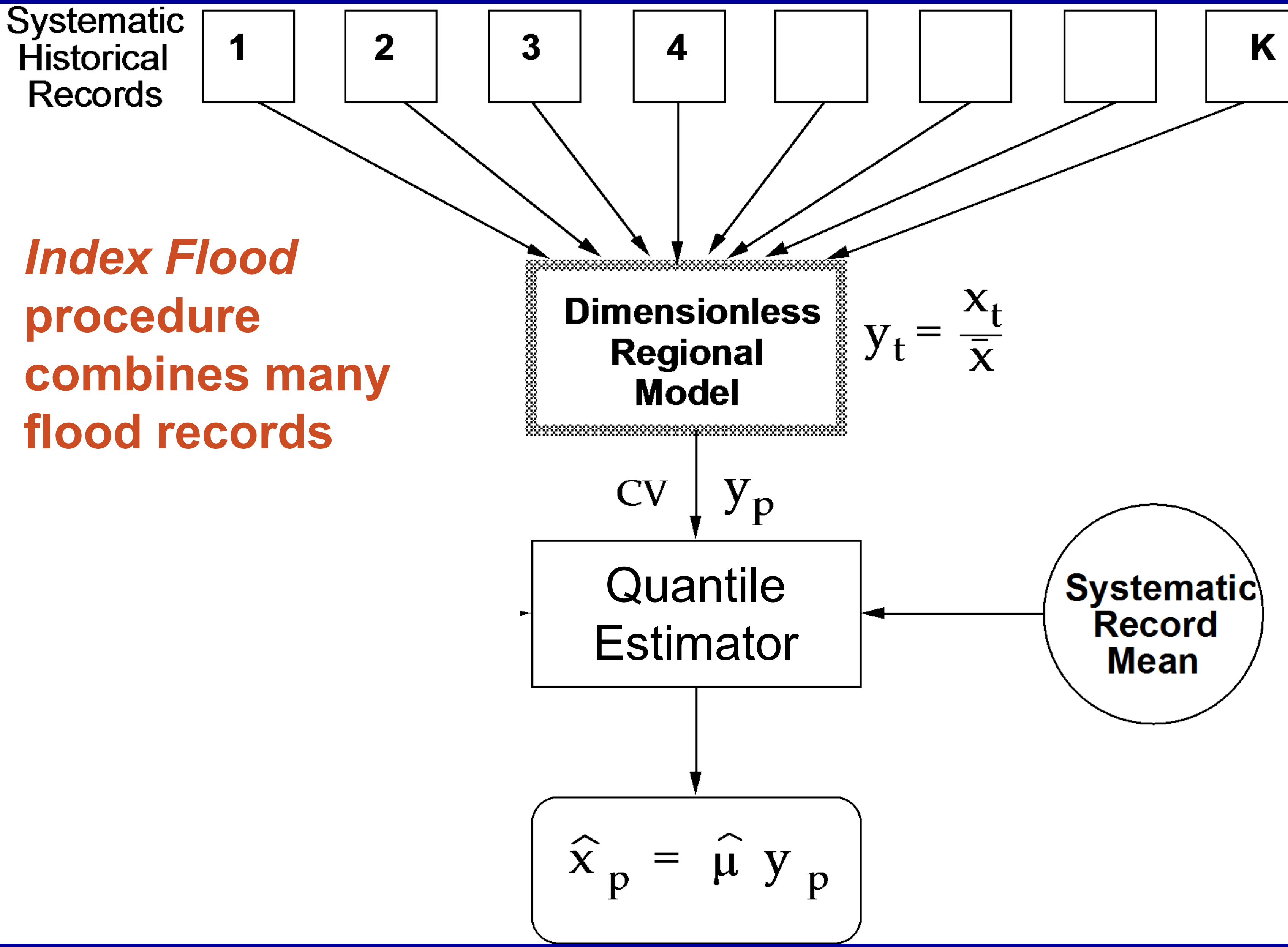
- Substitute space for time using "regionalization."
- Introduce additional structure into models based upon physical insight and hydrologic experience.
- Focus on extremes or "tails" of flood distribution, so less important and common floods do not distort fitted distribution for extreme events.

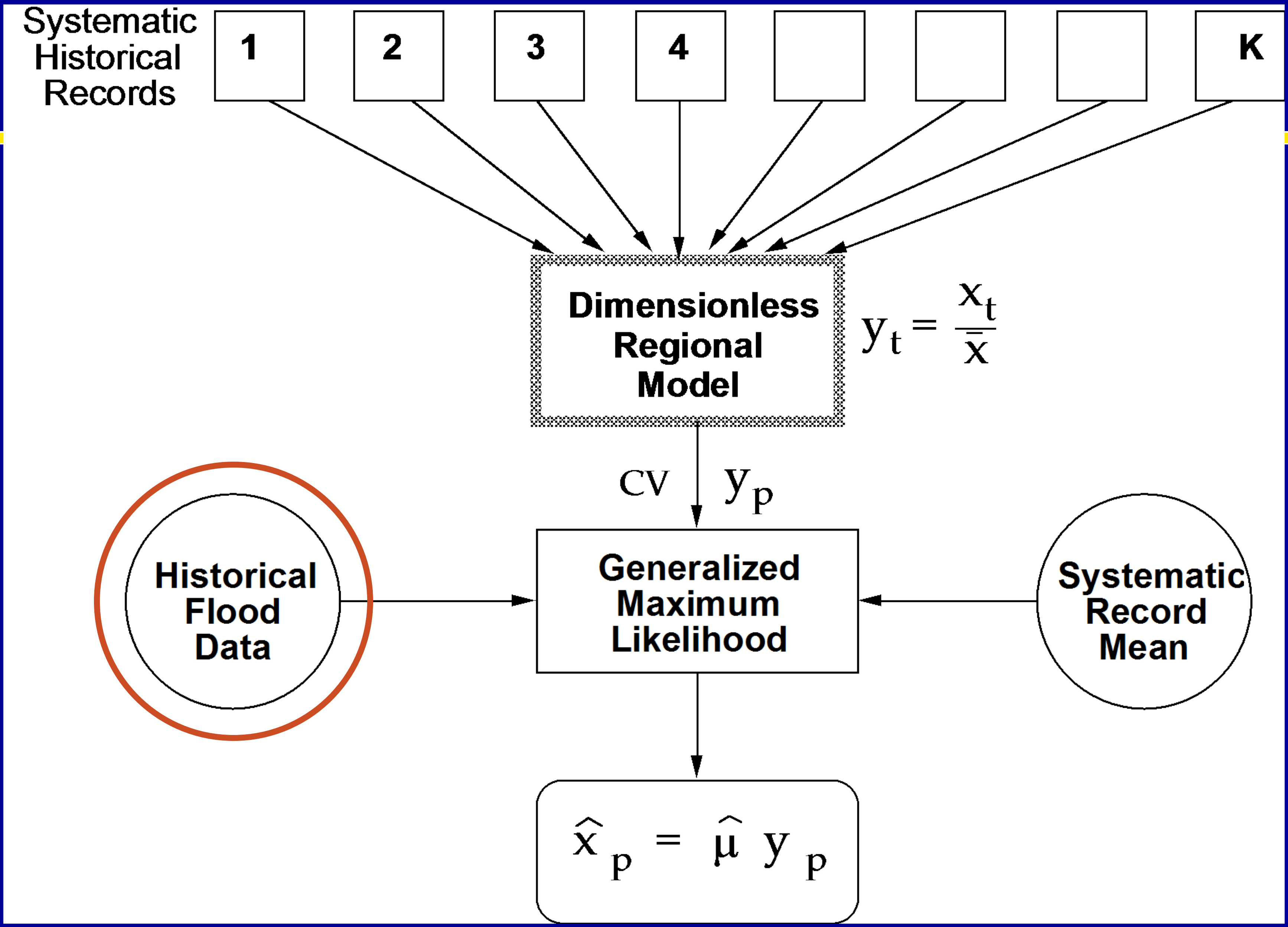


Hosking and Wallis (1997)

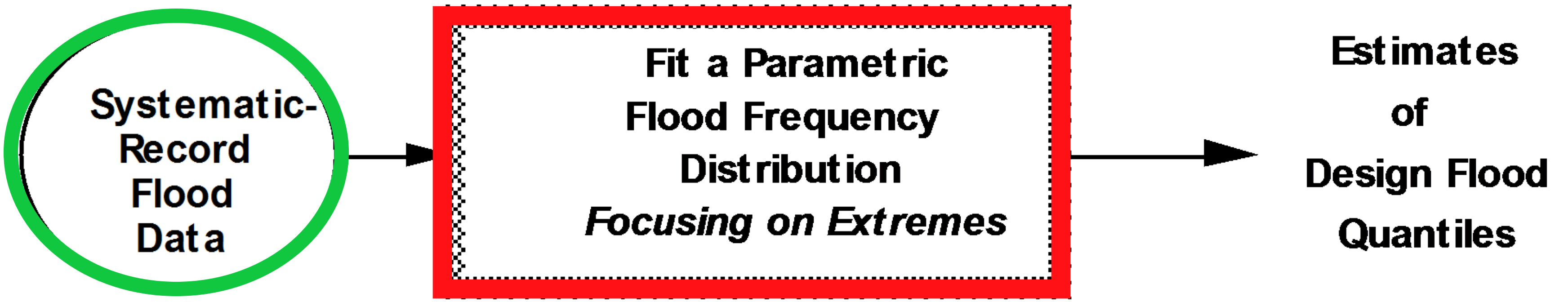
Development of L-moments for regional flood frequency analysis.

Index Flood procedure combines many flood records

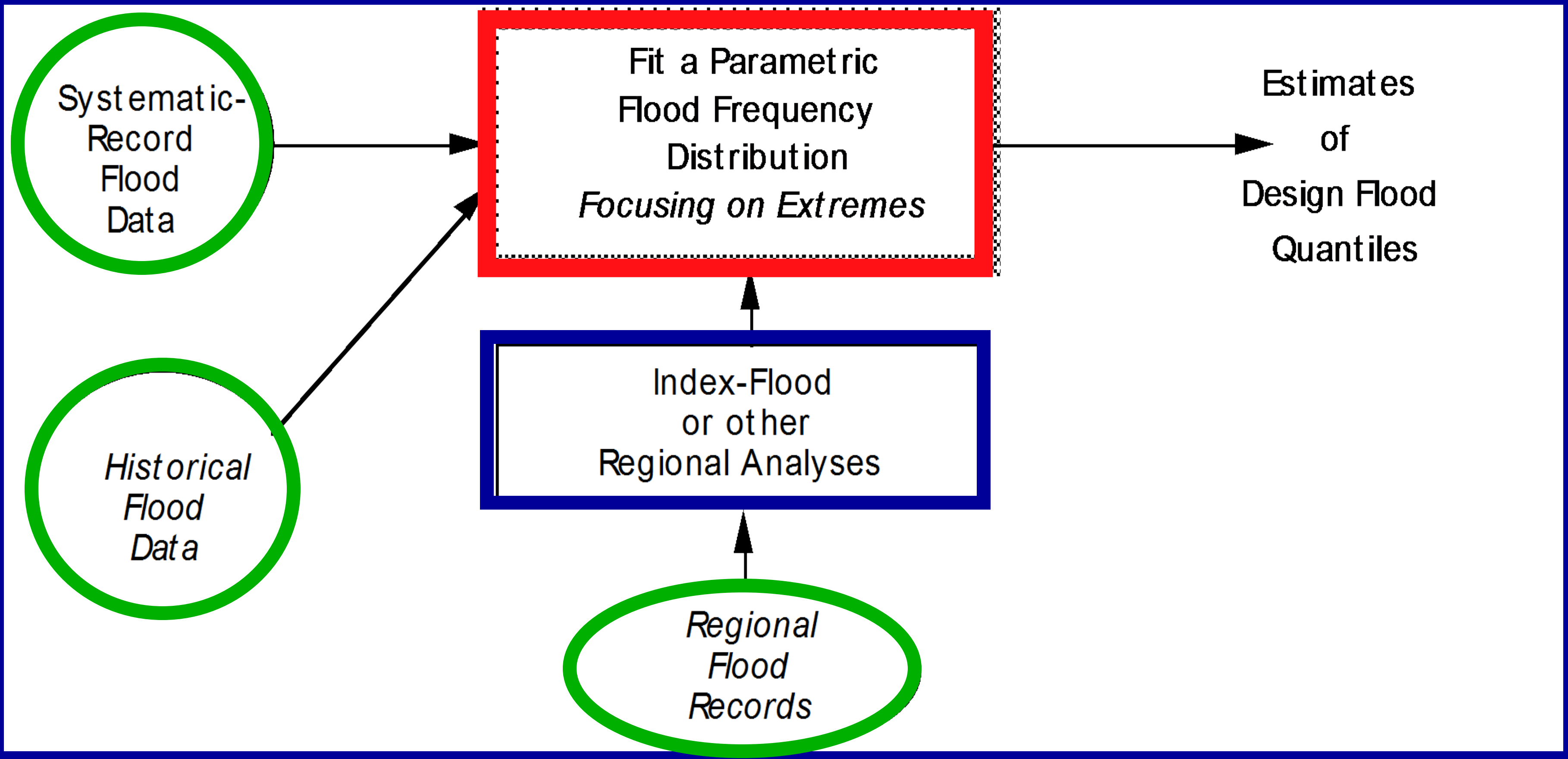



Systematic Historical Records
1
2
3
4
K
Dimensionless Regional Model
$y_t = \frac{x_t}{\bar{x}}$
CV
y_p
Historical Flood Data
Generalized Maximum Likelihood
Systematic Record Mean
$\hat{x}_p = \hat{\mu}\, y_p$

Flood Frequency Analysis Paradigm



New Paradigm for Flood Frequency Analysis



Credibility of Estimators

• At site record:	50 - 100 years
• With historical info:	100-200 years
• Regional 20 records:	20*50 = 1,000 years
• At-site & paleo. info:	1,000 years
• At-site & regional paleofloods	10,000 years

See USBR(1999, 2004) for similar analysis of limits of credibility of empirical estimators

Empirical Analysis Assumes

- Observed records contains representatives of critical events that represent LARGE & RARE floods at a site.
- Nature is “smooth” and “continuous” so that fitting a mathematically nice GEV or LP3 distribution is reasonable for extrapolation.

Estimating Flood Risk

B17B

PFHA (?)

↔

Empirical

Use observed

Flood Data

Imagine

Construct using

regional flood,

rainfall, climate,

storm-track, &

orographic data

T = 100 to 1000 comfortably

T = 10,000 to 1 million

Addressing Uncertainty

- Consider

Natural Variability (*Aleatory* Uncertainty) versus Knowledge Uncertainty (*Epistemic* Uncertainty-Limited data to estimate parameters)?

- Do they combined to get total risk?
- Do we give nominal risk with uncertainty bounds reflecting epistemic uncertainty?
- Flood risk estimates in US (following Bulletin 17B) include only aleatory uncertainty.

MCMC for LP3 Quantiles with only systematic information, s = 100

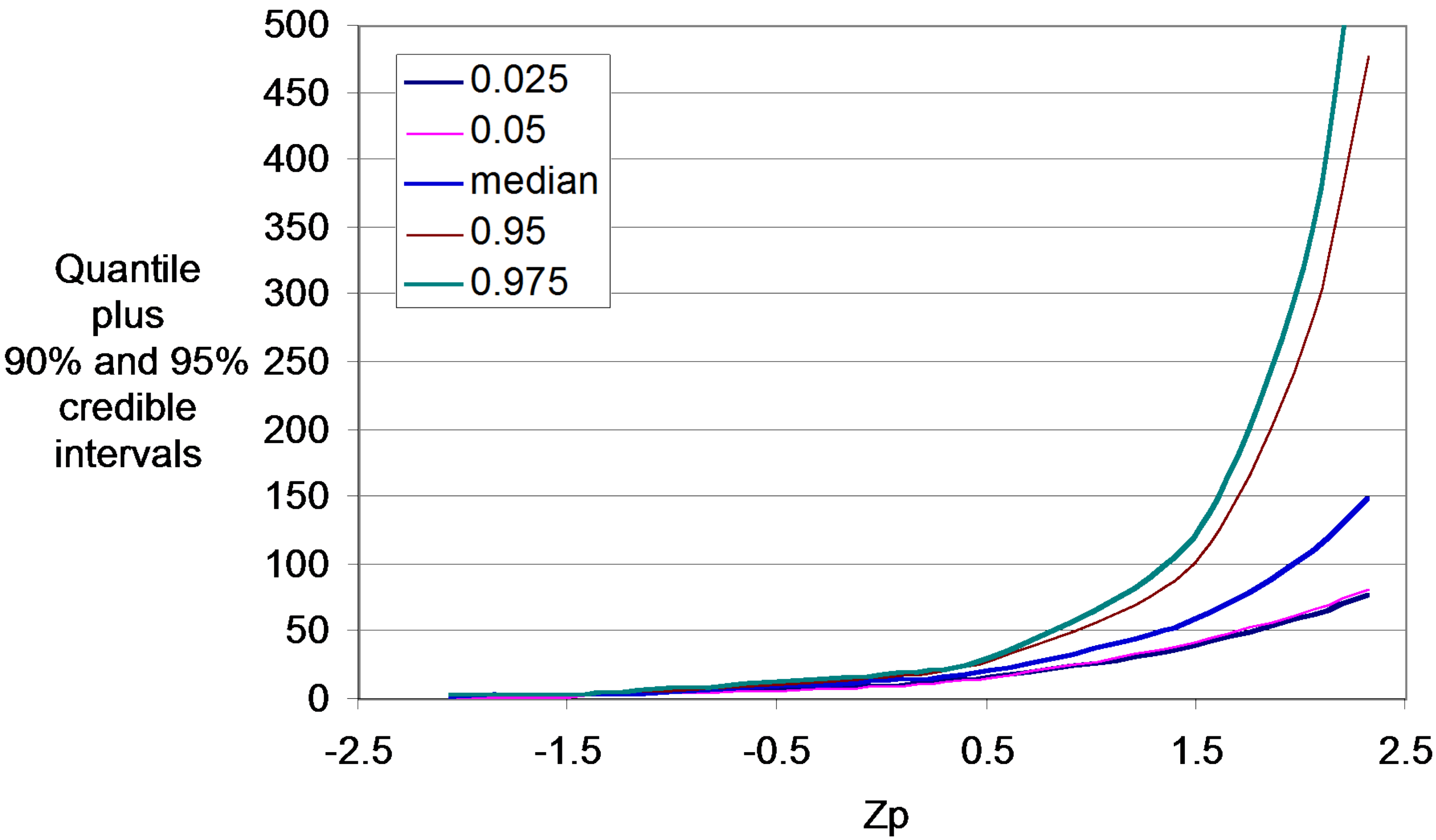


Illustration of Uncertainty

Drew samples of size n = 100

From 2-parameter lognormal distribution.

Fit 2-parameter lognormal distribution AND

Fit 3-parameter LP3 (with log moments)

Estimated events exceeded with probability of

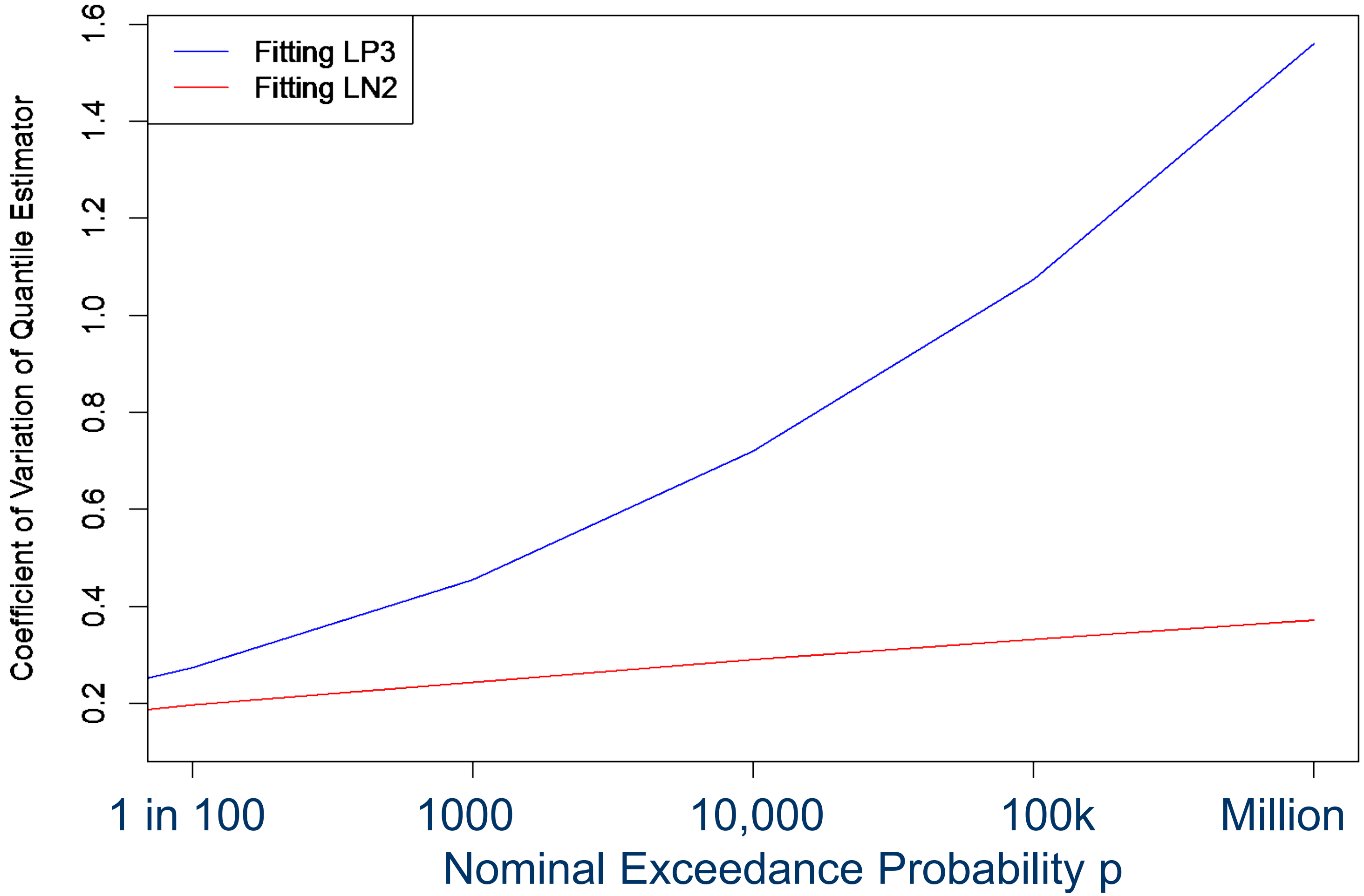
1 in 100 through 1 in a million.

Report ratio of exceedance probability of “design floods” to anticipated exceedance probability.

and Coefficient of Variation of “design flood” estimators.

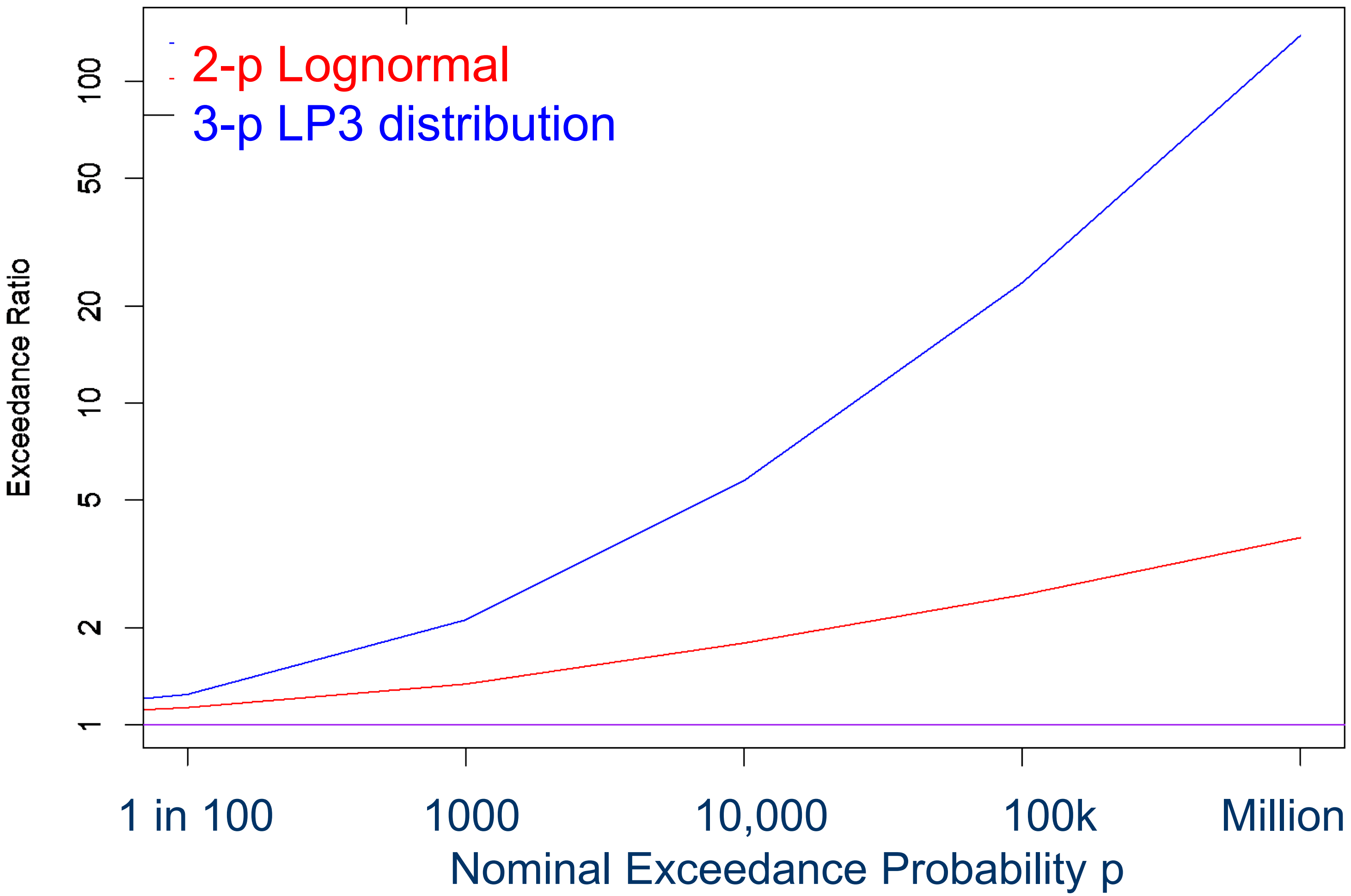
Coefficient of Variation of Design Flood Estimators

Consider 2-p Lognormal, and 3-p LP3 distributions

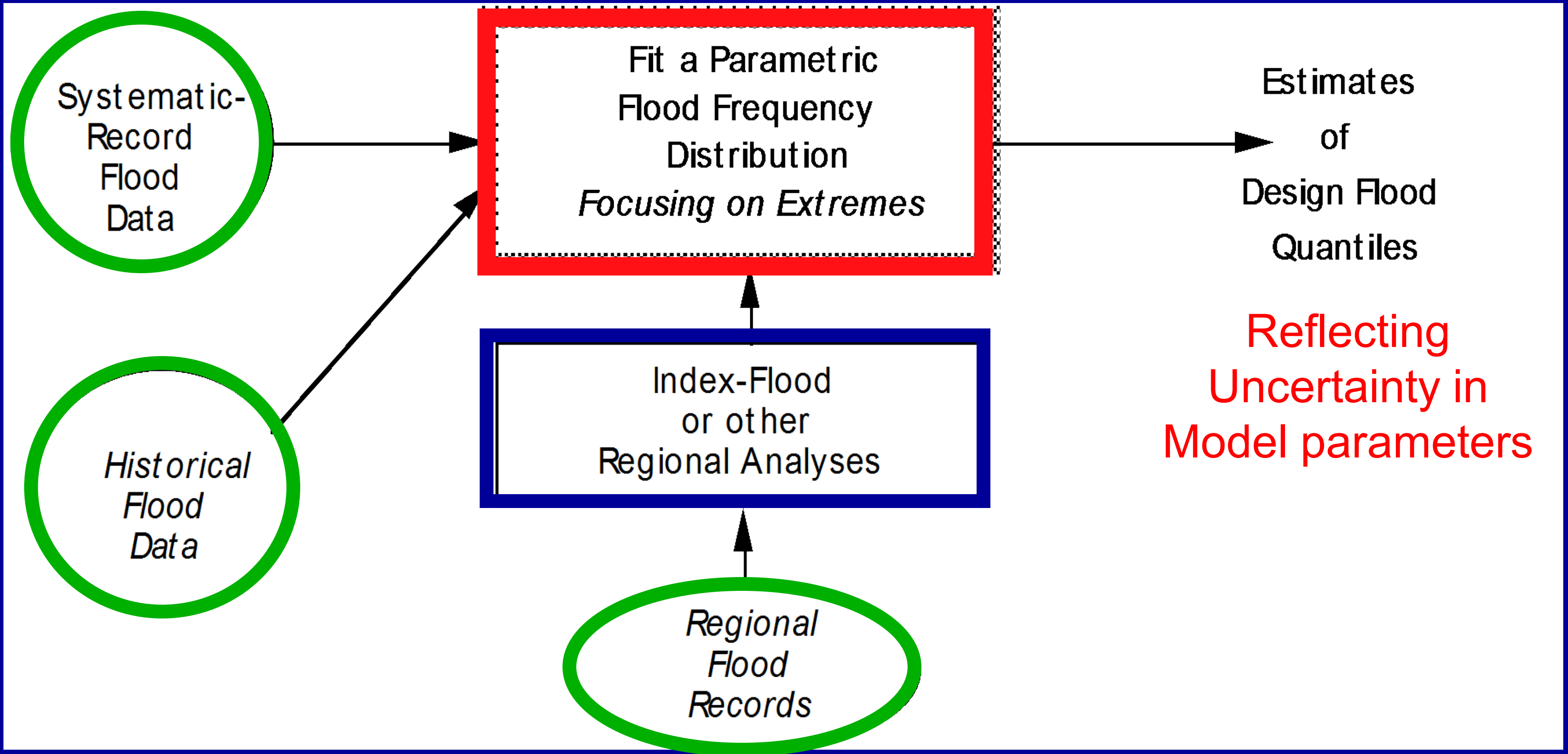


Error in Exceedance Probability

Ratio exceedance probability of “design flood” to p



New Paradigm for Flood Frequency Analysis



Historical advice

"We must accomplish a task more difficult to many minds than daring to know. We must dare to be ignorant."

Concluding two sentences:

Karl Pearson

The Grammar of Science, 1892

CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

P. C. D. Milly,[1]* Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]

"In view of the magnitude and ubiquity of the hydroclimatic change apparently now under way, however, we assert that stationarity is dead and should no longer serve as a central, default assumption in water-resource risk assessment and planning. Finding a suitable successor is crucial for human adaptation to changing climate."

Science, Feb. 2008

Clmate Change – So What?

(1) Gaged records tell us what common floods look like and where we start.

(2) Then we need to estimate the change.

(3) But how to determine where we go from here?

Climate Change & Risk Projection

- Imagine 50-100 year record of floods
- Plus paleoflood record illustrating largest floods over 1000-2000 years.
- Fit a line to estimate 1-in-100,000 risk ?
- Paleoflood record likely includes periods of greater & lesser risk, so risk extrapolation OVER estimates actual risk in our time frame.

Summary

- Flood records for last century do not reveal reliably flood risk of 1 in 10,000 or   1 in a million.
- At-site Historical and Paleoflood information helps.
- Regionalization of recent & paleoflood records helps
- Extrapolation more uncertain with 3-parameter LP3.
- Climate change confuses things
  - Public loss of confidence in analysis
  - Extrapolating beyond paleoflood data likely conservative

Issues for Discussion

- Records of real floods may be insufficient for our purposes: analysis instead needs to *imagine*.

- Uncertainty can be large part of computed total risk.
  - Are we eady to combine variability & knowledge uncertainty into a total risk?
  - Can we do the computation appropriately using honest informative Bayesian priors ?

Thank you for your attention.

Jery Stedinger

Donald Rumsfeld, Secretary of Defense

under President George W. Bush from 2001 to 2006
said at Department of Defense news briefing, February 2002:

"Reports that say that something hasn't happened are always interesting to me, because as we know,

there are *known knowns;*

there are things we know we know. We also know there are *known unknowns;* that is to say

we know there are some things we do not know.

But there are also *unknown unknowns*

-- the ones we don't know we don't know.

And if one looks throughout the history of our country and other free countries, it is the latter category

that tend to be the difficult ones."

Generalized Extreme Value (GEV) distribution

Gumbel's Type I, II & III Extreme Value distr.:

$$F(x) = \exp\{ - [1 - (\kappa/\alpha)(x-\xi)]^{1/\kappa} \} \quad \text{for } \kappa \neq 0$$

$$\mu_X = \xi + (\alpha/\kappa) [1 - \Gamma(1+\kappa)]$$

$$\mathrm{Var}[X] = (\alpha/\kappa)^2 [\Gamma(1+2 \kappa) - \Gamma^2(1+\kappa)]$$

$$E[(X-\mu_X)^3] = (\alpha/\kappa)^3 [- \Gamma(1+3\kappa) + 3 \Gamma(1+\kappa) \Gamma(1+2 \kappa) - 2\Gamma^3(1+\kappa)]$$

κ = shape; α = scale, ξ = location.

Mostly

$-0.25 < \kappa \leq 0$