ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
DEPARTMENT OF CIVIL, CHEMICAL, ENVIRONMENTAL, AND MATERIALS ENGINEERING

Mini-workshop on

Novel hydrological concepts for the engineering practice

29 September, 2021, Bologna, Italy

(Please note the EU Digital Covid Certificate – Greenpass – is required to attend the workshop and the HC Degree Ceremony)

TECHNISCHE UNIVERSITÄT WIEN

Flood Frequency Hydrology: Information vs. Uncertainty

Alberto Viglione

Politecnico di Torino

Flood Frequency Analysis:

The objective of frequency analysis of hydrologic data is to relate the **magnitude** of extreme events to their **frequency** of occurrence through the use of probability distributions.

…

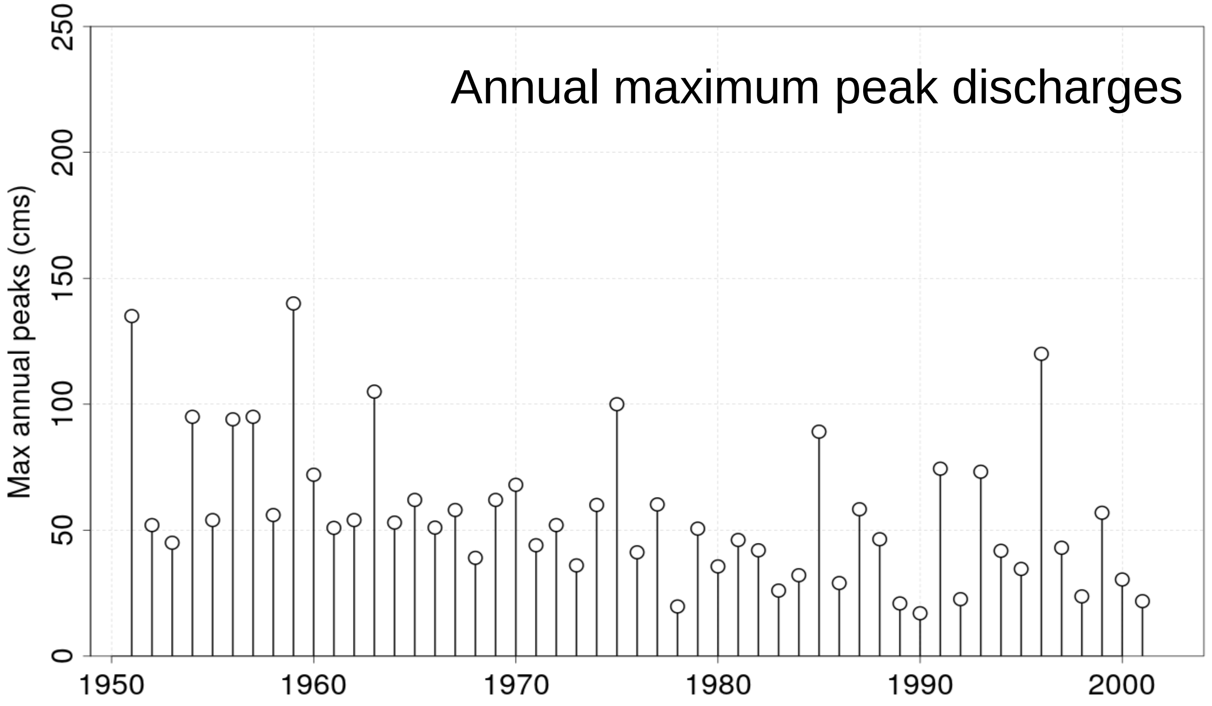
…

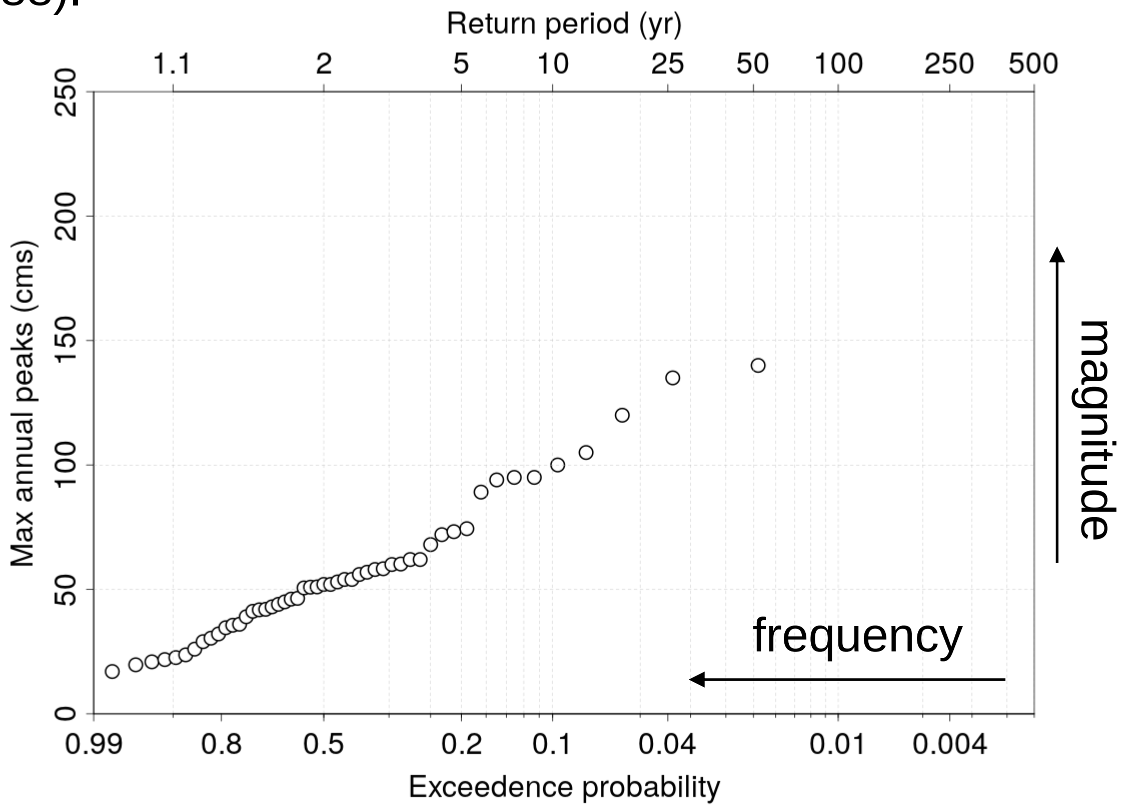
The results of flood flow frequency analysis can be used for many **engineering purposes**: for the design of dams, bridges, culverts, and flood control structures; to determine the economic value of flood control projects; and to delineate flood plains and determine the effect of encroachments on the flood plain.

(Chow et al., 1988)

Flood Frequency Analysis: selection and representation of data

The hydrologic **data** employed should be **carefully selected** so that the assumptions of independence and identical distribution are satisfied (Chow et al., 1988).



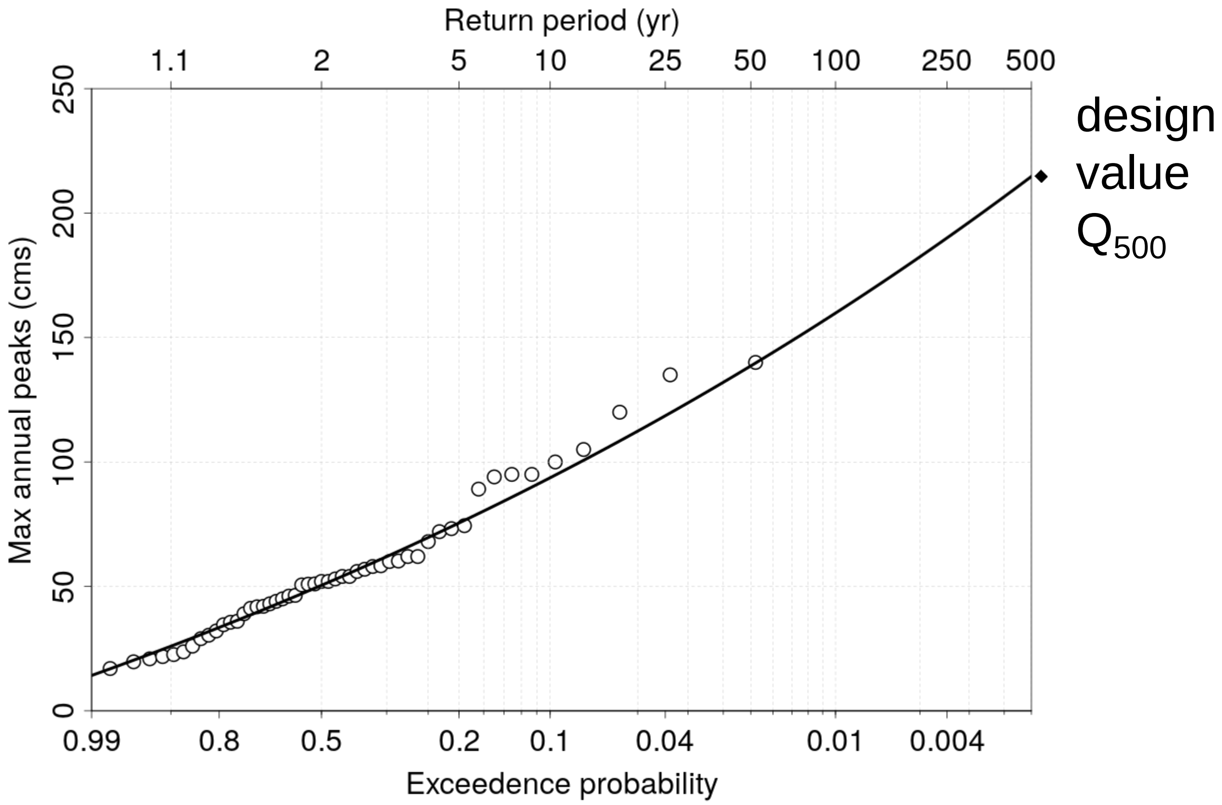


It is convenient to represent the data (and models) in a **probability plot** to better show their behavior for very small exceedence probabilities (i.e., the tail of the distribution).

Flood Frequency Analysis: probability distribution and design values

The objective of frequency analysis of hydrologic data is to relate the magnitude of extreme events to their frequency of occurrence through the use of **probability distributions** (Chow et al., 1988).

=> Fitting a **statistical model** to the data to represent the **population** of possible floods.



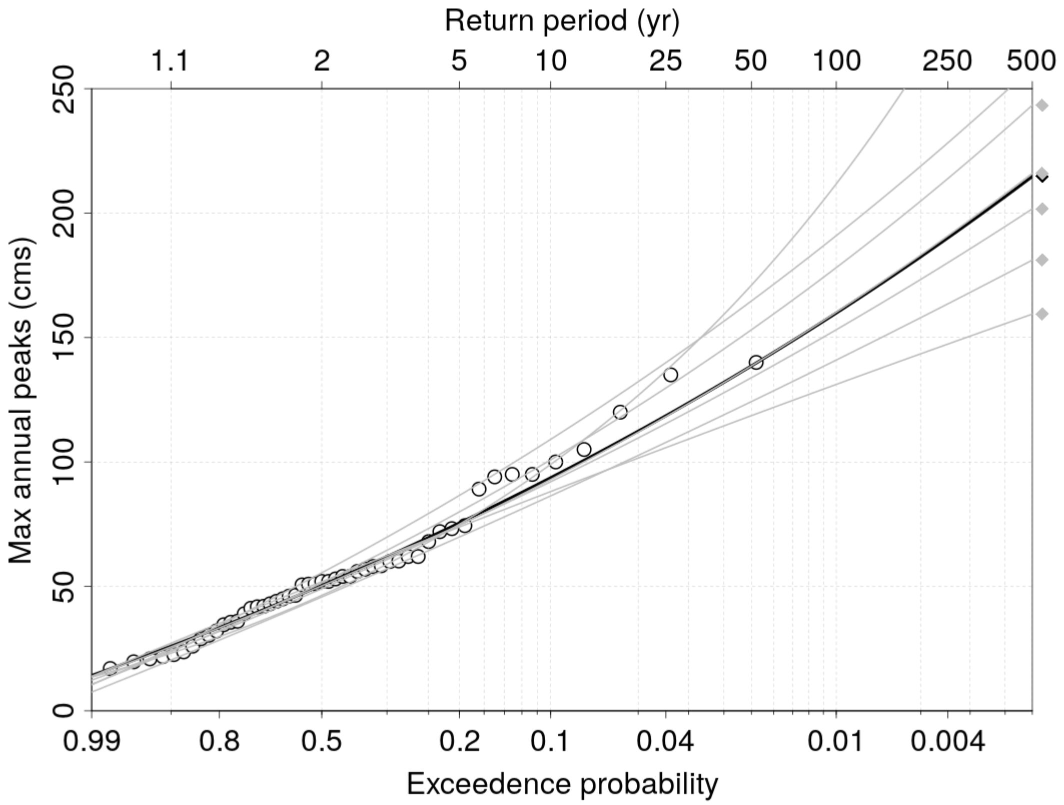
In general engineers end up by choosing **one model** and, from it, a **design value** (e.g., 500-yr peak discharge, which is expected to be exceeded once every 500 years on average)

Flood Frequency Analysis: uncertainties

Many uncertainties are there:

- uncertainty in the **chosen model** (i.e., what probability distribution: Gumbel, GEV, LP3, BurrIII, …)
- uncertainty in the estimation of its **parameters** (i.e., what inference method: method of moments, L-moments, …)
- **sample uncertainty** (i.e., the size of the sample dictates the amount of **information** we have)

For events which are very rare, there is a great deal of uncertainty. Small differences in what a distribution line looks can have large impacts on the probabilities of uncommon events.

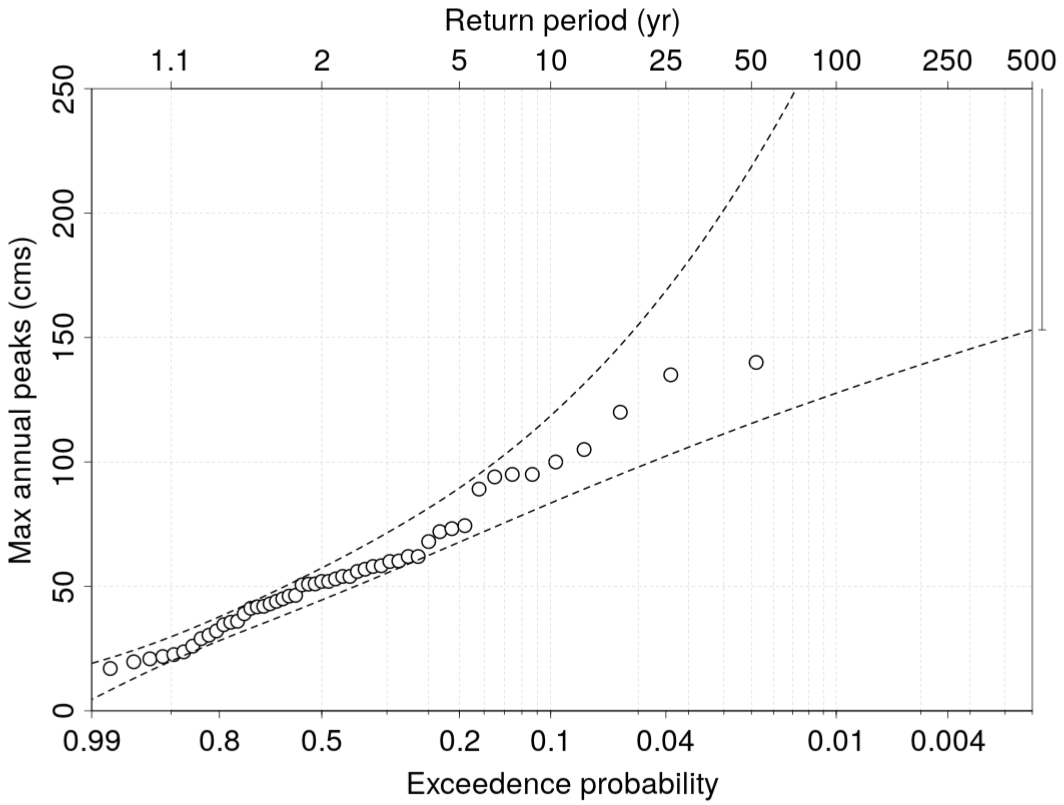


design value Q_{500} ?

Flood Frequency Analysis: uncertainties

Being honest, the outcome of the flood frequency analysis should be given in a **probabilistic way**, for example through uncertainty bounds, i.e., a range of values within which we do expect (with high probability) that the true probability distribution lies.

Problem: this is **not satisfactory in engineering practice** where a design value should be identified



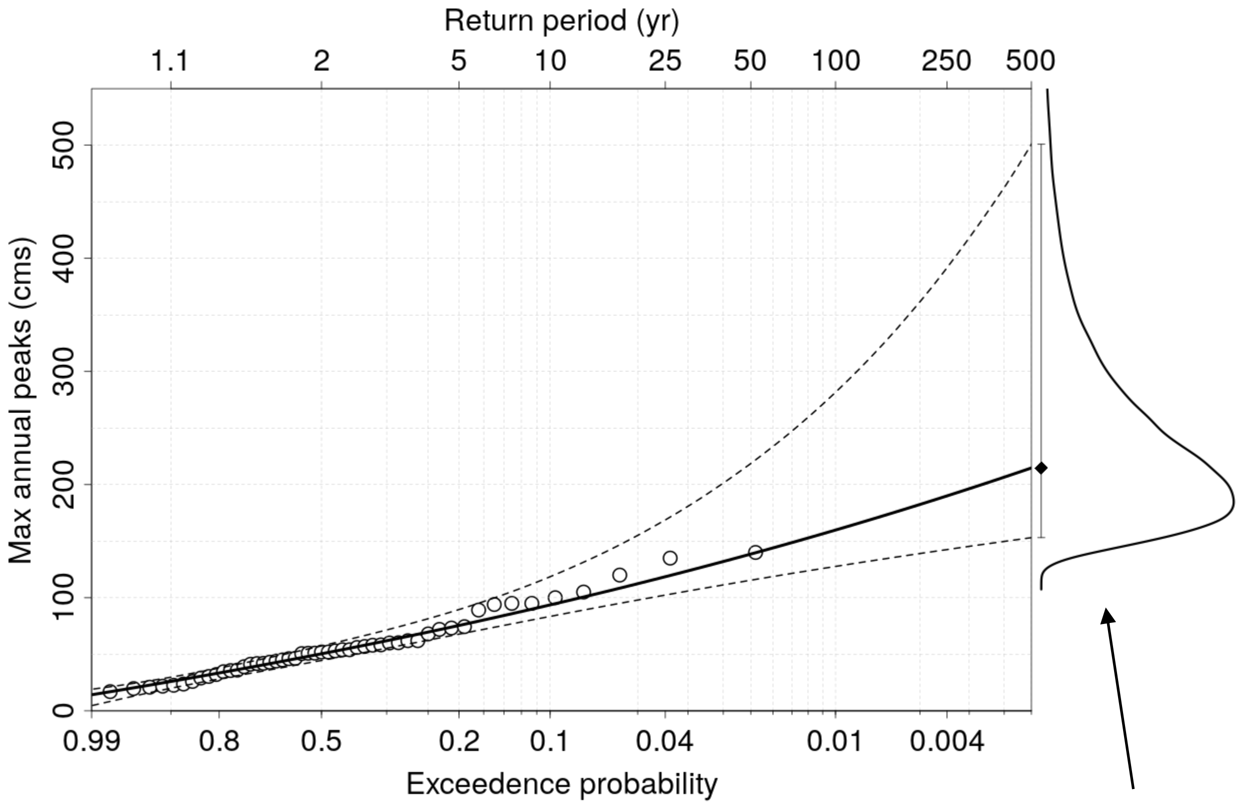
design value Q_{500} ?

Flood Frequency Analysis: design values

What value do we choose as design value?

Usually the **best point estimate** is selected, i.e., our "best guess" of, for example, the unknown 500-year flood peak

(we should give both then, the point estimate of Q_{500} and the estimate of its uncertainty)



best point estimate and distribution of the design value Q_{500}

But **other possible design values** could be selected **taking into account its estimated uncertainty** (its distribution): which ones?

Flood Frequency Analysis: design values (model averaging)

Mean (or median) of the estimated distribution of Q_{500} is a **robust** way to deal with uncertainty

HYDROLOGICAL SCIENCES JOURNAL
2018, VOL. 63, NOS. 13–14, 1913–1926
https://doi.org/10.1080/02626667.2018.1546389

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Model averaging *versus* model selection: estimating design floods with uncertain river flow data

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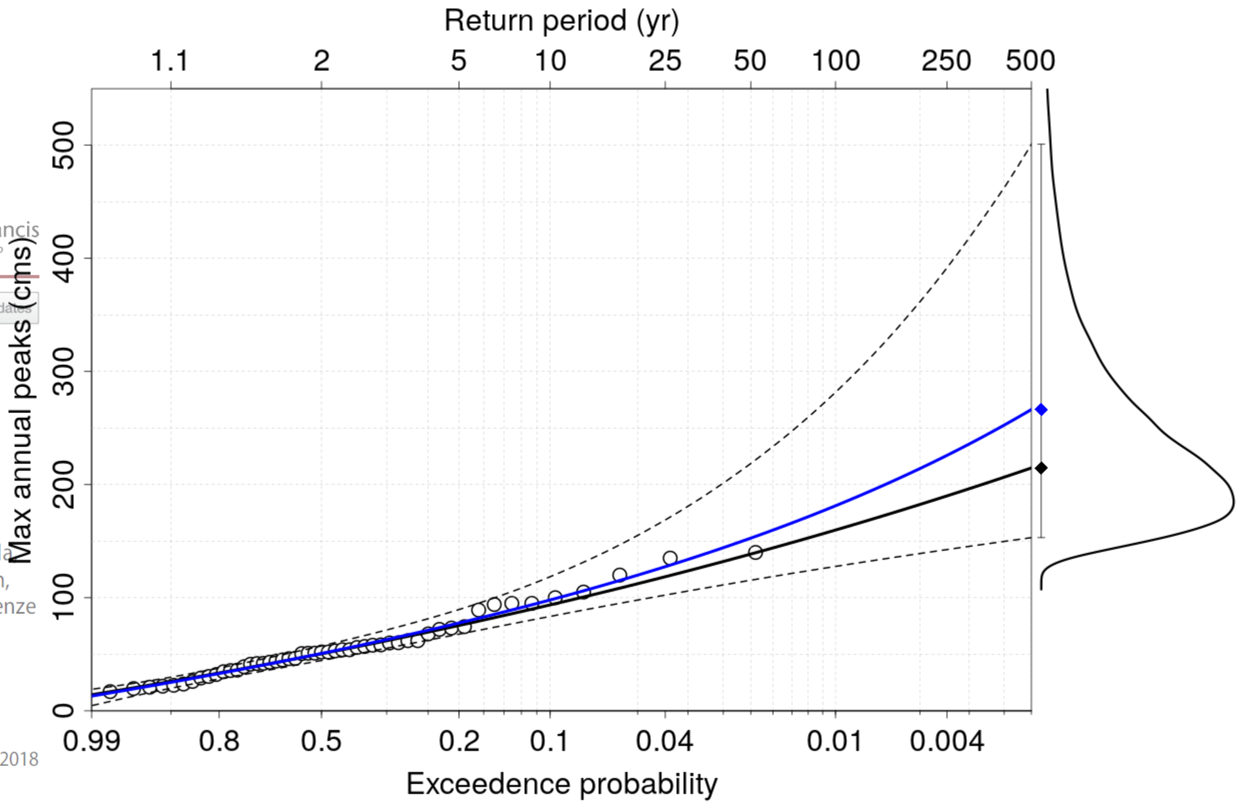
ABSTRACT
This study compares model averaging and model selection methods to estimate design floods, while accounting for the observation error that is typically associated with annual maximum flow data. Model selection refers to methods where a single distribution function is chosen based on prior knowledge or by means of selection criteria. Model averaging refers to methods where the results of multiple distribution functions are combined. Numerical experiments were carried out by generating synthetic data using the Wakeby distribution function as the parent distribution. For this study, comparisons were made in terms of relative error and root mean square error (RMSE) referring to the 1-in-100 year flood. The experiments show that model averaging and model selection methods lead to similar results, especially when short samples are drawn from a highly asymmetric parent. Also, taking an arithmetic average of all design flood estimates gives estimated variances similar to those obtained with more complex weighted model averaging.

ARTICLE HISTORY
Received 9 March 2018
Accepted 13 September 2018

EDITOR
A. Castellarin

ASSOCIATE EDITOR
S. Vorogushyn

KEYWORDS
model averaging; model selection; design flood; Akaike information criterion



Larger than point estimate because of the skewed uncertainty distribution

Flood Frequency Analysis: design values (posterior predictive)

Posterior predictive of Q_{500} is the value that has an **expected probability of exceedance** equal to 1/500 (in one year) according to the **full outcome of the inference procedure**, including uncertainties

Received: 25 October 2017 | Revised and accepted: 15 March 2018

DOI: 10.1002/wat2.1290

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PRIMER

Flood frequency analysis: The Bayesian choice

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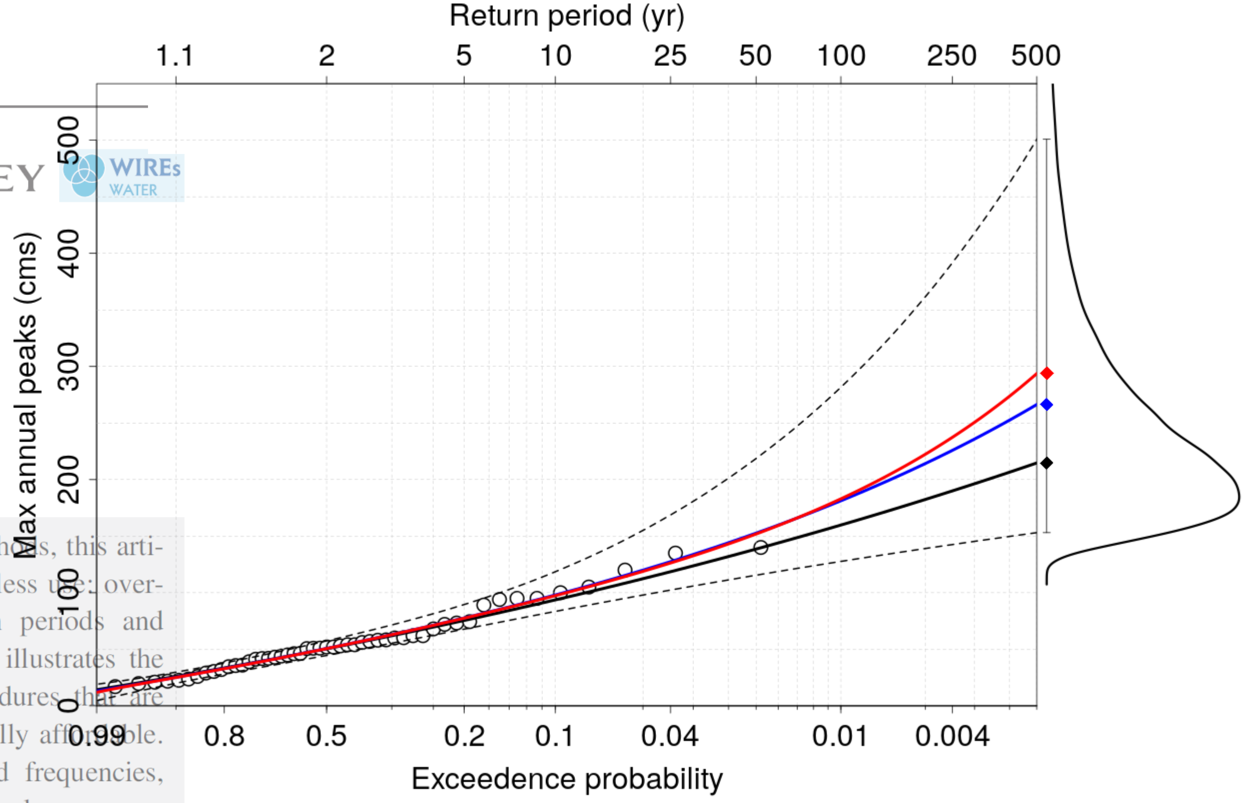
After an introduction to the traditional flood frequency analysis methods, this article discusses their limits and the risks associated with their thoughtless use: overconfidence in the estimated values of flood quantiles or return periods and systematic underestimation of risks. The article then presents and illustrates the added value of modern Bayesian flood frequency inference procedures that are statistically consistent, numerically accurate, and now computationally affordable. The implementation of such methods shows that estimated flood frequencies, based on observed samples of limited size, are generally affected by large uncertainties. This acknowledgement should be an incentive for increasing the size of the analyzed samples through a more systematic use of historic information as well as regional approaches in flood frequency analyses. It also clearly points out that the margin of errors should be considered when using inference results for design or risk assessment purposes. Several pieces of software are now available to conduct Bayesian flood frequency analyses relatively straightforwardly. There



Larger uncertainties (positively skewed) determine larger design values

Flood Frequency Analysis: design values (UNCODE)

The UNcertainty COmpliant DEsign value is defined based on a simplified **cost-benefit analysis**, with linear damage and cost functions, and accounts for uncertainty in flood frequency estimation


AGU PUBLICATIONS

Water Resources Research

RESEARCH ARTICLE

10.1002/2013WR014981

Key Points:
- Uncertainty is accounted by Uncertainty Compliant Design flood estimation method
- Uncertainty Compliant Design estimates are larger than Standard design values

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Citation:
Botto, A., D. Ganora, F. Laio, and P. Claps (2014), Uncertainty compliant design flood estimation, *Water Resour. Res.*, *50*, 4242–4253, doi:10.1002/2013WR014981.

Received 1 NOV 2013
Accepted 13 APR 2014

Uncertainty compliant design flood estimation

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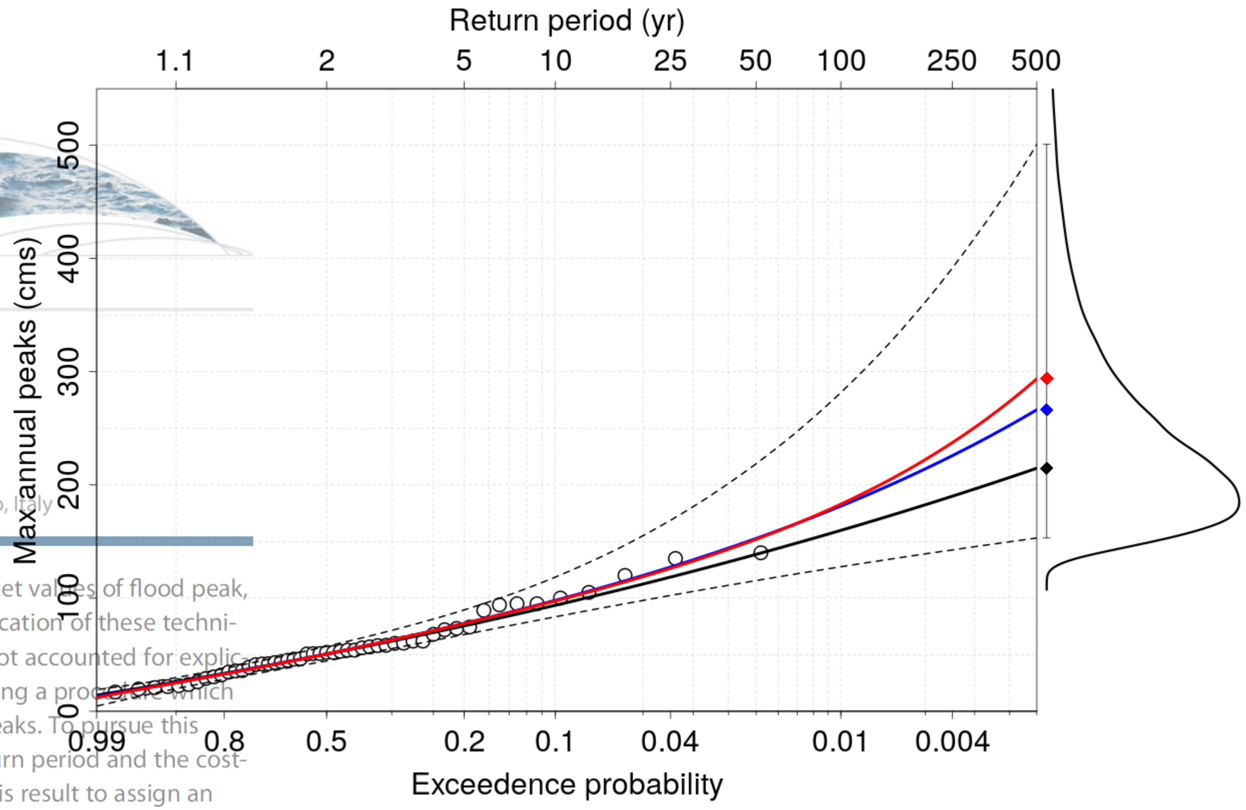
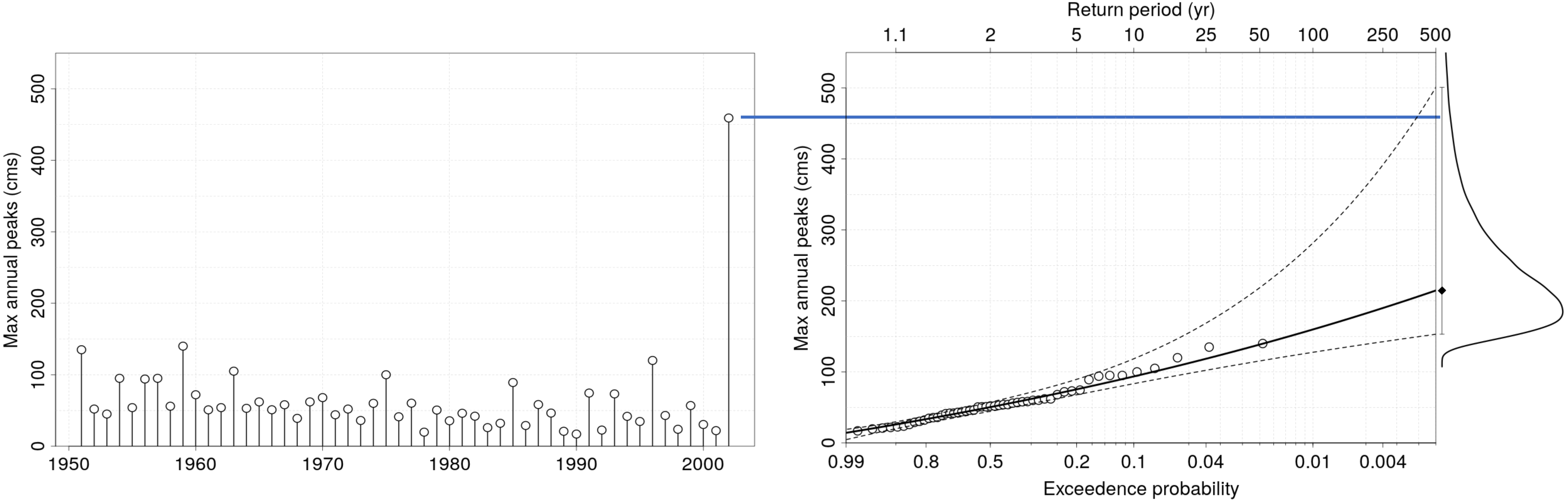
Abstract Hydraulic infrastructures are commonly designed with reference to target values of flood peak, estimated using probabilistic techniques, such as flood frequency analysis. The application of these techniques underlies levels of uncertainty, which are sometimes quantified but normally not accounted for explicitly in the decision regarding design discharges. The present approach aims at defining a procedure which enables the definition of Uncertainty Compliant Design (UNCODE) values of flood peaks. To pursue this goal, we first demonstrate the equivalence of the Standard design based on the return period and the cost-benefit procedure, when linear cost and damage functions are used. We then use this result to assign an expected cost to estimation errors, thus setting a framework to obtain a design flood estimator which minimizes the total expected cost. This procedure properly accounts for the uncertainty which is inherent in the frequency curve estimation. Applications of the UNCODE procedure to real cases leads to remarkable displacement of the design flood from the Standard values. UNCODE estimates are systematically larger than the Standard ones, with substantial differences (up to 55%) when large return periods or short data samples are considered.



is it equivalent to the posterior predictive design value

Black swan event!

Surprisingly severe flood of the Kamp river in 2002 (northern Austria)



Could we foresee an event like this before 2002?

Black swan event!

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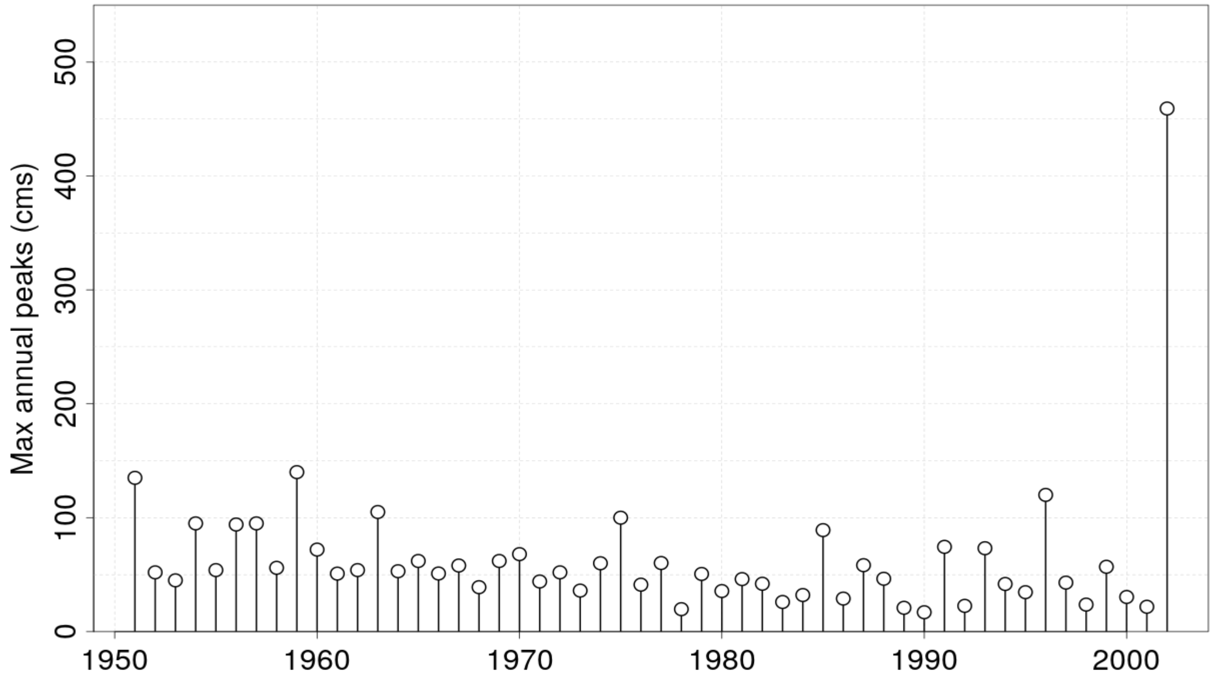
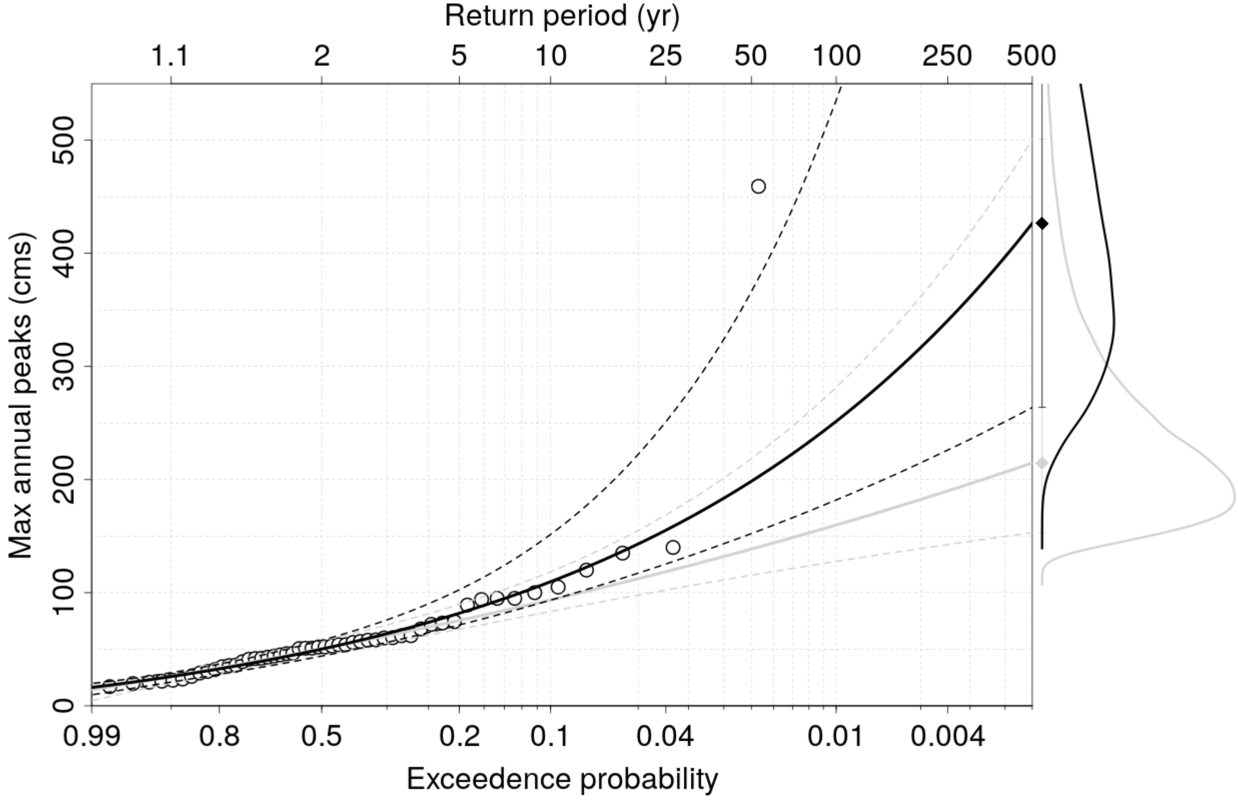


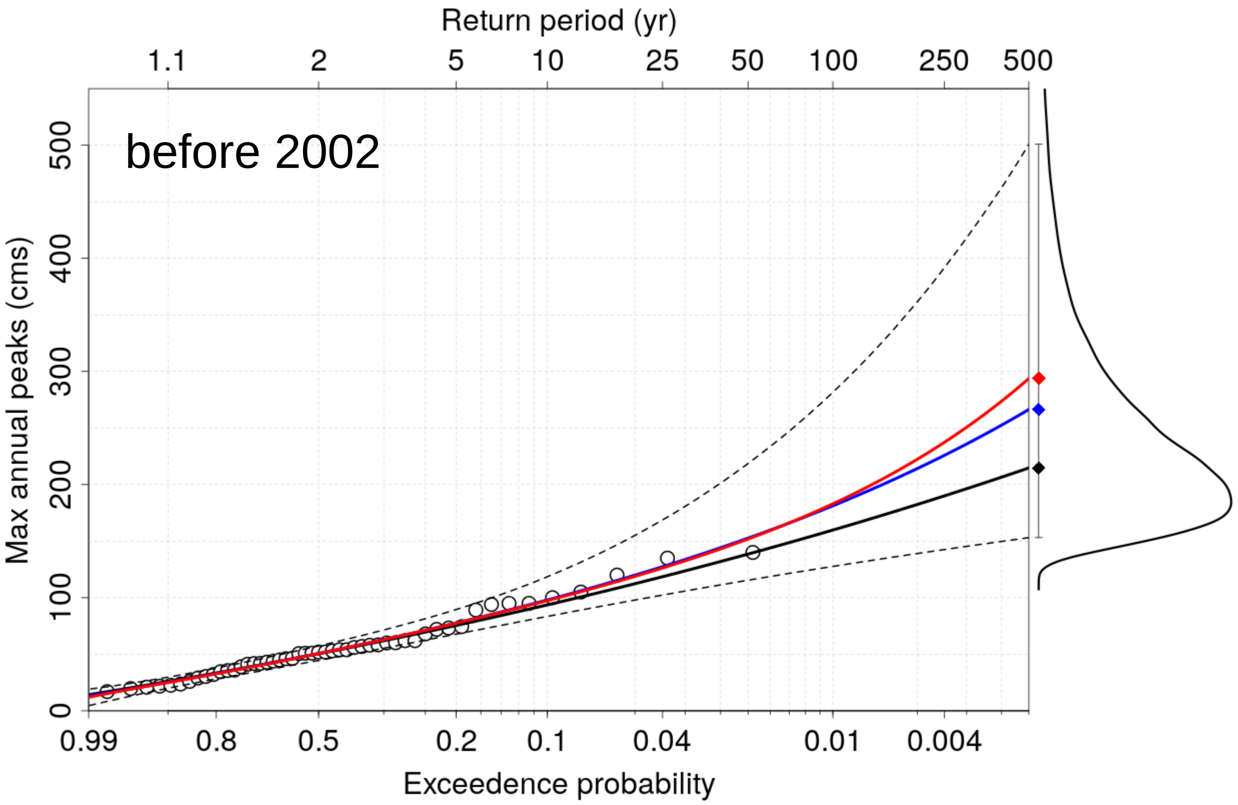


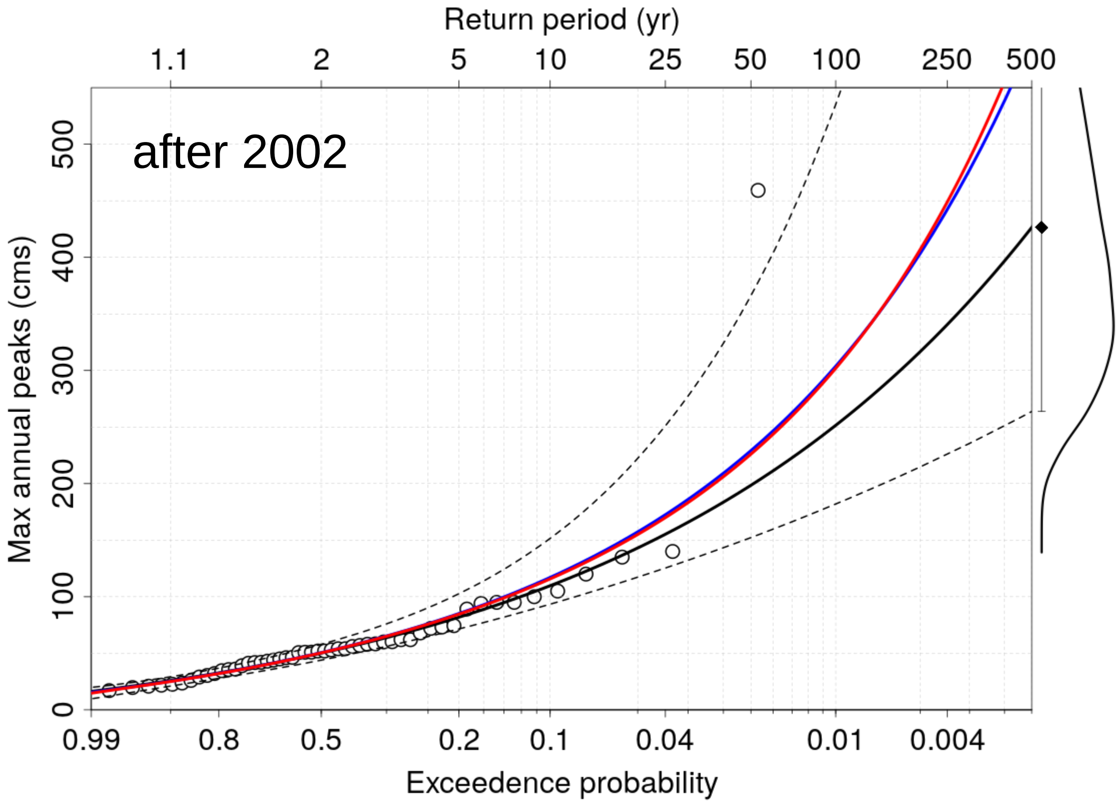
Paradox: New event => **more information -> larger uncertainty?** What is going on here?

New event has shed some light on **unknown-unknowns** (we knew less than we thought)

Flood Frequency Analysis: design values

The increased uncertainty is reflected in increased uncertainty compliant design values





The 2002 event has completely changed our perception on what could happen there…
…but **hydrologists/engineers can do more** than just flood frequency statistics

Flood Frequency Hydrology:

WATER RESOURCES RESEARCH, VOL. 44, W08432, doi:10.1029/2007WR006744, 2008

Flood frequency hydrology:
1. Temporal, spatial, and causal expansion of information

Ralf Merz[1] and Günter Blöschl[1]

Received 7 December 2007; revised 30 April 2008; accepted 20 May 2008; published 23 August 2008.

[1] The hydrological literature on flood frequency analysis in the past has placed undue emphasis on solving the estimation problem. In this paper we argue that much better use should be made of the wealth of hydrological knowledge gained in the past century and that it is essential to expand the information beyond the flood sample at the site of interest. We suggest that the expansion of information can be grouped into three types: temporal, spatial, and causal. We present a number of examples from Austria to illustrate the rich diversity of flood processes that are often site specific and difficult to capture by formal methods. On the basis of these examples, and the expansion of information, we illustrate that hydrological reasoning can provide diagnostic findings that give guidance on how to adjust quantitative estimates from formal methods to more fully capture the subtleties of the flood characteristics at the site of interest. We believe that this approach gives a more complete representation of flood processes at a given site than the existing formal methods alone and propose the term "flood frequency hydrology," as opposed to flood frequency statistics, to reflect the focus on hydrological processes and hydrological reasoning.

Citation: Merz, R., and G. Blöschl (2008), Flood frequency hydrology: 1. Temporal, spatial, and causal expansion of information, *Water Resour. Res.*, *44*, W08432, doi:10.1029/2007WR006744.

Hydrologists/engineers know more than just the time series of maximum annual peaks:

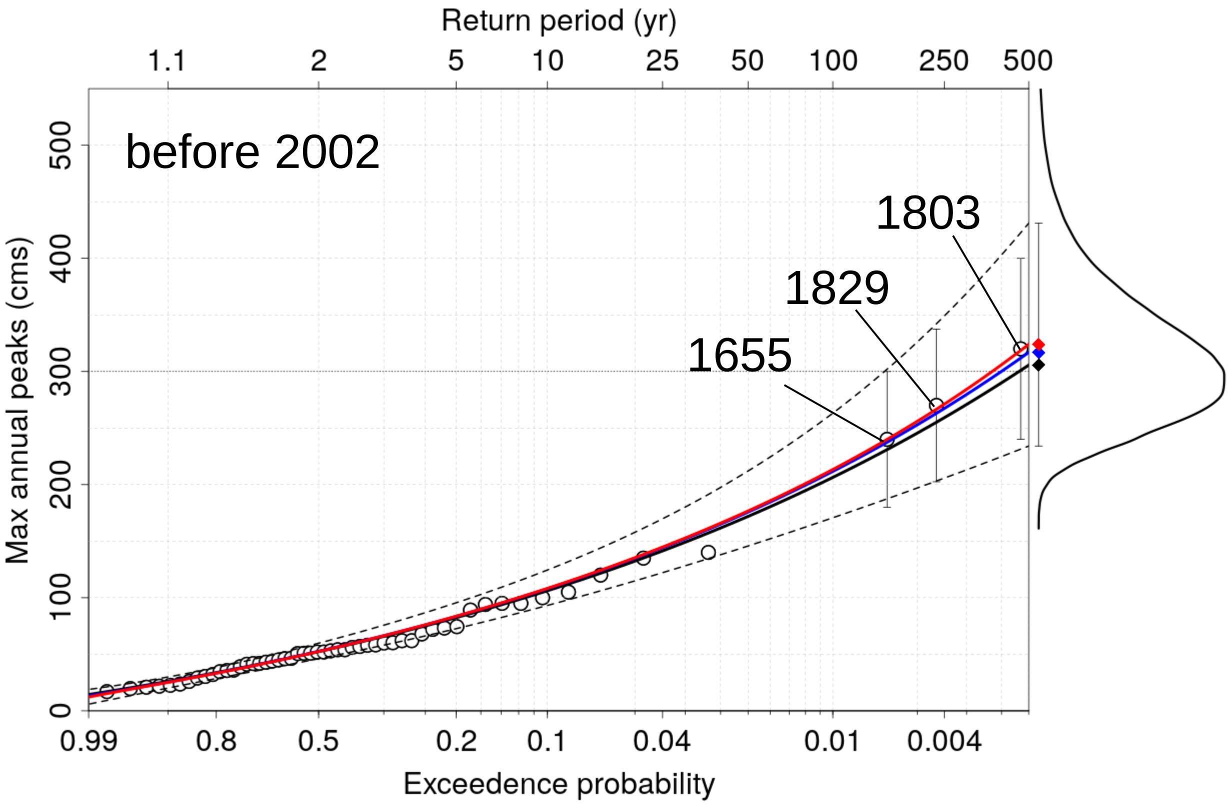
- **Temporal expansion**
based on historic floods reconstructed from archival evidence, surveys, watermarks

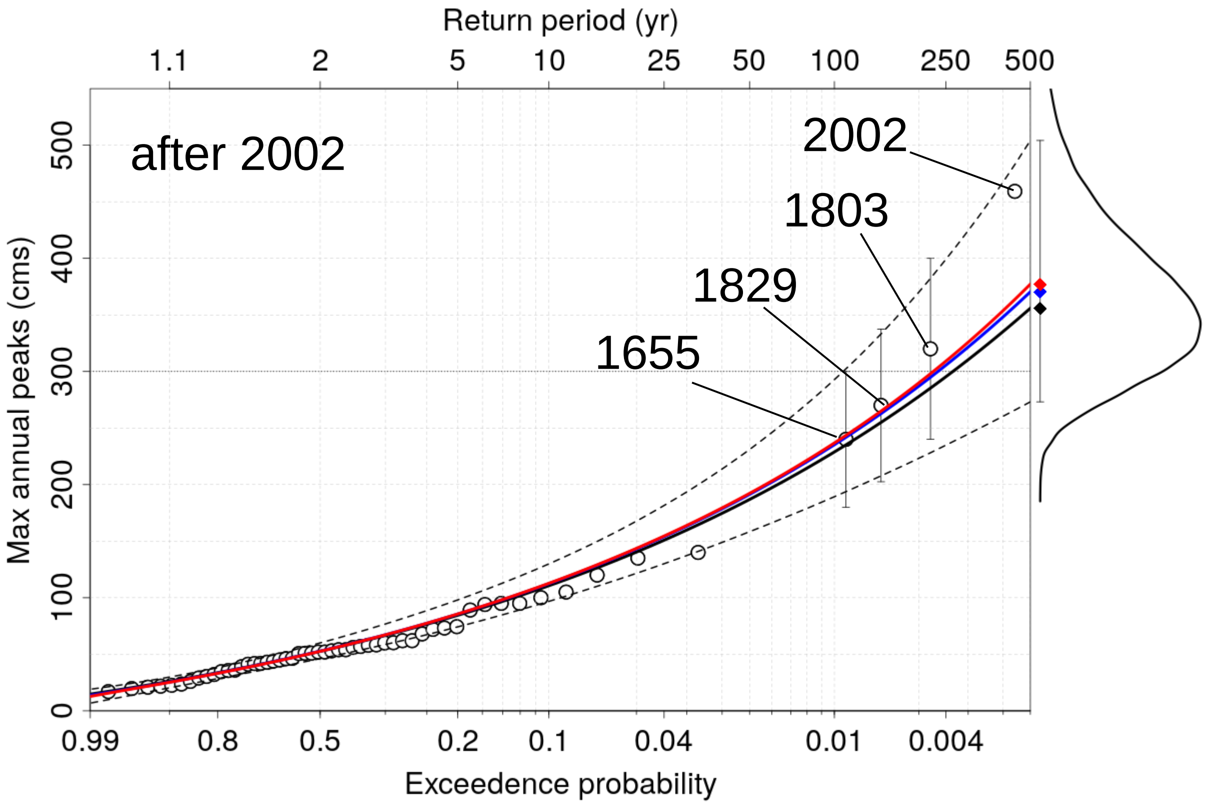
- **Spatial expansion**
from observations in neighboring and similar catchments (regionalization)

- **Causal expansion**
from process understanding and rainfall-runoff modelling

Flood Frequency Hydrology: Temporal expansion

Information on inundated areas allows to reconstruct three major historic floods of the Kamp





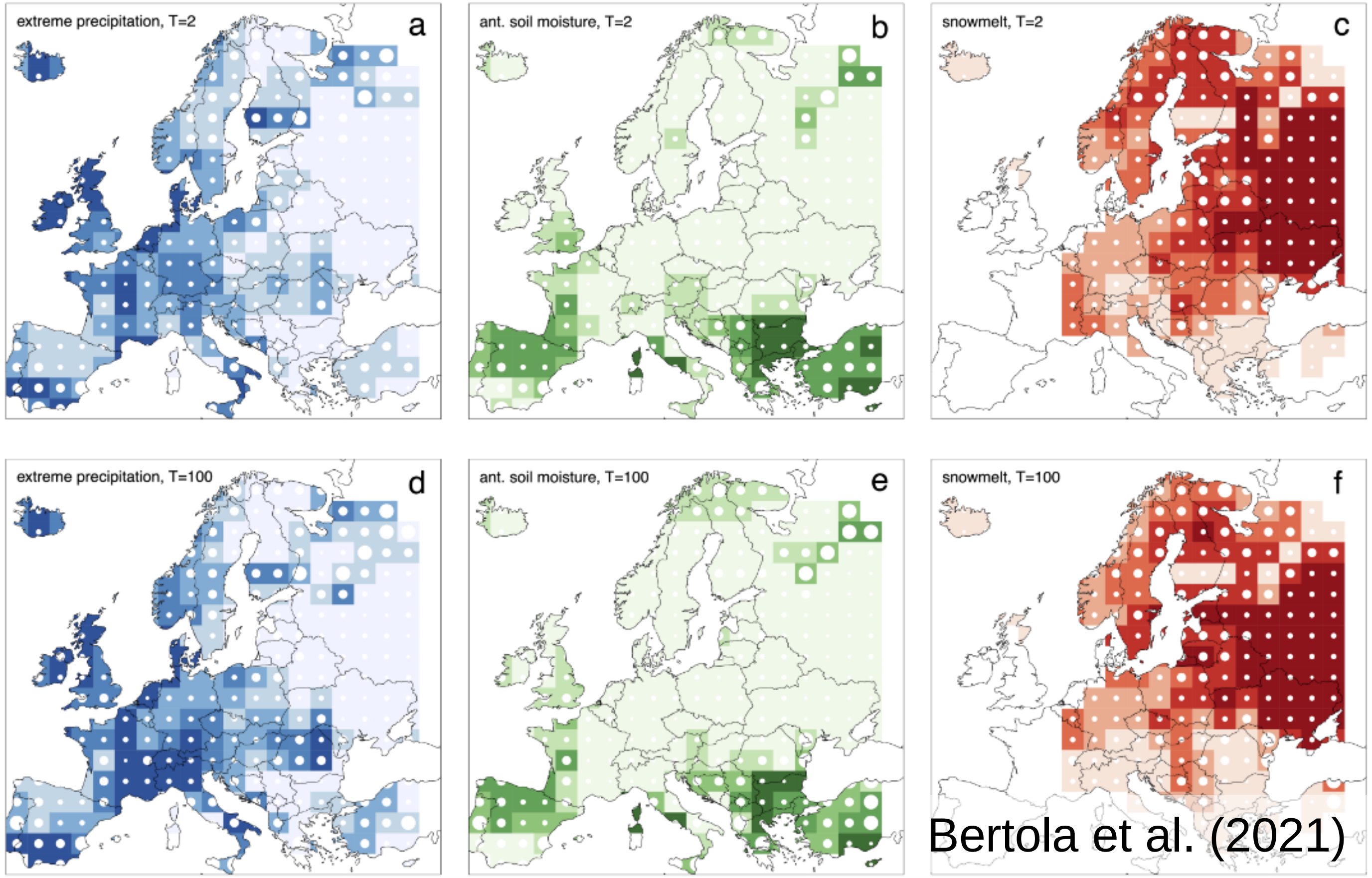
More information => smaller uncertainty => smaller mismatch between design values at large return periods => smaller difference between estimates with and without the 2002 event

Flood Frequency Hydrology in a changing world

Recognising that the future may be more complex than we thought is **information**, that however **may enlarge the “known” uncertainty**, like observing the 2002 Kamp event

Studies on detection and attribution of flood changes are needed for **informing flood design**, in the spirit of flood frequency hydrology

Blöschl et al. (2020)



Bertola et al. (2021)

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