Flood Frequency Analysis revisited under spatially and temporally Compound Flood Extremes: evidence from southern Valencia Metropolitan Area, Spain

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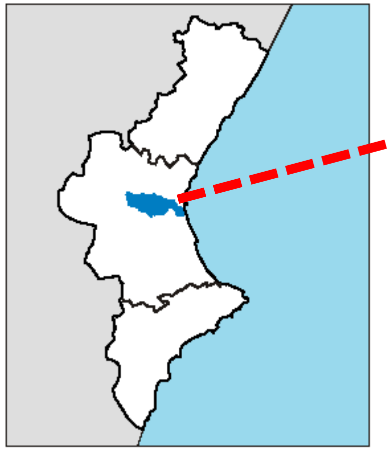
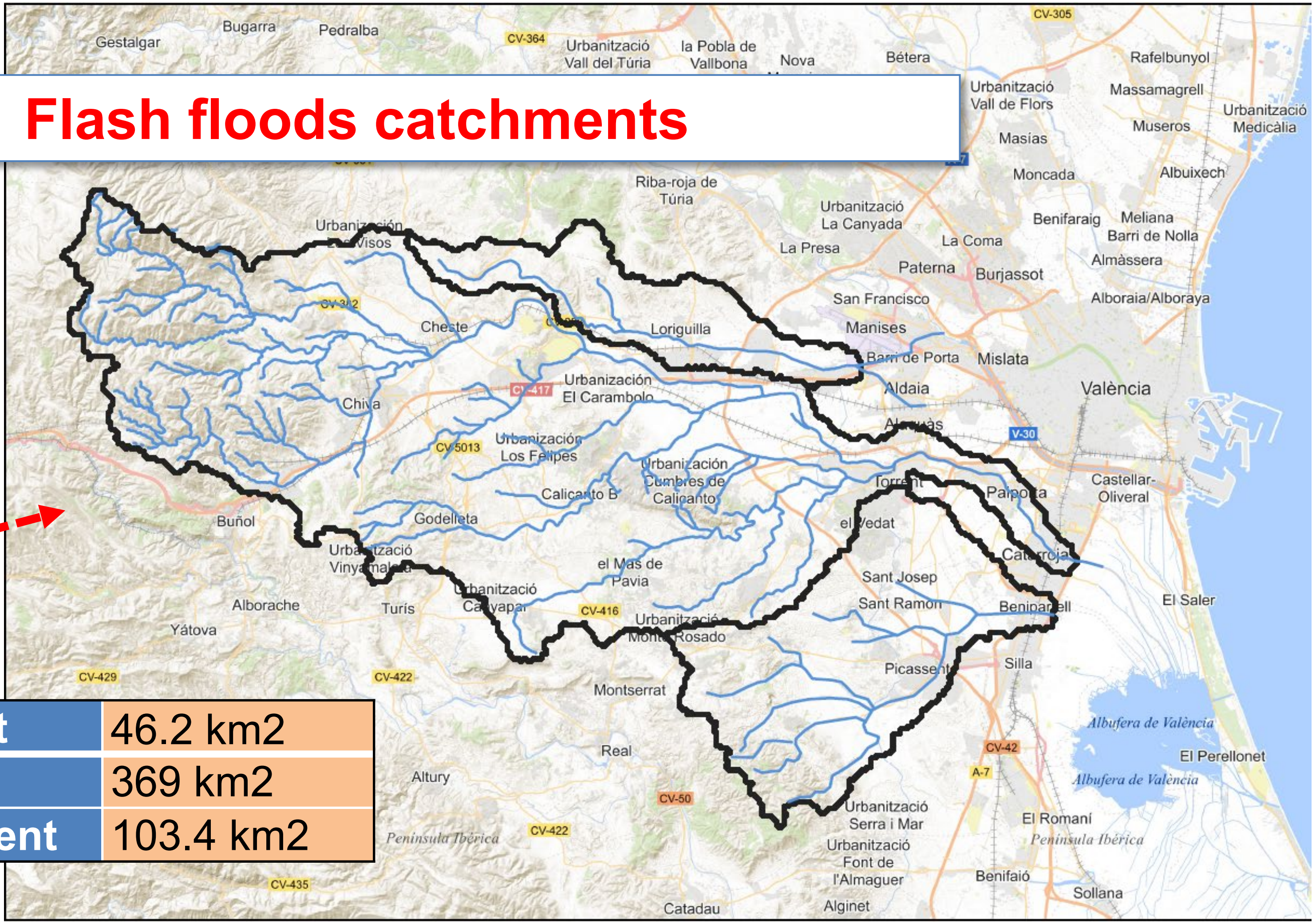
Drainage area of southern Valencia



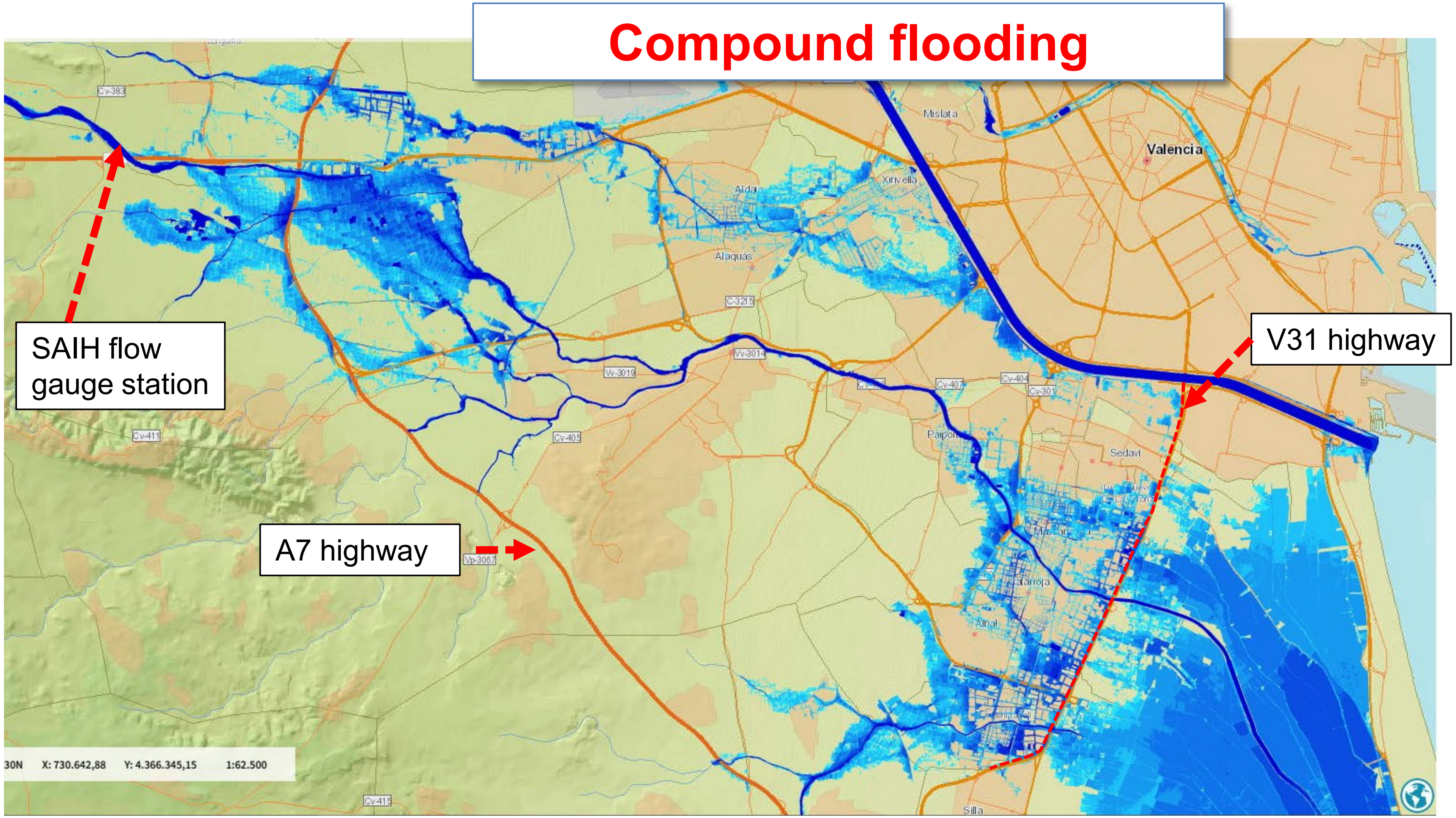
Flash floods catchments



Pozalet	46.2 km2
Poyo	369 km2
Picassent	103.4 km2

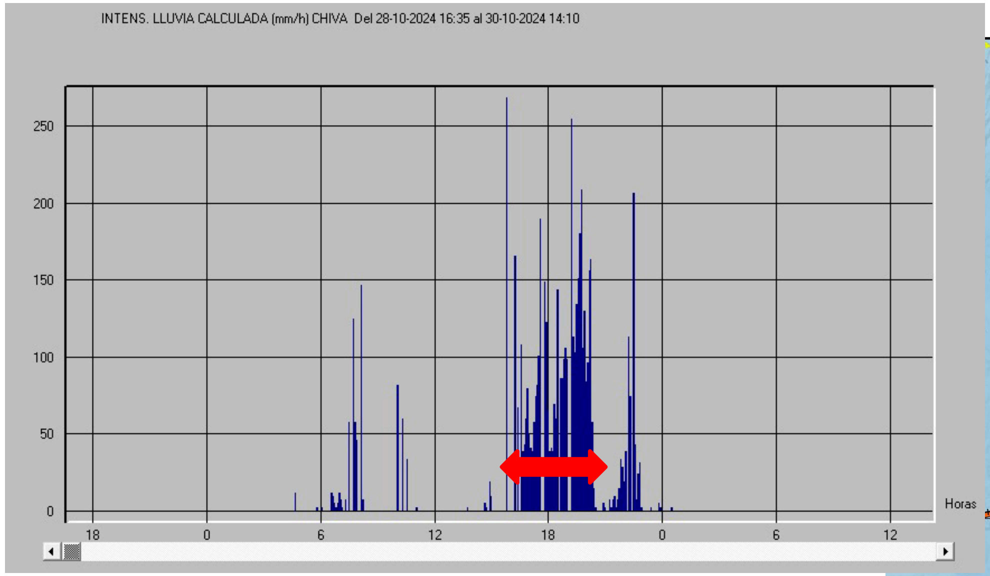
T500 flood hazard map in the inundation area

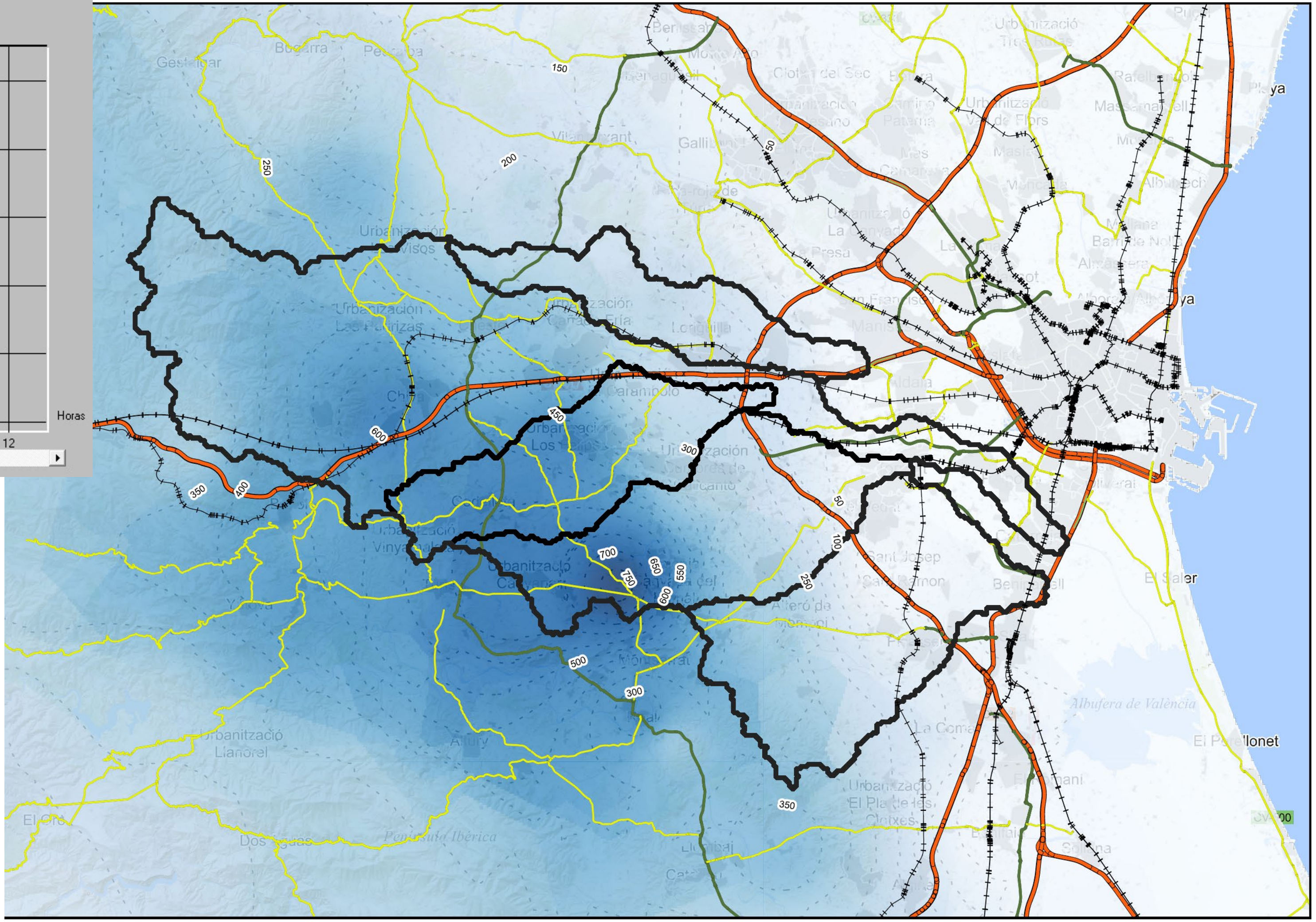
Application of European Directive 2007/60/EC on Flood Risk Assessment and Management



Source: SNCZI 2nd cycle

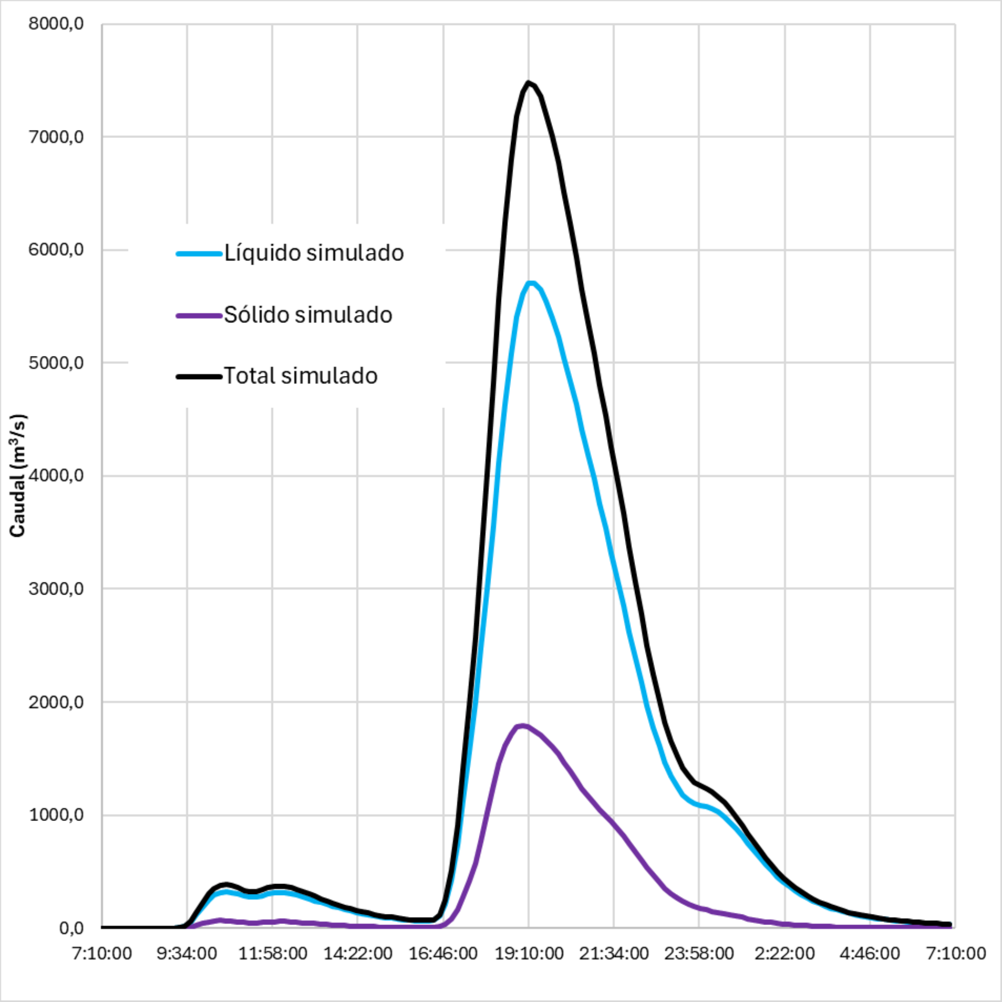
The storm on October 29, 2024

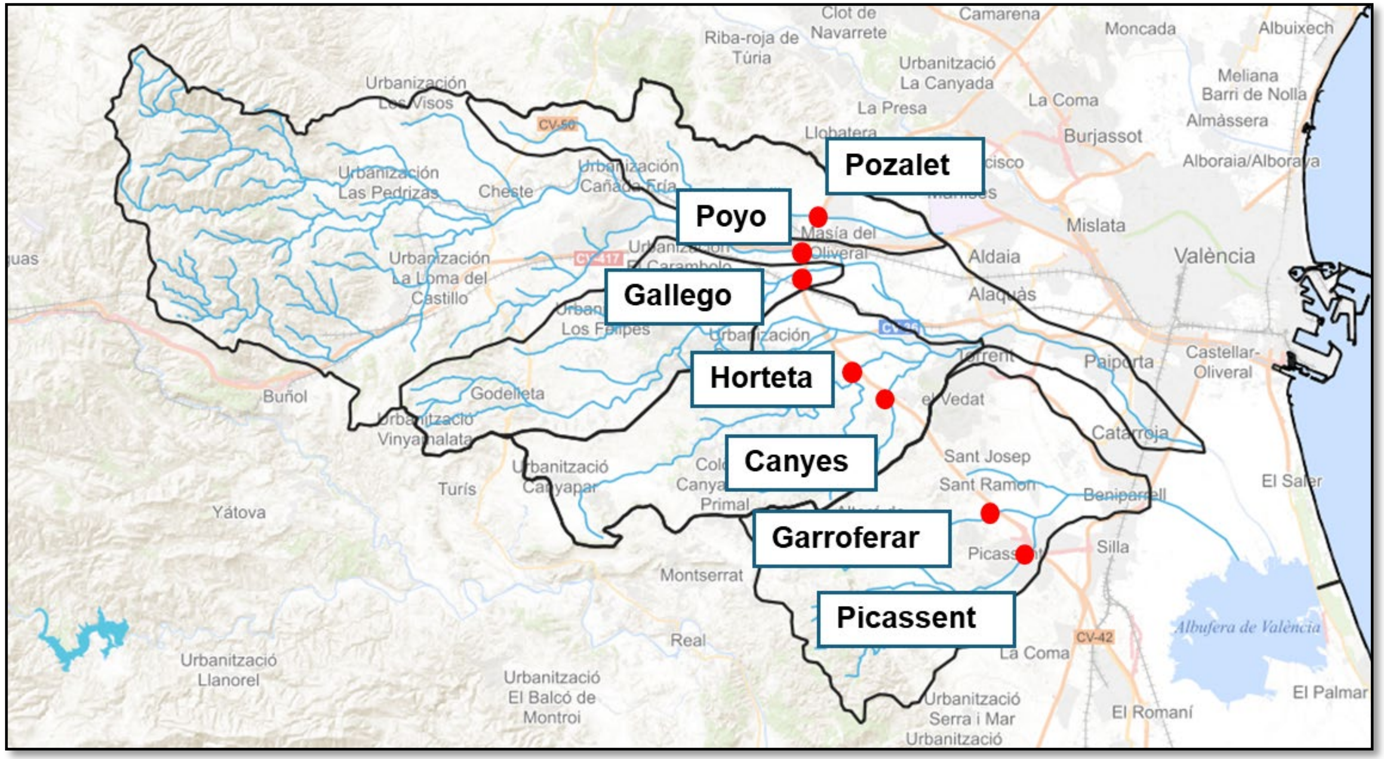




Main storm duration = 5 hours
Daily precipitation in Turis = **772 mm**
Max hourly intensity: **185 mm/h**

The flood on October 29, 2024



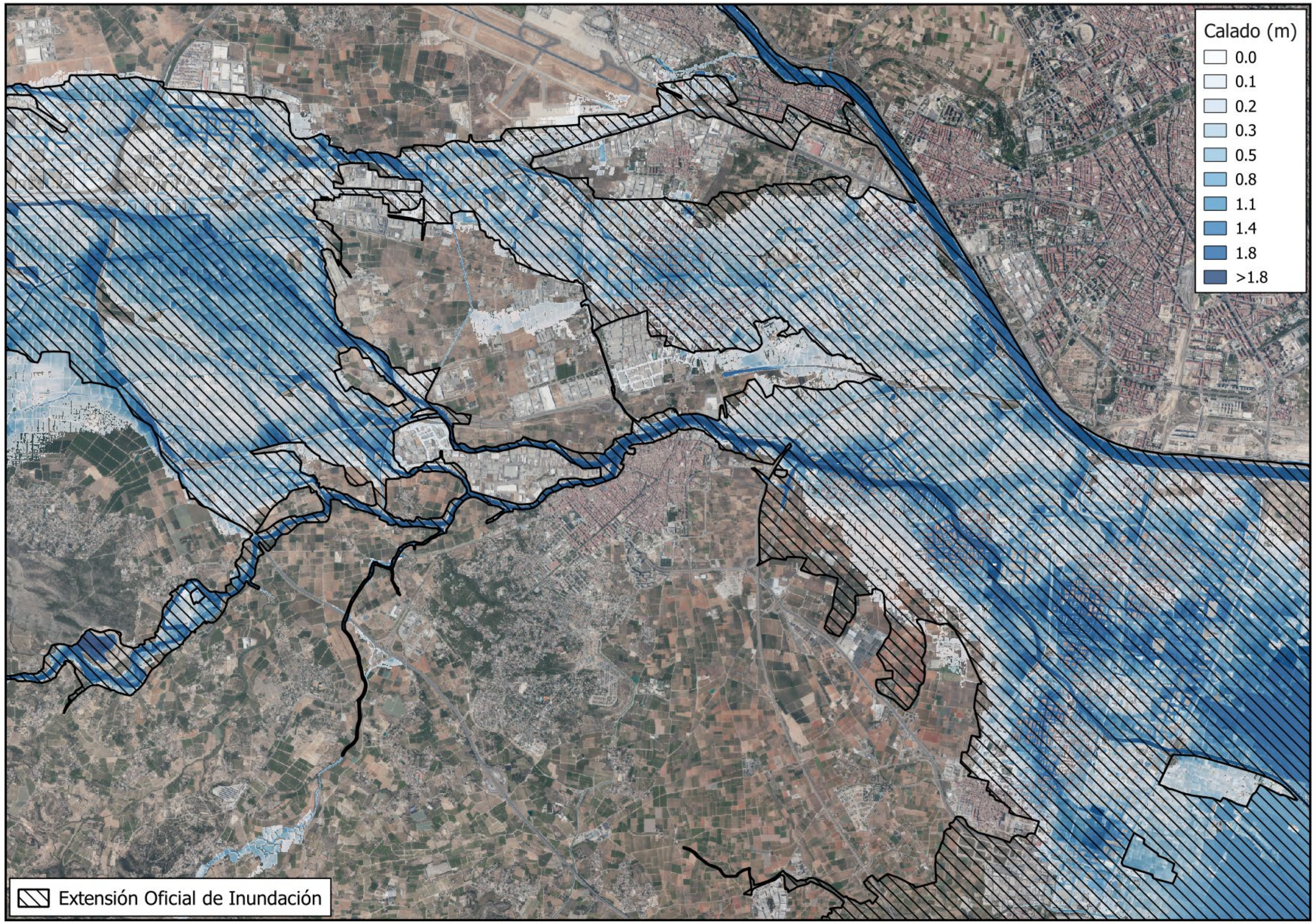


Source: Francés et al., IIAMA, 2025

Qp = 7.500 m³/s (24% sediments)

Volume= 125 Hm³ (**21% sediments**)

The inundation on October 29, 2024



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The catastrophe on October 29, 2024

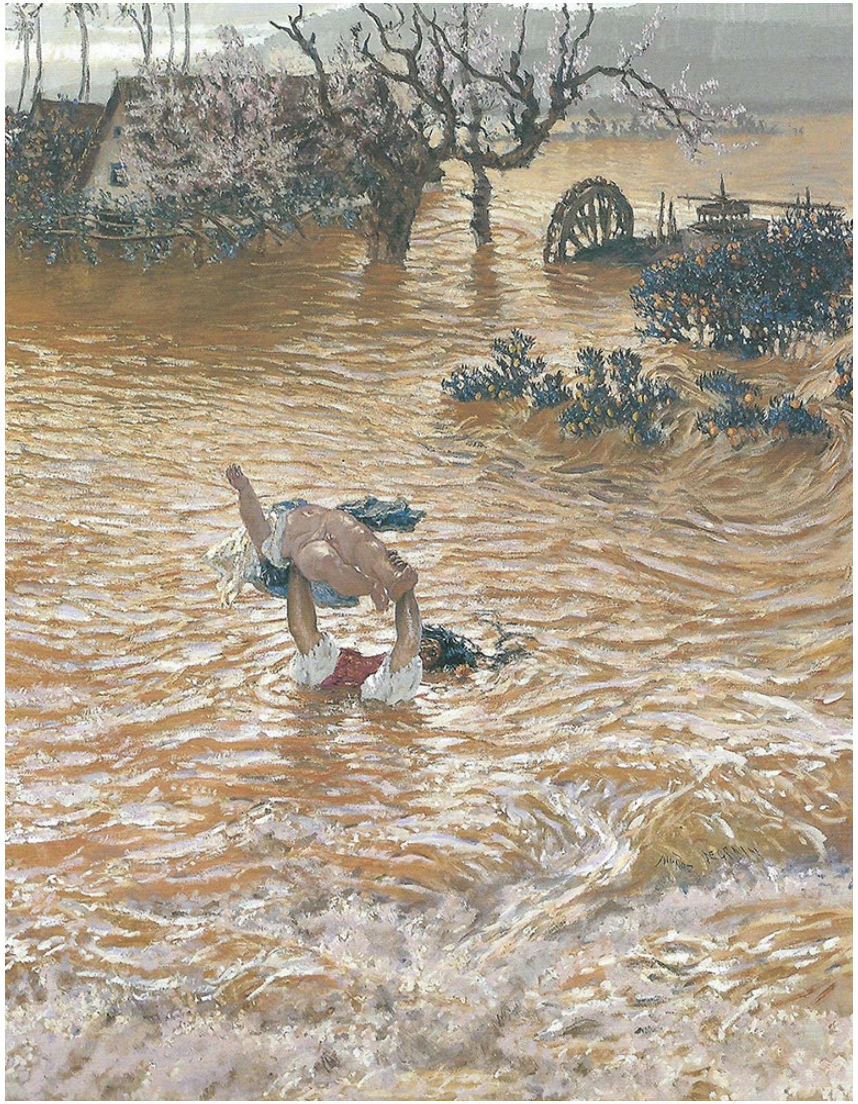
- **306,000 people** affected
- **11,242** houses damaged, mainly in ground floors
- Aprox. **10,000 elevators** out of service
- **2,823 industries** with damages
- **20 large bridges** and kilometers of roads and railway damaged or destroyed
- **141,000 cars** washed away or severely damaged
- During weeks thousands of people **cleaning the mud on streets and houses**
- Half of sewer system **collapsed**
- **230 victims** (mostly trap in ground floors and cars)
- **17,800 M€** only in direct damages

Objective

- How “rare” was the 2024 event?

- Estimate flood peak quantiles in several points within catchments and inundation area from 10 to 2000 years return period for updating:

  - Flood hazard maps
  - Flood Risk Management Plan
  - Urban and Land Use Planning and Management

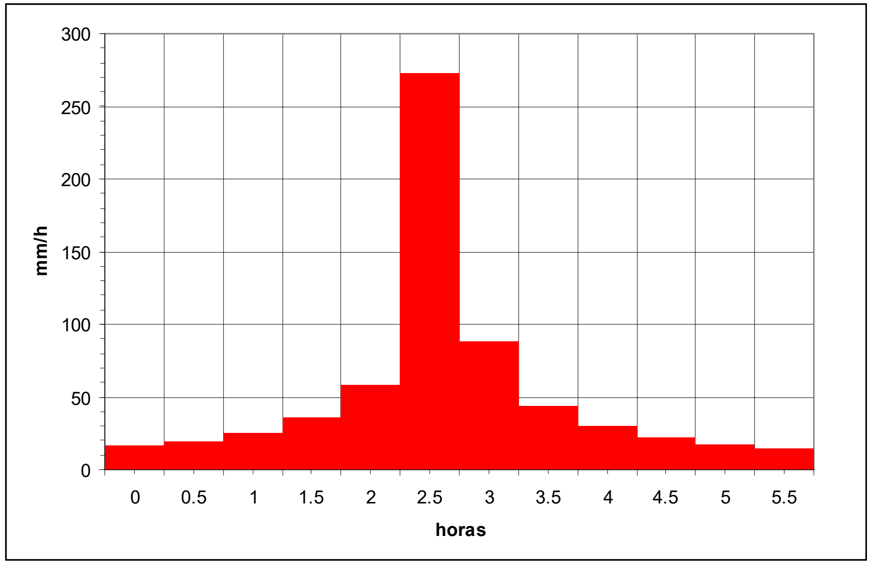


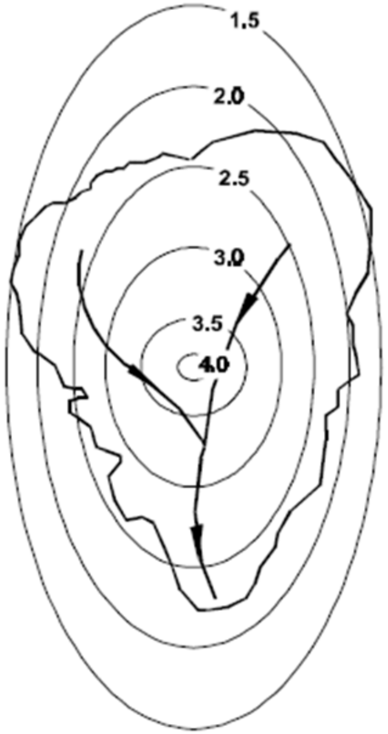
Detail of “Mother’s Love”, by Muñoz Degrain (1912), representing a large flooding of the orchards surrounding Valencia

Design storm methodology

Main hypothesis: Q_T is generated by Pd_T

- Pros:
  - One single simulation
- Cons:
  - Simple spatial and temporal distribution of design storm
  - What initial soil moisture?





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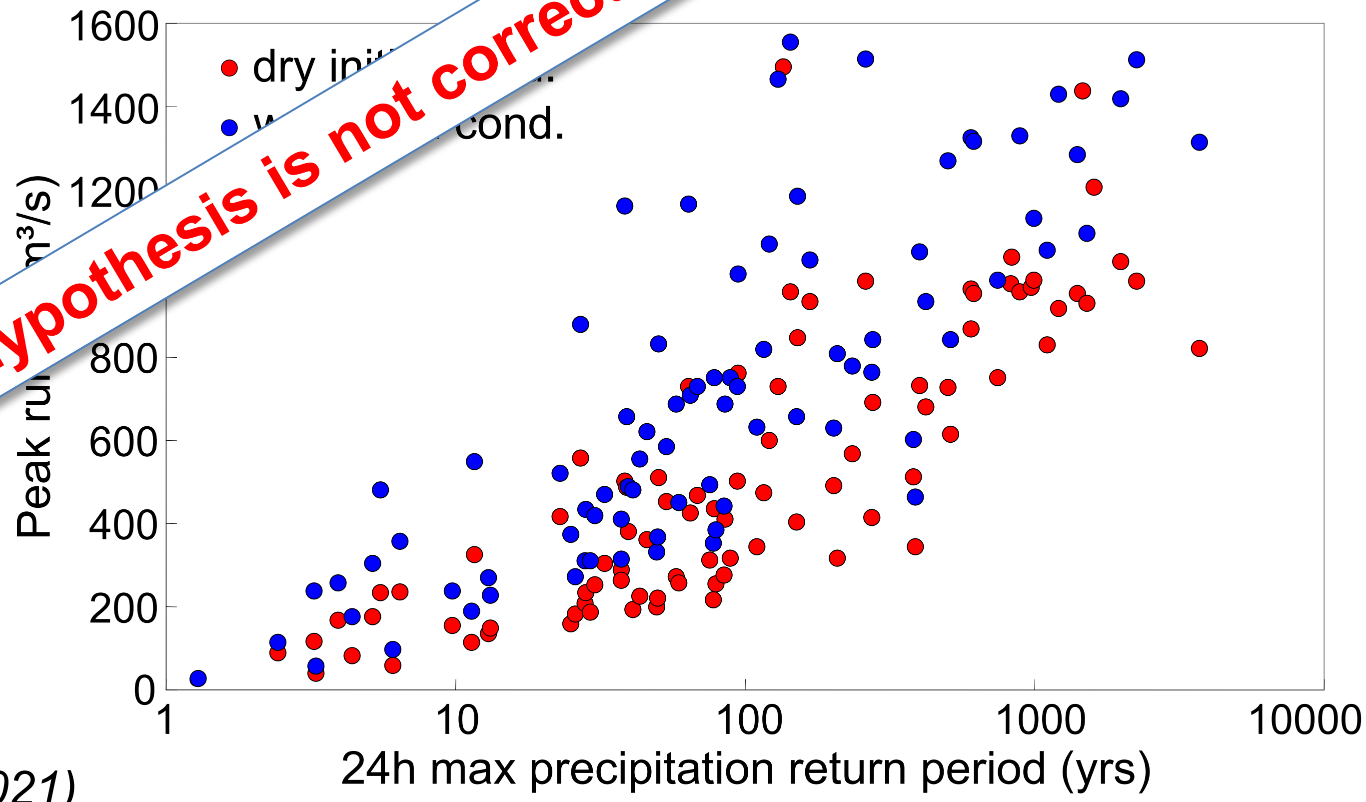
Experiment at Poyo flow gauge station

- 200 event simulations using 100 synthetic storms and two initial soil moisture conditions

- Peak runoff (and hydrograph) depends highly on:
  - Precipitation spatial and temporal variability
  - Initial soil moisture

Design storm hypothesis is not correct!



Salazar et al. (2021)

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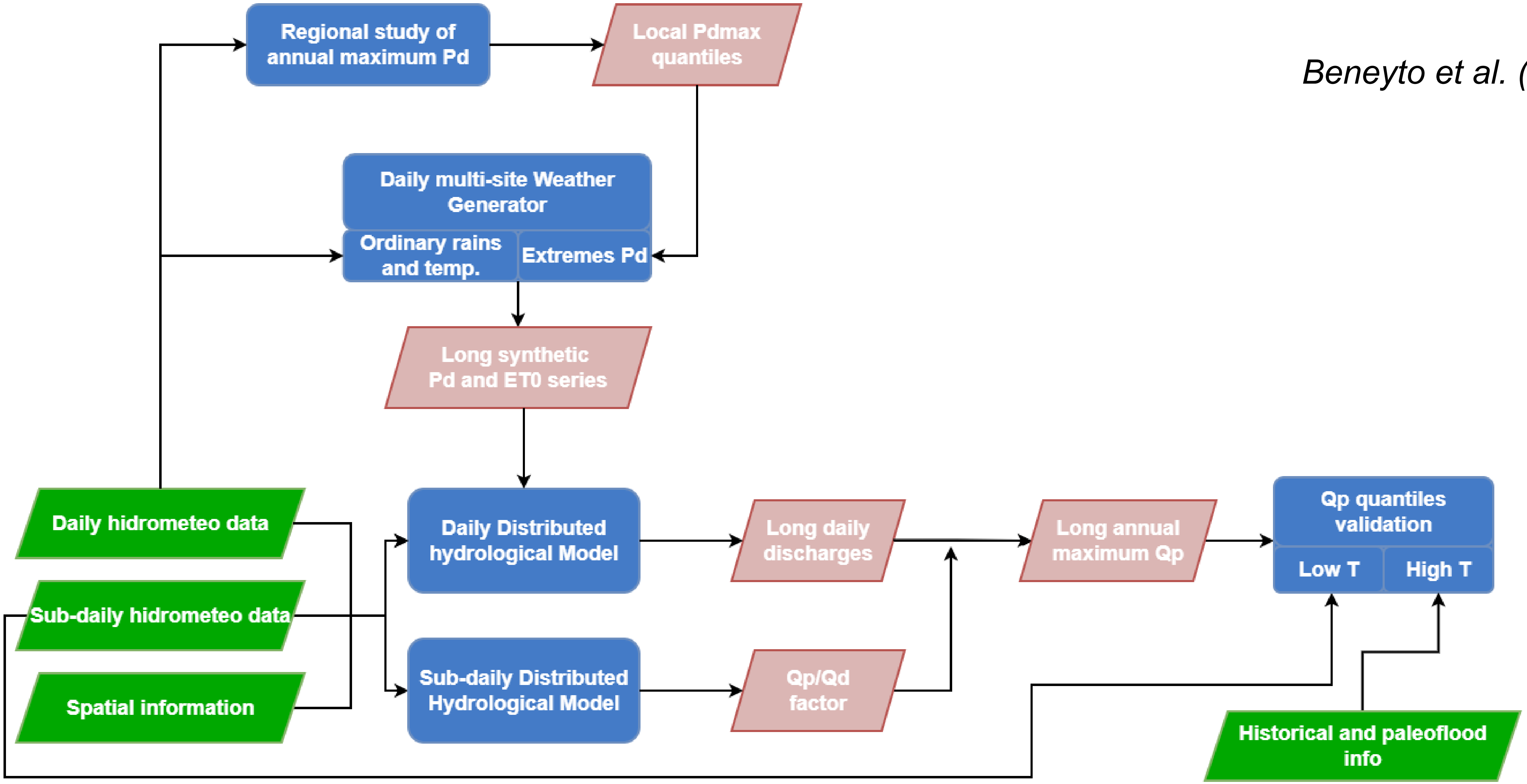
Methodology

Beneyto et al. (2022)



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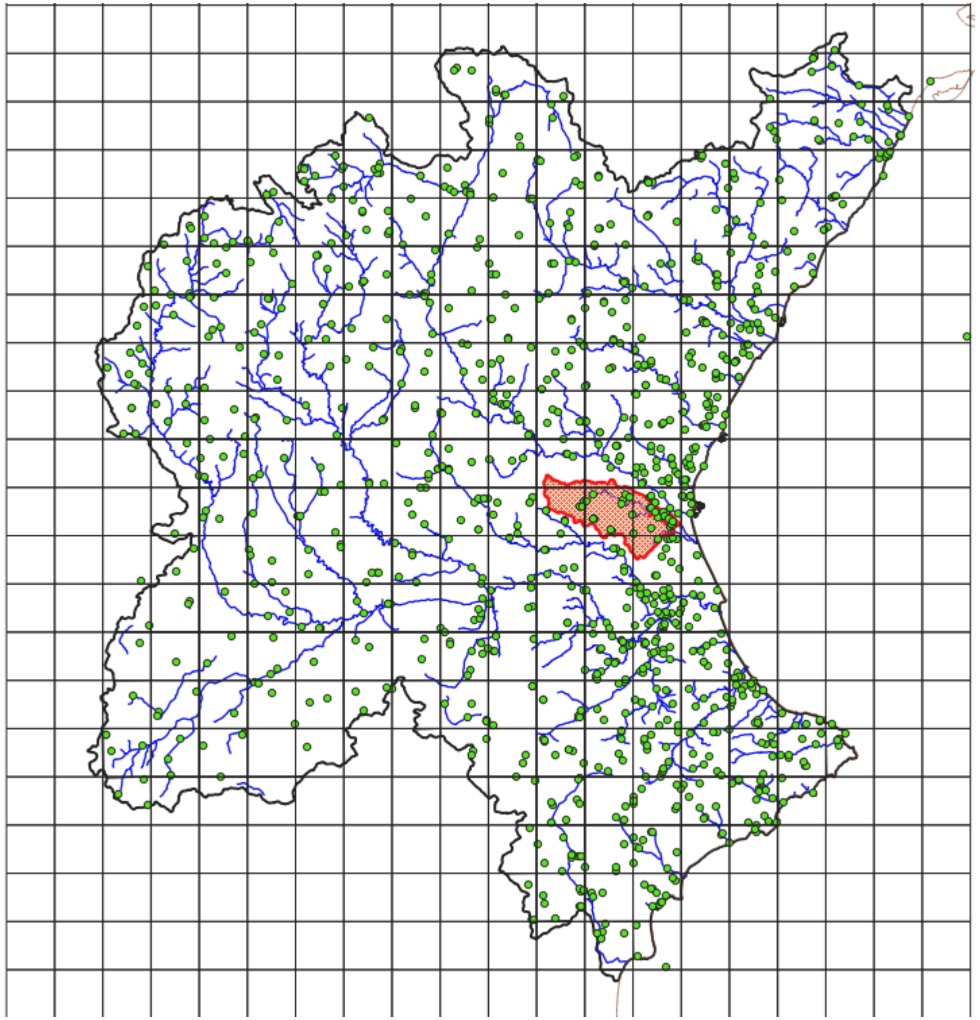
Precipitation data

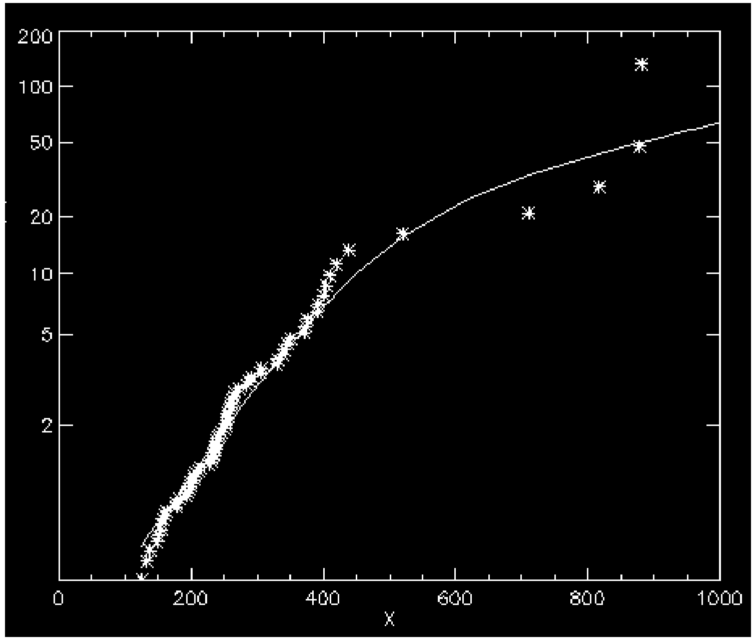
- Spatial scope: Jucar River Water Authority (CHJ) with 43,000 km^2
- 1090 pluviometers AEMET and CHJ
- 1951- 2024
- Cross-checking with news and reports if Pd ≥ 300 mm and vice versa
- 15x15 km cell division => 210 cells
  - Cell Pdmax = highest Pd among the stations within each cell
- 182 cells with at least 20 years
  - **Total data: 11,720**

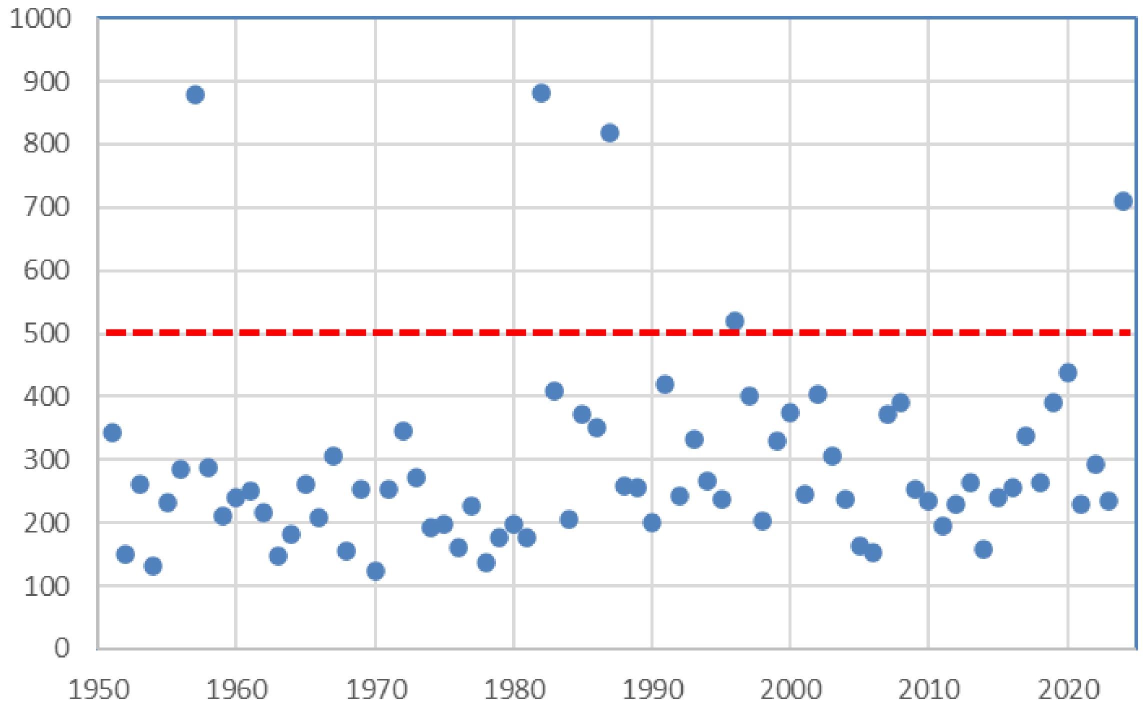


Frequency of extreme storms within the CHJ

- Every year from 1951 to 2024 (74 years), Pdmax > 100 mm
- Model TCEV-ML:
  - T5 years, Pdmax = 360 mm
  - T25 years, Pdmax = 620 mm

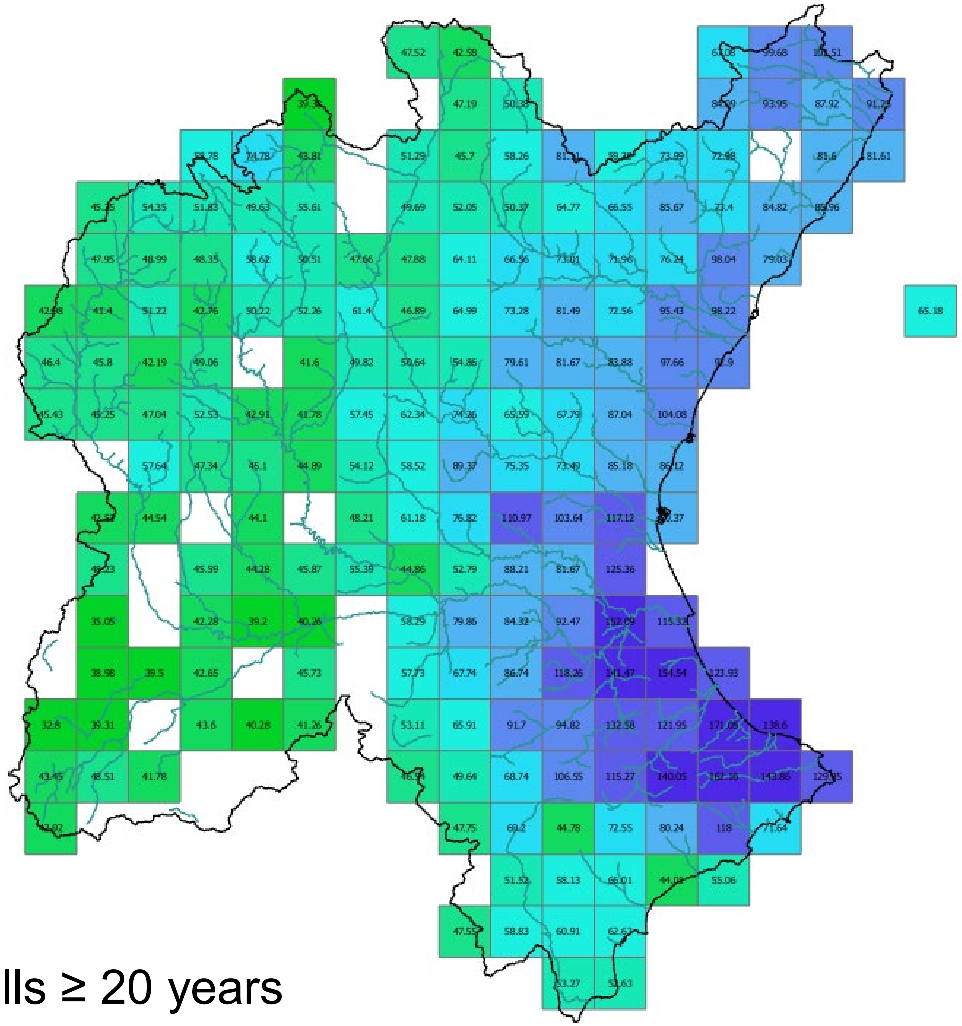
Important: somewhere in the CHJ





Regional Pdmax statistical model

- Hypothesis: CV uniform in space => regionalization dividing by the mean



Pdmax mean for cells ≥ 20 years

Regional Pdmax statistical model

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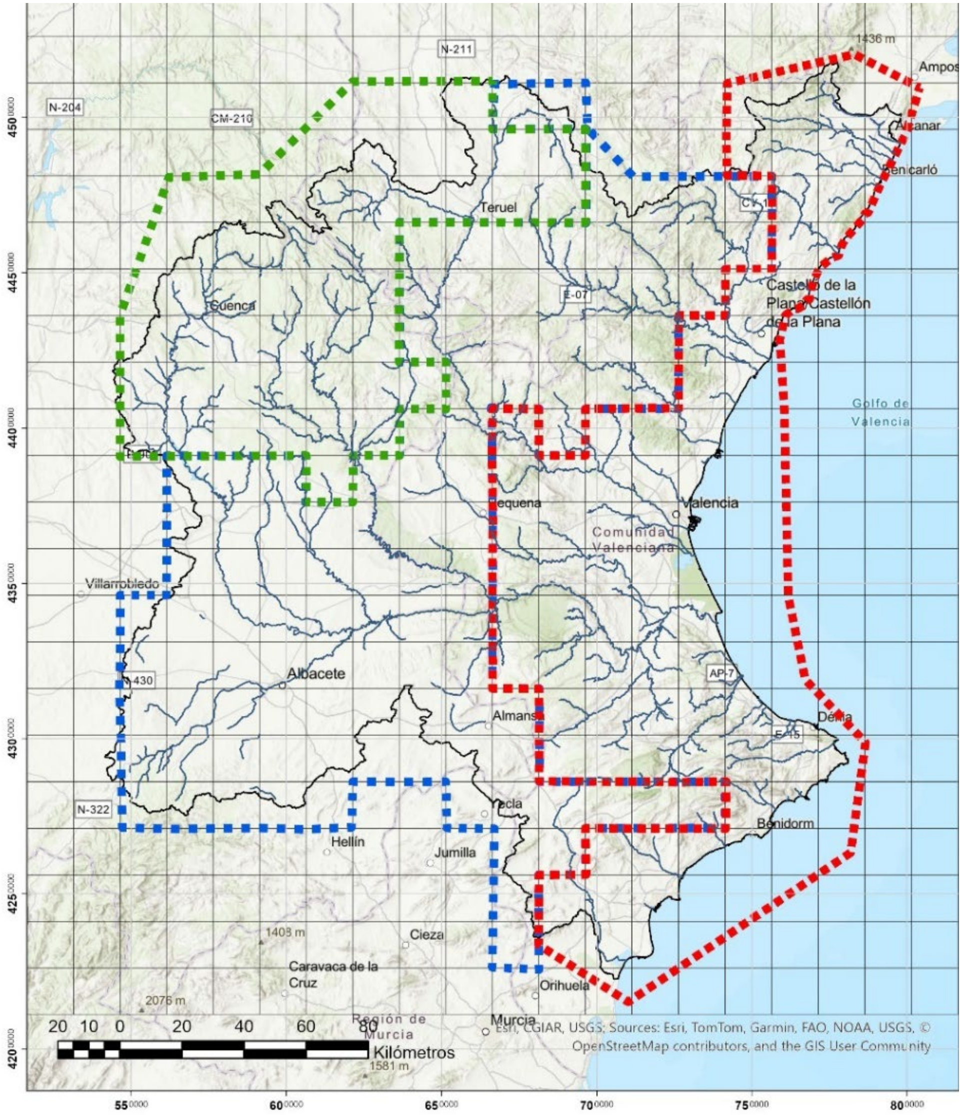
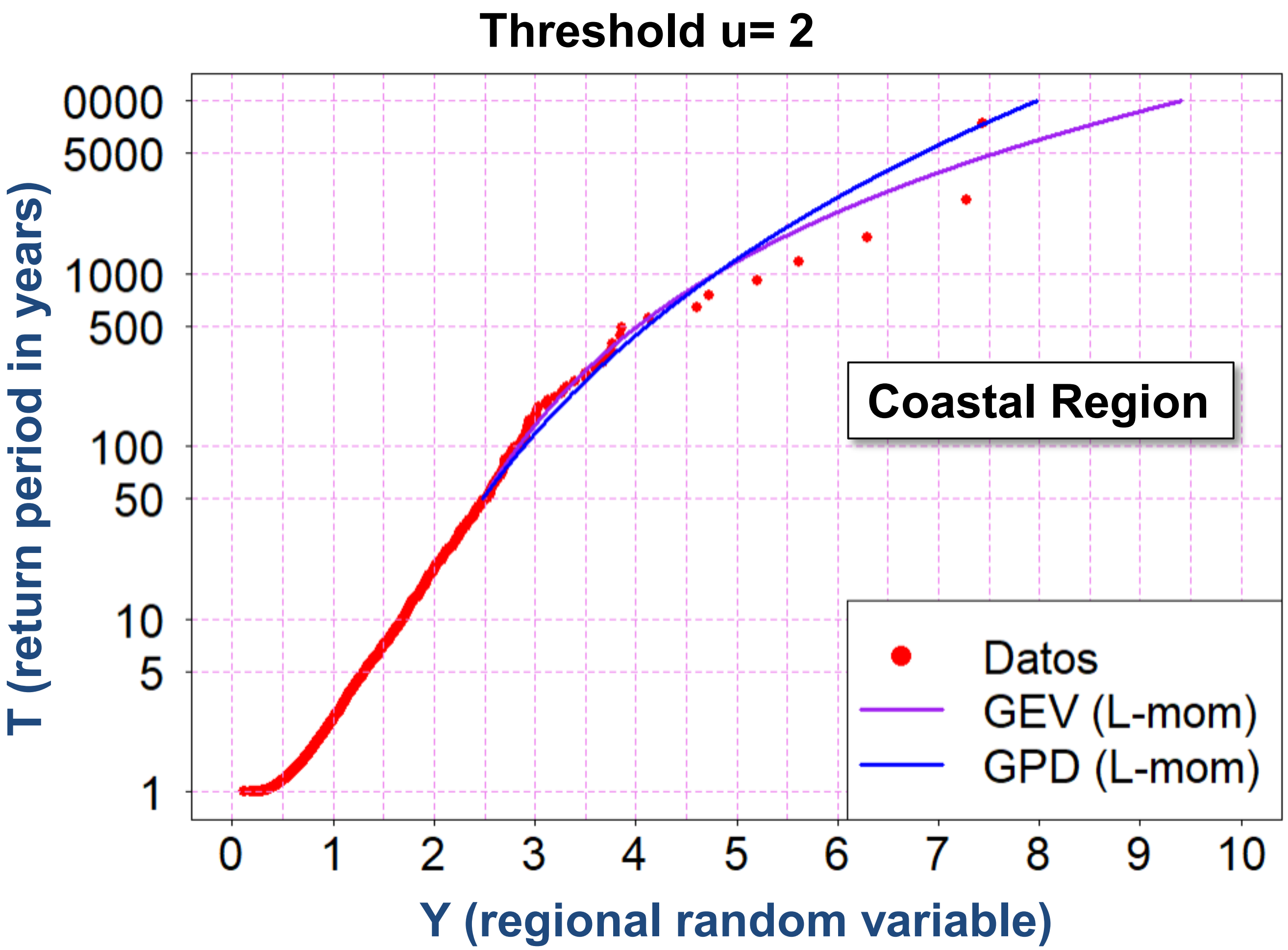
- Hypothesis: CV uniform in space => regionalization dividing by the mean
- Obtaining regions: Hoskings and Wallis (1997) based on L-moments

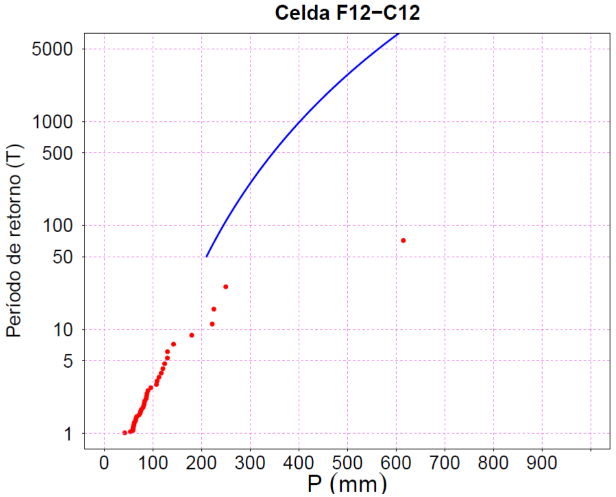


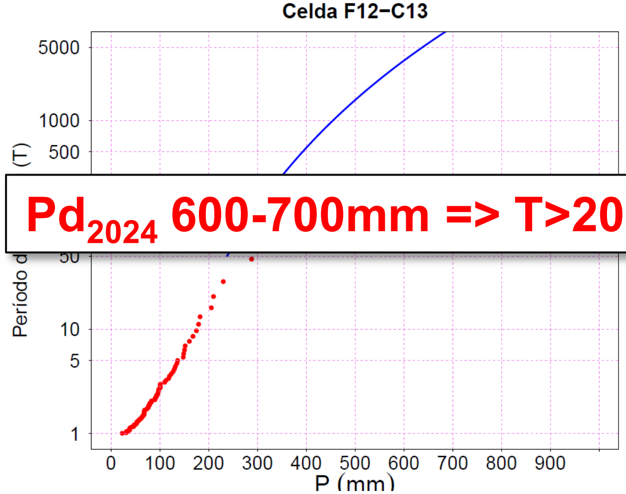
Selected regional model

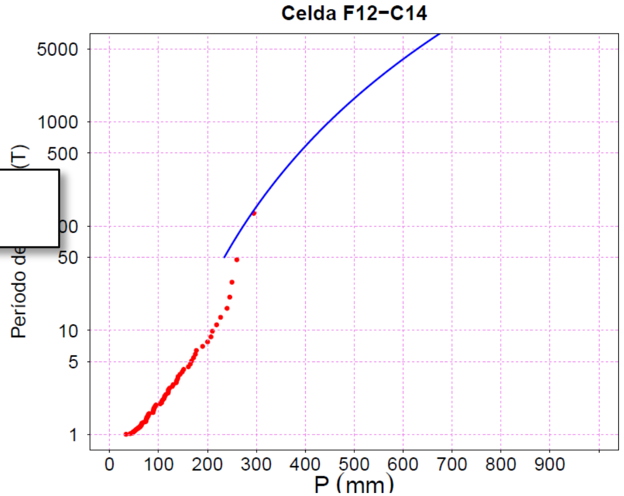
- **# of years: 4.144 (223 y > 2)**
- Selection from 8 models:
  - Akaike's criterion
    - **GPD (L-mom): 185.68**
    - GEV (L-mom): 220.41
  - Anderson Darling test
    - GPD (L-mom): p-value= 0.43 ; AD=0.92
    - **GEV (L-mom): p-value= 0.65 ; AD=0.58**



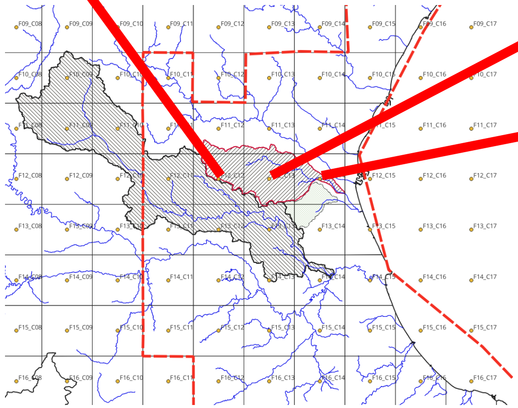
Local (cell) Pd quantiles







Pd_{2024} 600-700mm => T>2000 years



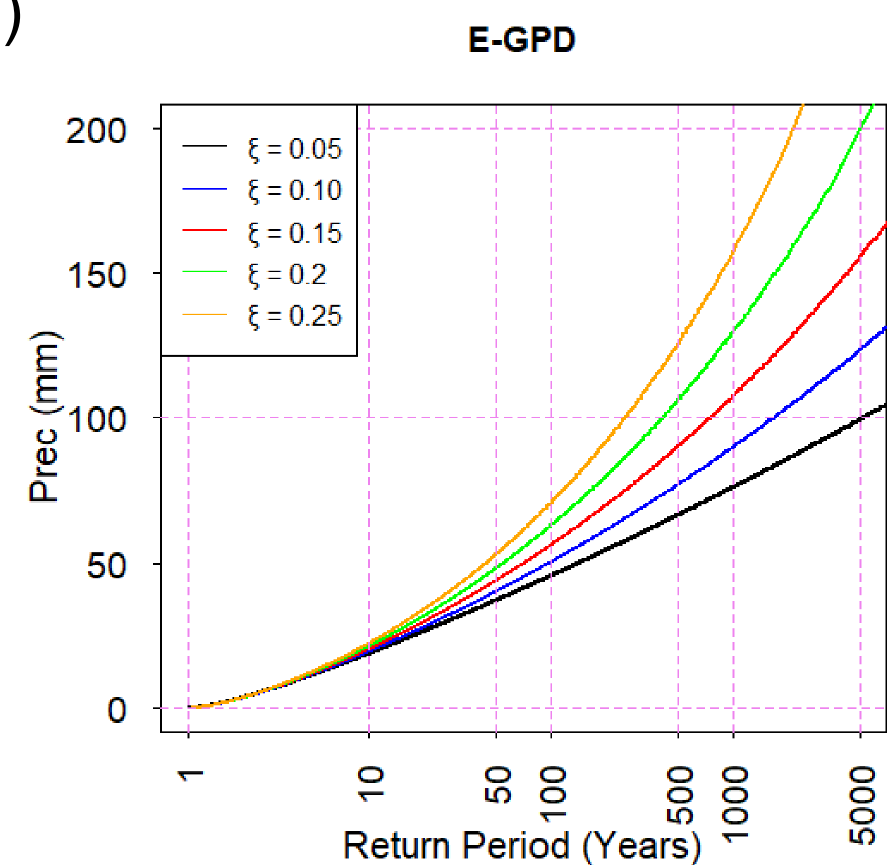
	GPD Pd (mm)		
T (years)	F12-C12	F12-C13	F12-C14
10	139.47	157.74	155.51
25	181.74	205.54	202.64
100	245.18	277.29	273.37
500	348.69	394.35	388.79
2000	471.68	533.45	525.92

Weather Generator: GWEX

- Developed by Evin et al. (2018)

- Extended Generalized Pareto Distribution (E-GDP) => heavy-tailed

$$F(x;\lambda) = \left[1 - \left(1 + \frac{\xi x}{\sigma}\right)_+^{-1/\xi}\right]^k, x > 0$$



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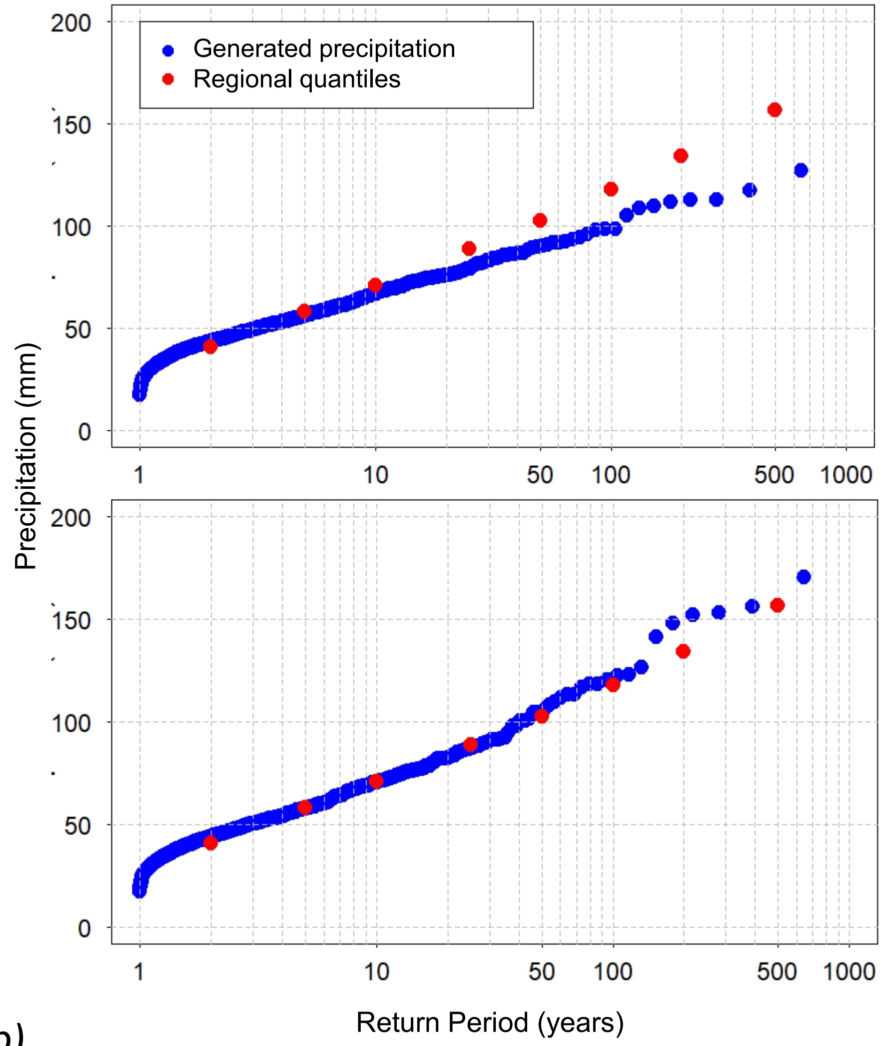
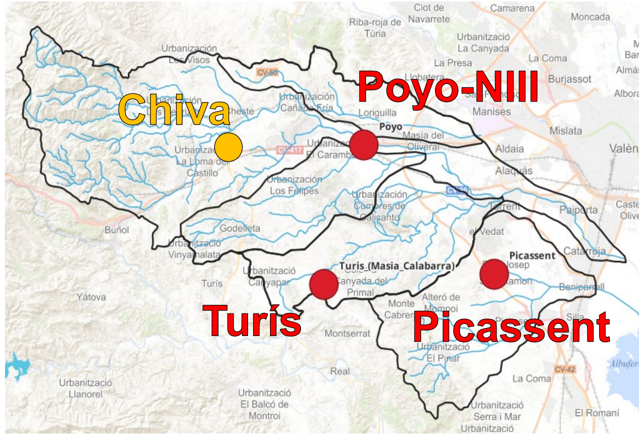
- Parameter estimation:
  - ξ: from a regional study of Pdmax
  - Rest of GWEX parameters: from local observations

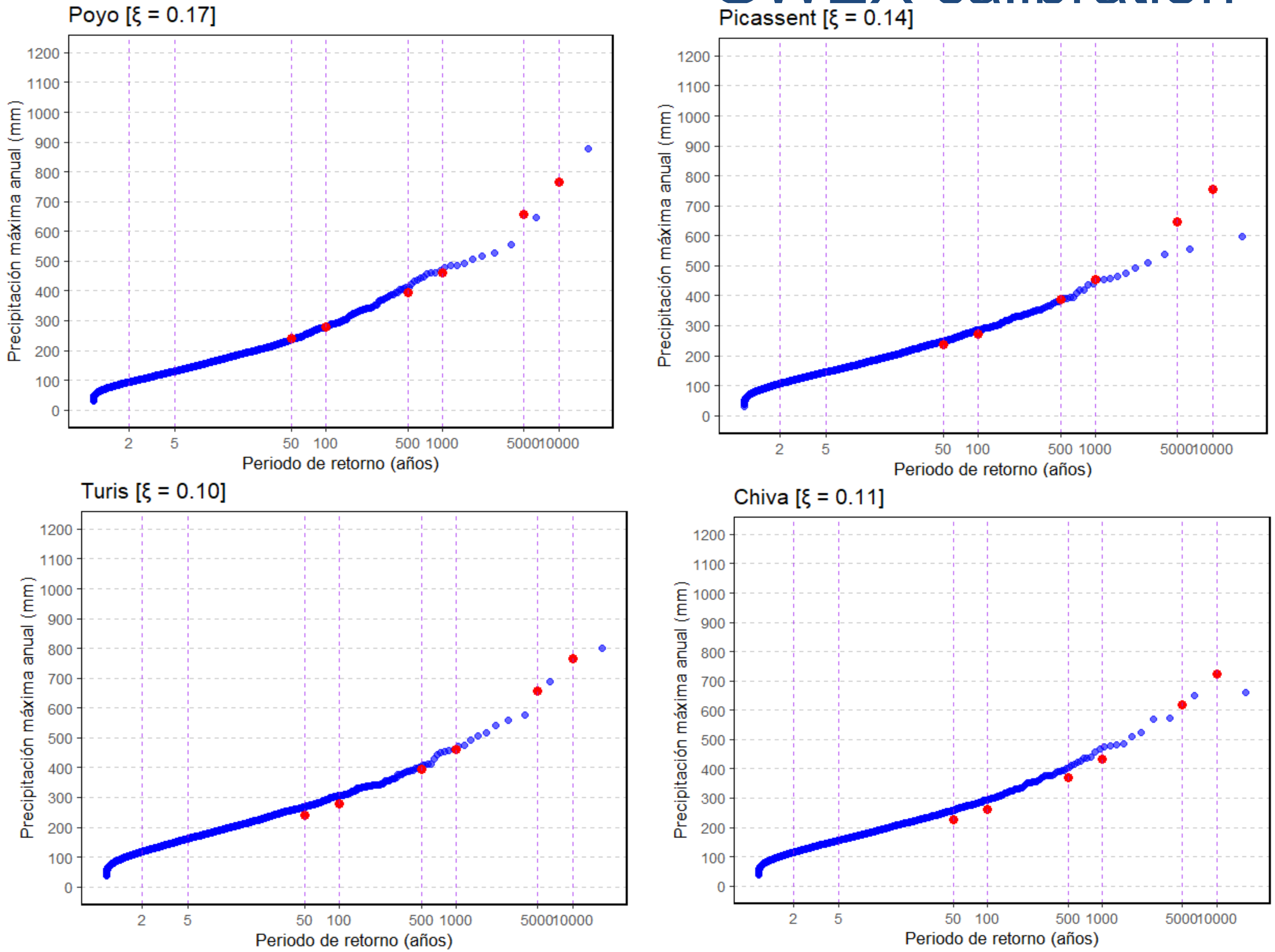


Beneyto et al. (2020, 2023a and 2023b)

GWEX calibration

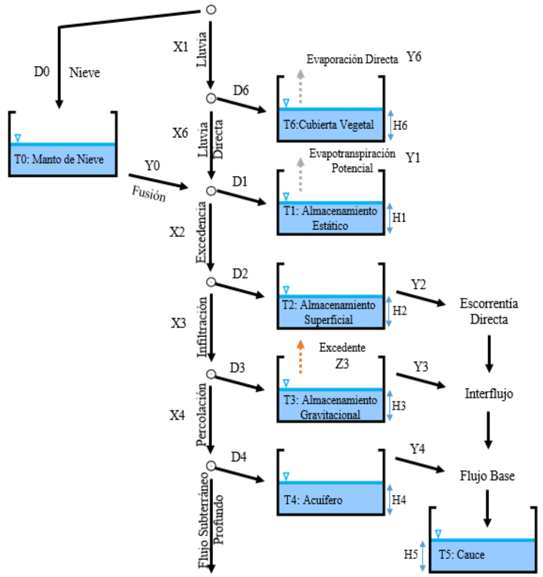
- Adjustment of the ξ parameter for each rain gauge



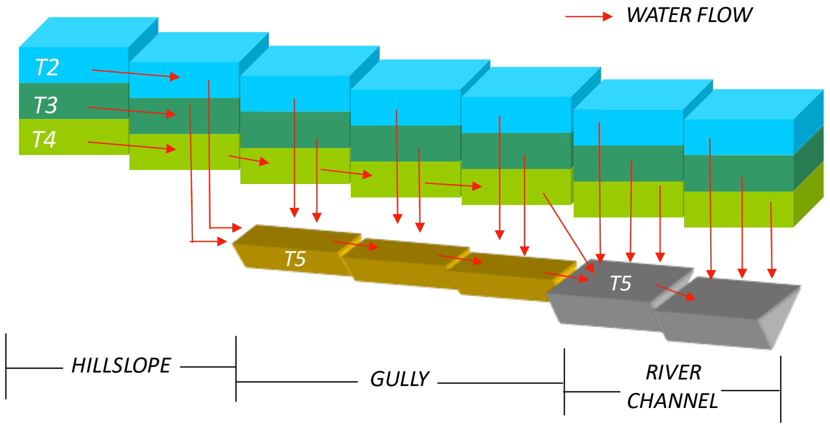


The eco-hydrological model TETIS

- Conceptual model with **physically based parameters**, developed as a *living-lab* by UPV-IIAMA since 1994 (v9 on the web)
  - Included sediments and transmission losses



- **Distributed in space**, so it can:
  - => Reproduce the spatial variability
  - => Reduce spatial scale effect
  - => Exploit all available environmental information
  - => Obtain results at any point of the basin

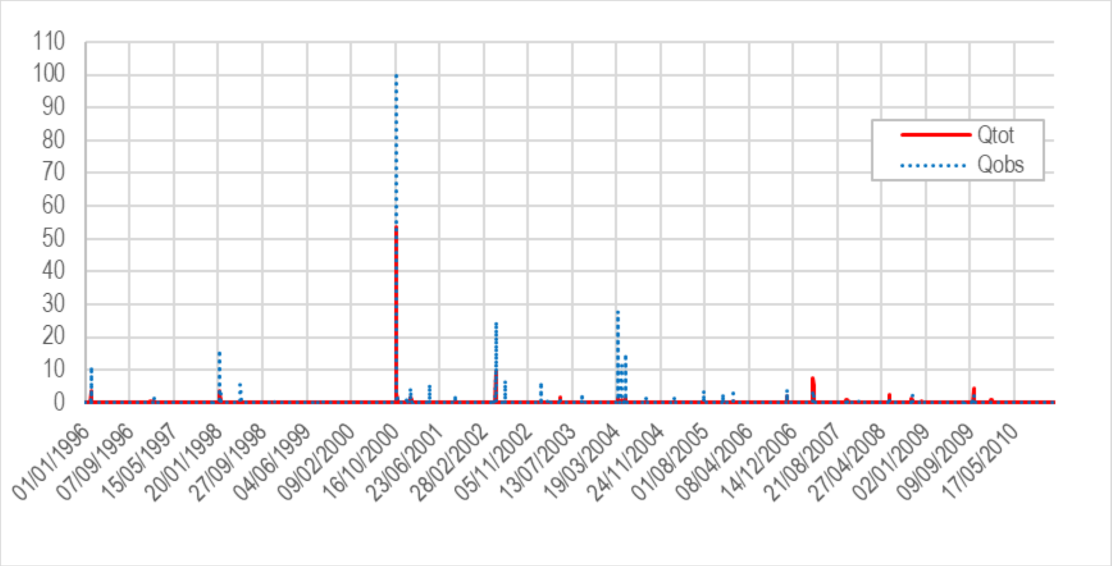


(Francés et al., 2007; Vélez et al., 2009)

TETIS implementation: 100m & daily

Sediments, check dams and transmission losses

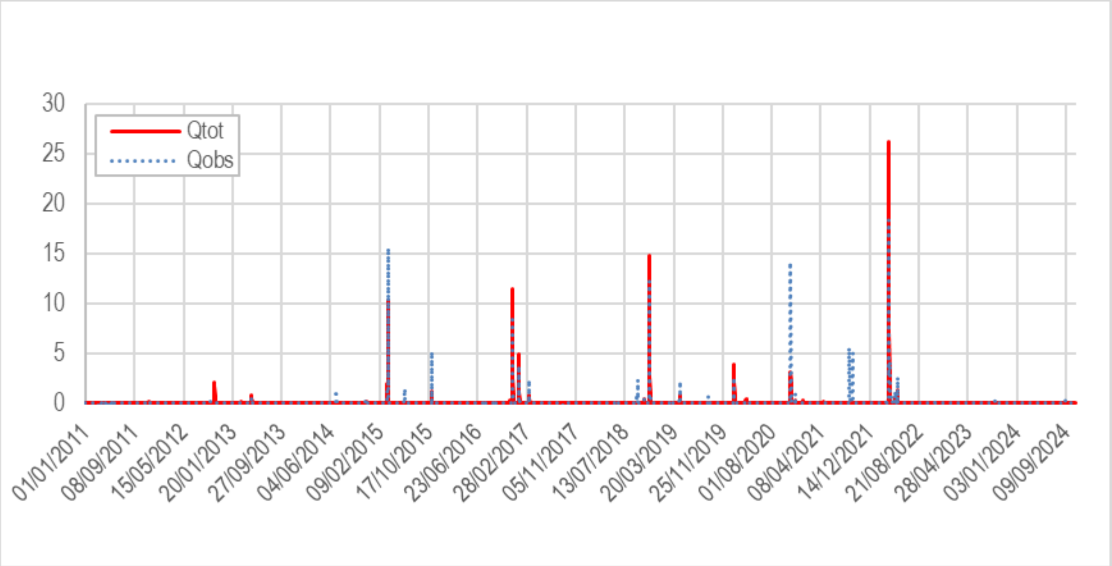
Calibration (1996-2010)



NSE = 0.701

	Observed	Simulated
$Q_d > 0\ m^3/s$	124	133
$Q_d > 1\ m^3/s$	51	35
$Q_d > 5\ m^3/s$	17	8

Validation (2011-2024)



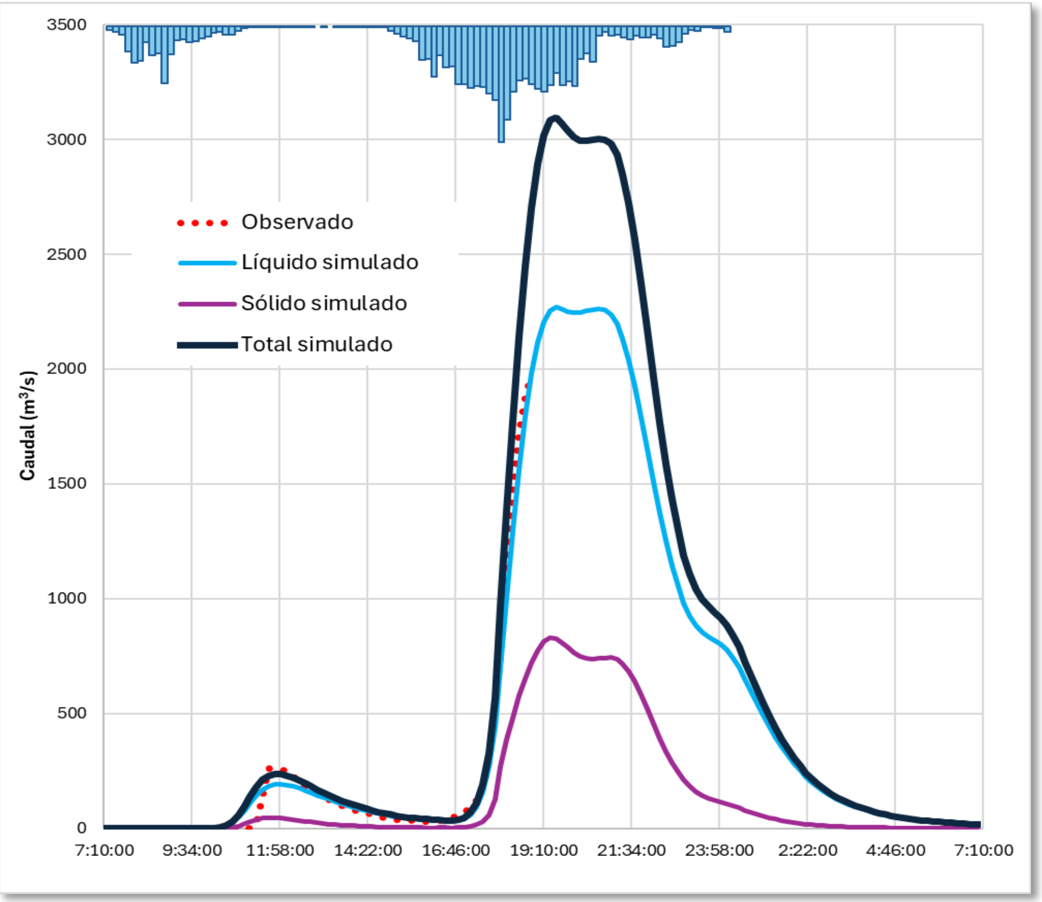
NSE= 0.67

	Observed	Simulated
$Q_d > 0\ m^3/s$	115	104
$Q_d > 1\ m^3/s$	35	35
$Q_d > 5\ m^3/s$	11	11

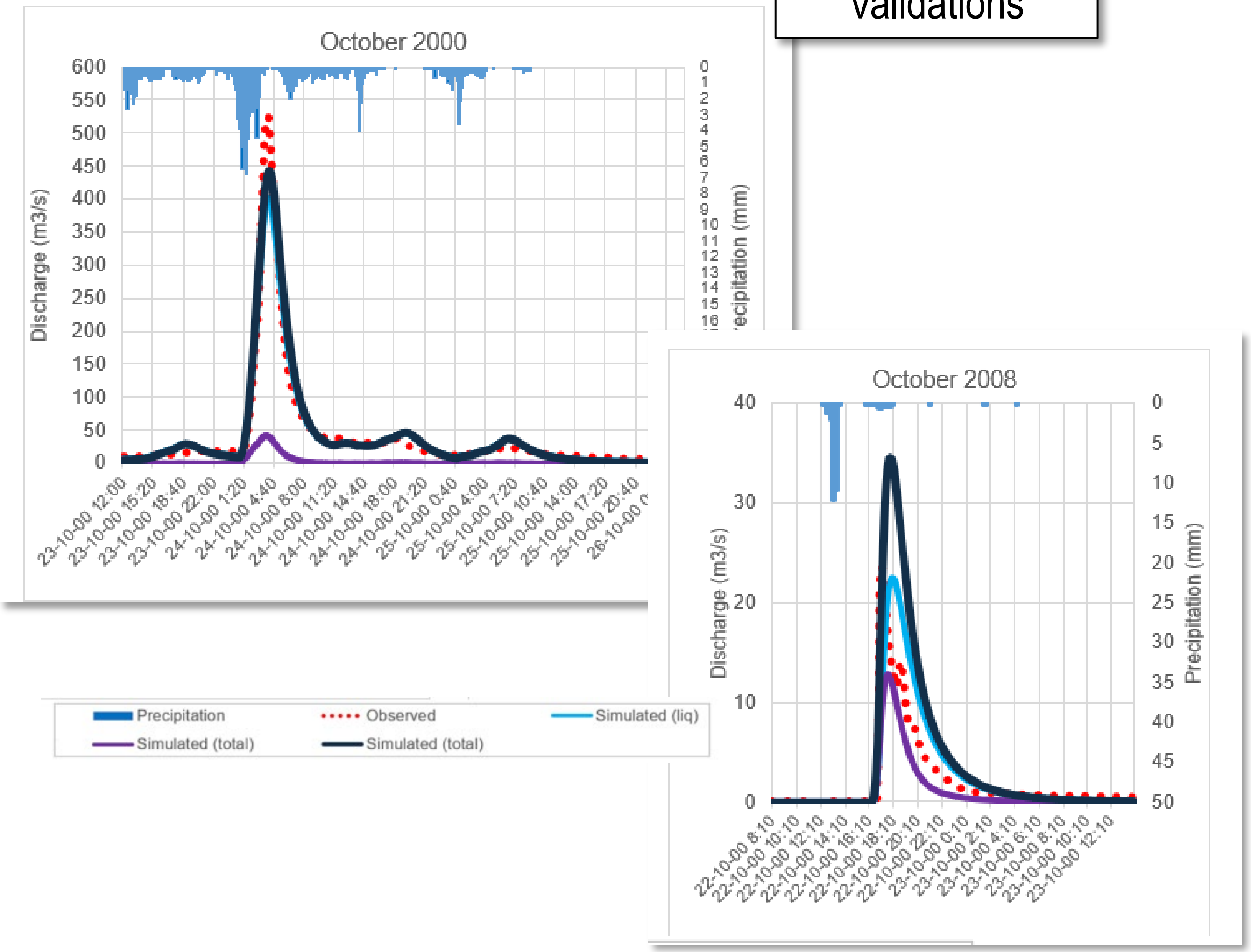
TETIS implementation: 100m & 10min

Sediments and check dams

Calibration at 2024 event



Validations



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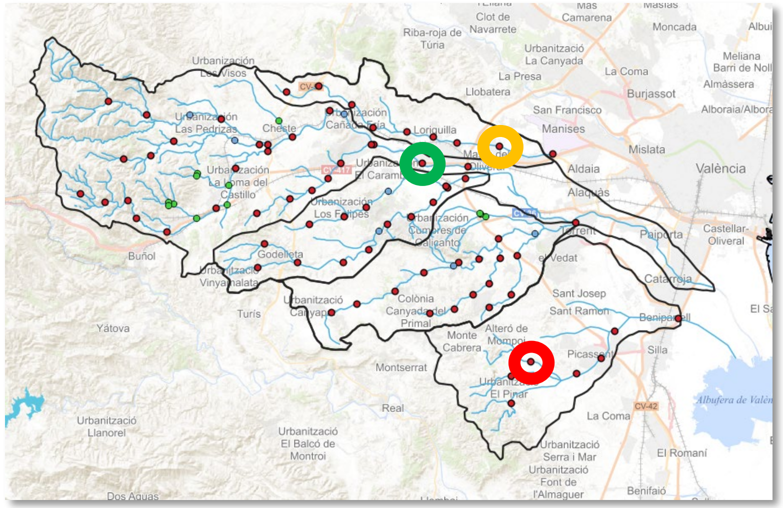
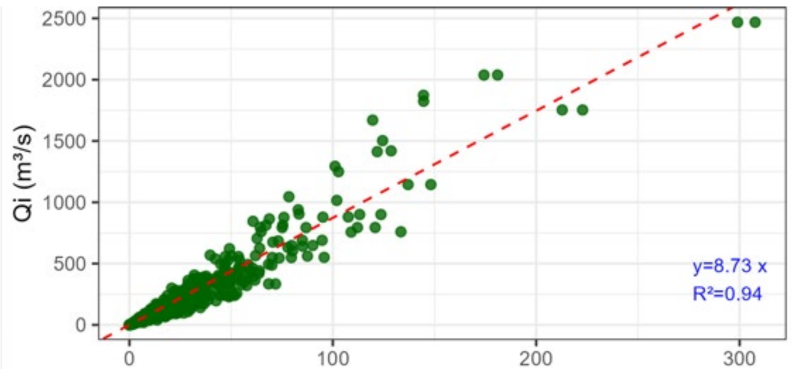
Qp/Qd relationship in 95 locations

- 600 synthetic storms using the storm generator RainGen *(Salsón and García-Bartual, 2003)*
- TETIS Δt 10 min
- Different initial soil moisture conditions of the catchment

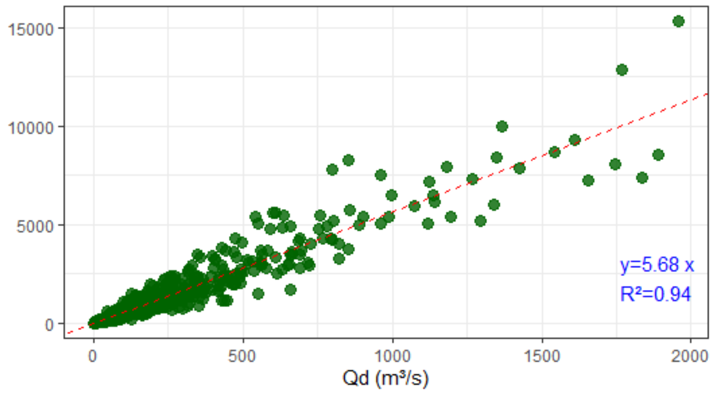


Examples:

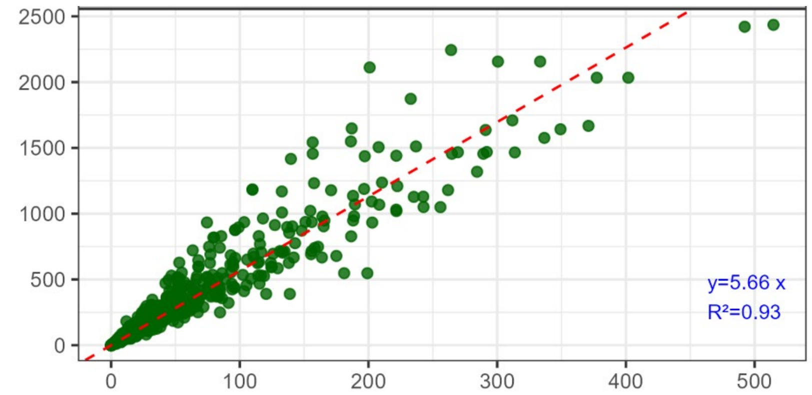
Picassent (Minyerola)



Poyo (sensor)

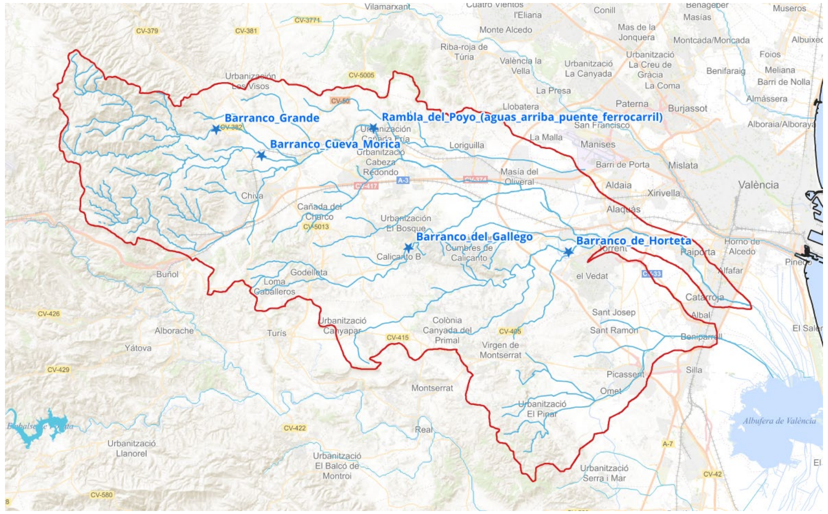


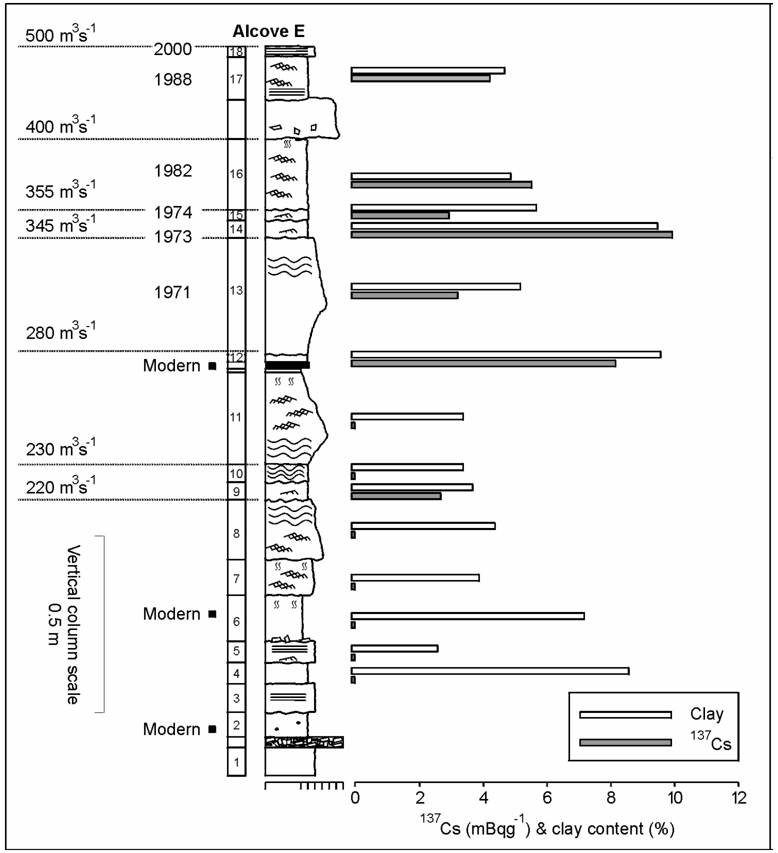
Pozalet (Pl Oliveral)



Paleoflood info in 5 locations

- Non-systematic binomial censored information

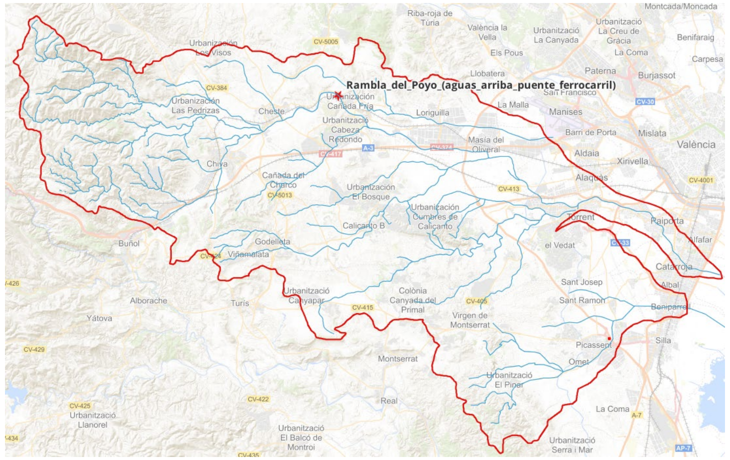


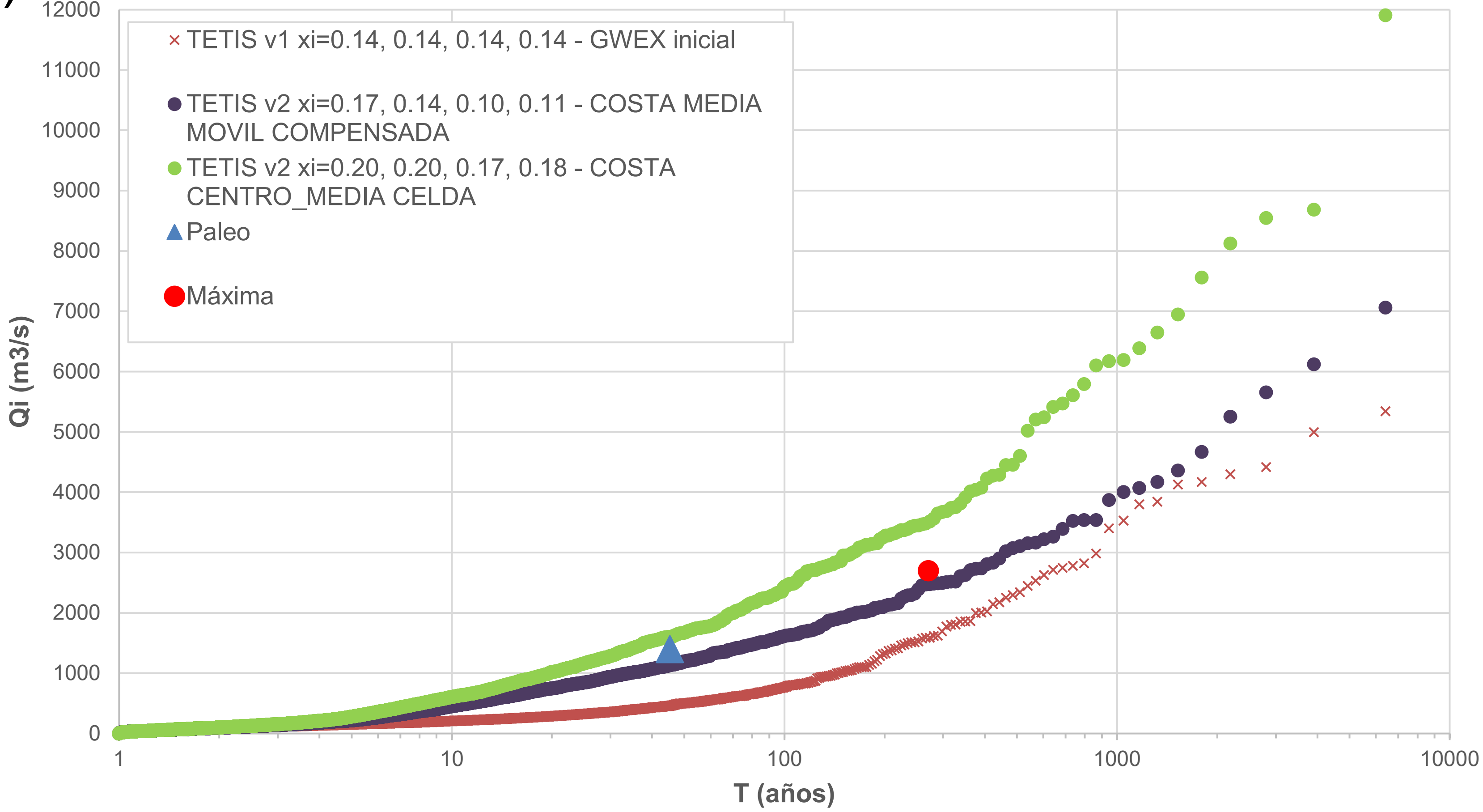


CHJ Report: Paleofloods in Rambla del Poyo (Benito et al., 2025)

Validation using paleofloods

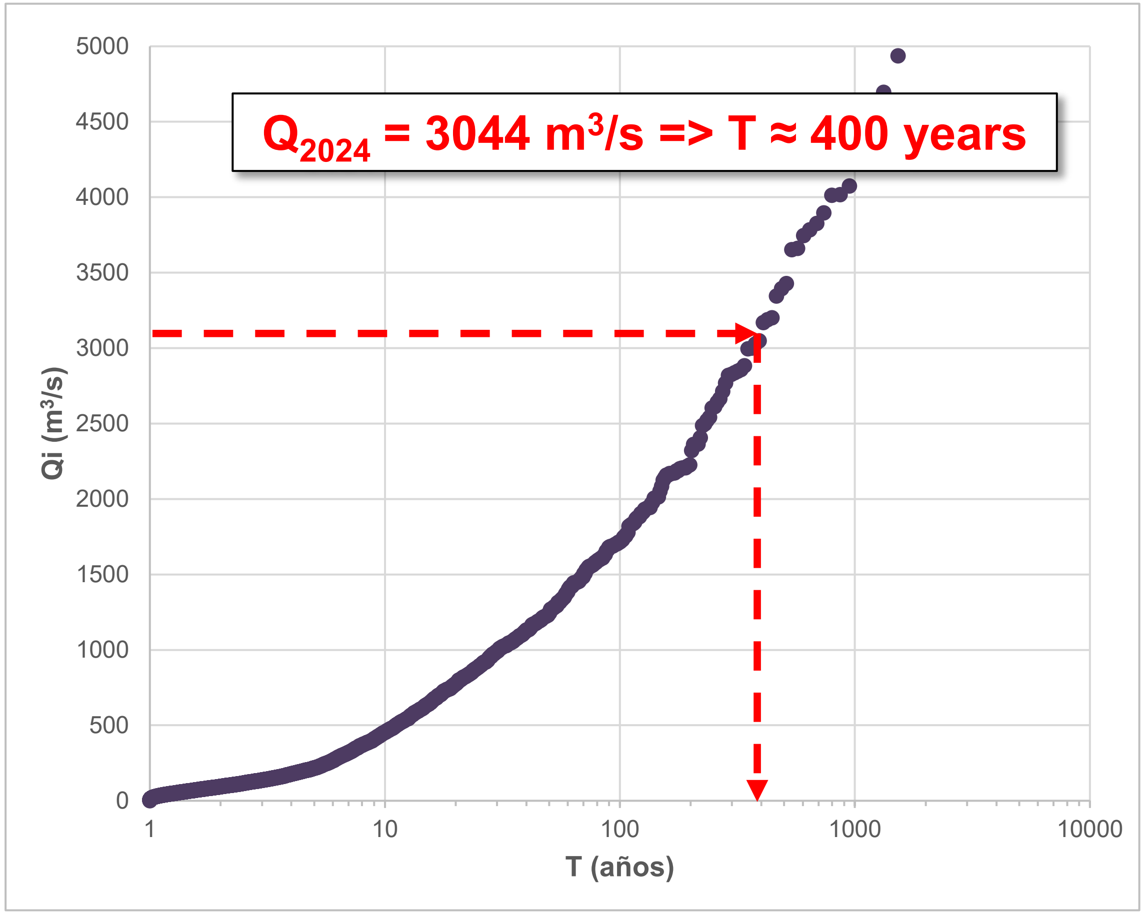
- Sensitivity to “plausible” hidrometeorological models at Rambla del Poyo in Cheste (railway bridge)



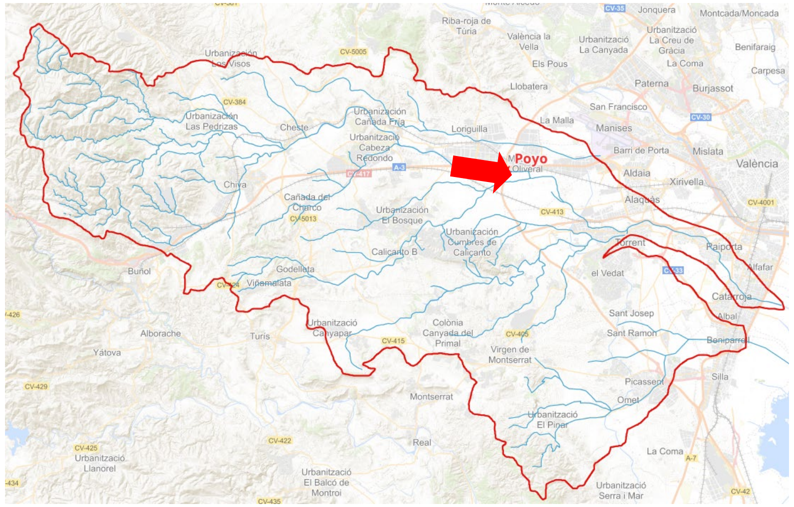


Frequency laws at points of interest

Poyo crossing the A7 highway



T (years)	Q (m^3/s)
25	886
50	1,244
100	1,716
200	2,276
500	3,370
1,000	4,157



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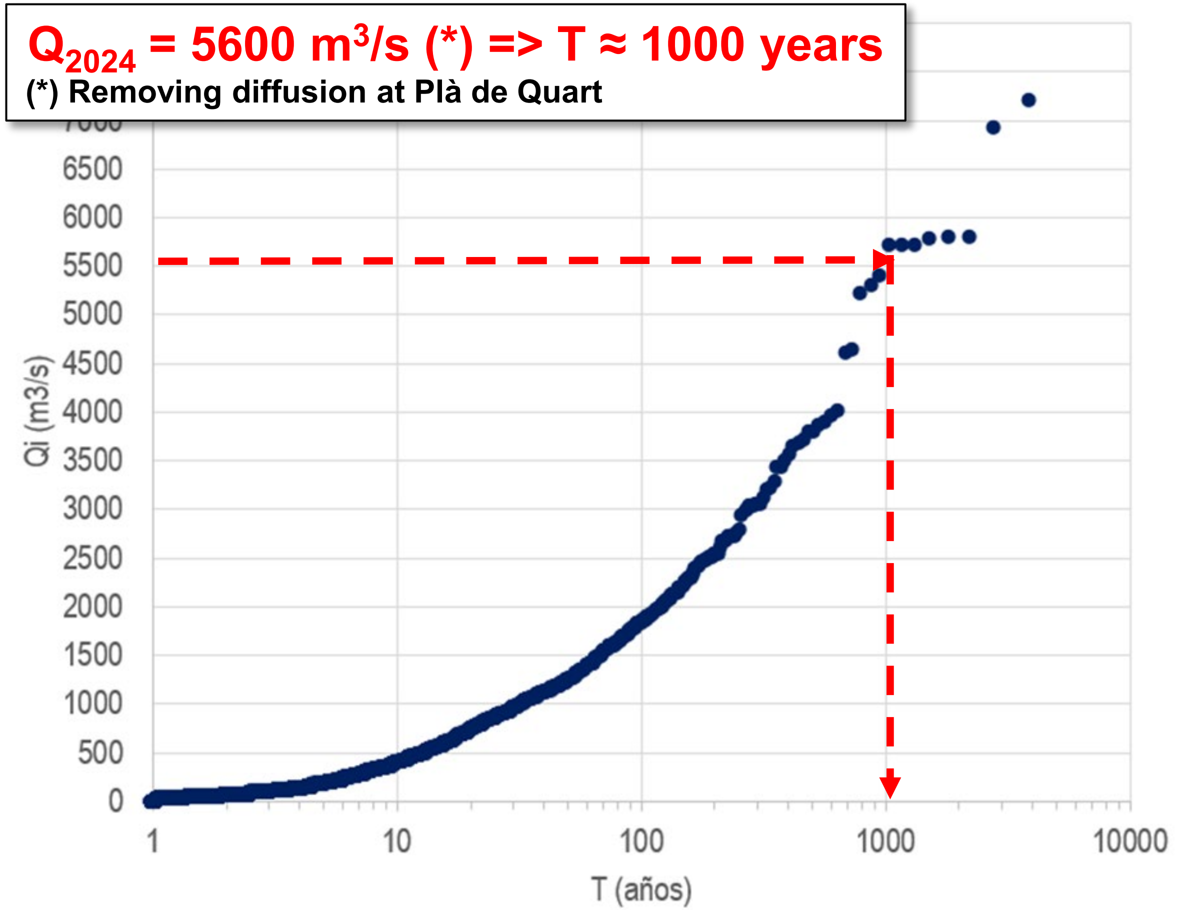
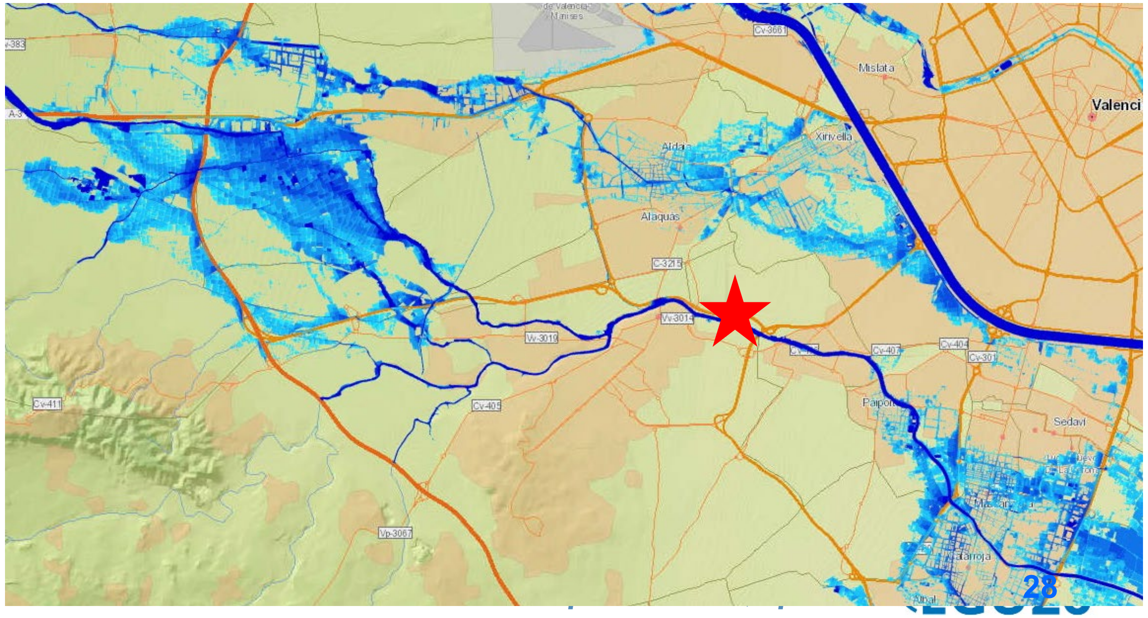
Frequency laws at points of interest

Poyo at Picanya

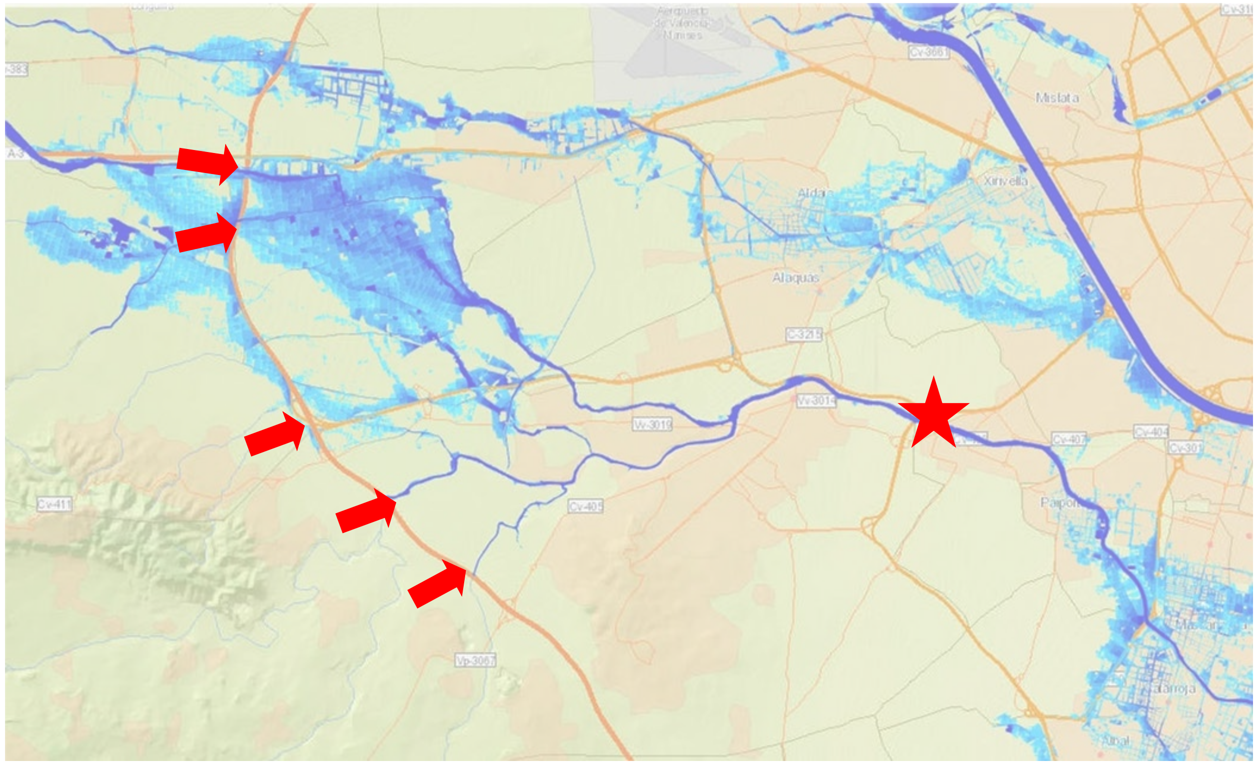


T (years)	Q (m^3/s)
25	866
50	1,250
100	1,846
200	2,546
500	3,818
1,000	5,566



Quantiles "do not sum up" at junctions

Rambla del Poyo	Q 500 (m^3/s)
Poyo A7	3,370
Gallego A7	1,101
Horteta A7	1,177
Santo Domingo A7	350
Canyes A7	252
Sum	**6,250**
Poyo at Picanya (w/o diffusion)	**3,818**



Conclusions

- **Temporal and spatial variability** of actual storms cannot be reproduced by a “simple” design storm, specially with compound floods: more than one catchment draining to the inundation area

  => Solution: the use of **weather generators**

- **Distributed models** can exploit the spatial variability of precipitation and hydrological characteristics
- **Sediments** can be important in flash floods
- To **reduce uncertainty** for high return periods:
  - Regional Pdmax
  - Use of non-systematic information (historical and/or paleofoods)
- The measurement of **“extraordinary” depends** on the random variable

EGU26 GENERAL ASSEMBLY

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Thanks for your attention

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https://gimha.upv.es/

Solidarity Bridge
(01/11/2024)