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## Hydrogeology of Dévoluy karstic system: New insights with dye tracing and rainfall-discharge model

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## Introduction

Dévoluy is an important limestone massif of the French western pre-Alps covering about 160 km<sup>2</sup>. It is the highest massif in the French Subalpine domain with average altitude of 1620 m and the highest culminate point as Grande Tête de l'Obiou (2789 m). Due to its geographical position, it has been influenced by Pyrenean-Provençal and Alpine orogeneses. As a result, it is intensely fractured and karstified. It is also a strategic water resource identified at the national level (1). This study was born from a questioning of amateur cavers of the massif. Indeed, during deep explorations closer and closer to the saturated zone, no important active conduit could be discovered. A project was therefore conducted by the regional committee of speleology "Provence-Alpes-Côte d'Azur" to answer the question: how are the underground flows structured?

Beyond the speleological interest, this study aims to answer questions of more general interest: What is the watershed and the vulnerability of the water resource? What is the system's response to rainfall? This last issue is of particular importance for the management of a hydroelectric dam operated by Electricité De France (EDF) located just downstream from main exurgences.

## Geological setting

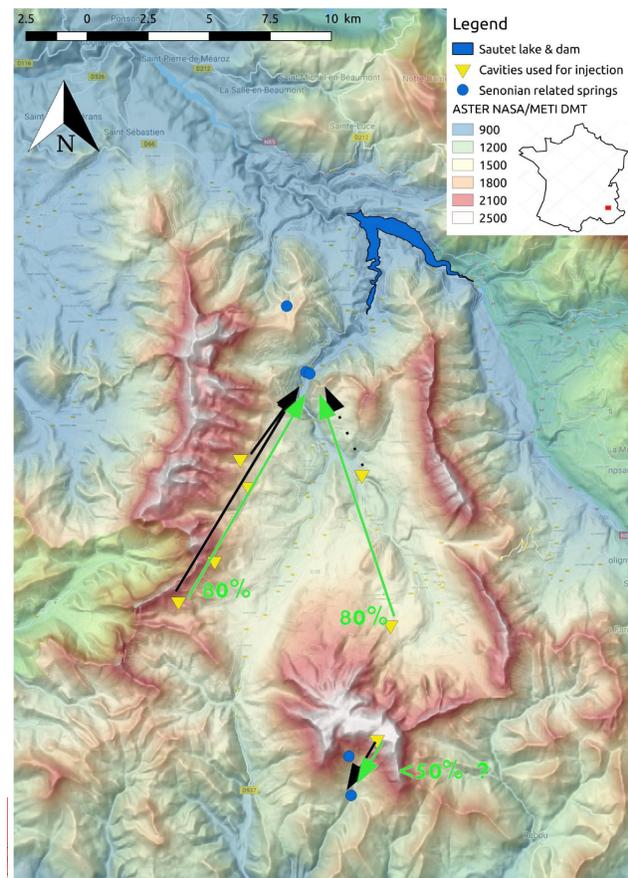
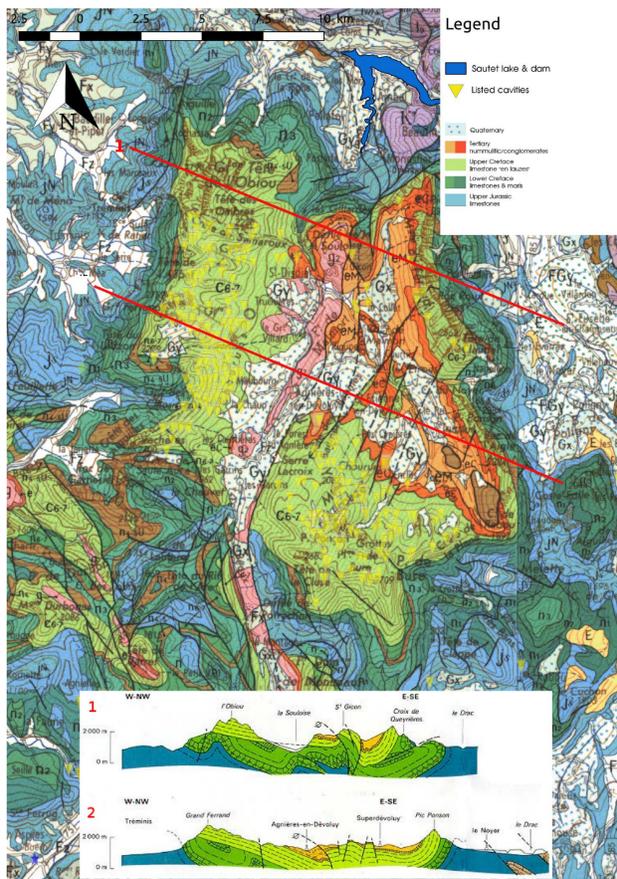
The Dévoluy is a part of a remnant foreland basin, which was active during Eocene-Oligocene period (2). The Dévoluy forms a dissymmetric syncline of NNE-SSW orientation with a steeper Eastern flank. The syncline is individualized by a deep Drac and Grand Buëch valleys in the East and West, respectively. The internal domain of syncline is disrupted by the Median Dévoluy thrust of N-S orientation. This thrust is a continuation of the Digne thrust and links to the subvertical Aspès-les-Faults (3) (4) affecting the crystalline basement. The Dévoluy syncline is composed of Senonian cherty limestones (Turonian-Maastrichtian age) with the maximum thickness of 700 m. Senonian cherty limestones overlay in discordance pre-Senonian folds with E-W folding-axes in Lower-Cretaceous marls-limestones and Jurassic terrains (Barremian to Oxfordian).



Photo 3: typical senonian limestone in Tune aux Renards cavity



Photo 4: Grand Ferrand peak (2758m)



**Dye tracing experiments**

- Positive new with restitution rate
- Positive past
- Negative past



Photo 1: Grandes Gillardes spring in summer



Photo 2: Puits des Bans outflow during flood event

## News dye tracing experiments

Several old qualitative tracing experiments have been carried out showing relatively fast circulation inside the massif (figure 1, black arrows). Several attempts to trace have failed between the *Puits des Bans* cavity and Gillardes springs although the cavity is connected to the saturated zone, which makes it a "local mystery" (5) (6). From 2015, we have taken a quantitative dye tracing experiments plan using modern means (Figure 1, green arrows). This objective implies the control of the discharges of monitored outlets. Two tracings connect the cavities of the *Chorum des Aiguilles* and *Trous de la Tune* with Gillardes springs with restitution times of the order of one week and high restitution rates of the order of 80%. A third tracing has just been made on the *plateau de Bure* on the southern edge of the massif. The dye is massively released south (confirming the old experiments) on two separate springs.

## Rainfall-discharge sequence

In order to manage the inflow of water into the Sautet Lake dam, EDF measures the flow of the river that has drained the massif to the north (*La Souloise*) for more than 50 years. Its flow is 90% supported by Gillardes springs. At the end of 2014, a new measuring station was installed upstream of the Gillardes in order to calculate the discharge of the springs more accurately. Figure 3 shows the Gillardes rainfall-discharge sequence over the last three years. The average discharge is 4.5 M<sup>3</sup>/s. The low discharge is of the order of 0.8 M<sup>3</sup>/s. Floods can be violent with a record of 100 M<sup>3</sup>/s. Spectacular karstic loads are then activated: a waterlevel more than 220m in the cavity of the *Puits des Bans* which then turns into a temporary resurgence (photo 2). There is strong snow influence in the spring.

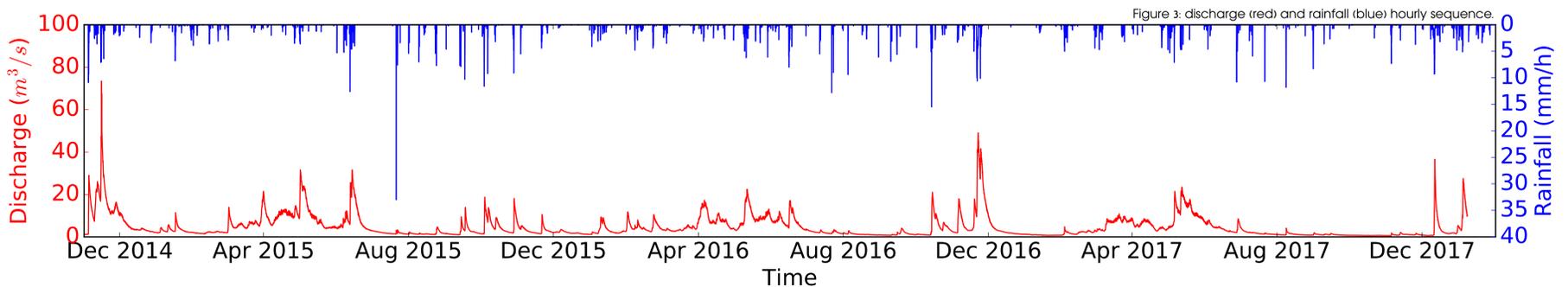


Figure 3: discharge (red) and rainfall (blue) hourly sequence.

## Conclusions and perspectives

The tracings carried out show fast movements (speed of the order of 1.5 km / days) with high restitution rates (approximately 80%). These results allow strong constraints on underground flows: (1) The Gillardes are the main outlets of the massif. (2) The *Bure Plateau* constituting 10% of the catchment area is drained to the south. (3) The marl-limestones of the lower Cretaceous form an extremely impermeable hydrogeological wall over the entire reservoir. These tracing results suggest karstic circulation with open drains. However this is in contradiction with a previous study on the hydrodynamics of the system (7) as well as with the observations made by speleologists in the deep karst (no significant flows, important traces of loading). A modeling of flows and transport would undoubtedly lead to some interesting answers.

A final tracing experiment is planned for 2019 to delimit the catchment area to the north. On the other hand, a rainfall-discharge model using the reservoir method including a snow model is being developed. Additional data of karstic water level and electrical conductivity are also available to better constrain models.

## Agreements

The authors warmly thank all the speleologists who participated in this project as well as the local structures of the French Federation of Speleology: the Regional Committee of Speleology Provence Alpes Côte d'Azur, the Departmental Committee of Speleology and Canyon of Bouches-du- Rhône and the departmental committee of speleology of the Hautes-Alpes.



## Founded by



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