Young water fractions at diverse time scales are driven by varying runoff generation processes in a Mediterranean small research catchment

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Outline

→ **The concept of young water fraction (F_{yw},, 1) is an emerging approach for analysing the turnover of waters in catchments, eluding questionable assumptions on Transit Time Distributions.**

→ **The F_{yw} in stream waters usually increases with catchment wetness (2)**

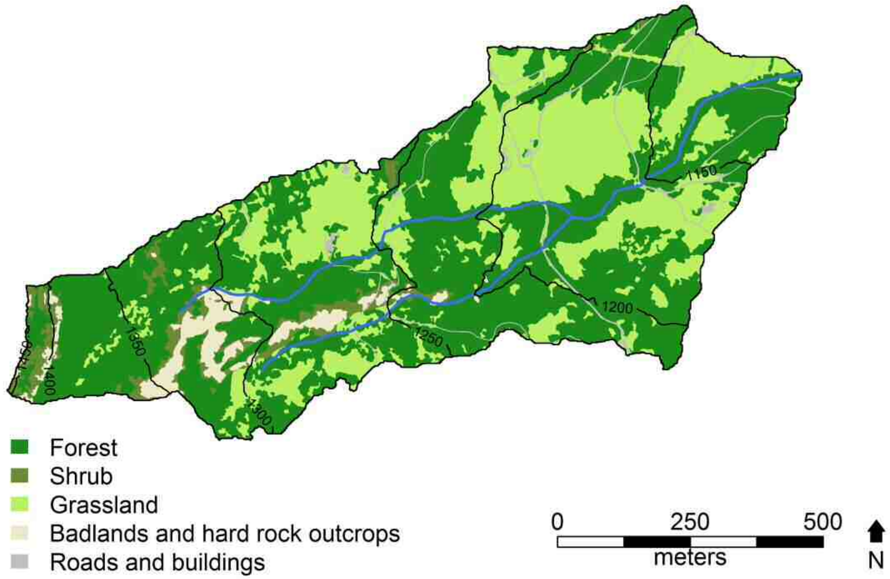
→ **But some studies (3, 4) alert that different investigated periods may give significantly different F_{yw} results in the same catchment.**

- **The working hypothesis of this study is that F_{yw} cannot only be investigated for full year periods or flow ranges (2, 5, 6) but also for selected groups of events with similar characteristics.**
- **Runoff events with similar forcing and response characteristics, selected from a wide range, might be associated to given runoff generation mechanisms and hopefully to comparable young water fractions.**

- **This test is possible at the Can Vila catchment thanks to its highly varying response and the intensive isotopic sampling performed there**

1: Kirchner (2016a) HESS
2: Kirchner (2016b) HESS
3: Stockinger et al., 2019 HESS
4: Gallart et al., (2020b) HYP
5: von Freyberg et al., 2018 HESS
6: Gallart et al., 2020a HESS

Can Vila catchment (Vallcebre)



Established:	1994
Location:	Catalan Pyrenees
Area:	0.56 km^2
Altitude:	1,100–1,462 m a.s.l.
Mean Ann. Precipitation:	862 mm
Eto:	823 mm
Recording step:	5 min
Precipitation sampling	5 mm intervals
Stream water sampling	30 min to 1 week.

Precipitation is mainly equinoctial but intense rainstorms usually occur in summer.
Flow is rainfall dominated
Flow usually ceases a few weeks in late summer
Flow duration curve is highly skewed:
27% of flow occurs during 1% of time.

Former research results using hydrometric data (1, 2) showed that the rainfall-runoff events in this catchment can be classified into three types:

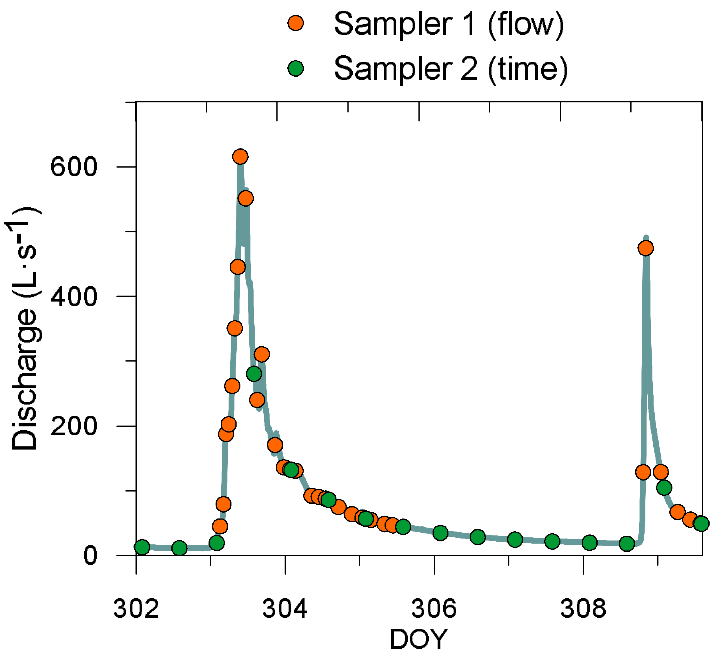
Type 1: Flashy events due to short intense showers during dry antecedent conditions
Type 2: Moderate events with limited recessions due to large rainfall events during dry antecedent conditions
Type 3: Moderate to large long-lasting events due to moderate precipitation fallen during wet antecedent conditions

1: Latron & Gallart (2008) JoH **2: Llorens et al, (2018) GRL**

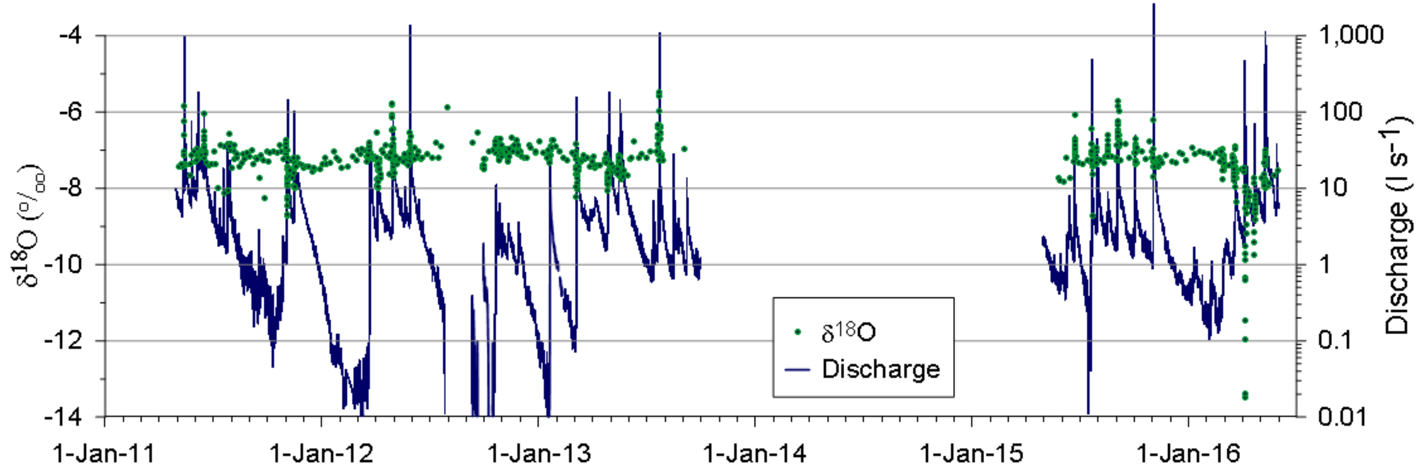
Sampling design

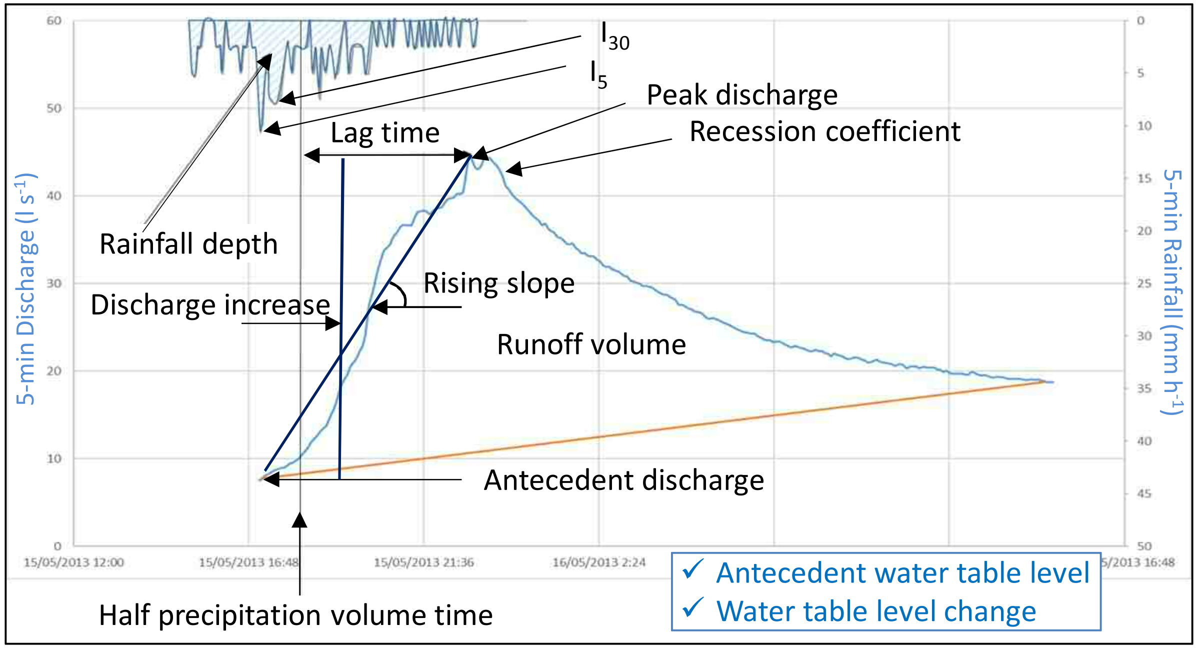
Precipitation:
Weekly and 5mm steps
464 samples

Stream waters: ‘smart sampling’ using two automatic samplers
One triggered by time and the other by flow rate
Variable time sampling: 30 minutes to 1 week.
859 samples



Sampling results (40 months)



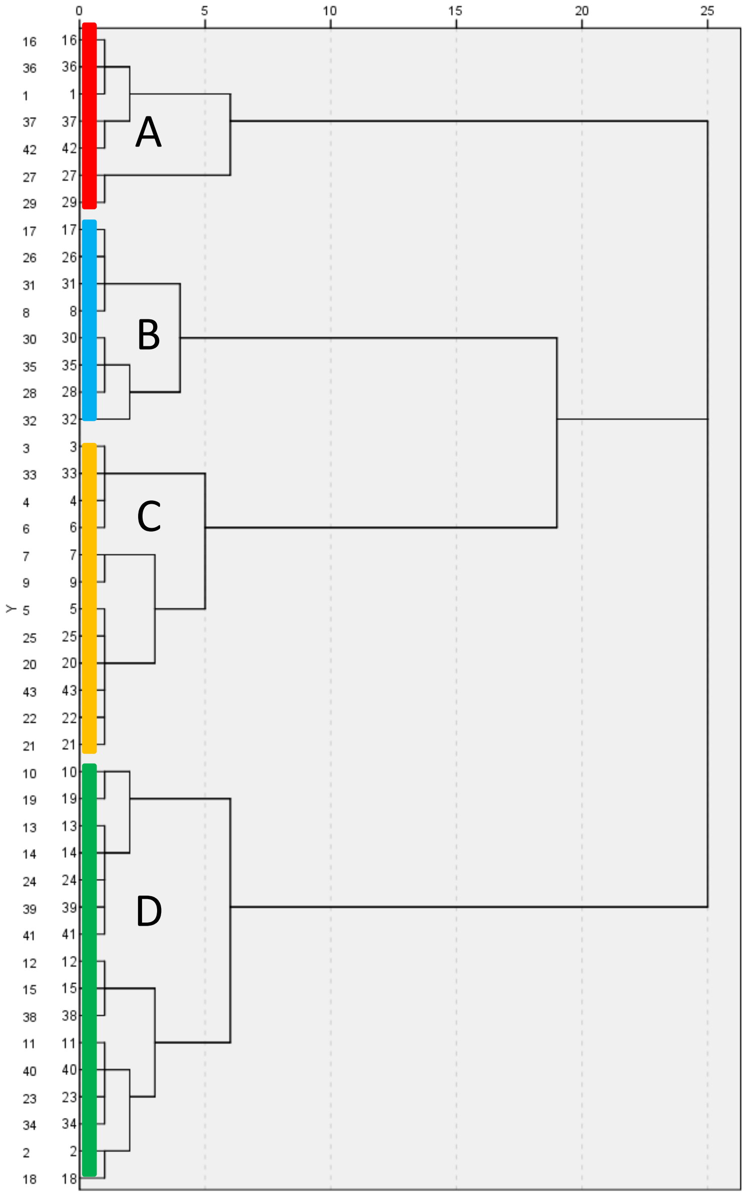


Precipitation during the sampling period was similar to that of the long term record

42 rainfall-runoff events were identified and characterized.

15 hydrometric variables were used for identifying these events

Event classification



Vx Rotated Factor	Squared Load	Variance %	Cumulated %
1	**4.9**	**34.8**	**34.8**
2	**3.2**	**22.6**	**57.5**
3	**2.8**	**19.9**	**77.4**

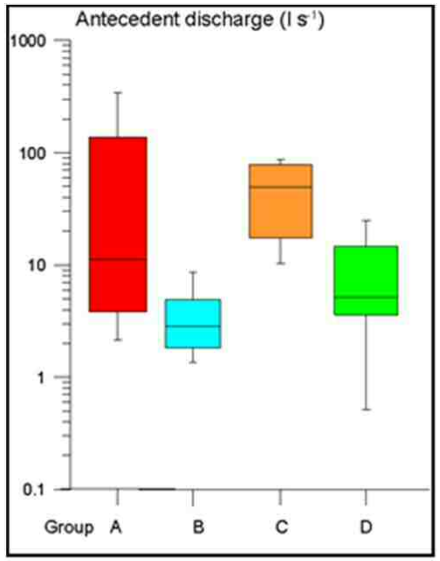
A factor analysis was performed with the 15 hydrometric variables, after logarithmic transformations when needed.

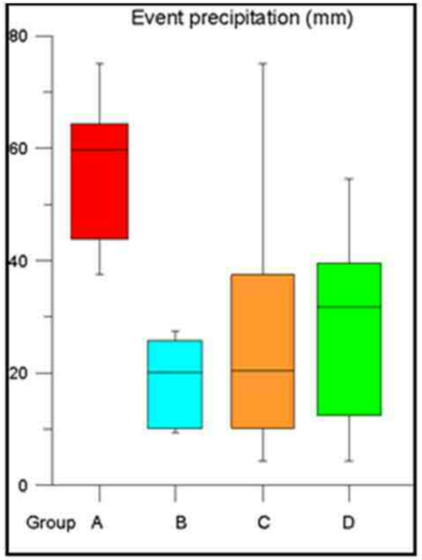
The three first VARIMAX rotated factors were mainly related to:

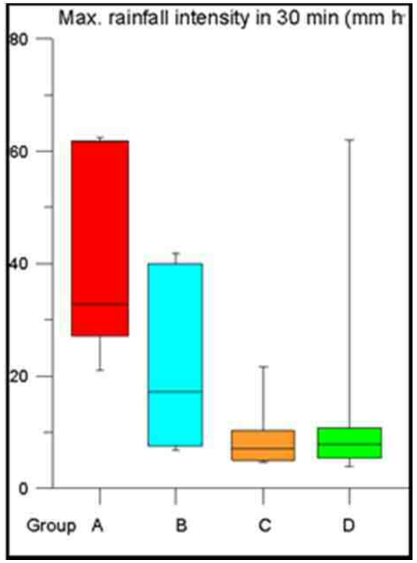
Factor 1: Event volumes
Factor 2: Event intensities
Factor 3: Antecedent conditions

Four well defined clusters were obtained using the Ward method analysis

Event classification: forcings







The event forcings had some significant differences between the four types:

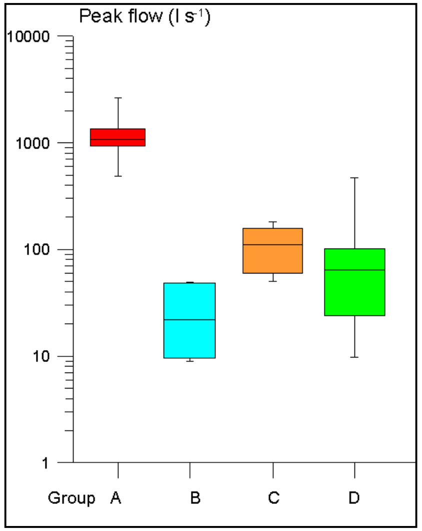
A: Wide range of antecedent discharges, except the driest. Highest precipitation volumes and intensities

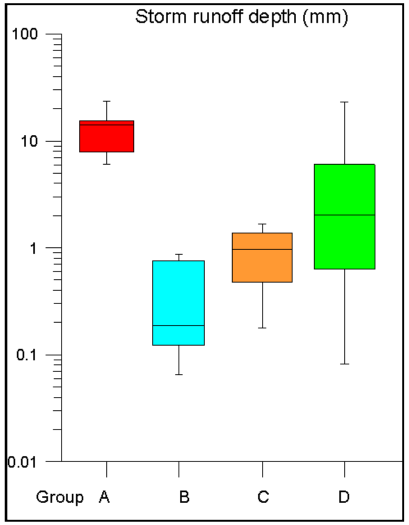
B: Lowest antecedent discharges, low-moderate precipitation volumes medium to high rainfall intensities

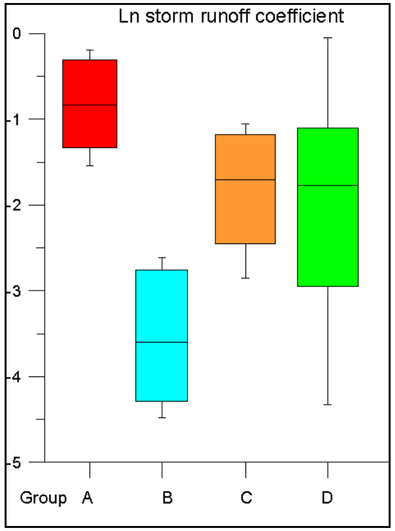
C: Highest antecedent discharges, moderate rainfall volumes and low rainfall intensities

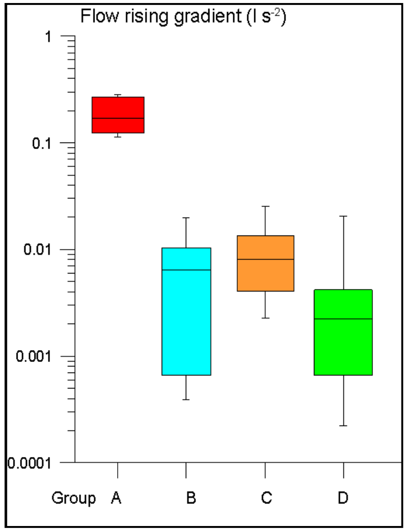
D: Intermediate antecedent discharges and rainfall volumes, low rainfall intensities

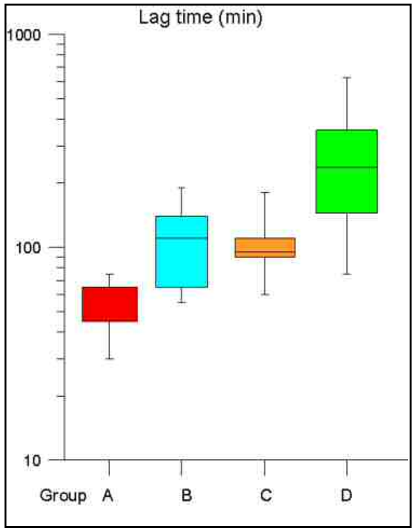
Event classification: responses

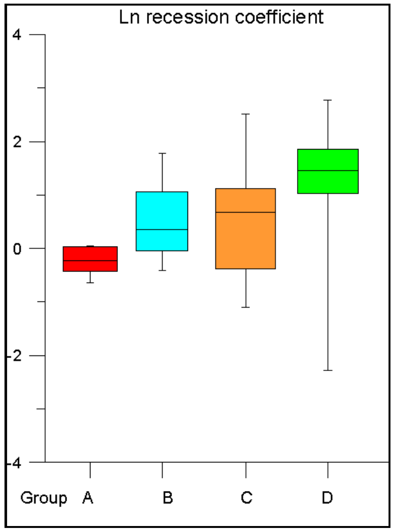












The event responses can be summarized as:

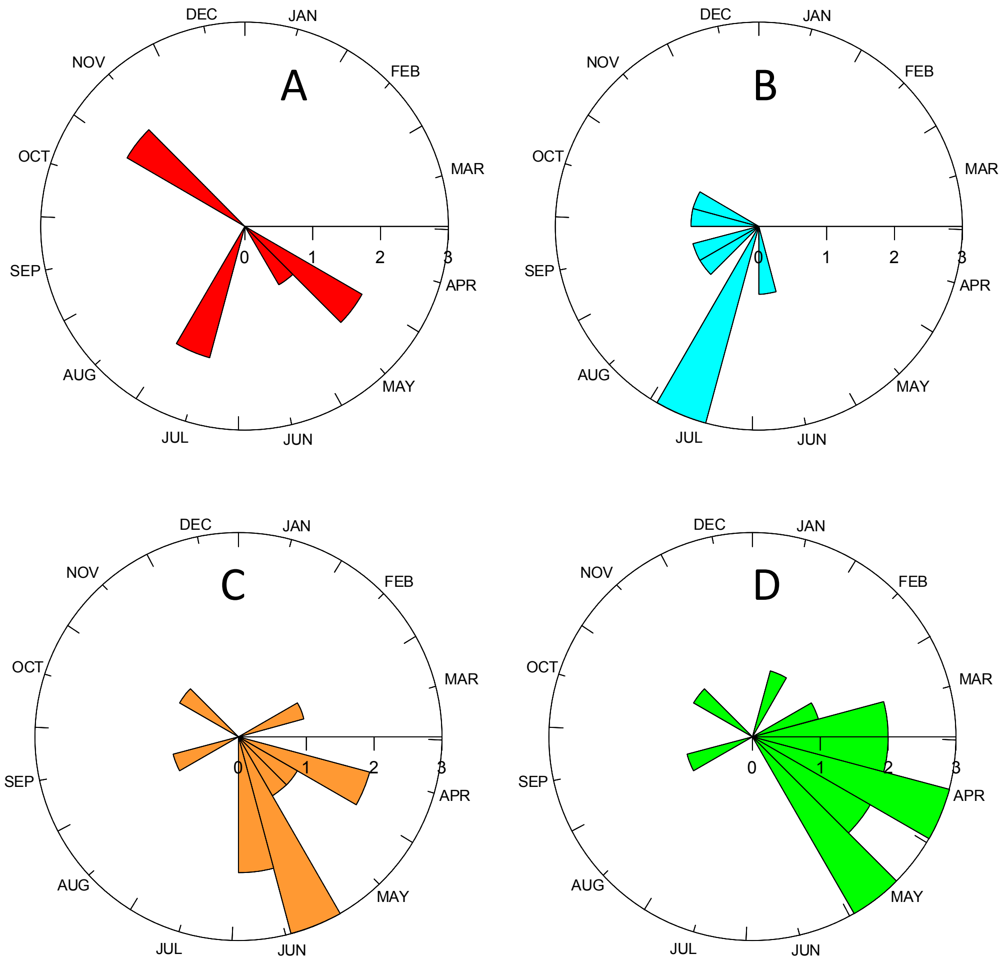
A: The highest values for volumes, intensities and celerities

B: The lowest values for volumes and moderate for celerities

C: moderate values for all variables

D: moderate values for volumes and intensities and the lowest for celerities

Event classification: seasonality



The temporal distribution of events show that these occurred almost only from March to November:

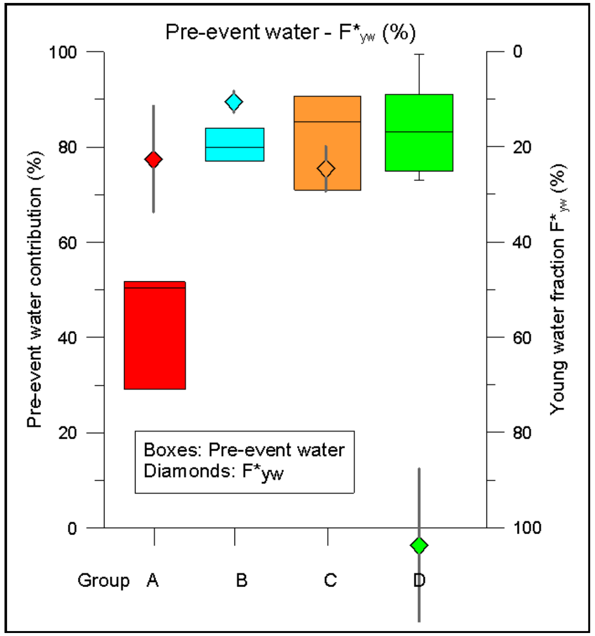
A: occurred in both equinoxes but also in Summer

B: were predominant for July but spread from mid-June to early October

C: were mainly spread from mid-April to June

D: were mainly spread from March to May (before C events, increasing catchment antecedent wetness)

Pre-event and young water fractions



Pre-event water was estimated for 16 events, using isotope-based hydrograph separation (1,2).

Flow-weighted young water fractions (F^*_{yw}) were estimated from the ratios between (event group) stream water and (whole period) precipitation amplitudes of the annual sinusoid functions of ^{18}O ratios (3)

Pre-event water contributions show a simple clear pattern: low (<52%) for events type A and high (>70%) for the remaining types of events.

F^*_{yw} estimates demonstrate a irregular and rather incoherent pattern:

A events had a moderate F^*_{yw} value, not consistent with high volume events and contradictory with the low pre-event water contributions

B events had the lowest F^*_{yw} value, incongruous with events occurring during the lowest antecedent conditions.

C events had a intermediate F^*_{yw} value, similar to the result for the whole period

D events had a surprisingly F^*_{yw} value close to the unity.

1: Cayuela et al. (2019), HYP, 2: Latron et al. (2015)) 3: Kirchner (2016a) HESS

Discussion

Pre-event water estimations provided coherent results for most of the event types, except for type B, as we expected lower pre-event water contribution for such events occurring during dry antecedent conditions. The results obtained for F^*_{yw} are more awkward and threaten the validity of this F^*_{yw} approach for this kind of application.

A possible explanation for this inconsistency is that isotopic ratios of precipitation during the events may be too scattered from the annual sinusoid, so the amplitude ratios method is not applicable at these scales.

A further test was made by examining the $F_{yw}(Q)$ that would correspond to every sample within the event type, by combining eqs. (6) and (8) in Gallart et al (2020a).
Substituting the right term of the equation for the definition of S_d discharge sensitivity:

$$F_{\mathrm{yw}}(Q) = 1 - (1 - F_0) \cdot \exp(-Q \cdot S_{\mathrm{d}})$$

in the equation used for obtaining the S_d and F_0 parameters,

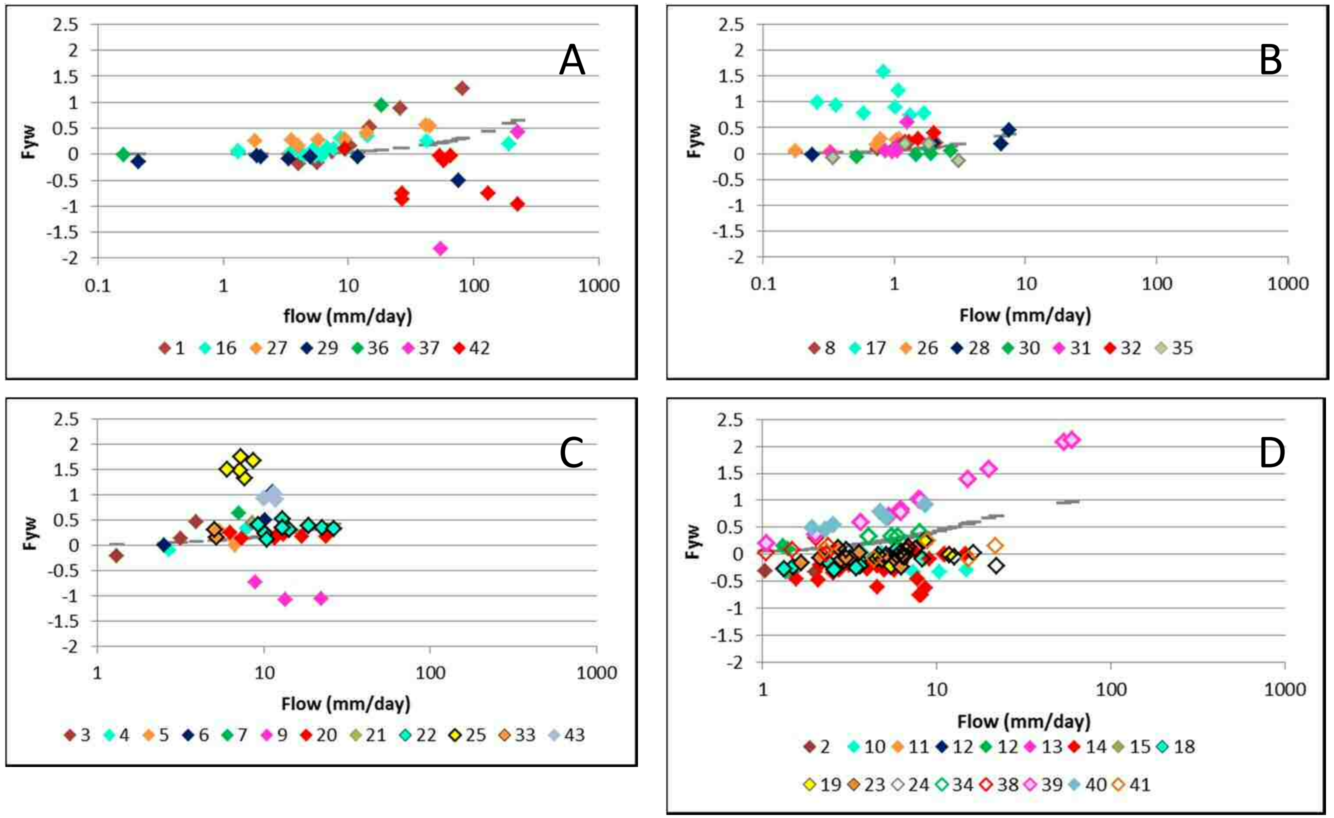
$$c_{\mathrm{S}}(Q,t) = A_{\mathrm{P}} \cdot [1 - (1 - F_0) \cdot \exp(-Q \cdot S_{\mathrm{d}})] \cdot sin(2\pi ft - \varphi_{\mathrm{S}}) + k_{\mathrm{S}}$$

We can obtain the likely $F_{yw}(Q)$ corresponding to each sample :

$$F_{\mathrm{yw}}(Q) = [c_{\mathrm{S}}(Q,t) - k_{\mathrm{S}}]/[A_{\mathrm{P}} \cdot sin(2\pi ft - \varphi_{\mathrm{S}})]$$

Where $c_{\mathrm{S}}(Q,t)$ is the isotopic ratio for every sample with Q discharge, A_{P} is the amplitude of the annual sinusoid fitted to the isotopic ratios of precipitation and k_{S} and φ_{S} are, respectively, the isotopic shift and phase of the sinusoid equation fitted to the event type stream water isotope ratios.

Discussion



This test helps analysing the behaviour of the diverse events within their corresponding types.
Some events (1, 27, 15, 39…) show the expected increase in F_{yw} with increasing discharge.
Other events (16, 20, 10…) show stable low F_{yw} values, insensitive to discharge.
Some other events (42, 9, 14…) show negative values with unclear patterns respect to Q.
Finally some other events (17, 21, 25) show high F_{yw} values with unclear patterns.

Conclusion

→ **The analysed period evidenced a wide range of hydrological forcings and corresponding responses in the Can Vila catchment.**

→ **The hydrometric analysis resulted in a clear classification of the events that is consistent with and improves the classification previously made with a more limited number of observations.**

→ **Pre-event water estimates made a clear separation between large events with restrained pre-event contribution and medium and small events, dominated by pre-event water. Nevertheless, the high pre-event water estimated for events occurring during dry antecedent conditions was unexpected.**

→ **Young water fractions estimated with the sinusoid ratio method for the diverse types of events were rather inconsistent with hydrometric and pre-event water results. Sample and event examination showed a wide scatter of responses that deserve further investigations.**

→ **More research is needed to advance in the knowledge of the strengths and limitations of the young water fraction approach.**

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