

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

Félix Francés, Carles Beneyto and José Á. Aranda

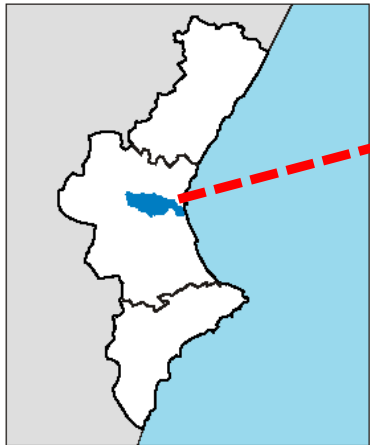
Research Group of Hydrological and Environmental Modelling (GIMHA)

Research Institute of Water and Environmental Engineering (IIAMA)

Universitat Politècnica de València (UPV), Valencia, Spain

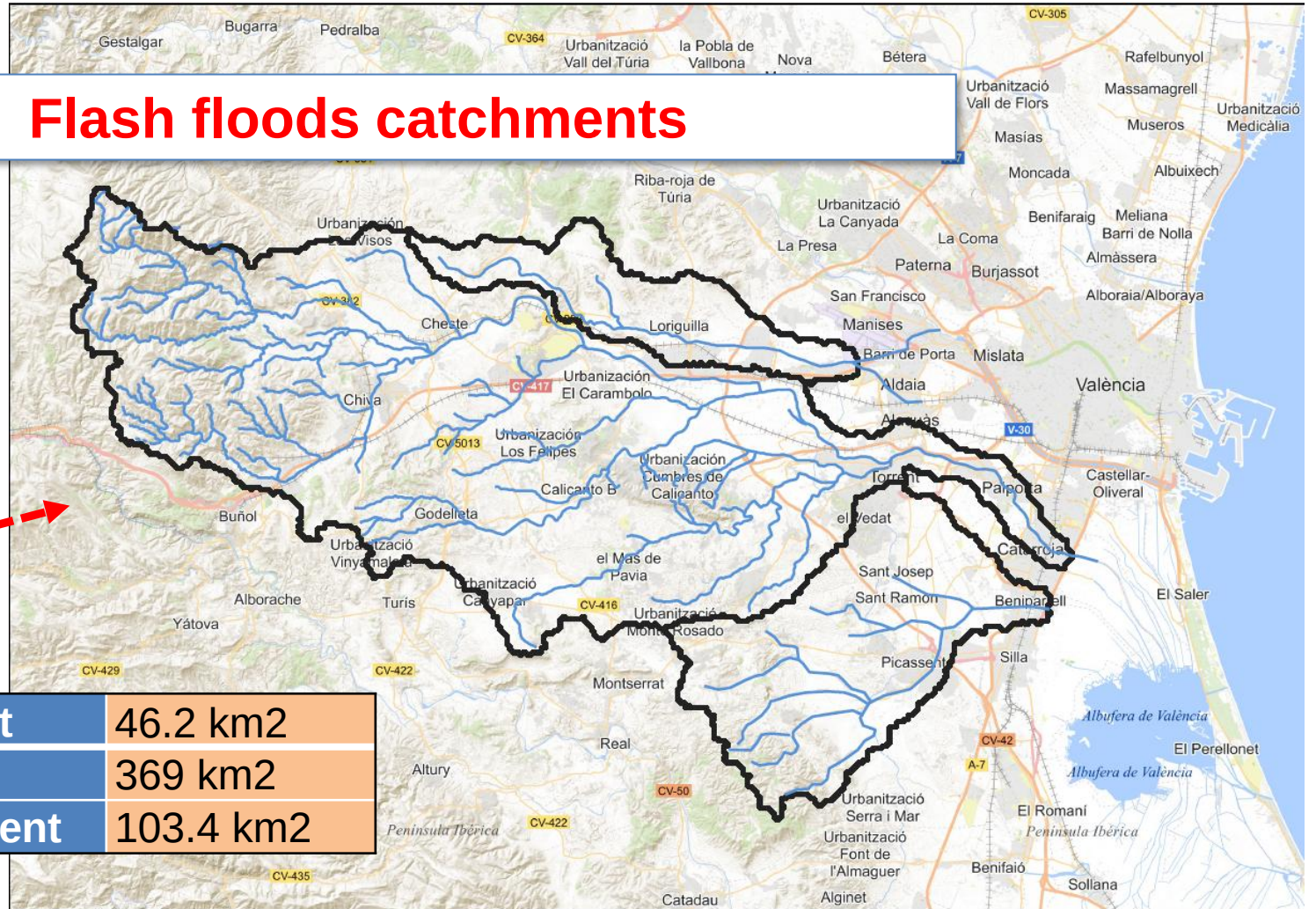


Drainage area of southern Valencia



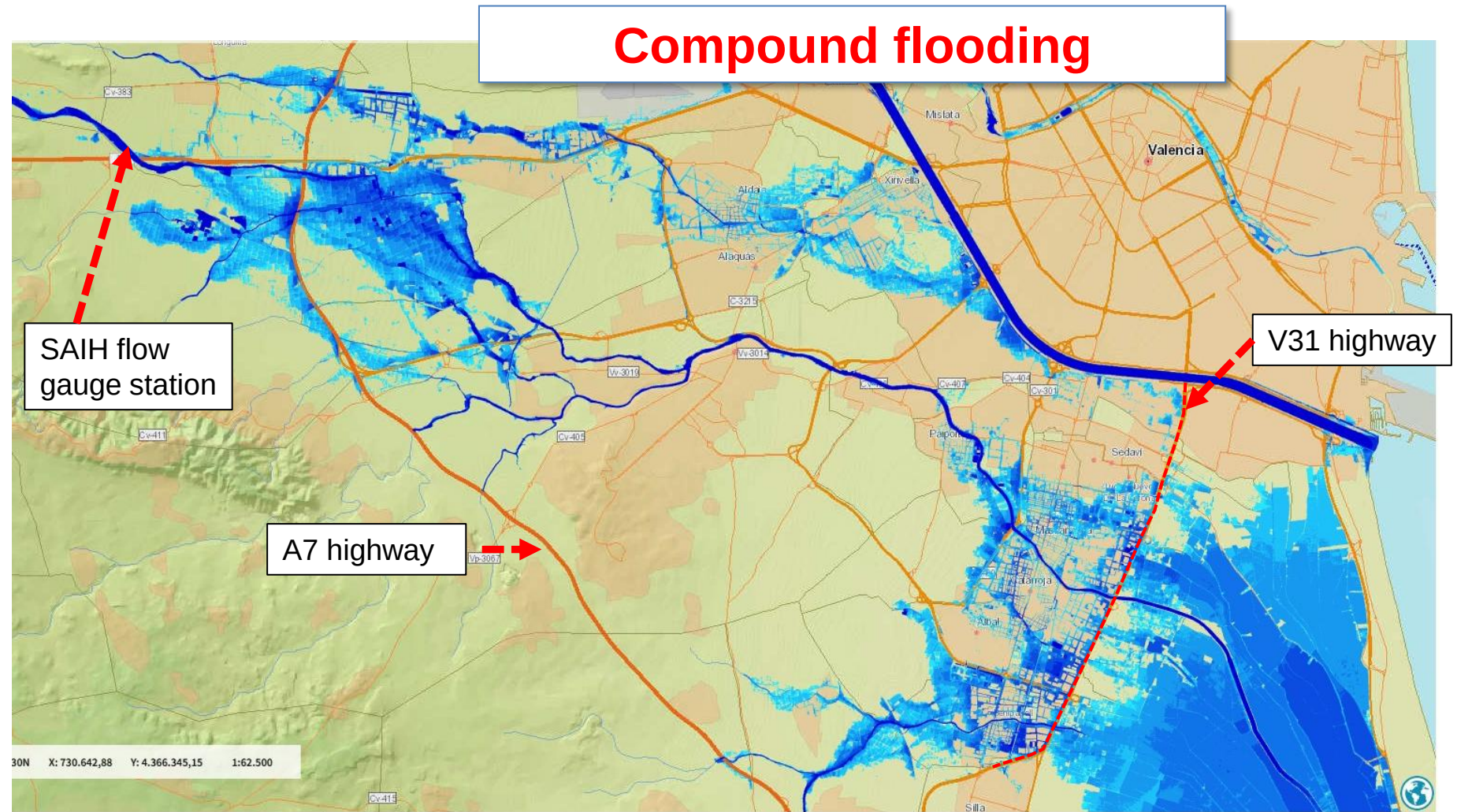
Flash floods catchments

Pozalet	46.2 km ²
Poyo	369 km ²
Picassent	103.4 km ²



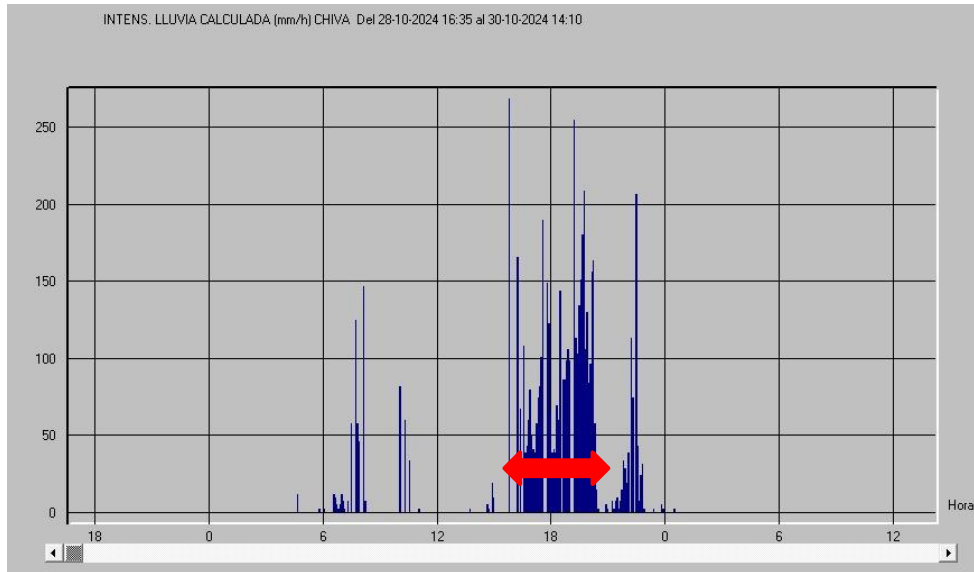
T500 flood hazard map in the inundation area

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

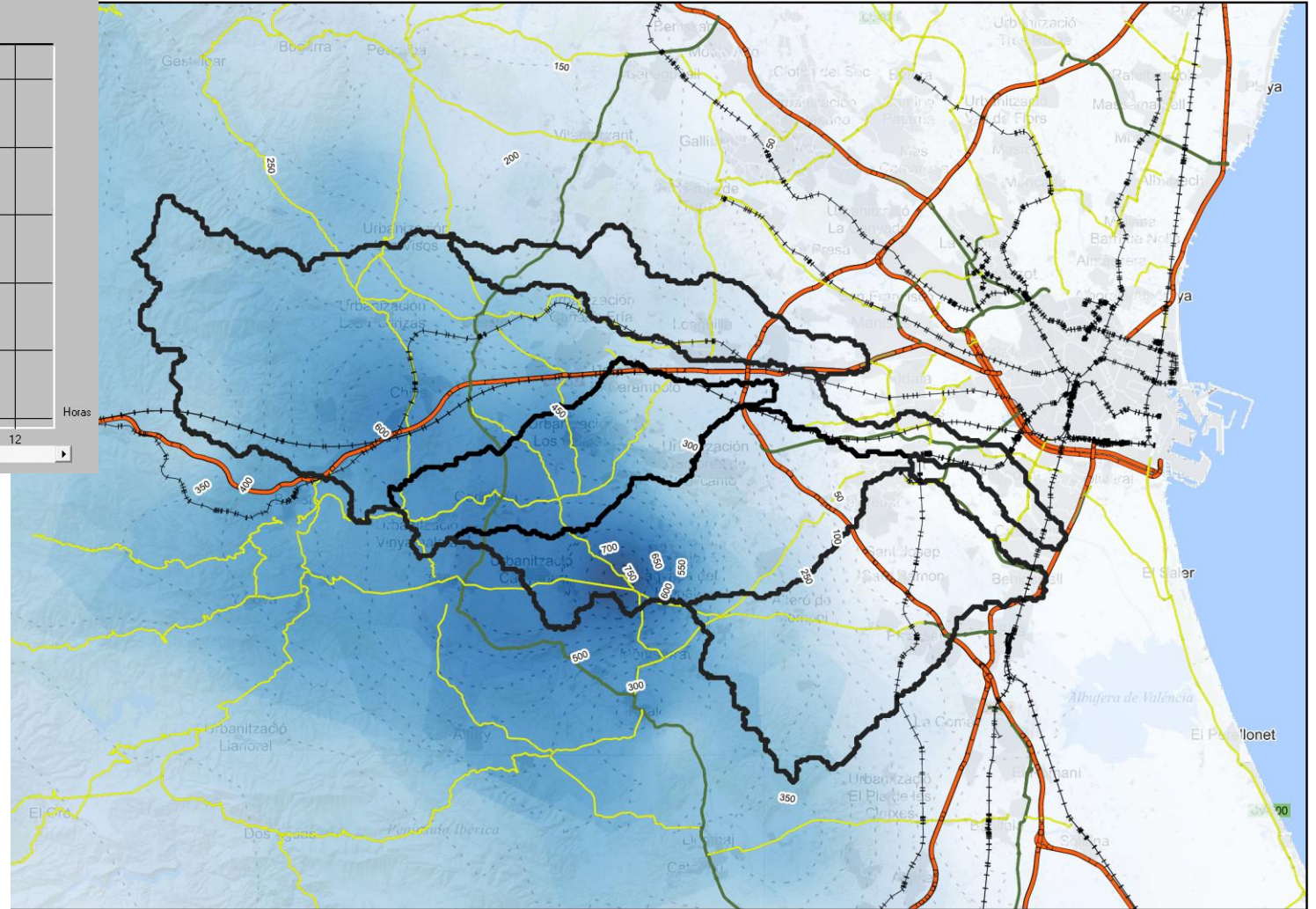


Source: SNCZI 2nd cycle

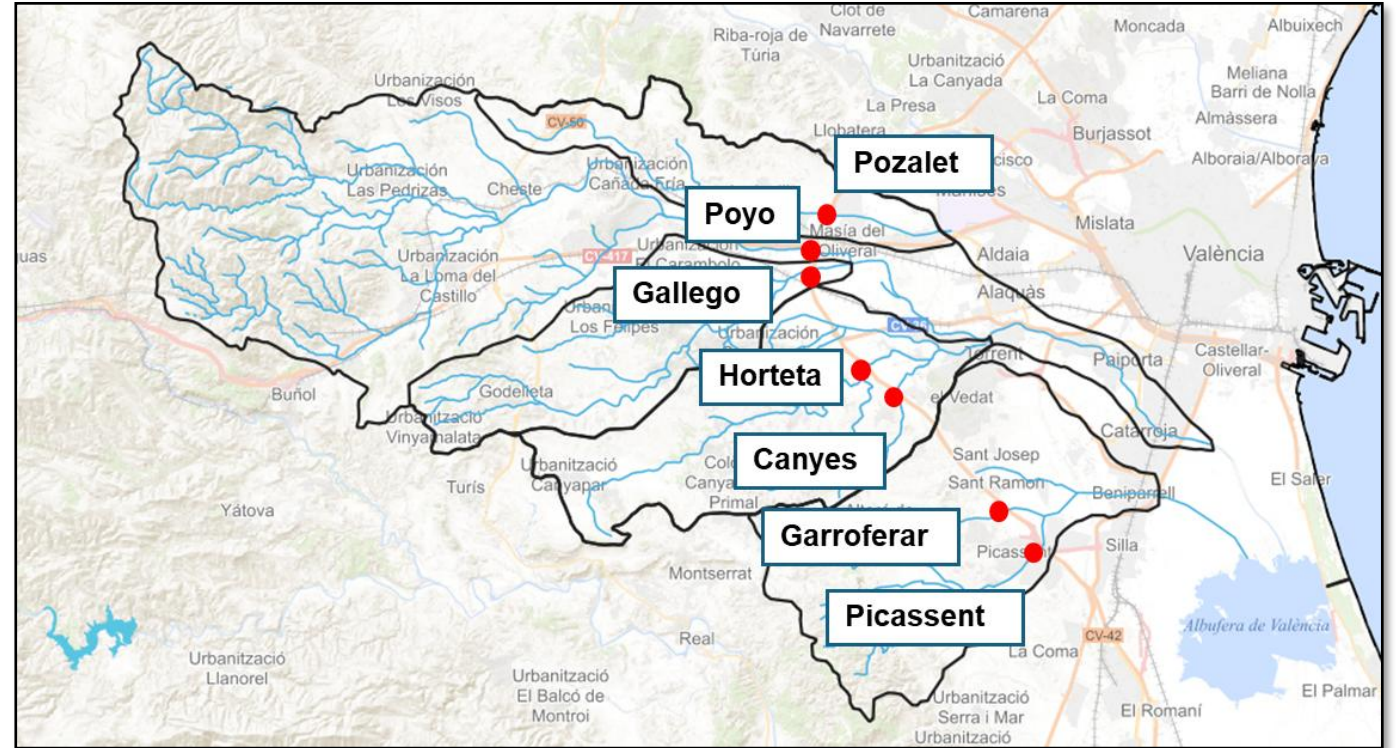
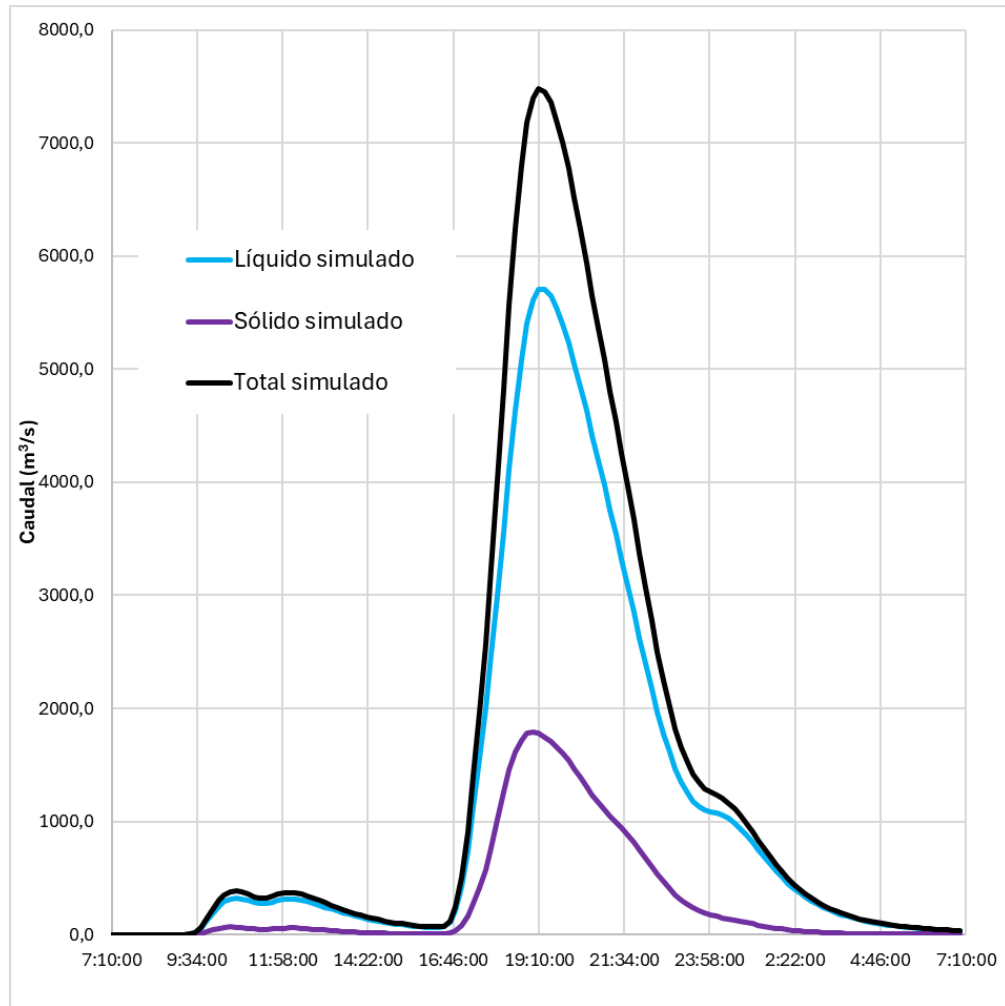
The storm on October 29, 2024



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



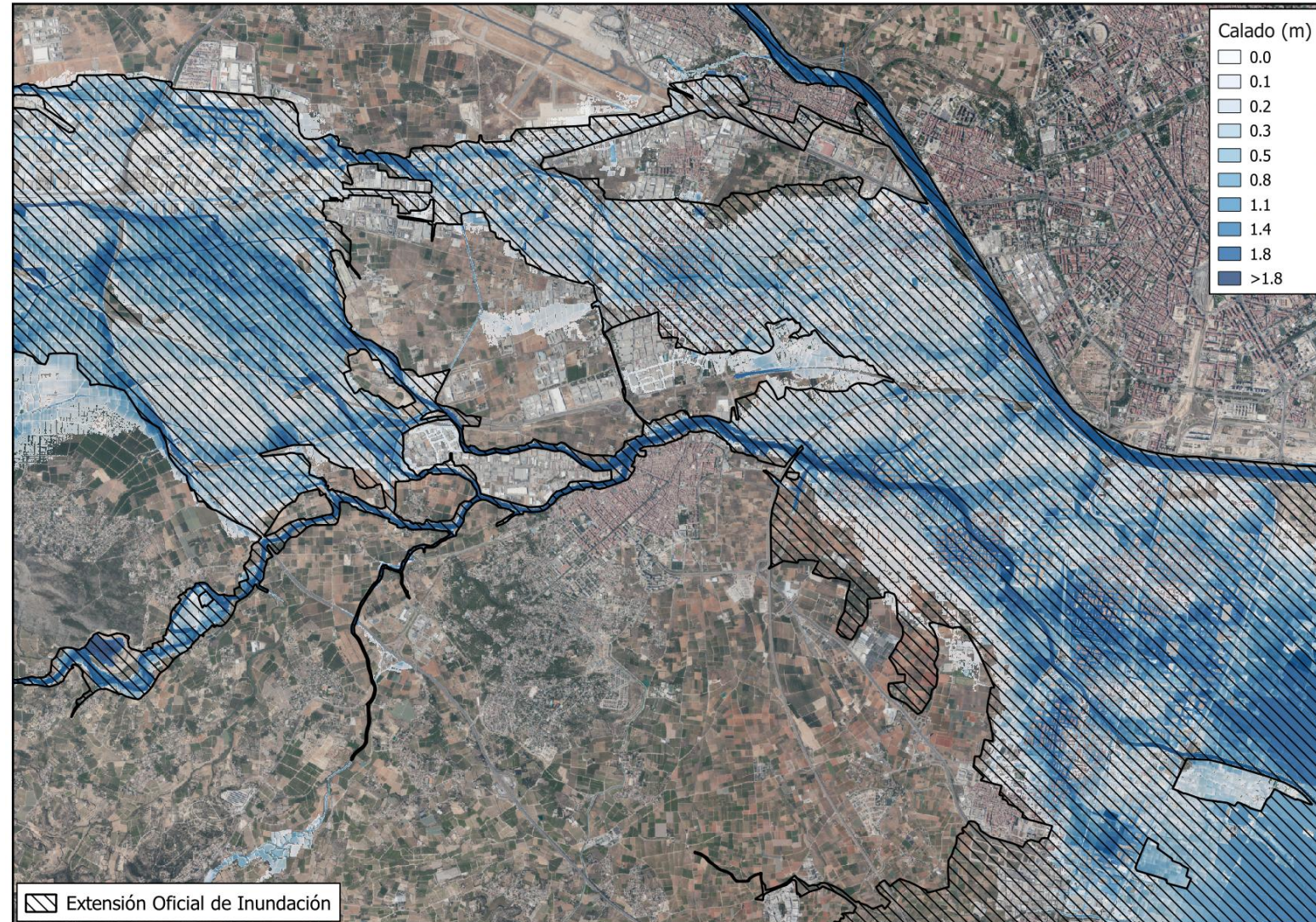
The flood on October 29, 2024



Source: Francés et al., IIAMA, 2025

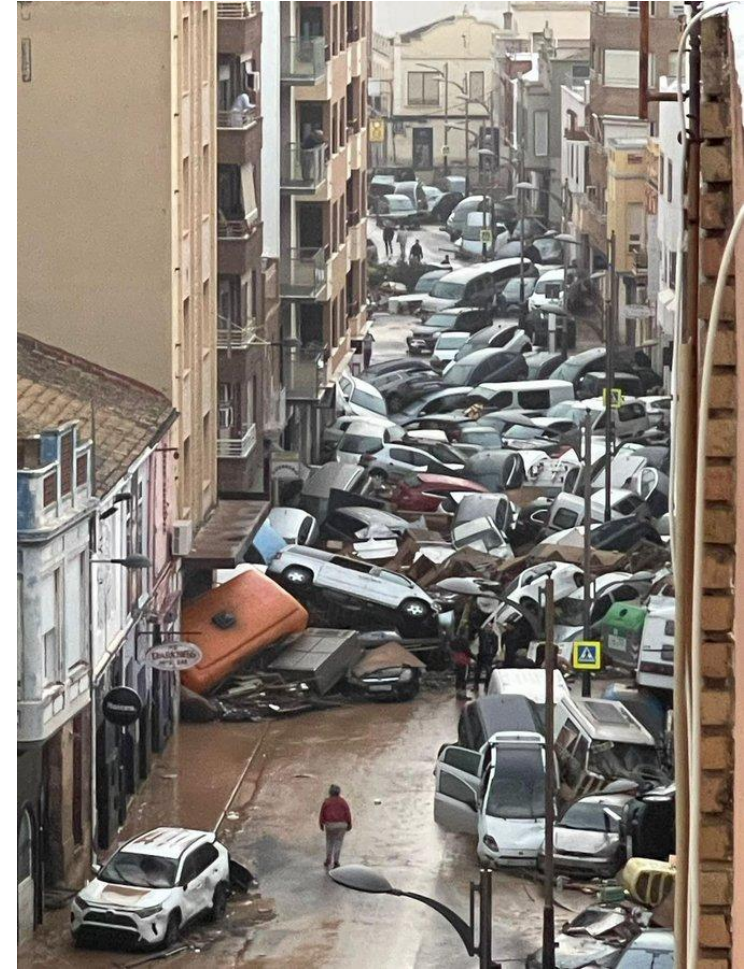
$Q_p = 7.500 \text{ m}^3/\text{s}$ (24% sediments)
Volume= 125 Hm^3 (21% sediments)

The inundation on October 29, 2024



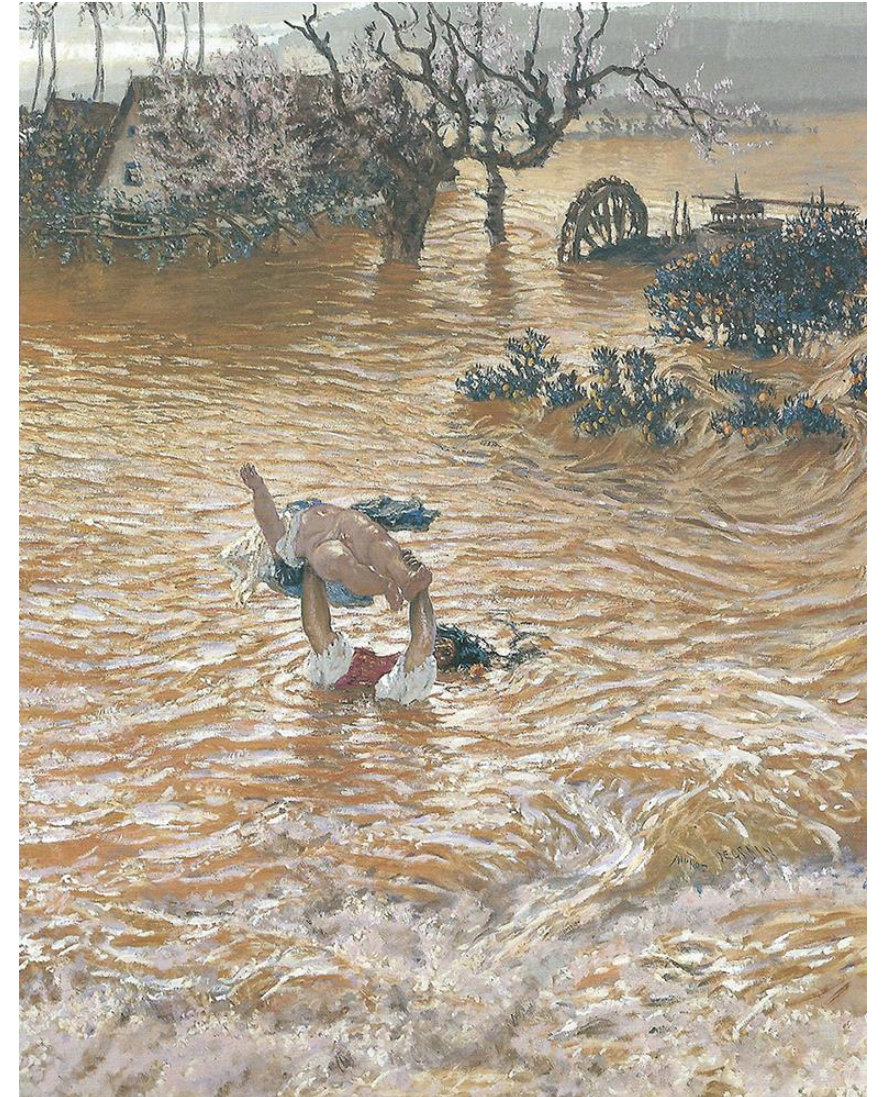
The catastrophe on October 29, 2024

- ❑ **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



- ❑ 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

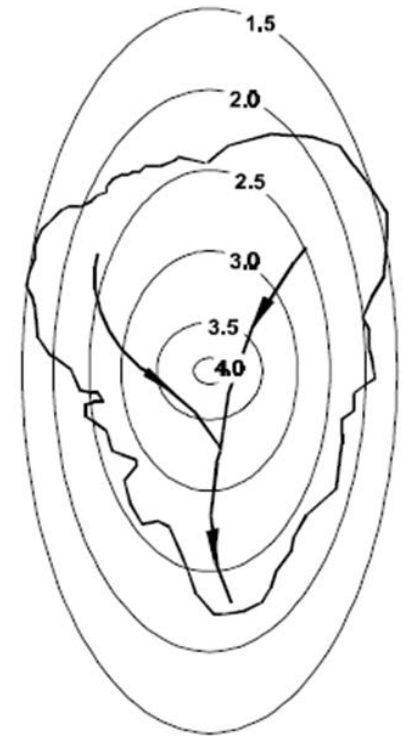
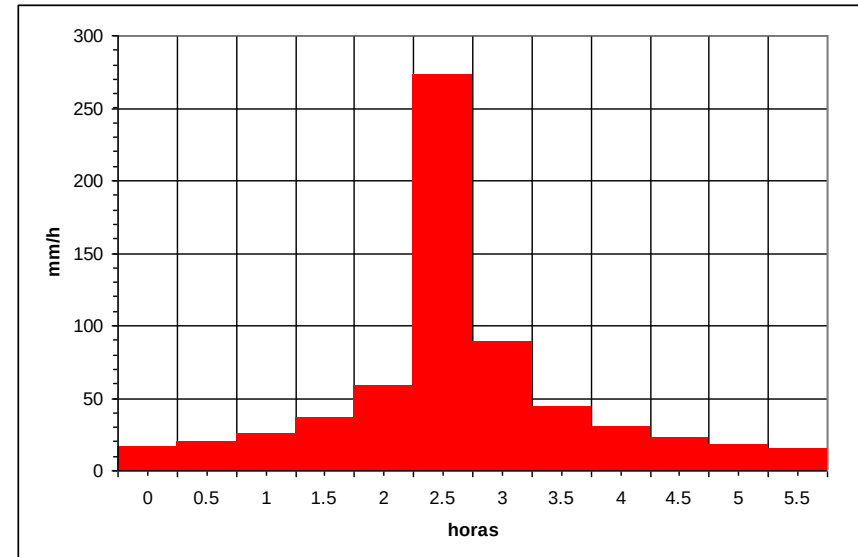
Main hypothesis: Q_T is generated by Pd_T

□ Pros:

- One single simulation

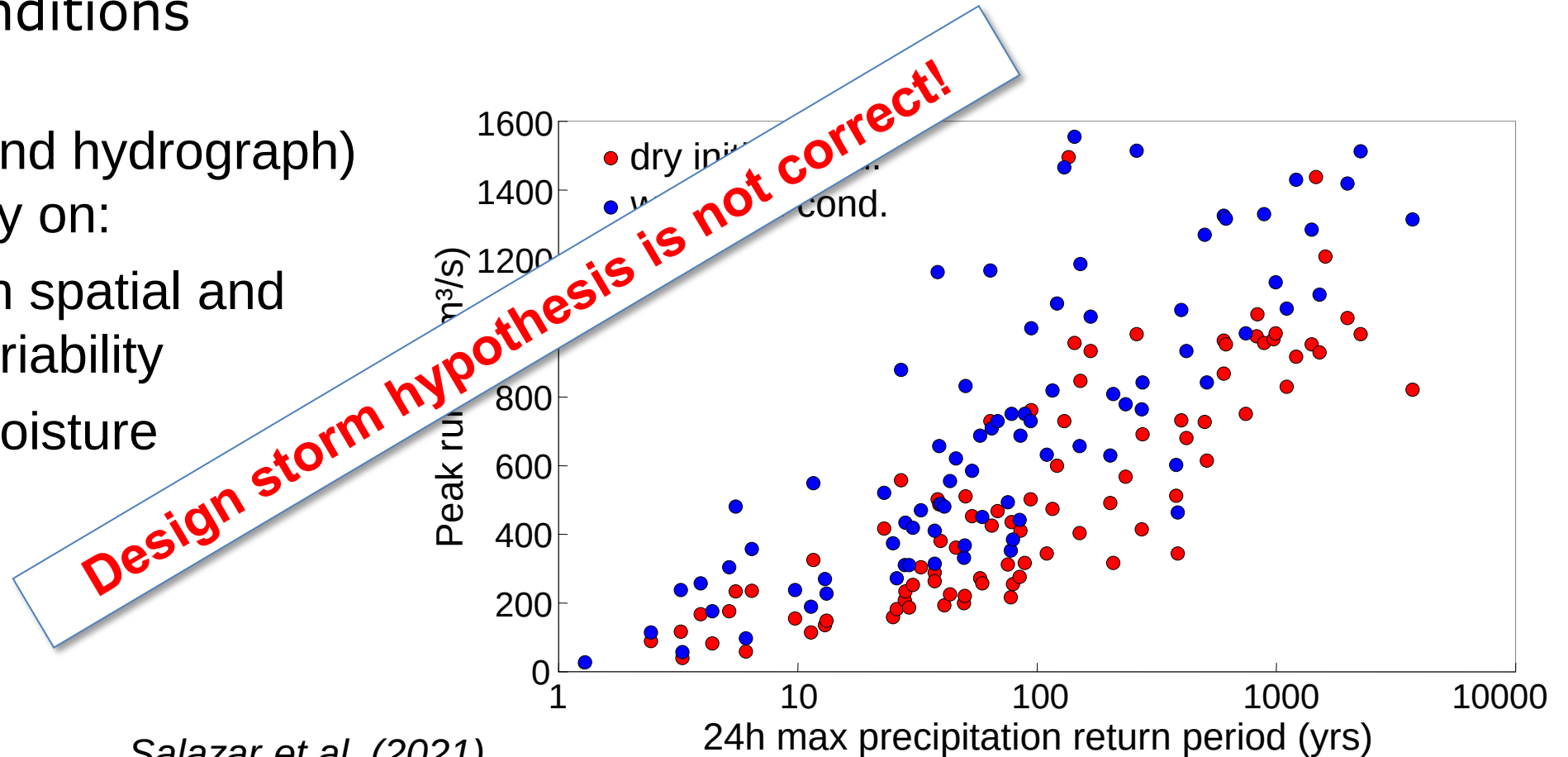
□ Cons:

- Simple spatial and temporal distribution of design storm
- What initial soil moisture?



Experiment at Poyo flow gauge station

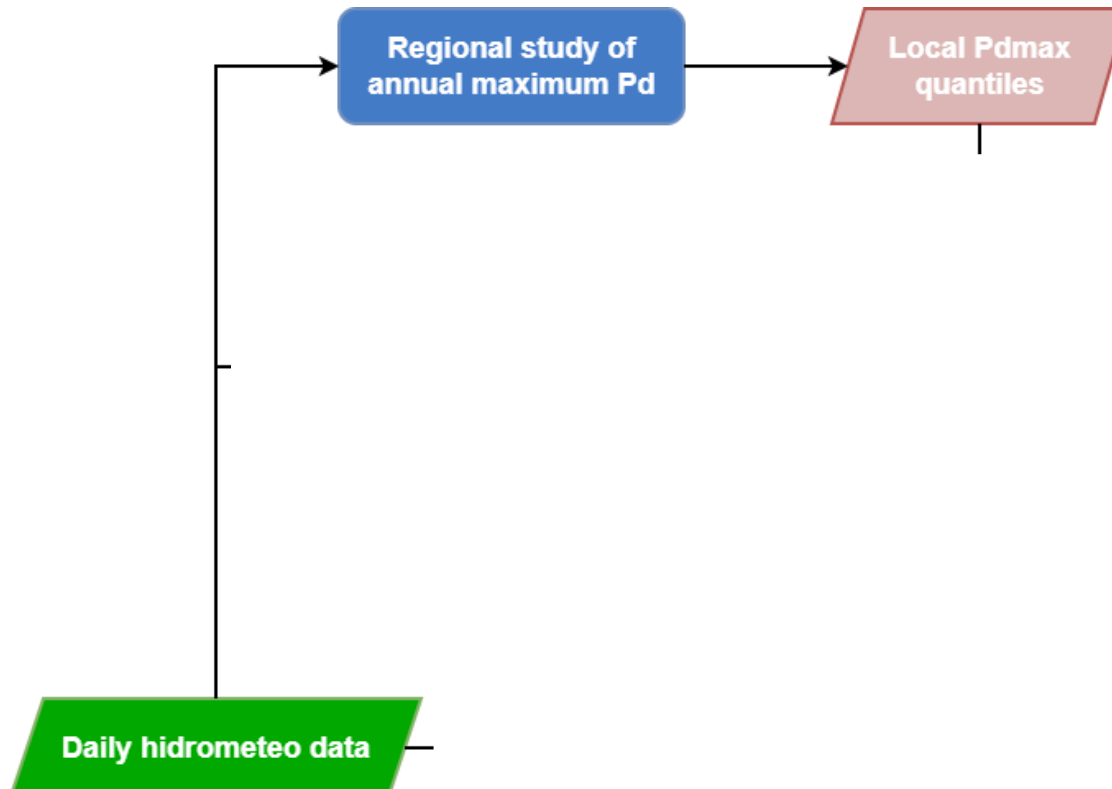
- 200 event simulations using 100 synthetic storms and two initial soil moisture conditions
- Peak runoff (and hydrograph) depends highly on:
 - Precipitation spatial and temporal variability
 - Initial soil moisture





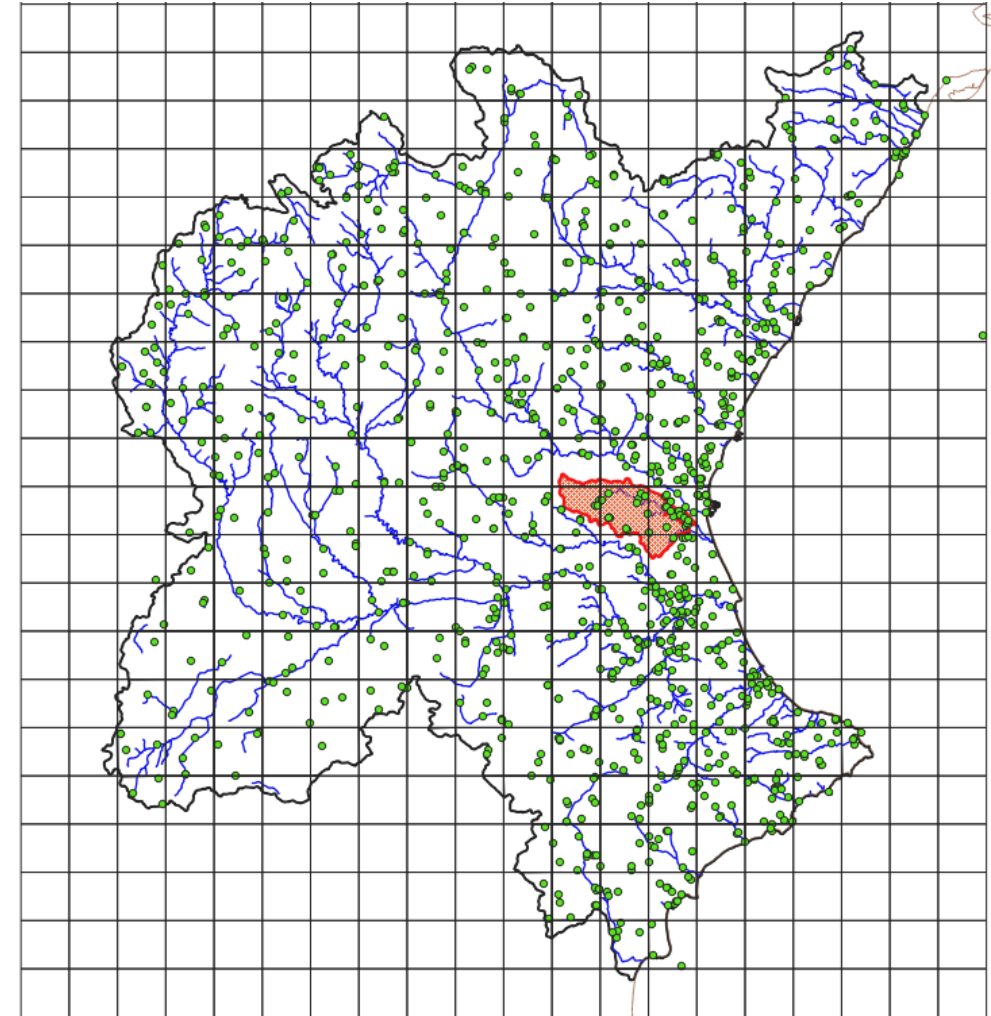
Methodology

Beneyto et al. (2022)



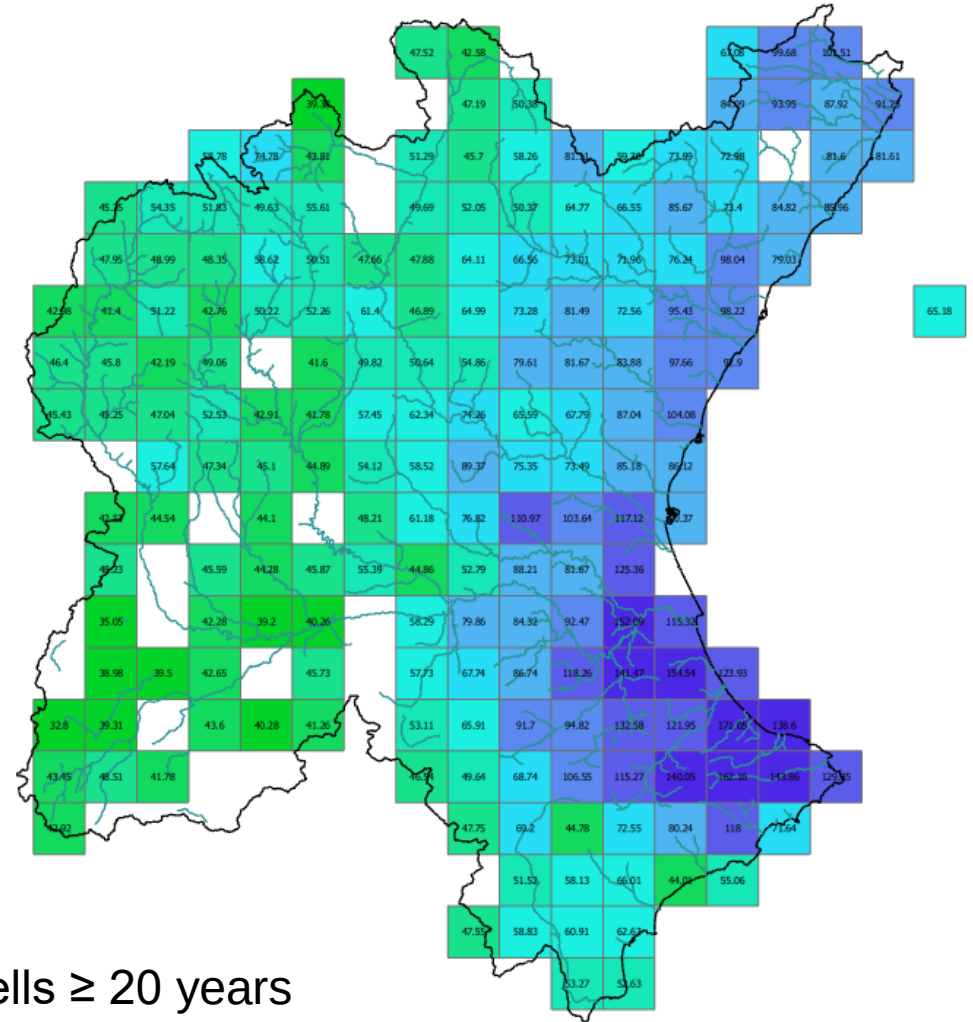
Precipitation data

- ❑ Spatial scope: Jucar River Water Authority (CHJ) with 43,000 km²
- ❑ 1090 pluviometers AEMET and CHJ
- ❑ 1951- 2024
- ❑ Cross-checking with news and reports if $P_d \geq 300$ mm and vice versa
- ❑ 15x15 km cell division => 210 cells
 - Cell P_{dmax} = highest P_d among the stations within each cell
- ❑ 182 cells with at least 20 years
 - **Total data: 11,720**



Regional Pdmax statistical model

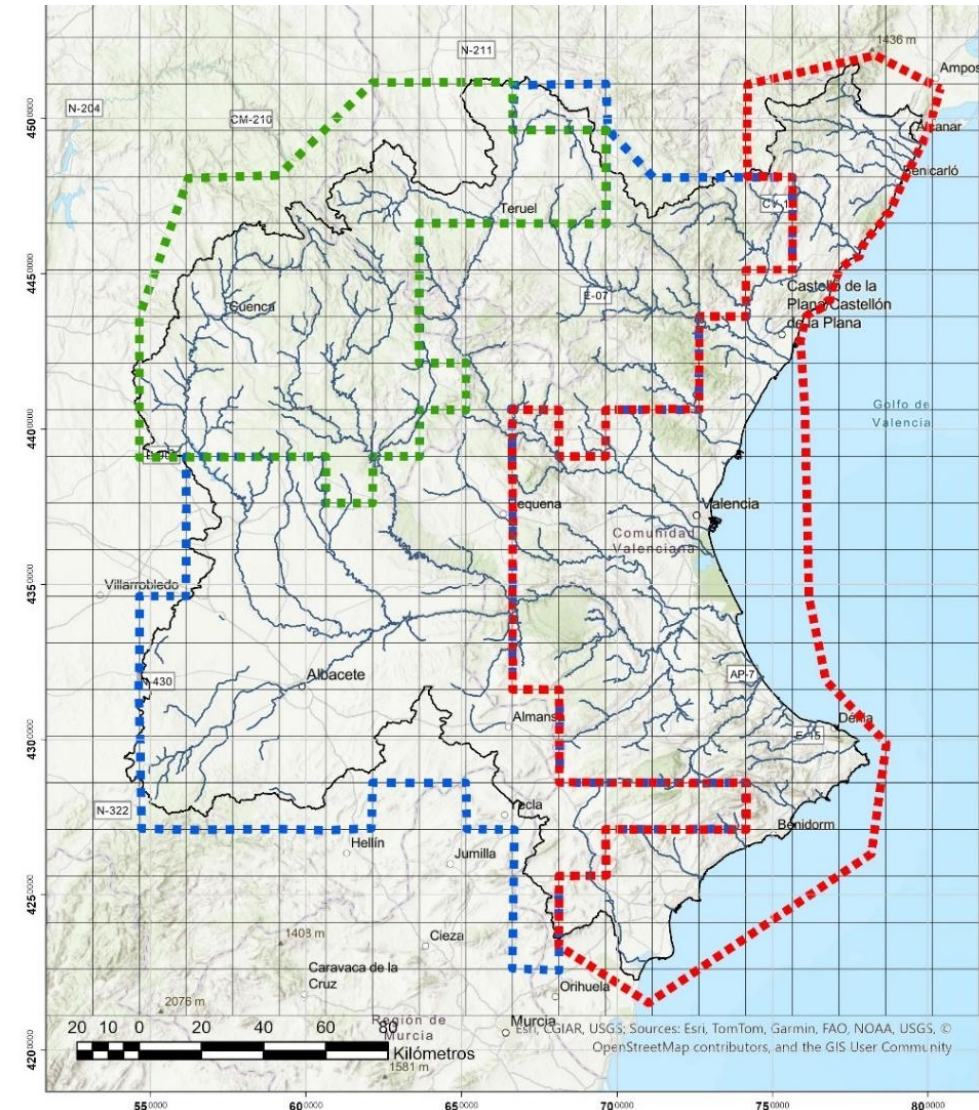
- Hypothesis: CV uniform in space => regionalization dividing by the mean



Pdmax mean for cells ≥ 20 years

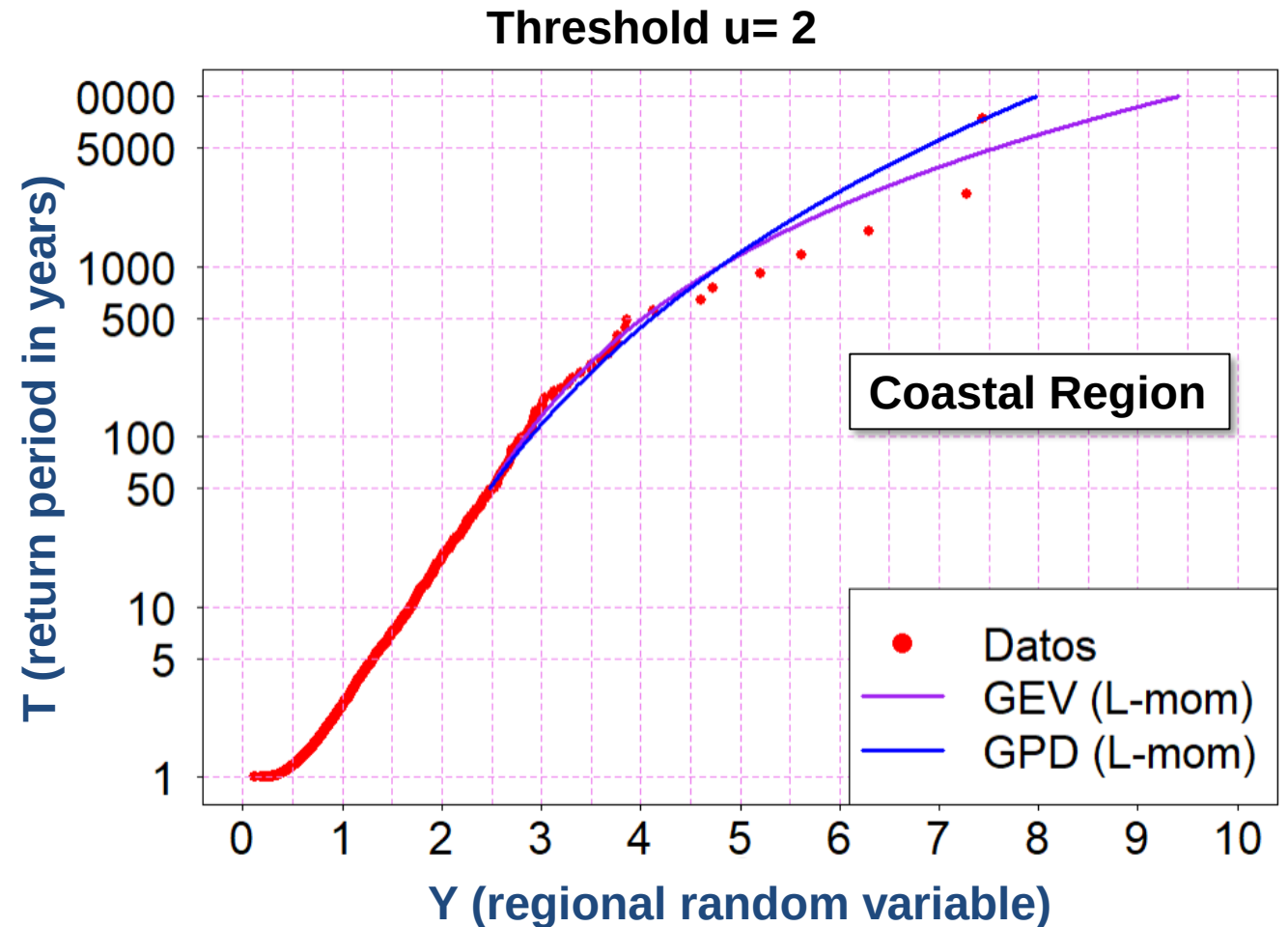
Regional P_{dmax} statistical model

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

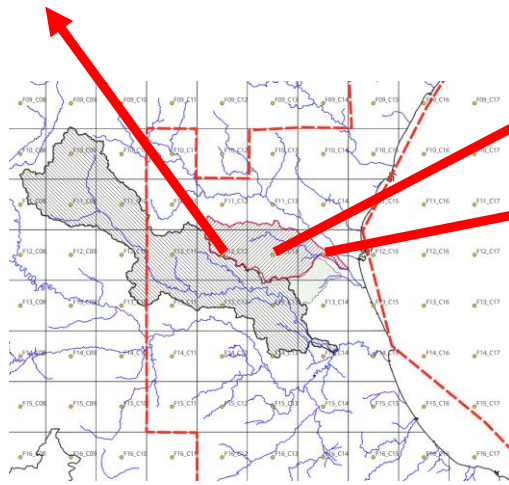
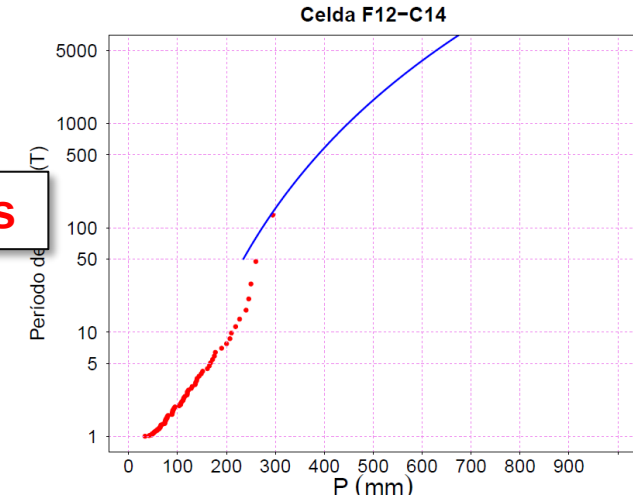
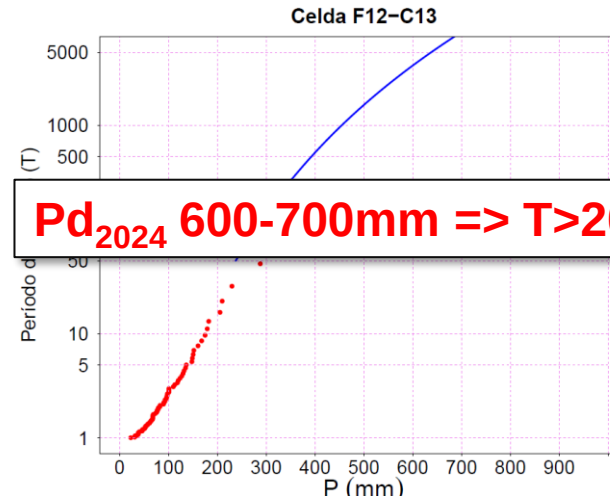
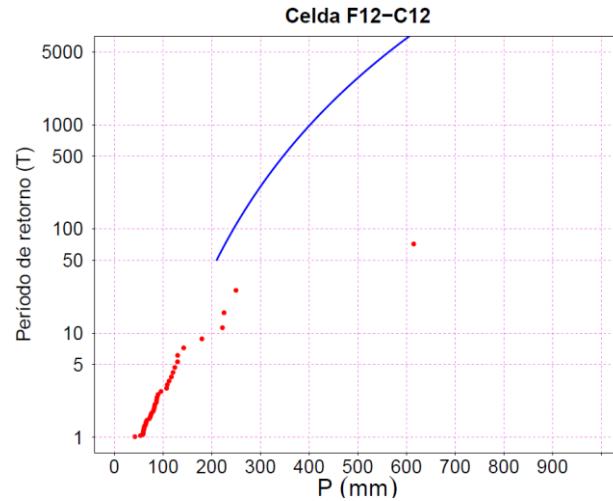


Selected regional model

- ❑ **# 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**



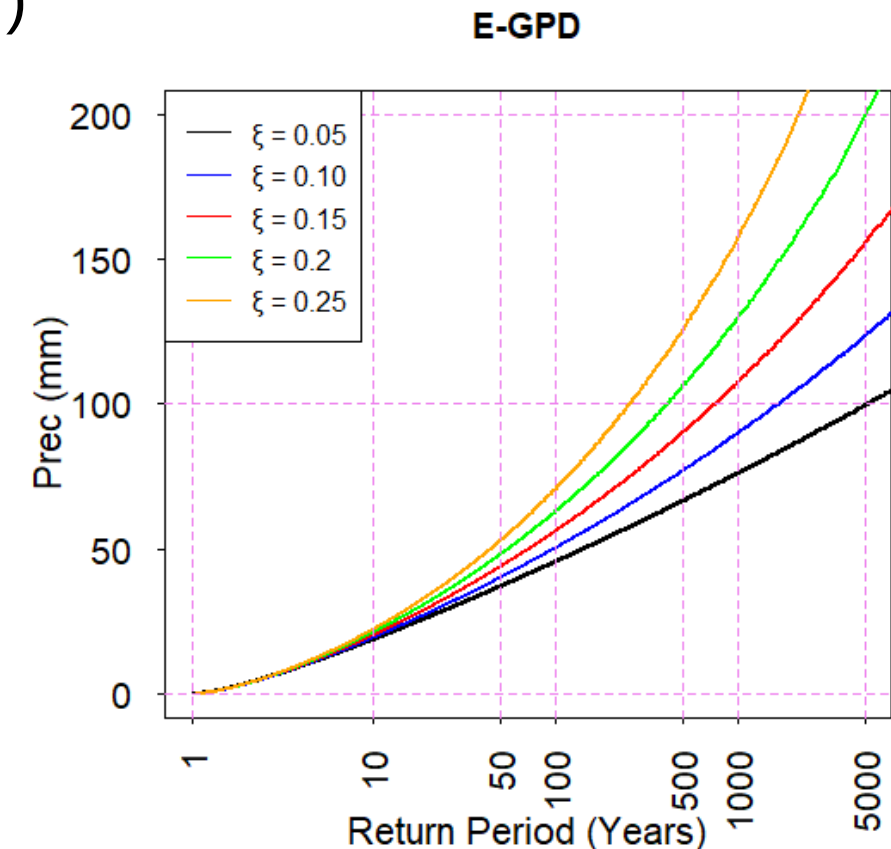
Local (cell) Pd quantiles



	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

- ❑ Developed by Evin et al. (2018)
- ❑ Extended Generalized Pareto Distribution (E-GPD)
=> heavy-tailed

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

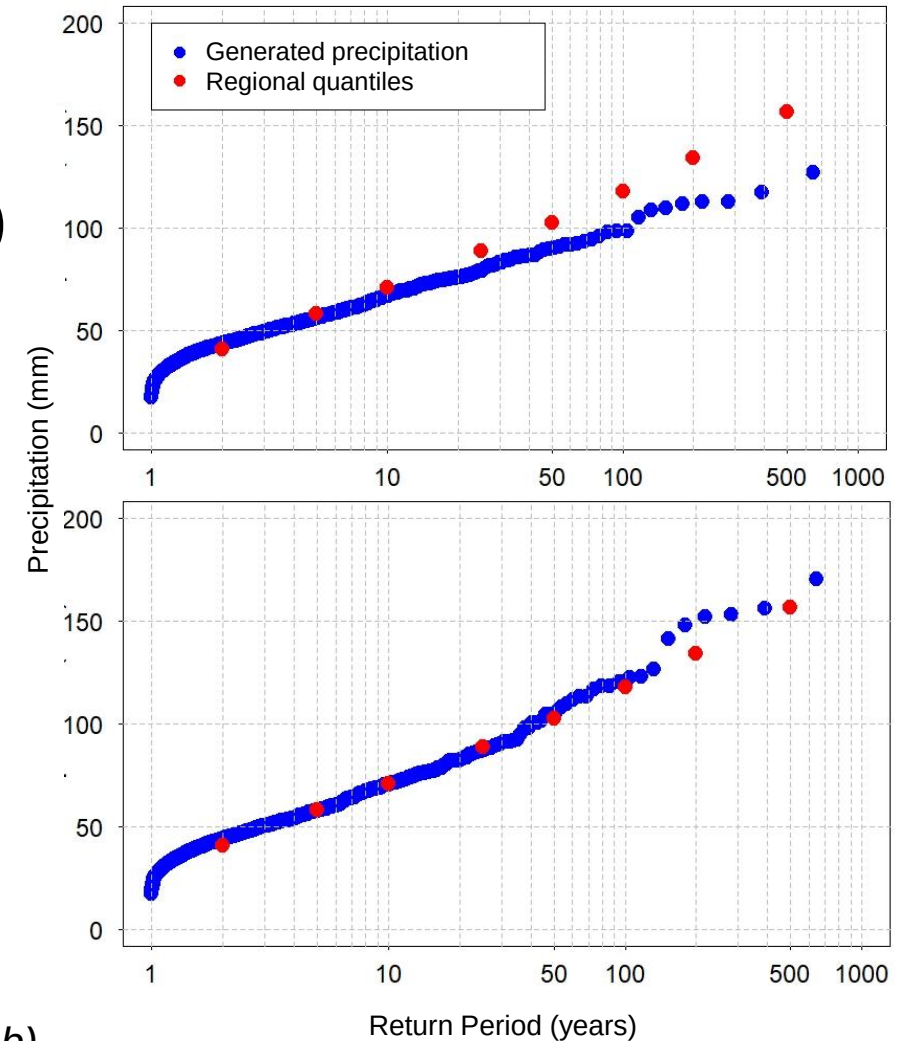


- ❑ Developed by Evin et al. (2018)
- ❑ Extended Generalized Pareto Distribution (E-GDP)
=> heavy-tailed

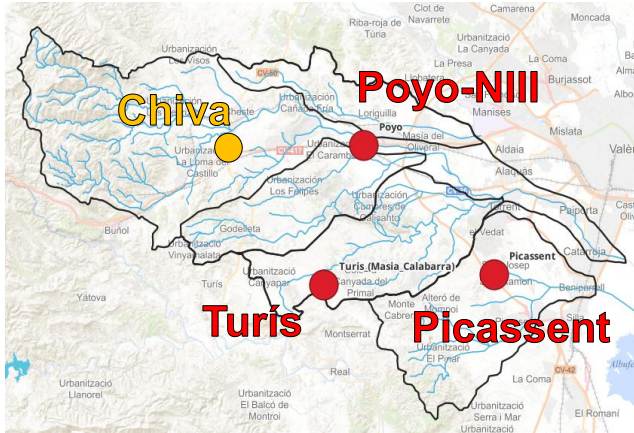
$$F(x; \lambda) = \left[1 - \left(1 + \frac{\xi x}{\sigma} \right)_+^{-1/\xi} \right]^k, x > 0$$

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

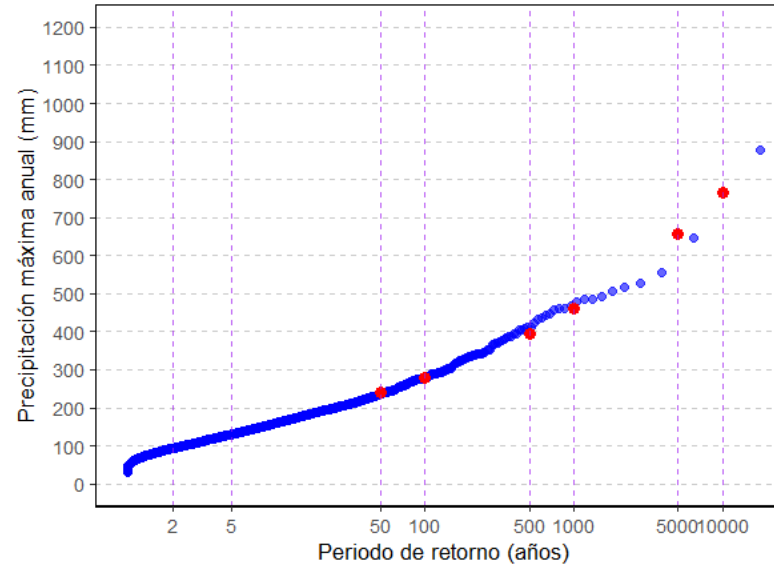
Beneyto et al. (2020, 2023a and 2023b)



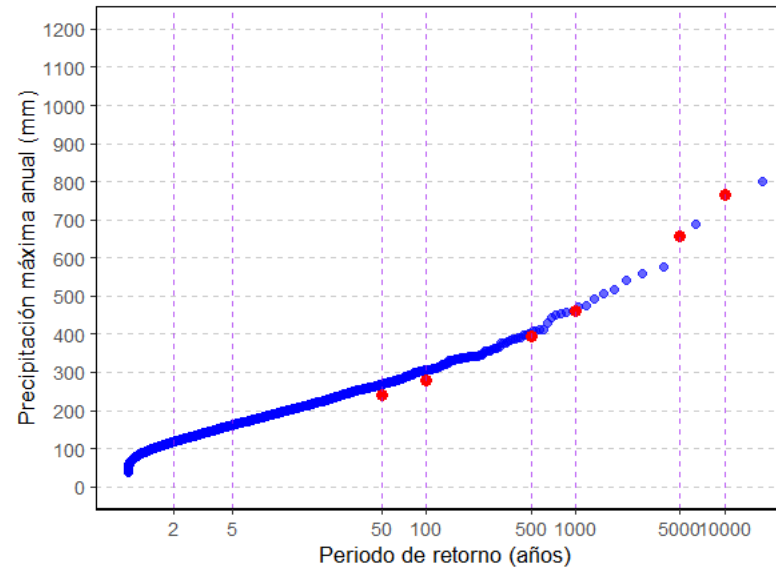
- Adjustment of the ξ parameter for each rain gauge



Poyo [$\xi = 0.17$]

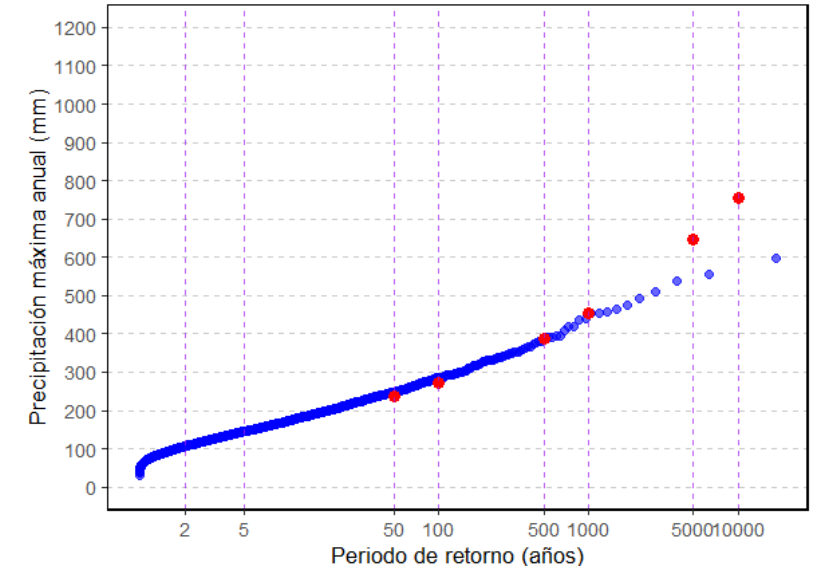


Turis [$\xi = 0.10$]

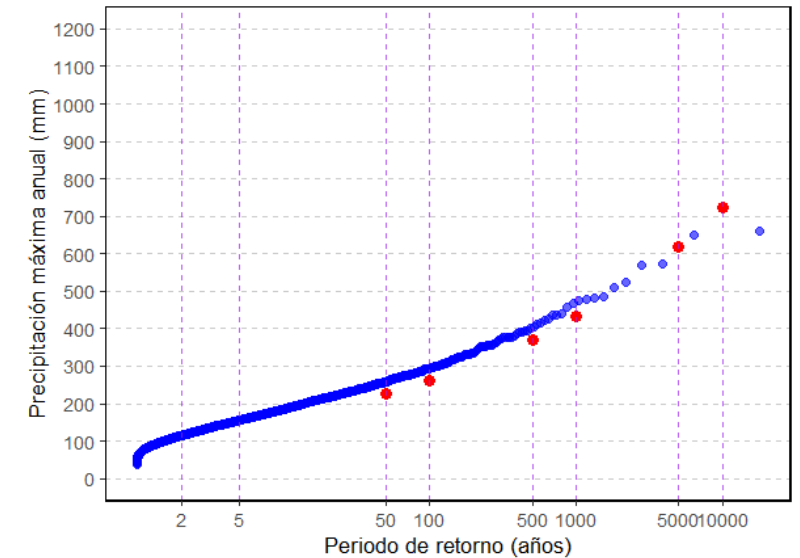


GWEX calibration

Picassent [$\xi = 0.14$]



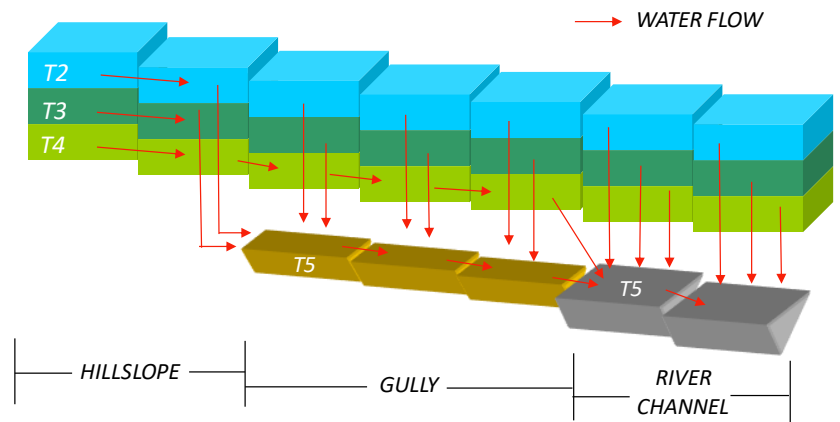
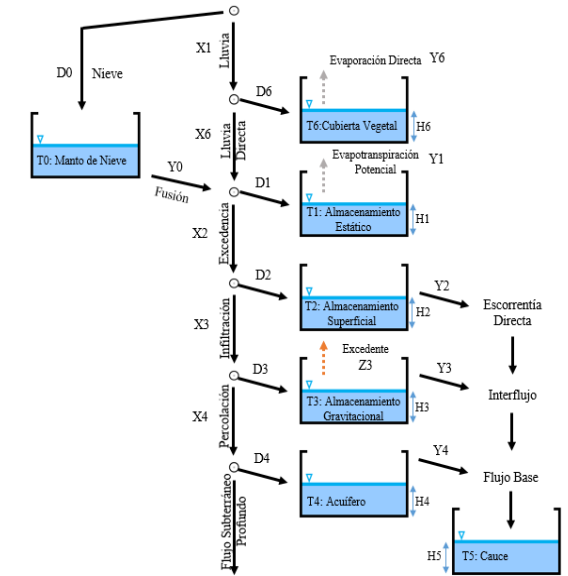
Chiva [$\xi = 0.11$]



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

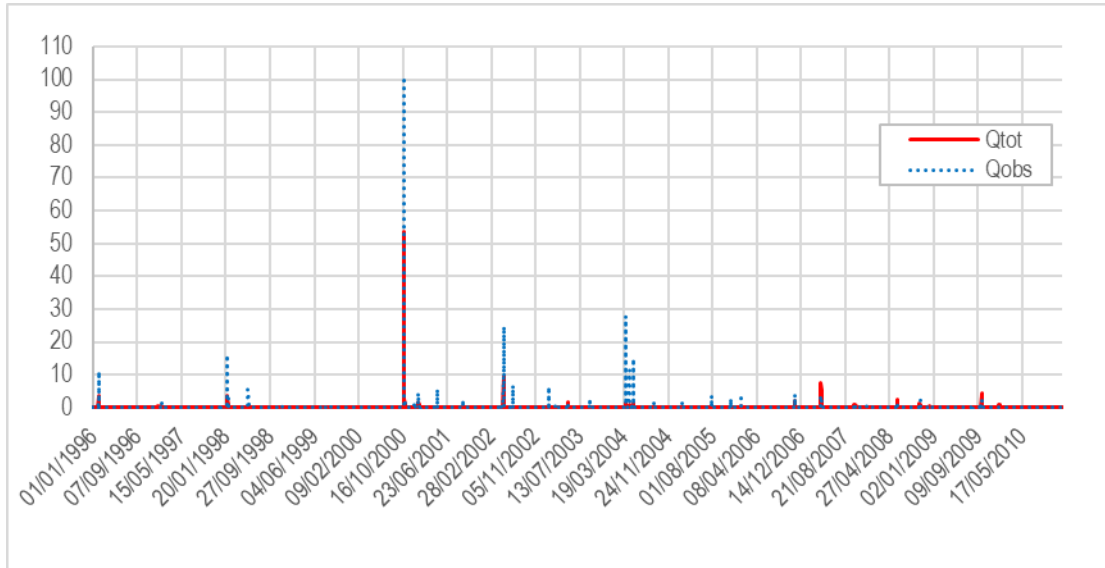
(Francés et al., 2007; Vélez et al., 2009)



TETIS implementation: 100m & daily

Sediments, check dams and transmission losses

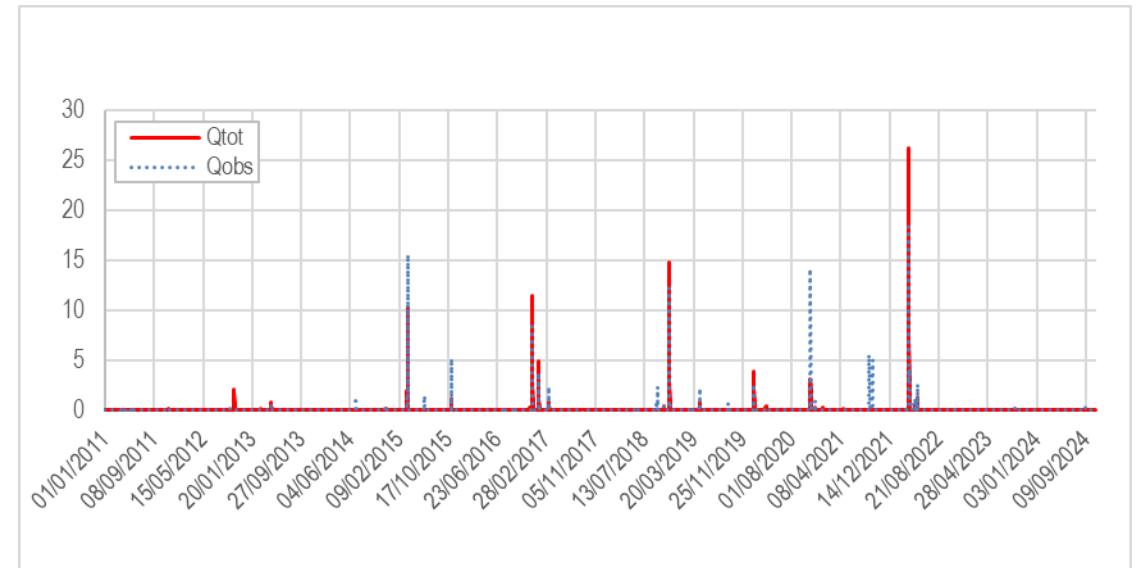
Calibration (1996-2010)



NSE = 0.701

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

Validation (2011-2024)



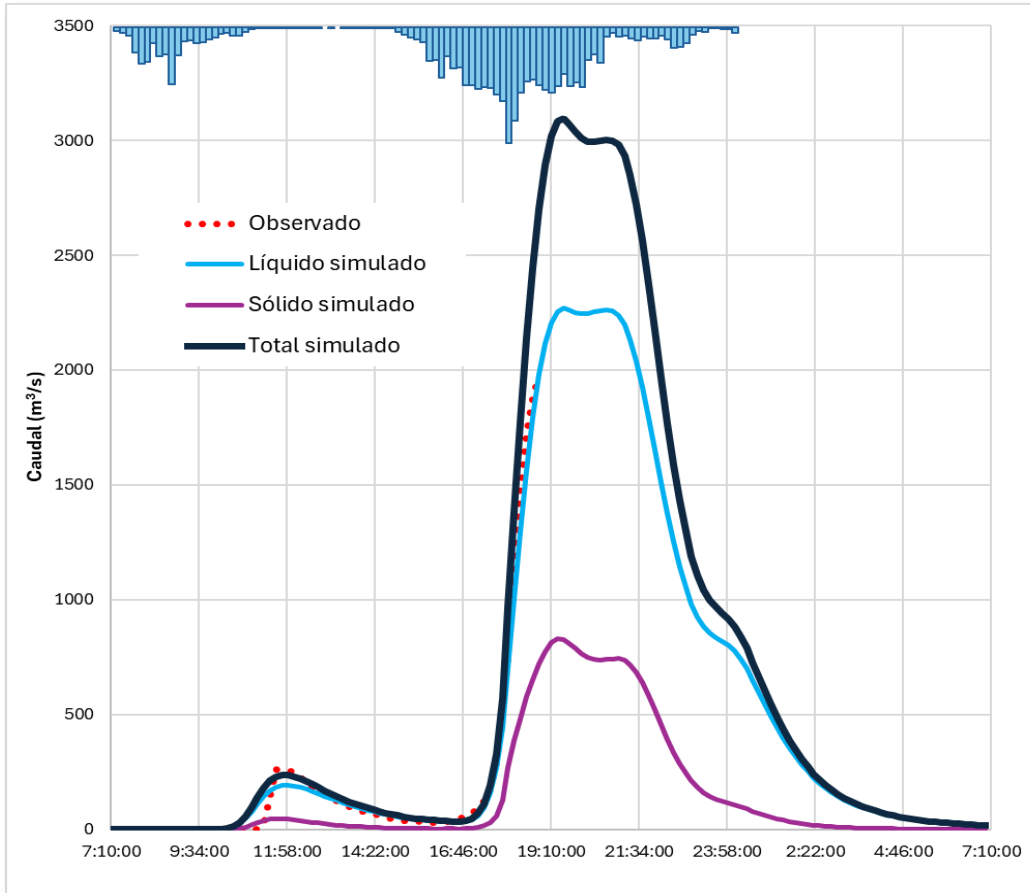
NSE= 0.67

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

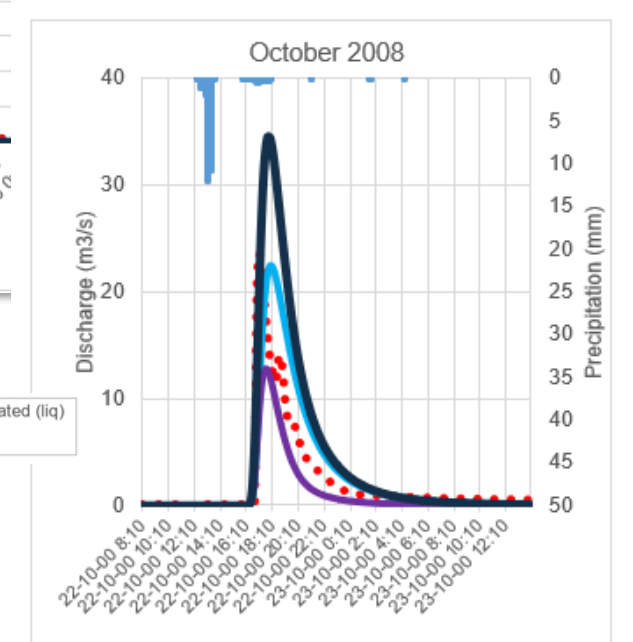
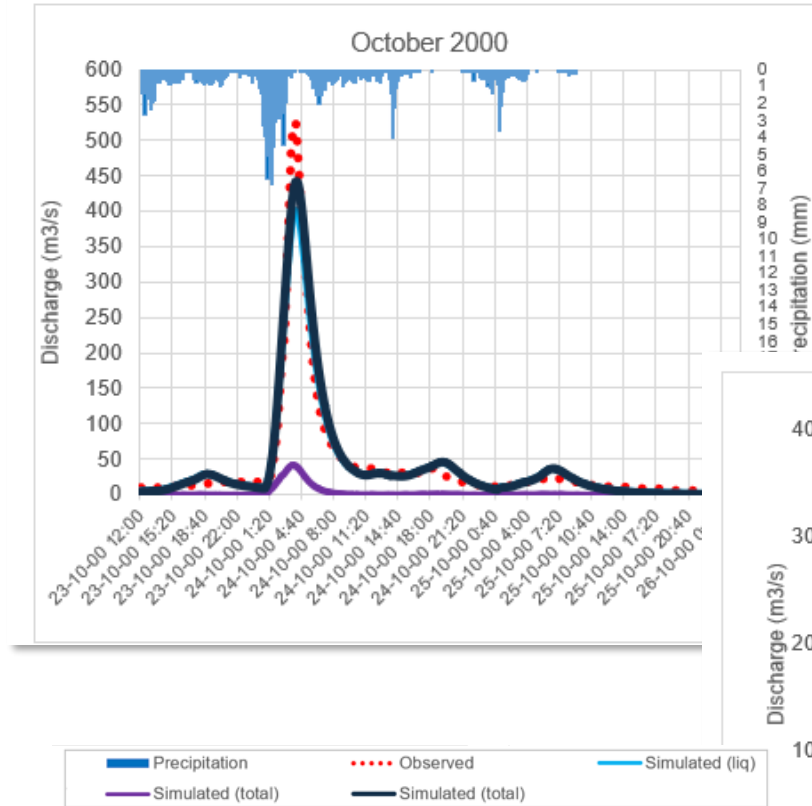
TETIS implementation: 100m & 10min

Sediments and check dams

Calibration at 2024 event

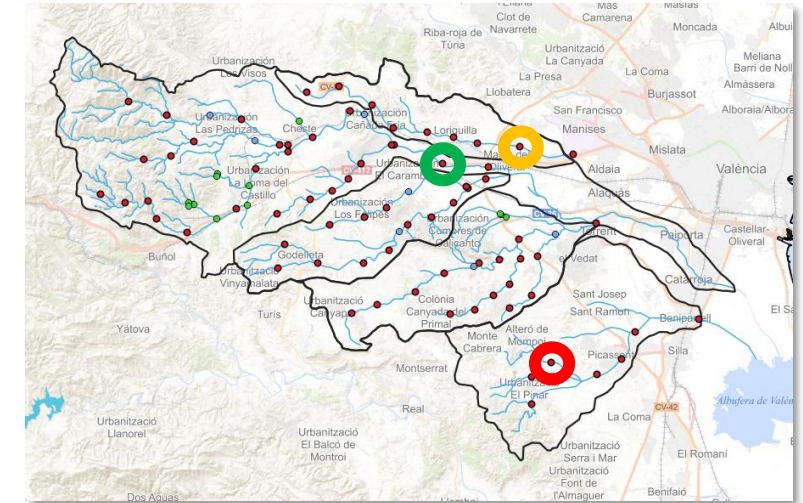


Validations



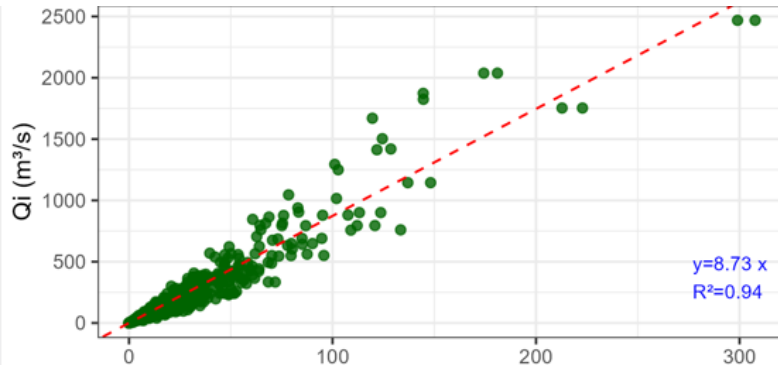
Qp/Qd relationship in 95 locations

- 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

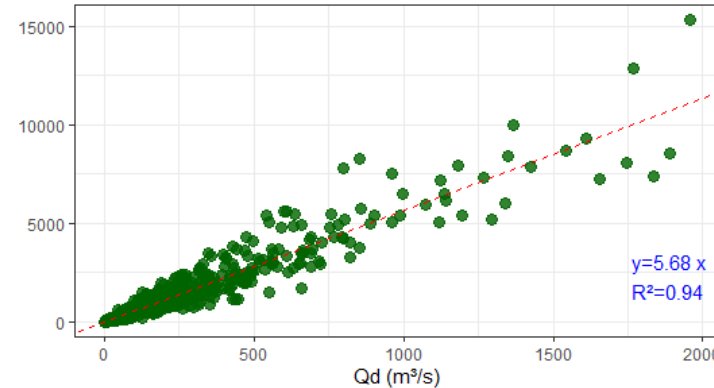


Examples:

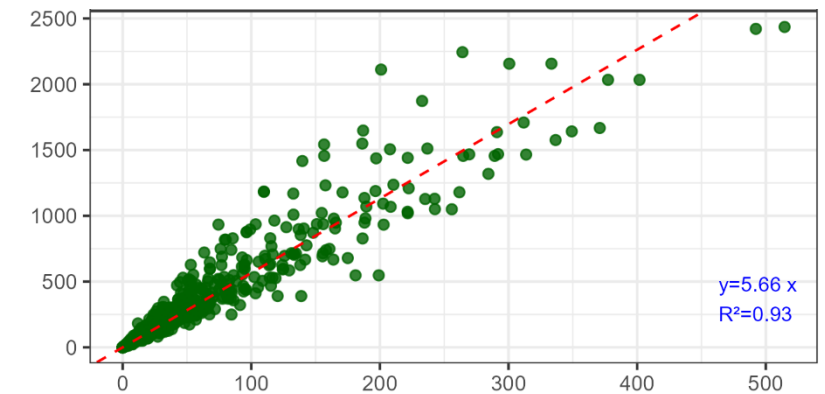
Picassent (Minyerola)

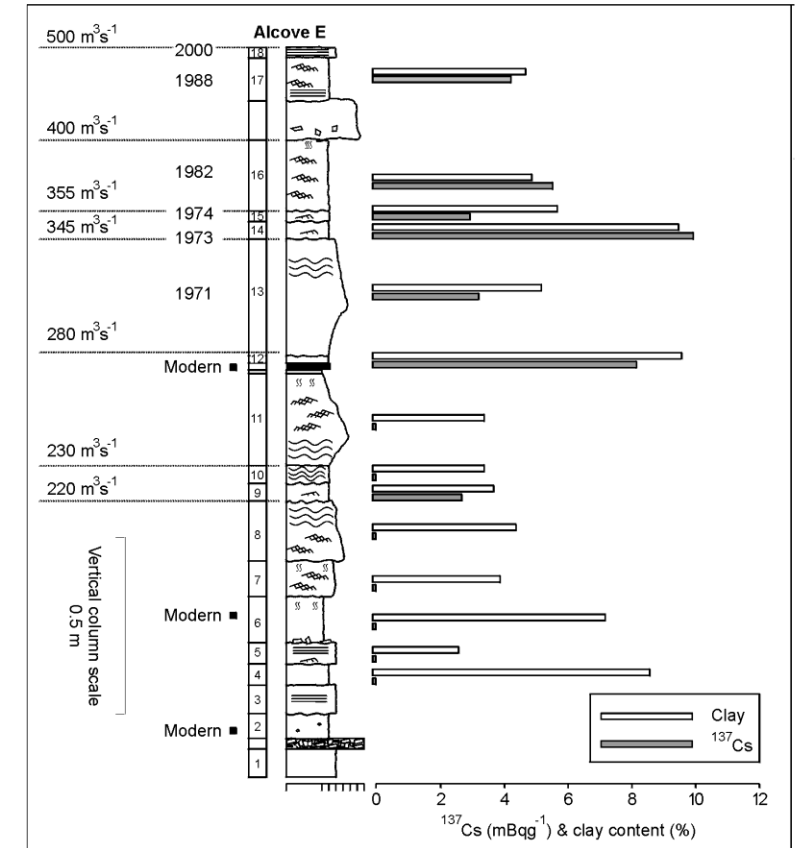


Poyo (sensor)



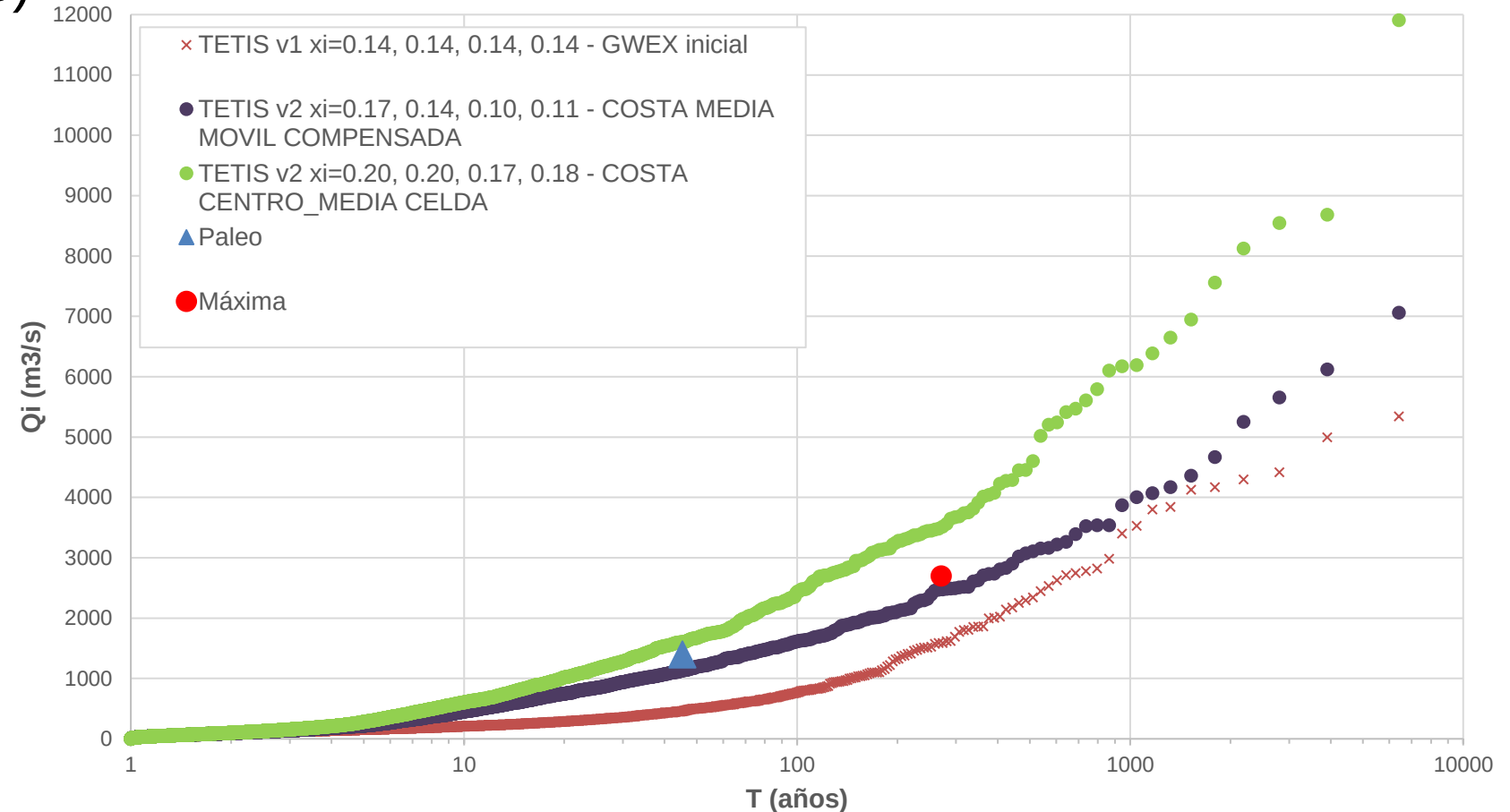
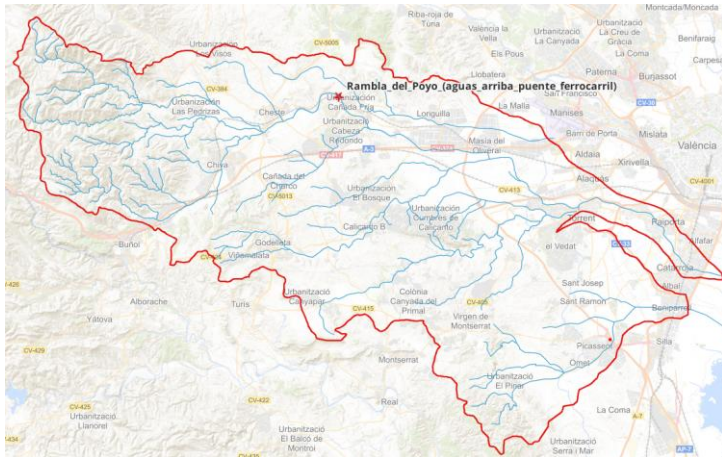
Pozalet (PI Oliveral)





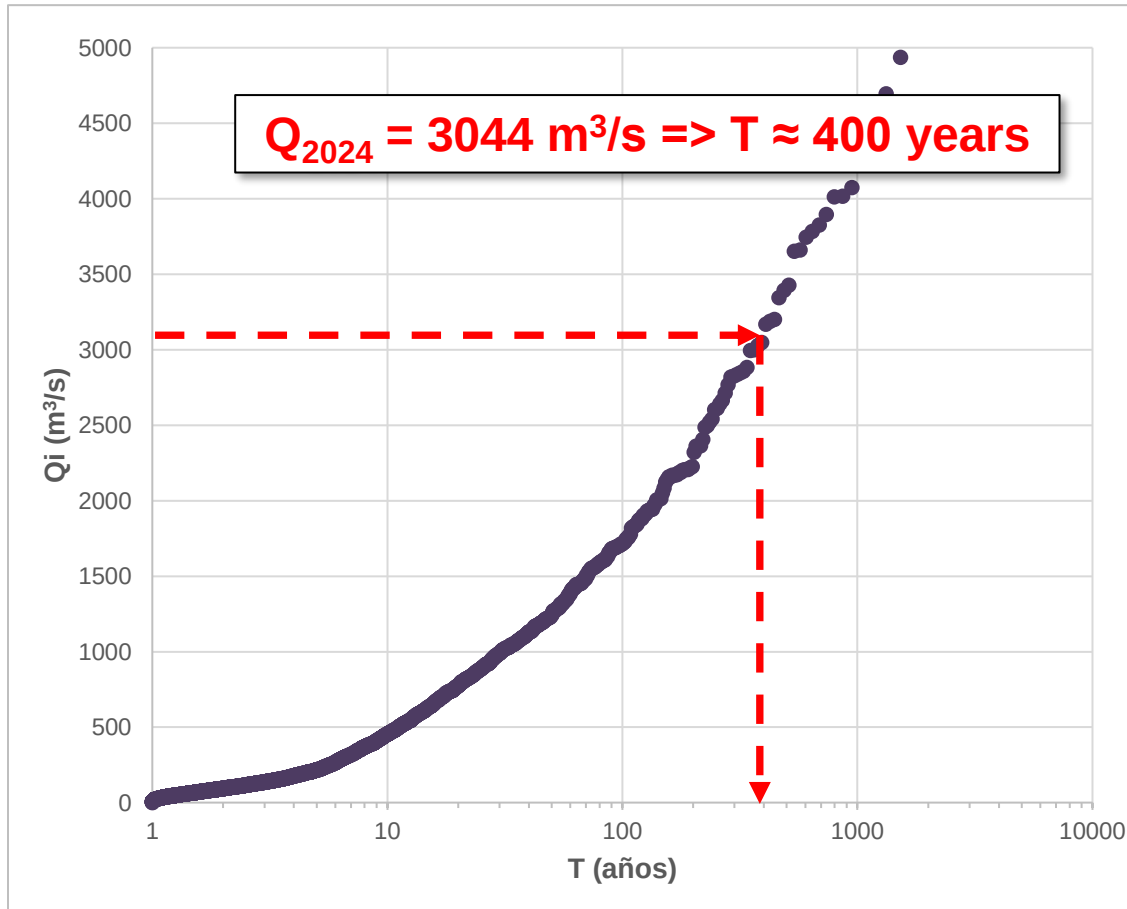
Validation using paleofloods

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

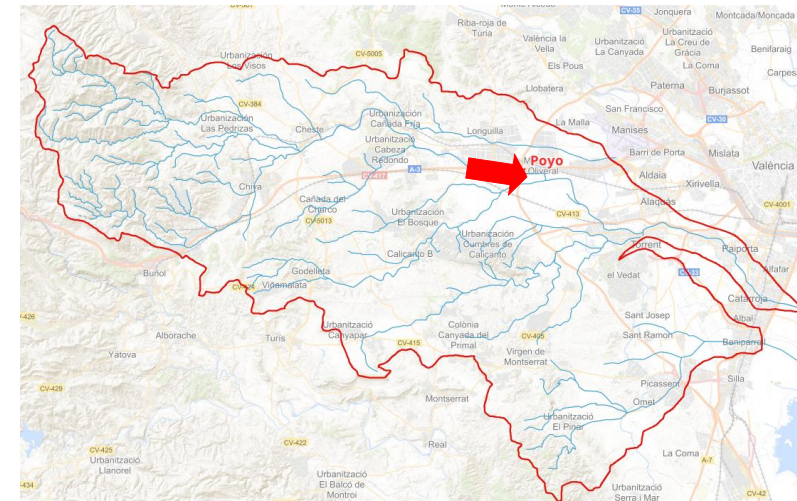


Frequency laws at points of interest

Poyo crossing the A7 highway

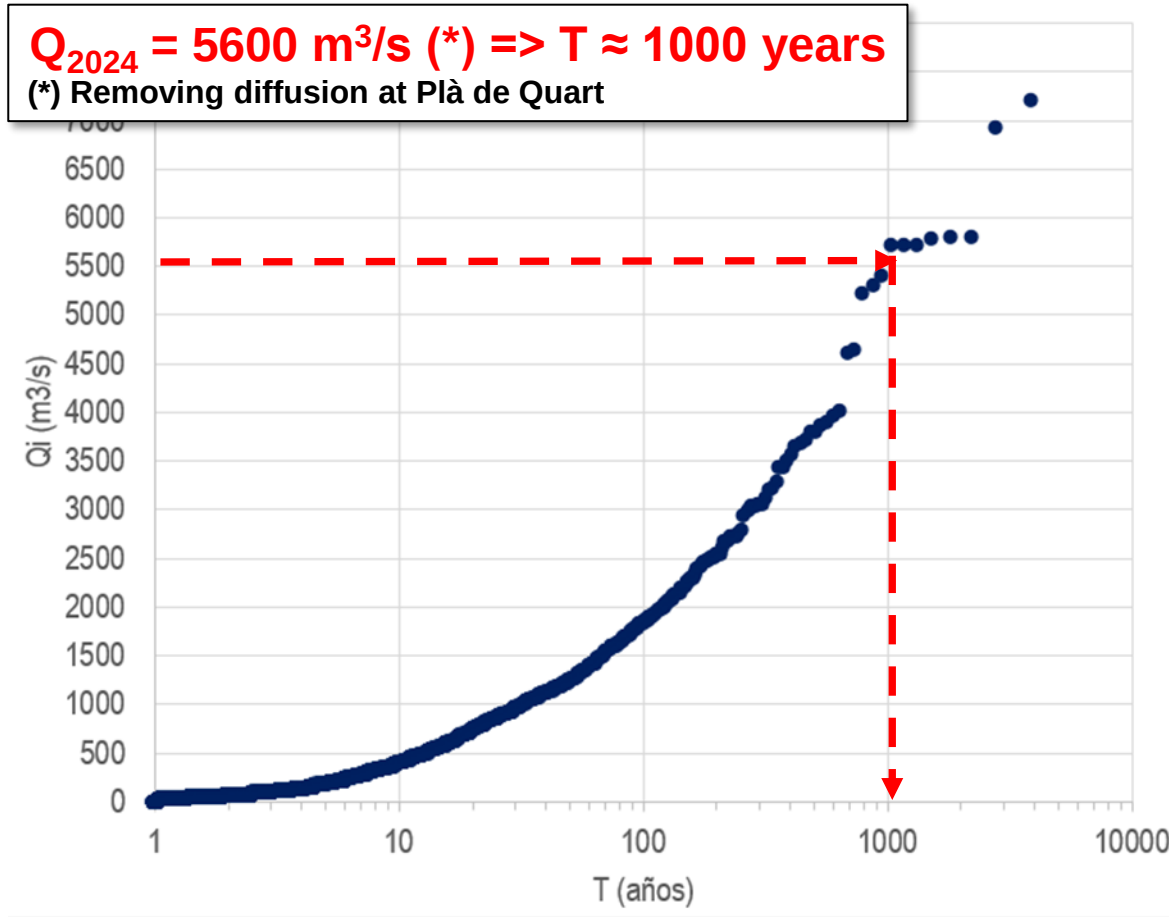


T (years)	Q (m ³ /s)
25	886
50	1,244
100	1,716
200	2,276
500	3,370
1,000	4,157

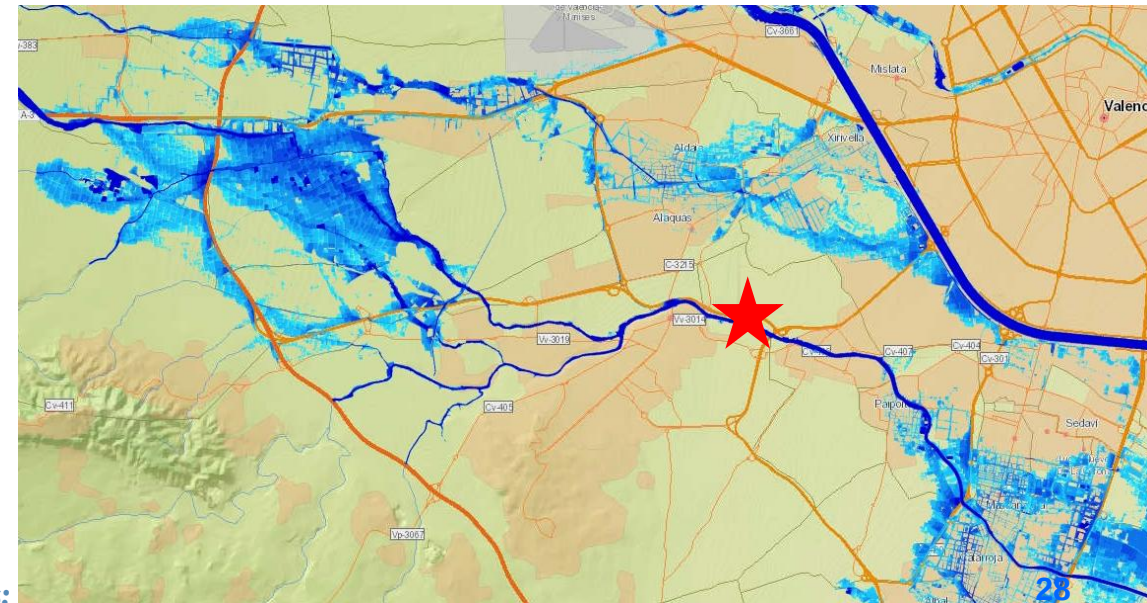


Frequency laws at points of interest

Poyo at Picanya

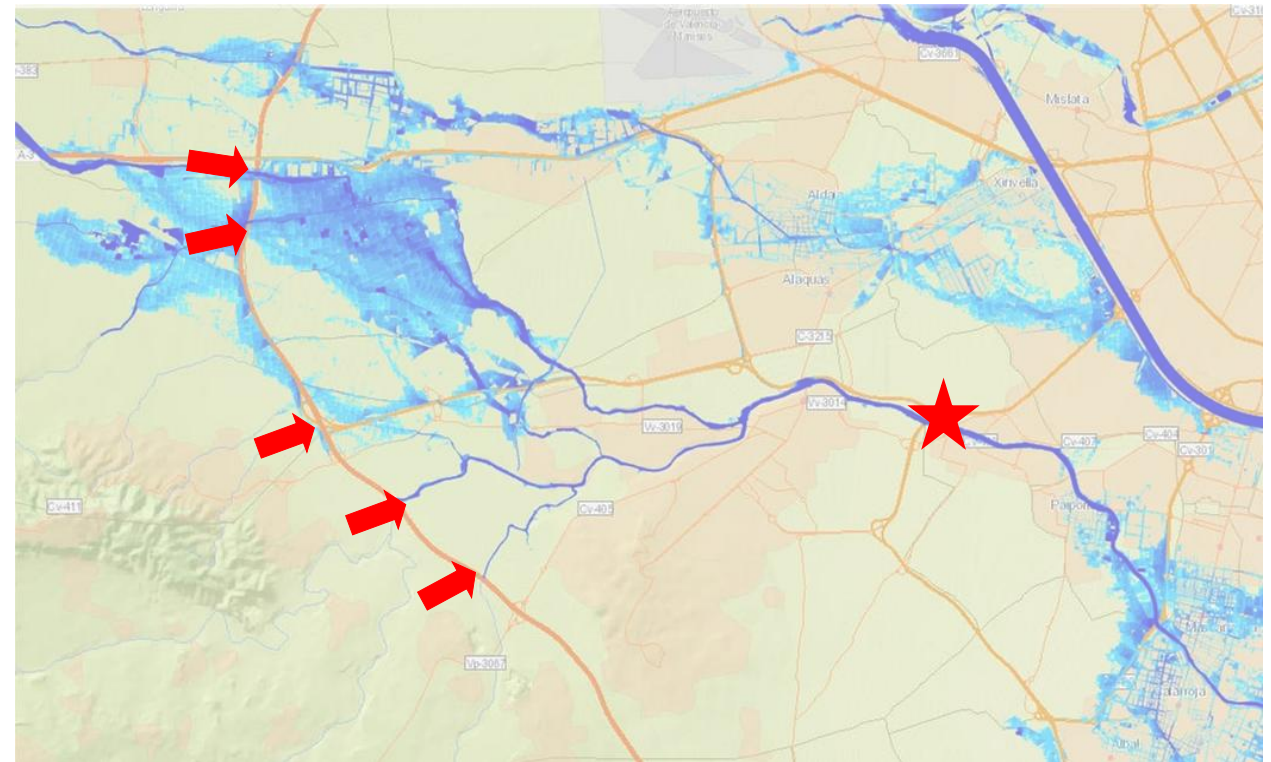


T (years)	Q (m³/s)
25	866
50	1,250
100	1,846
200	2,546
500	3,818
1,000	5,566



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



- ❑ **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 P_{dmax}
 - Use of non-systematic information (historical and/or paleofloods)
- ❑ The measurement of **“extraordinary” depends** on the random variable

Thanks for your attention

Prof. Félix Francés (ffrances@upv.es)

Research Group of Hydrological and Environmental
Modelling (GIMHA)

<https://gimha.upv.es/>



Solidarity Bridge
(01/11/2024)