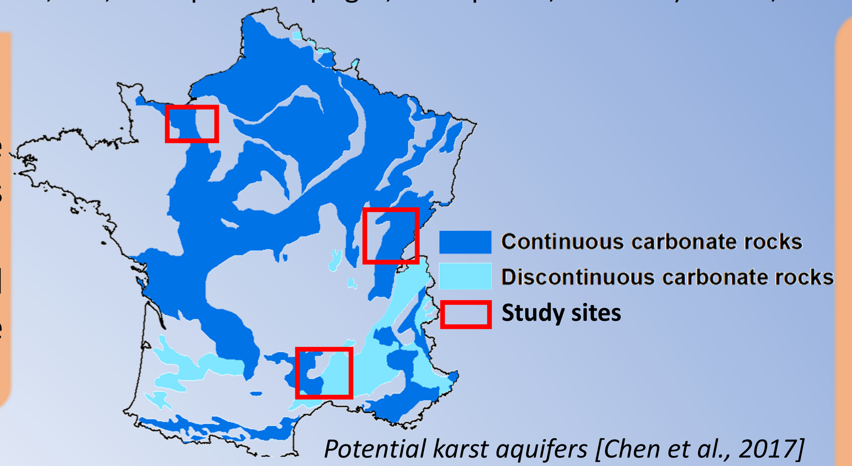
INVESTIGATING THE ROLE OF GEOLOGY ON THE SPATIAL VARIABILITY OF CATCHMENT WATER BALANCE AND ITS IMPACT ON FLOOD PROCESSES

Martin Le Mesnil[1,2], Jean-Baptiste Charlier[1], Roger Moussa[2], Yvan Caballero[1], Nathalie Dörfliger[3] 1) BRGM, Univ. Montpellier, Montpellier, France - email : martin.le-mesnil@inra.fr 2) LISAH, Univ. Montpellier, INRA, IRD, Montpellier SupAgro, Montpellier, France 3) BRGM, F-45060 Orléans, France

INTRODUCTION

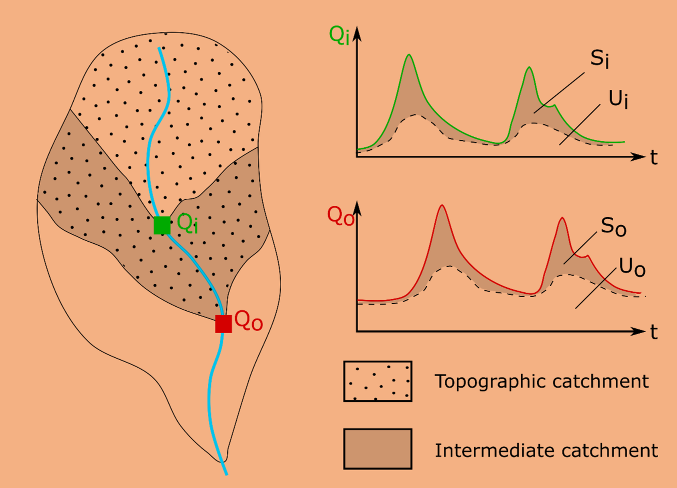
Geology is a main pattern of catchment organization, and we ask whether it impacts the hydrological response of catchments, especially during floods. The aim of our study is to assess which hydrological processes are linked to the geological and karst pattern, and to which extend the latter can affect water balance and runoff coefficient during floods. Indeed, karst catchments are generally prone to Interbasin Groundwater Flows (IGF), resulting in streamflow losses or gains. Common examples of IGF in karst are underground river losses, or springs draining areas out of the topographical catchment.

The proposed approach is a combined analysis of the spatial variability of hydrological flood indices and geomorphological indicators. Hydrological indices are multi-annual average values obtained from daily streamflow and rainfall records of 9 to 30 hydrological years. Geomorphological parameters are IDPR (see dedicated box), and drainage density. Such indicators, easily calculable, could allow the transferability of results to ungauged catchments. The study site (total of 25 000 km²) includes 12 French catchments, located in various karstic regions and equipped with 120 gauging stations.



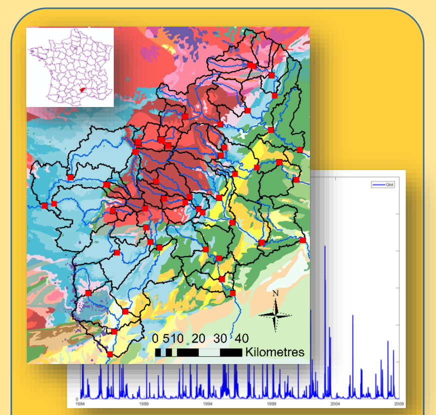
Potential karst aquifers [Chen et al., 2017]

TOPOGRAPHIC & INTERMEDIATE CATCHMENTS

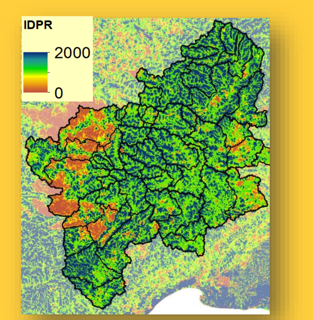


	Topographic	Intermediate
Streamflow	Q_o	$Q_o - Q_i$
Surface runoff	S_o	$S_o - S_i$
Underground runoff	U_o	$U_o - U_i$

DATA SETS AND METHODOLOGY



- *Daily streamflow*
- *Daily rainfall and ETP (8x8km mesh)*



- *IDPR + geological maps*
- *Drainage density*
- *Endorheic zones*

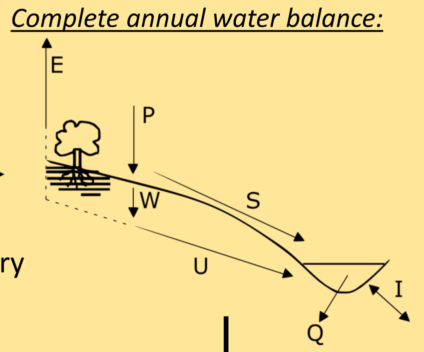
INPUT DATA

Baseflow separation [Lyne & Hollick, 1979]

Evapotranspiration estimation [Thornthwaite, 1948; Edijatno et al., 1999; Dingman, 2002]

Adapted L'Vovich water balance theory [L'vovich, 1979]

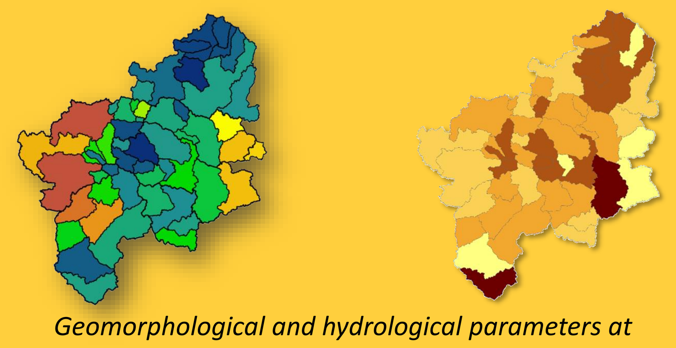
Complete annual water balance:



in mm/yr
P: Precipitations
Q: Streamflow
S: Surface runoff
U: Underground runoff
W: Wetting
E: Evapotranspiration
I: Interbasin Groundwater Flow

Annual flood indices: S/P, S/Q, Q/P

Downscaling + Karst analysis

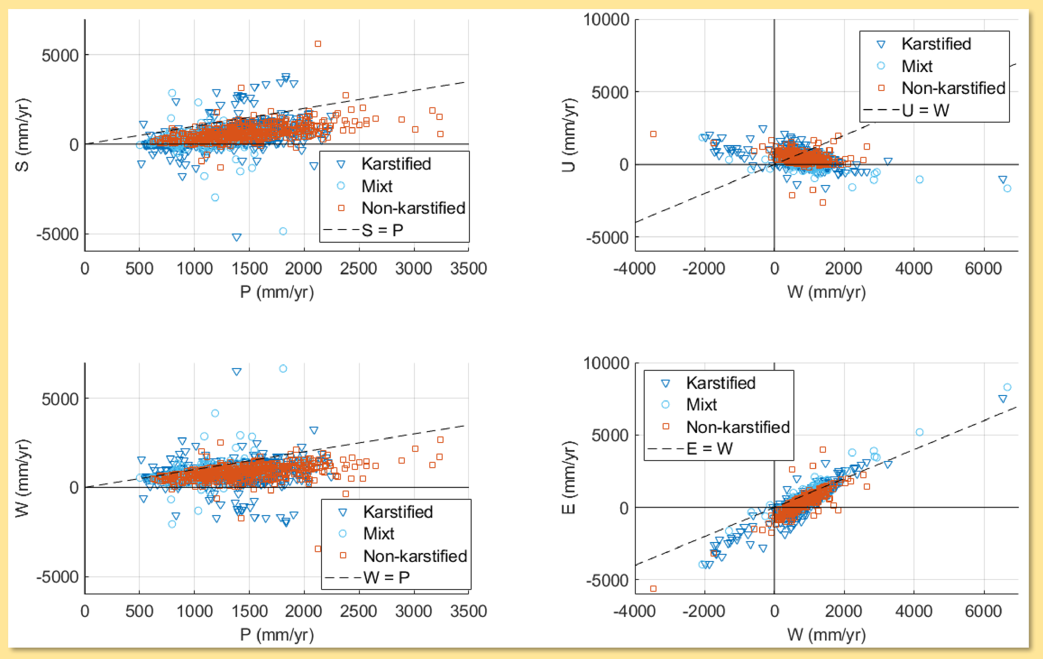


Geomorphological and hydrological parameters at intermediate catchment scale

PROCESSED DATA

Correlation study:
- **Flood hydrology**
- **Geomorphology**
- **Geology** (karst, hard-rock, mixt)

ADAPTING L'VOVICH WATER BALANCE THEORY TO NON-CONSERVATIVE BASINS

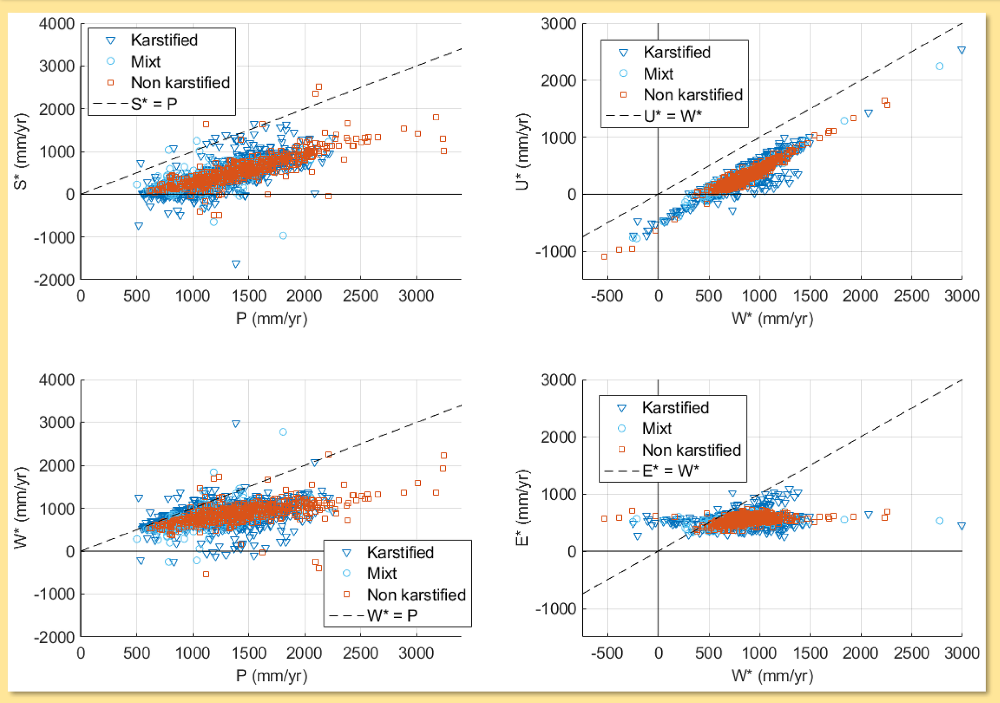


1. Initial L'Vovich annual water balance

- Measurement of P and Q
- S and U ← Hydrograph separation
- W = P - S
- E = P – Q

\+ Highlighting a **specific hydrological flood response in karst basins**
IGF affects both slow (U) and fast (S) runoff components

-- Model provides some extreme values (negative or very high)
Terms include IGFs and do not represent hydrological processes



2. Separation of IGF component

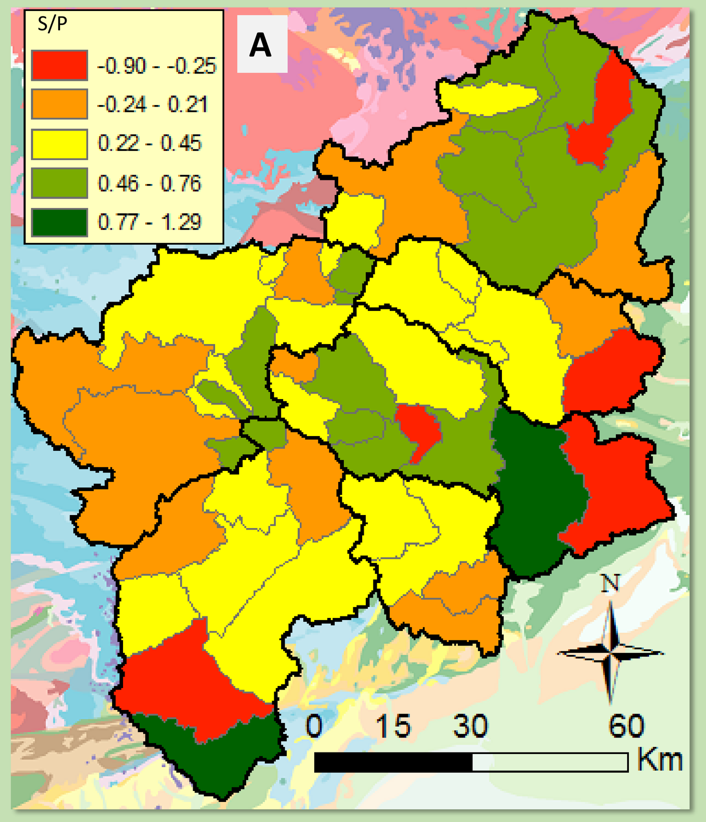
- Independent estimation of evapotranspiration E*
- Assessment of IGF: **I = P – Q – E***
- Corrected water balance terms: $S^* = S + I/2$, $U^* = U + I/2$, $W^* = P - S^*$

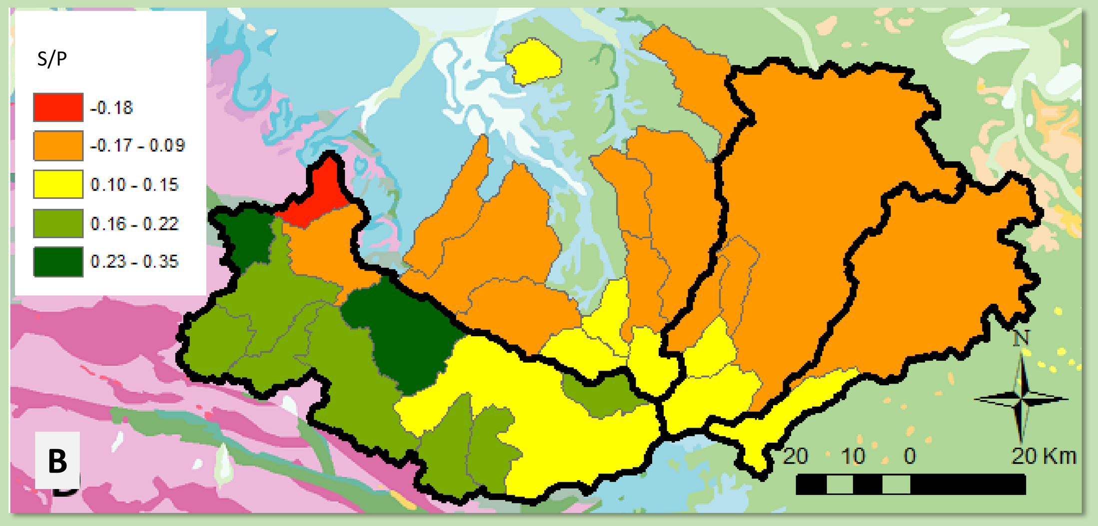
\+ **Model improved**: more consistent values, with physical meaning

\- Still few unexpected values (out of « conservative » zones)
A better repartition of I between S and U is under research…

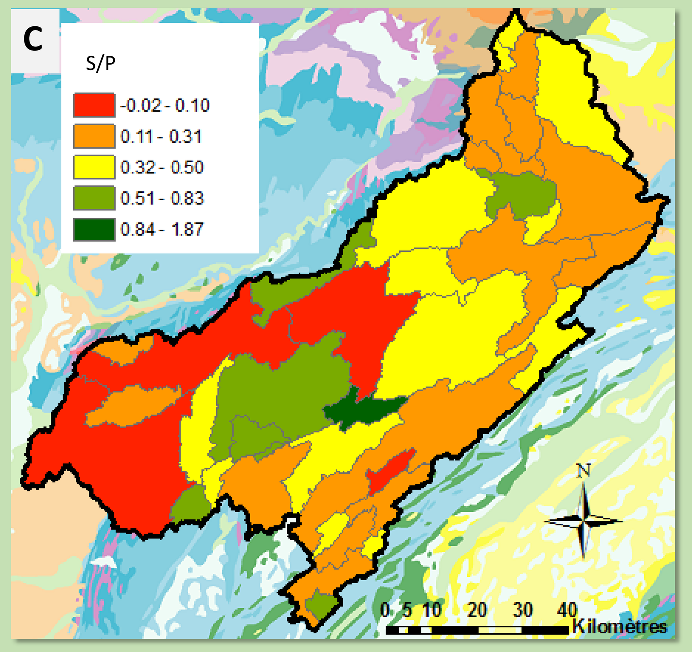
RESULTS: FLOOD INDICES SPATIALISATION AND LINK WITH GEOMORPHOLOGY

1. Mapping flood runoff

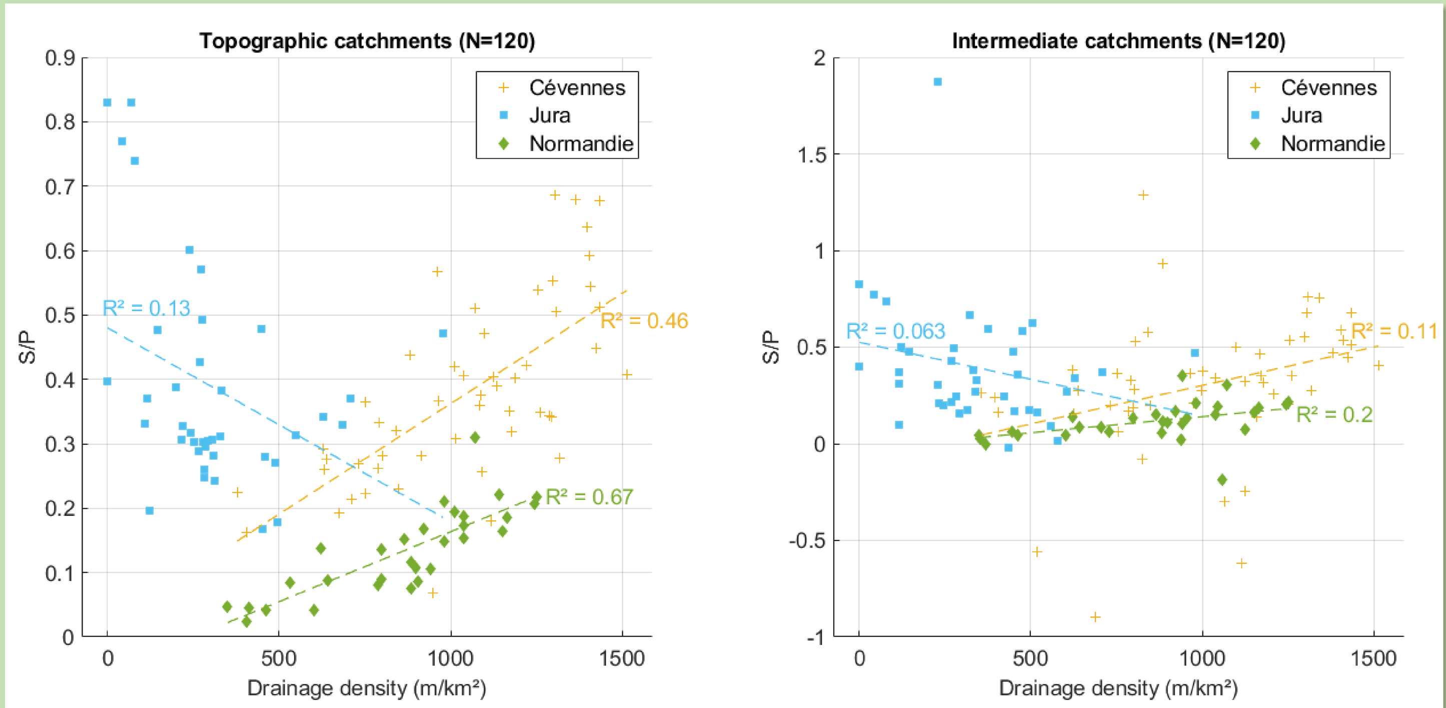




S/P index mapping (quick flow component normalised by rainfall) shows the spatial variability of flood runoff. It appears to be correlated with geology, especially in Cévennes (A) and Normandy (B). Similar results are obtained with IDPR or drainage density.
S/P values are low on karstified limestone basins, and higher on hard-rock terrains. Other flood indices are not presented here.

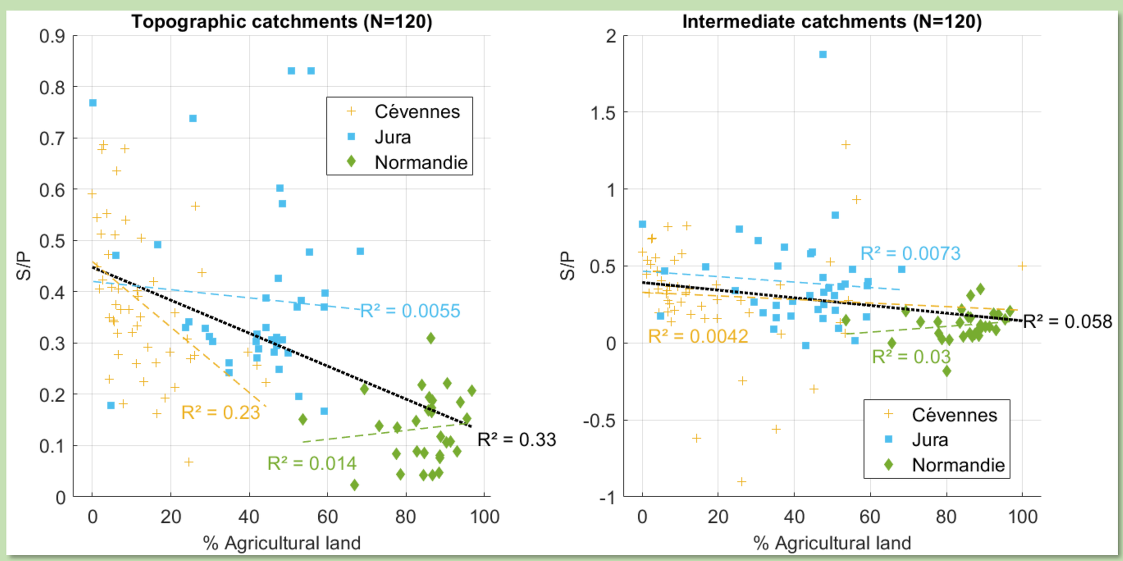


2. Hydrology – Geomorphology correlations



Mapping of indicators shows consistency between physiographical and hydrological parameters at the intermediate catchment scale.
Regressions between those indicators show correlations at the topographic catchment scale, between S/P and geomorphological indices (drainage density and IDPR), especially for Cévennes and Normandy. Weak correlation for the Jura Mountains can be explained by an intense karstification, promoting strong groundwater influence, not reflected in surface geomorphological parameters.

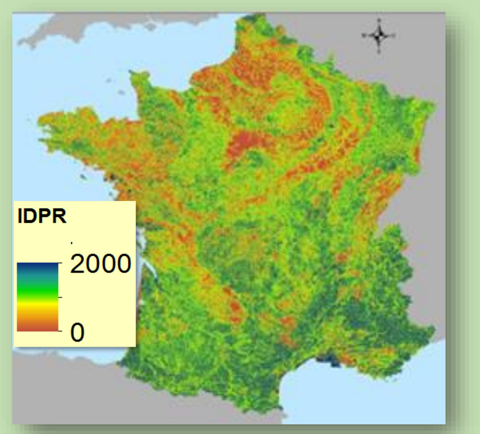
3. Influence of land use



In a similar way, several land use indicators are computed and their correlation with hydrological index studied. Within each study site, determination coefficient values are low (all R² < 0.23), showing a less important influence than geomorphology on the S/P index.
Yet, unlike with geomorphological parameters, the global regression (all 3 study sites) gives interesting results (R² = 0.33) for the topographic catchment scale.

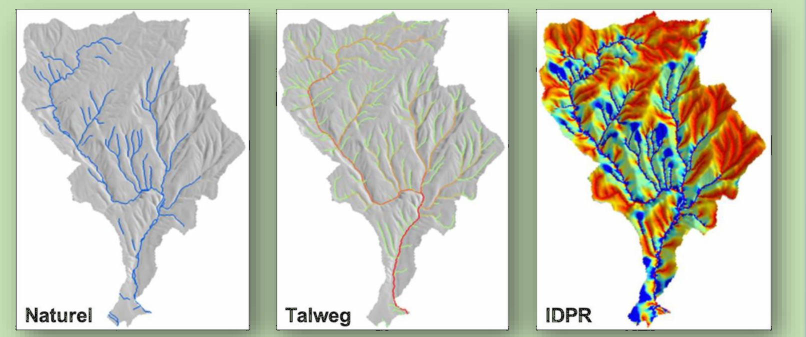
IDPR

The Index of Development and Persistency of River network characterizes the connectivity of terrains to the hydrographic network. It is non dimensional and its value ranges from 0 to 2000. IDPR is available at the 25 m spatial resolution over France.



2017 IDPR grid – BRGM

This index is computed by estimating the gap between a theoretical river network corresponding to the topographic thalweg network, and the existing hydrographic network. For example, a dry thalweg will give an IDPR close to 0, and a wetland corresponds to a high IDPR value (close to 2000).



IDPR computation by crossing the hydrographic network and the thalweg network

IDPR value at each node is obtained from the following conceptual equation:

$$IDPR = \frac{\textit{Distance to closest theoretical river}}{\textit{Distance to closest existing river}} \times 1000$$

REFERENCES

Chen, Z., Goldscheider, N., Auler, A., Bakalowicz, M., Broda, S., Drew, D., Hartmann, J., Jiang, G., Moosdorf, N., Richts, A., Stevanovic, Z., Veni, G., Dumont, A., Aureli, A., Clos, P., Krombholz, M. (2017). World Karst Aquifer Map (WHYMAP WOKAM). BGR, IAH, KIT, UNESCO, doi: 10.25928/b2.21_sfkq-r406
Dingman S. L. (2002). Physical Hydrology, pp. 575, Waveland Press, 2nd edition, ISBN: 978-1-57766-561-8
Edijatno, De Oliveira Nascimento, N., Yang, X., Makhlouf, Z., Michel, C., 1999. GR3J: a daily watershed model with three free parameters. Hydrological Sciences Journal 44, 263–277.
Gay, A., Cerdan, O., Mardhel, V., Desmet, M. (2016), Application of an index of sediment connectivity in a lowland area. J Soils Sediments, (16), pp. 280–293, DOI 10.1007/s11368-015-1235-y
Lyne V., Hollick M. (1979). Stochastic time-variable rainfall–runoff modelling. Institute of Engineers Australia National 357 Conference, 79/10, 89–93
L'vovich, M. I. (1979), World Water Resources and Their Future, translated from Russian by R. L. Nace, 415 pp., AGU, Washington, D. C.
Thornthwaite C.W. (1948). An approach toward a rational classification of climate. Geographical Rewiew 38:55 – 94.

CONCLUSIONS

The L'Vovich annual water balance theory, adapted to non-conservative basins thanks to independent evapotranspiration data, is applied in a first step. It shows that many catchments are prone to IGFs, and that it can often be linked to the catchment geology (differentiating hard-rock, karst, and other sedimentary formations). Results also show that both quick and slow flow components are correlated with geology. In a second step, we characterize relationships between those hydrological specificities and some simple geomorphological parameters (i.e. drainage density and IDPR). Results show that correlations exist, relatively strong depending on the study sites and geology. The impact of land use is less important within each site, but is significant when considering all 3 sites. The case of intensely karstified areas is highlighted due to the highest variability of hydrological indicators in catchments covers by such patterns. Finally, our results highlight the geological control of catchment hydrology and the specific role of groundwater flows in karst areas on flood flows. Knowing that karst areas cover 20% of Europe outcrops, this work promises interesting perspective in mapping hydrological indicators in link with catchment organization and geology.