Runoff variability of an extreme flash flood event on the Catalan Coastal System-Ebro Basin water divide (NE Iberian Peninsula)

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The Espluga de Francolí bridge just after the flood

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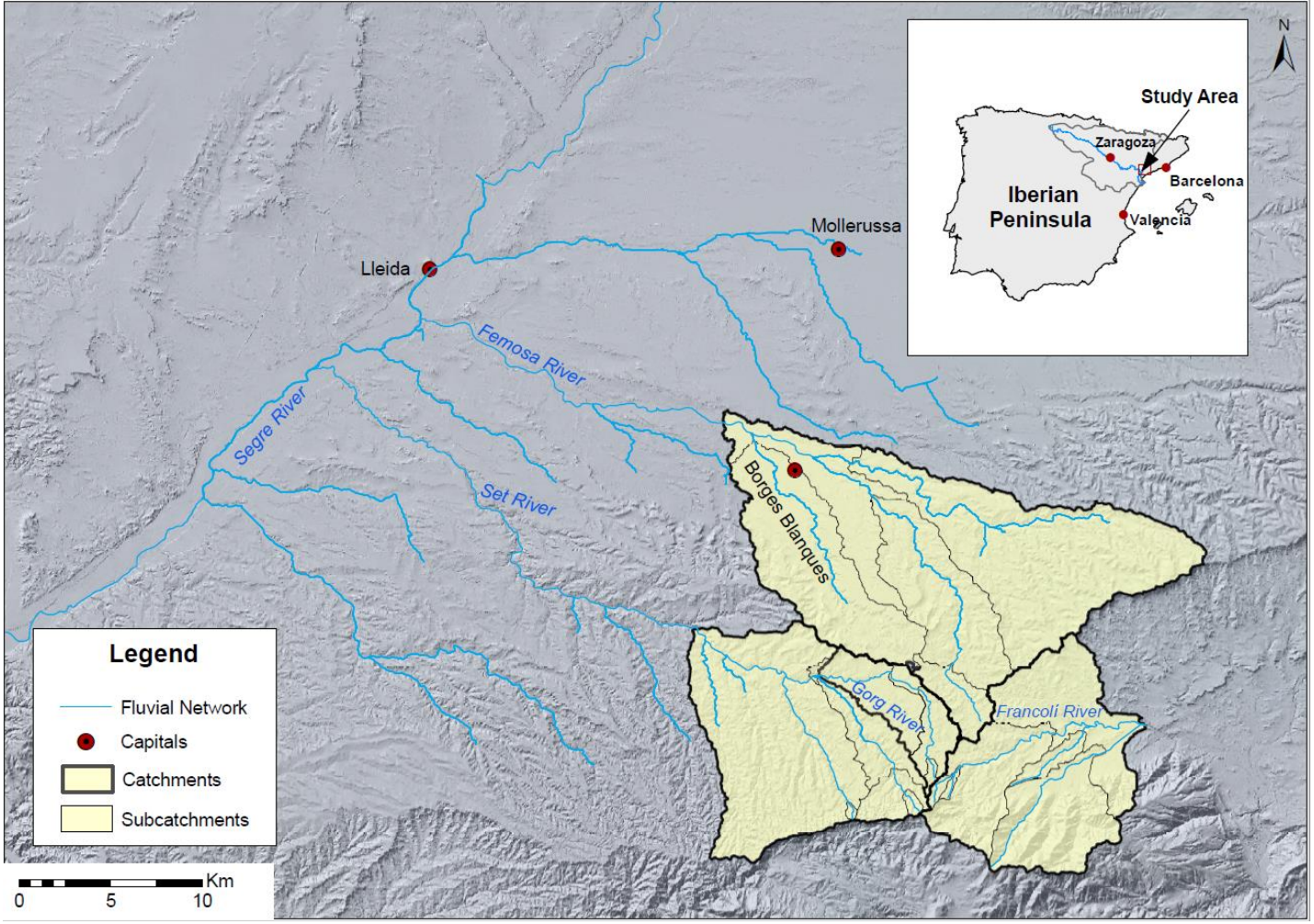


Figure 1. Location of the studied area in the border of Ebro Depression and in the corner NE of Iberian Peninsula

INTRODUCTION On the 22nd and 23rd of October 2019 a severe rainfall produced floods in the basins of the Catalan Coastal Range-Ebro Depression border (Francolí, Gorg, Set, and Femosa rivers) affecting various towns such as Espluga de Francolí, Montblanc, l'Albi, and Vinaixa, among others, causing 6 deaths and material damages that exceeded 100 million euros (Figure 1). According to the instrumental records, the return period for the rainfall episode would exceed 500 years in this region and the maximum heights reached by the water are comparable, or exceed, those of the well studied Santa Tecla flash flood on September 1874, which would have a recurrence period of more than 250 years.

OBJECTIVE

To assess the spatial and temporal distribution of rain and runoff generated by the flash flood in the most affected basins and to evaluate the influence of factors involved in the hydrological response.

METHODOLOGY

Delimitation of affected basins and subcatchments

Measurement of morphometric variables (surface, basin slope, channel slope) and soil uses in the subcatchments

Rainfall map distribution by radar measurement and rain gauges validation

Peak discharges obtained in water discharge gauges and reconstruction from water paleostage indicators (mud, vegetation) using Manning formula and HEC-RAS hydraulic modelling

Runoff volume reconstruction from synthetic unit hydrographs for each subcatchment following the Témez formulas

Spatial and temporal comparison of rainfall and runoff distribution

THE RAIN The precipitation was caused by a S-SE warm and wet Mediterranean air mass affecting the Catalan Coastal System (Prades and Llena Ranges). The area of maximum rainfall depth was located at the headwaters of the rivers Set, Francolí and Montsant (> 200 mm) (Figure 2). The hourly distribution at El Vilosell and Prades rain gauges shows 50 mm from 6 to 14 UTC and maximum intensities of 10 to 15 $mm \cdot h^{-1}$, followed by a second pulse of 180-220 mm from 16 to 01 UTC and maximum intensity of 65 $mm \cdot h^{-1}$ (maximum 3.1 $mm \cdot min^{-1}$)(Figure 3).

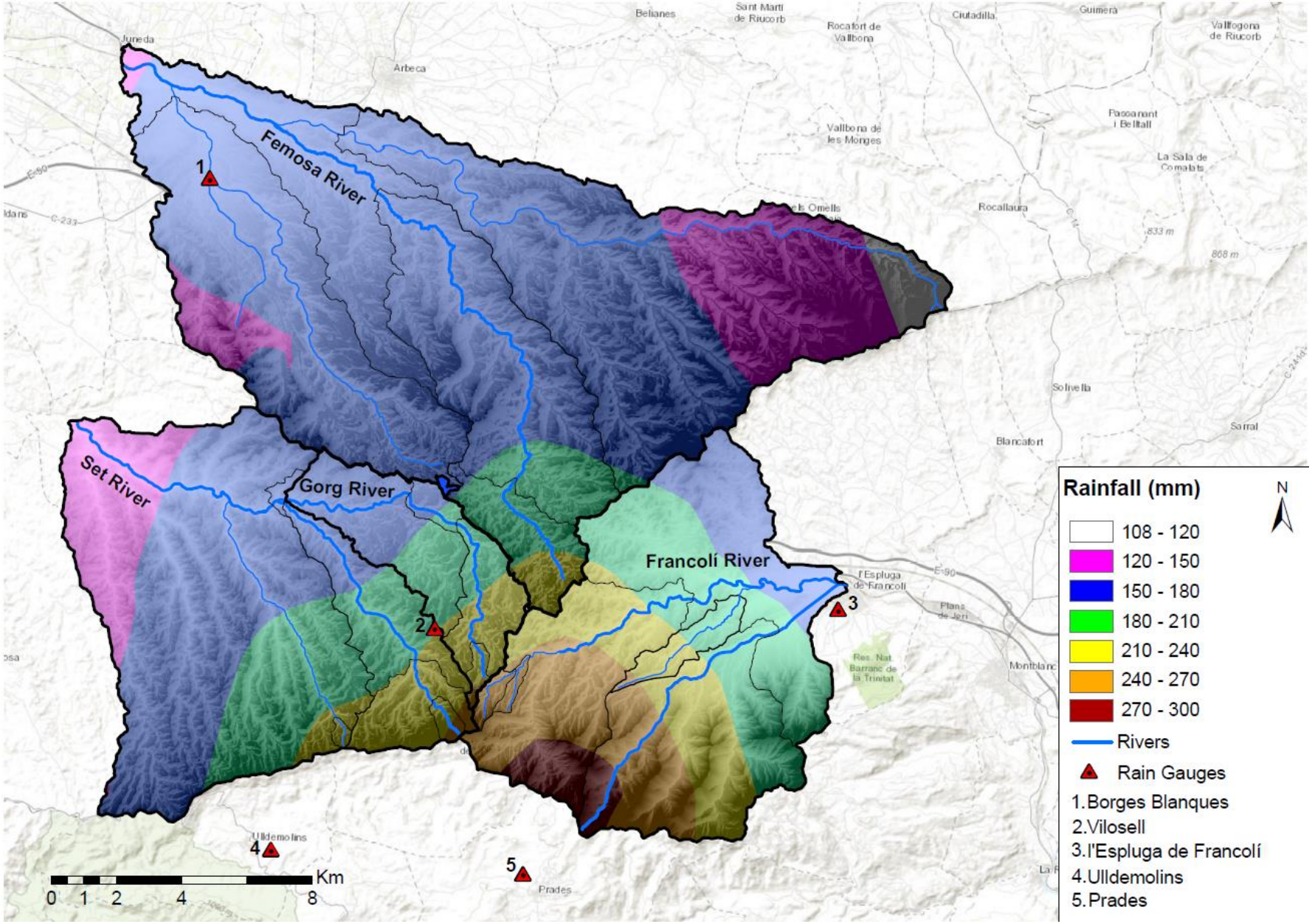
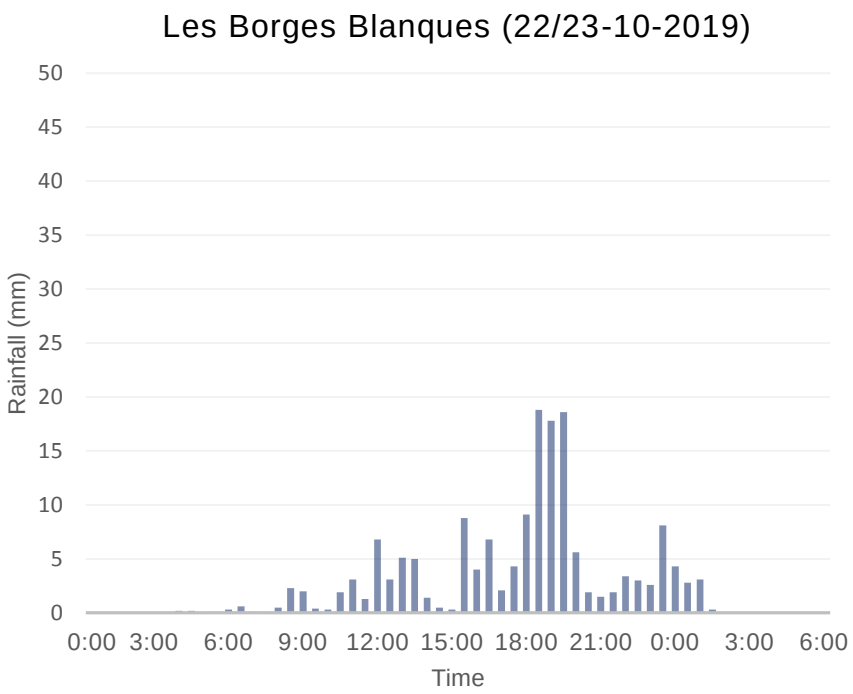
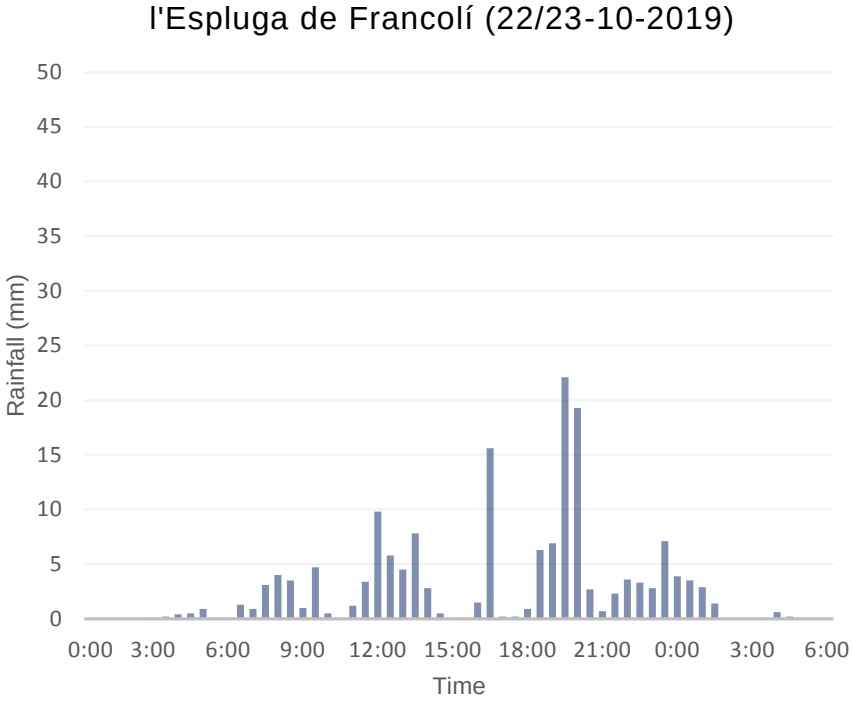
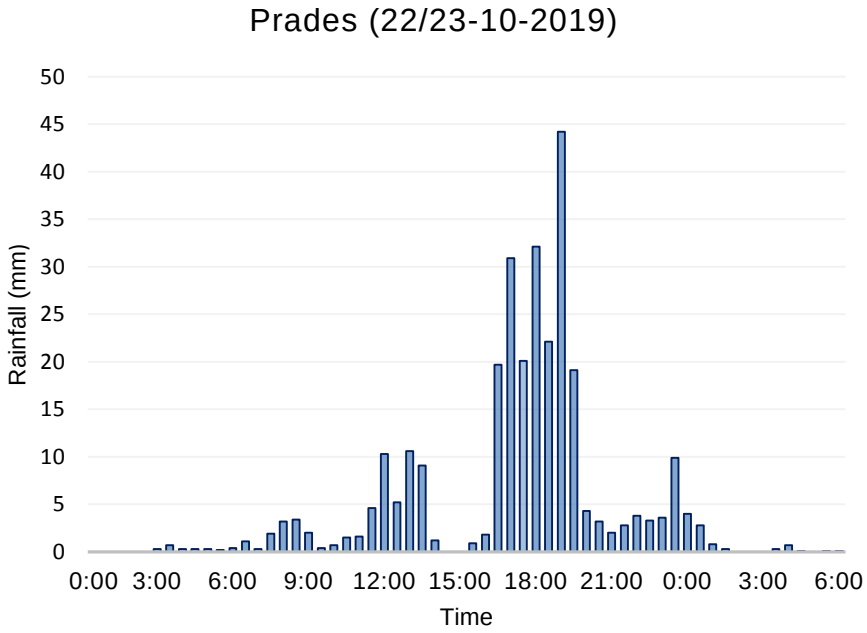


Figure 2. Total rainfall depth distribution (24 h) on the catchments and location of rain gauges







The highest rainfall intensity occurred around 18-19 UTC (Figure 3) and the peak flow response was immediate, around an hour later in the smallest basins, and four hours in the largest ones.

Early precipitation saturated the topsoil. Consequently, the second rainfall event generated a hortonian overland flow.

Figure 3. Rainfall hietographs in several points of the catchments. Intensities corresponds to intervals of 30 minutes

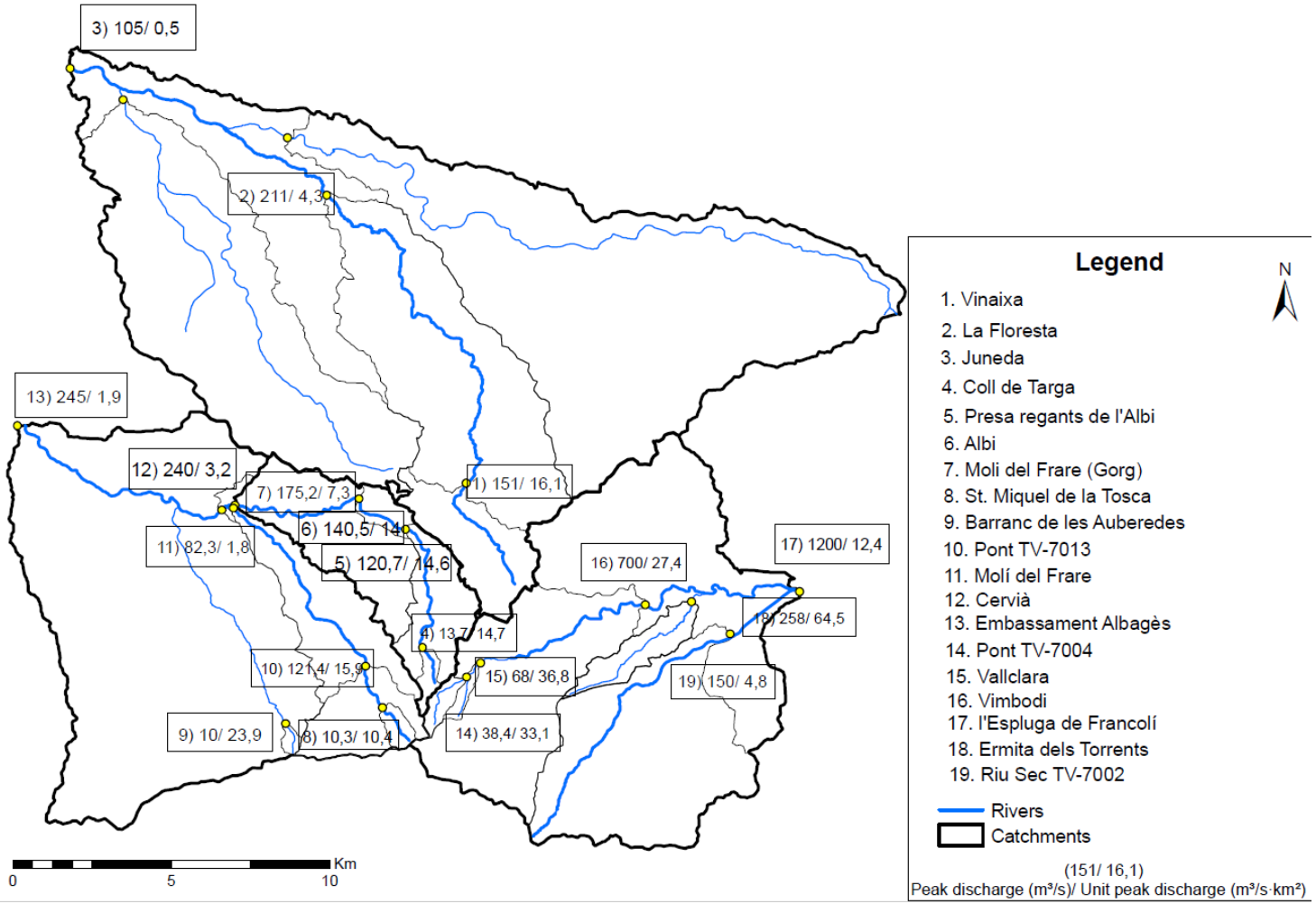


Figure 4. Peak flow and unit peak discharge distribution

HYDROLOGICAL RESPONSE (I): PEAK FLOWS AND UNIT PEAK DISCHARGES

Despite the similar characteristics of the rainfall in the headwaters and the initial soil moisture conditions, the hydrological response in the analyzed basins was markedly different. Table 1 and Figure 4 show the results of the hydraulic and hydrological analysis. The flows generated in the Set, Gorg and Femosa basins have unit peak discharges between 10 to 24 $m^3 \cdot s^{-1} \cdot km^{-2}$ for the smallest basins (size: 1-10 km^2) and values between 0.5-1.8 $m^3 \cdot s^{-1} \cdot km^{-2}$ for the largest (size > 100 km^2). In contrast, in the Francolí basin the unit peak discharges were higher than 30 $m^3 \cdot s^{-1} \cdot km^{-2}$ for small basins (1-10 km^2) and reached 13.7 $m^3 \cdot s^{-1} \cdot km^{-2}$ for the Espluga de Francolí basin (100 km^2).

Table 1. Morphometric and hydrological variables of the catchments. Tc is the Time of concentration

Catchment	Surface	Length	s (slope)	Tc	Peak discharge	Unit peak discharge	Runoff volume	Rain depth	Rain volume	Runoff Coefficient
	(km^2)	(km)	(m/m)	(h)	(m^3/s)	($m^3/s \cdot km^2$)	(m^3)	(mm)	(m^3)	
FEMOSA RIVER										
Vinaixa	9,36	4,06	0,025	1,75	151	**16,13**	572750,7	206,1	1929096	**0,30**
La Floresta	48,77	12,61	0,0203	4,31	211	**4,33**	1970240	177	8632290	**0,23**
Fondo Trull	88,3	22,69	0,0196	6,79				152	13421600	
Fondo Salat	55,18	15,7	0,0187	5,18				156	8608080	
Juneda	220,39	26,56	0,0126	8,32	105	**0,48**	1890818	159	35042010	**0,05**
GORG RIVER										
Coll de Targa	0,93	1,11	0,0404	0,59	13,7	**14,73**	50625,09	235,3	218829	**0,23**
Presa regants de l'Albi	8,25	5,72	0,0264	2,25	120,7	**14,63**	587950,9	217	1790250	**0,33**
l'Albi	10,02	7,6	0,0233	2,86	140,5	**14,02**	869790,3	201,3	2017026	**0,43**
Molí del Frare	23,98	12,13	0,0206	4,18	175,2	**7,31**	1583985	191,4	4595514	**0,35**
SET RIVER										
St Miquel de la Tosca	0,99	1,34	0,2451	0,48	10,3	**10,40**	60405,63	239,3	236907	**0,25**
Bc. de les Auberedes	0,42	0,73	0,2697	0,30	10,05	**23,93**	54885,08	218	91560	**0,60**
Pont TV-7013	7,62	2,7	0,1452	0,92	121,4	**15,93**	241768,1	223,5	1703070	**0,14**
Molí del Frare	19,78	10,47	0,0521	3,13	82,3	**4.16**	557798,9	193,4	8859654	**0,15**
Cervià Garrigues	44,37	11,82	0,0472	3,50	240	**5,41**	1817478	195,1	14490077	**0,21**
Albagès reservoir	130,98	17,72	0,0338	5,07	245	**1,87**	2689192	174,3	22829814	**0,12**
FRANCOLÍ RIVER										
Pont TV-7004	1,16	1,2	0,0543	0,59	38,4	**33,10**	142050,6	240,2	278632	**0,51**
Vallclara	1,85	1,88	0,0517	0,85	68	**36,76**	288551,8	241	445850	**0,65**
Vimbodí	25,57	8,77	0,0307	3,02	700	**27,38**	4584996	249,2	6372044	**0,72**
l'Espluga de Francolí	96,99	14,64	0,0233	4,71	1330	**13,71**	12226788	220,5	21386295	**0,57**
Ermita dels Torrents	4	1,88	0,0048	1,33	258	**64,50**	745867	218,7	874800	**0,85**
Riu Sec a TV-7002	31,15	6,92	0,0361	2,45	220	**7,06**	795725,1	233	7257950	**0,16**

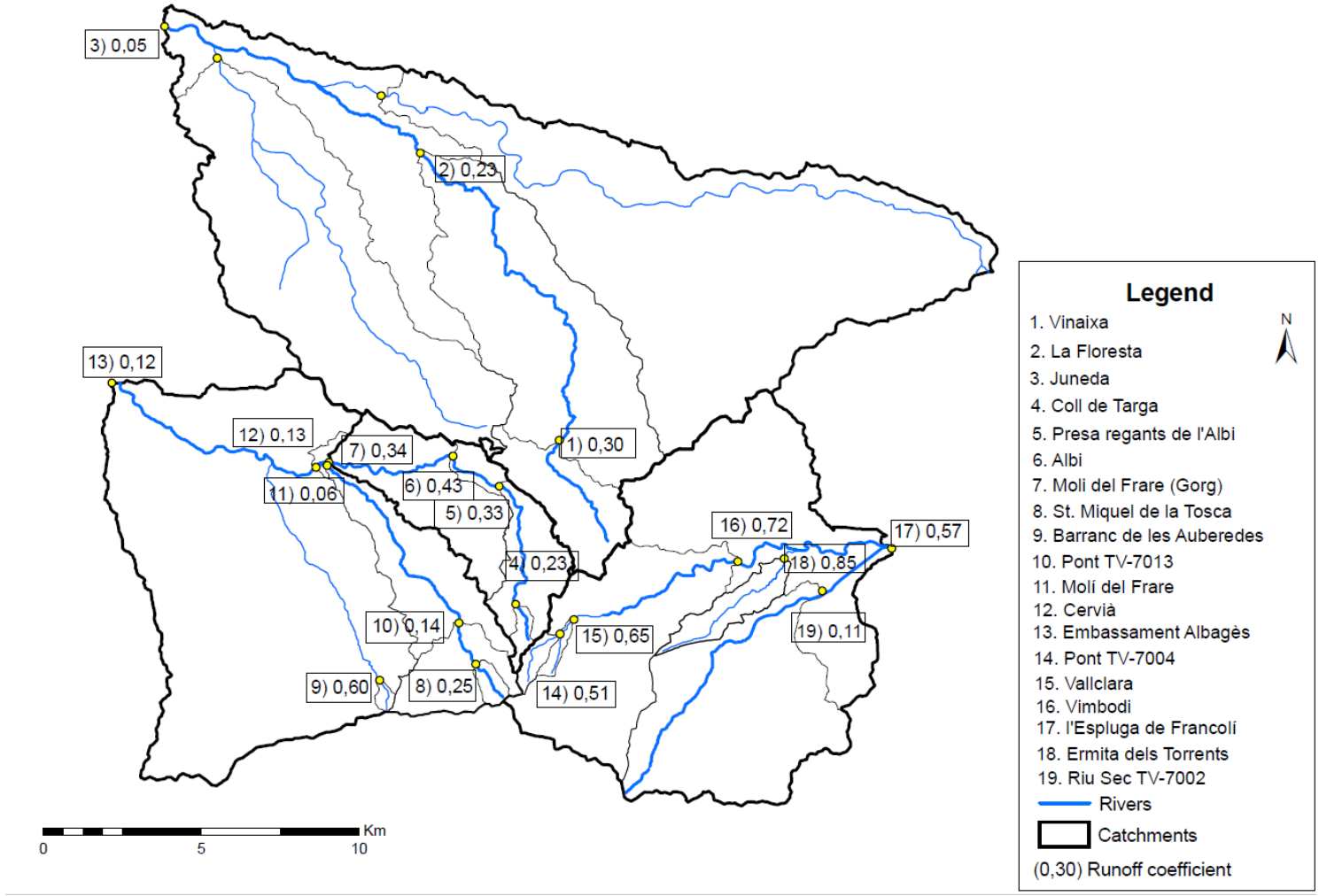


Figure 5. Runoff ratios distribution in the catchments

HYDROLOGICAL RESPONSE (II): RUNOFF RATIOS

The runoff ratio or relation between runoff and rainfall for a catchment also shows contrasted behaviour (Table 1 and Figure 5). In the Set, Gorg and Femosa basins the runoff ratio oscillates between 0.05 in the lower reaches and 0.43 in headwaters. Low runoff ratios are related with runoff losses by retention and infiltration in the floodplain of the lower courses by an old agricultural croplands transformation. The runoff ratios in the Francolí river catchments were very elevated ranging between 0.51-0.85. The low ratio in Riu Sec is provoked by karstic losses and this water yields the Espluga springs and the Ermita dels Torrents creek.

ROLE OF THE LAND USE The Set, Femosa and Gorg river basins are basically agricultural with old terraced slopes that retained much of the precipitation and only releasing it after the flood has occurred, as baseflow. The Francolí river basin is dominated by an extensive forest cover but very poorer soils that caused little water retention, giving rise to a major hydrological response, an order of magnitude larger than that of the Set, Gorg and Femosa rivers in the case of maximum peak discharges.

CONCLUSIONS

- During the flash floods of October 22, 2019 in Catalonia, intense precipitation over an already saturated soil generated a very sudden and rapid response with huge and destructive peak flows. Although the characteristics of the rainfall and the morphology of the basins and rivers were similar throughout the affected area, the western basins of the rivers Set, Femosa and Gorg had a lower hydrological response than that of Francolí due to water retention and delay produced by the agricultural terraces, much more frequent in the first sector.
- The specific peak flows of these flash floods in the headwaters (S <10 km^2), especially those in the Francolí river are among the highest of the available records with values of up to **36,7 $m^3 \cdot s^{-1} \cdot km^{-2}$**. In the NE of the Iberian Peninsula only similar values are found in the events of Vallès (1962), Biescas (1996) or Montserrat (2000). Historically, these values are similar to the ones estimated during the Santa Tecla flash flood of 1874.
- Much of the transverse structures (bridges) of the headwaters were overgrown or destroyed, a symptom of a clearly insufficient hydraulic design.

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