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2-6 Jul 2018
Besançon
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Using simple pseudo-3D hydrogeological modelling and a simplified agronomical representation to build a pertinent decision-making tool for local stakeholders: the Vivier karstic spring (France) case study

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The Syndicat des Eaux du Vivier (Vivier Water Agency - SEV) is a public agency monitoring the production, treatment, distribution and quality control of drinking water in Niort town in western France. The municipal drinking water supply mainly comes from a karstic resurgence, the Vivier spring, which is registered as a "Grenelle" priority water supply since 2013. There is a strong pressure from agriculture, which is illustrated since the 90' by nitrate concentration that exceed the European drinking water standards. There is also an increasing pressure on water quantity, mainly due to irrigation and drinking water demand, particularly in low water periods when the karst can be subject to collapses due to the low pressure in the karstic galleries. Modelling the hydrogeology of the area will help to optimize the effective quantitative and qualitative water resource management.
Hydrogeological and agronomical modelling is done using the BICHE-MARTHE software chain, developed at the BRGM. Comparing observed and simulated groundwater levels, stream flows, springs flows and overflow at the Vivier spring gives satisfactory results considering the limited knowledge on the area. This part of the modelling has been strengthened by a comparison with a sensibility approach with GARDENIA regarding irrigation and with an approach using neural networks. The model integrates Agricultural practices observed in the catchments area to simulate nitrate transfers. The resulting nitrate concentrations are correct for the Vivier spring and its associated catchments (Gachet I and III) and stays within a reasonable range for other observation points on the catchments area.

Modelling, together with the learnings of the measurements campaign analyses, allows us to better understand how the Vivier hydrosystem works. The spring has two supply methods: a short one-year-cycle, during which meteoric waters get through the karstic system and join the Vivier spring, and a multi-year cycle during which the effective rainfall slowly percolates through non-karstic rocks.

Basic simulations are conducted to better identify the impact of agricultural and quantitative pressures on the water supply. They outline the karstic system sensibility to any change in the

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groundwater pumping plan, which induce an immediate effect on the spring flows.

Simplified scenarios for the nitrate pressure reduction suggest that the system reacts quite slowly due to the multi-year cycle: a significant shift in the nitrate concentration takes a decade. These scenarios also evidence the high sensibility of nitrate levels to the annual effective rainfall.
This tool is intended to be used as a regional pilot in the decision-making process regarding drinking water quality. Perspectives include enhancements in the description of the agronomical system (through recent software developments at BRGM) to test multiple scenarios of agricultural evolution in terms of regulation or climate change.

Keywords: Case study, Modelling, Nitrate, Karst, MARTHE, BICHE

Assessment of permeability evolution and scaling in karst aquifers based on multiscale DFN models

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Karstic carbonate aquifers are one of the most complex systems in nature. The complexity arises from the wide range of geological, physical and chemical processes that dominate the evolution of their permeability structure. In response to tectonic movements, fractures form on all observable scales. The interconnected fractures form intricate heterogeneous networks, which exhibit strong scale effects and, often, intriguing fractal properties. An additional complexity comes from further modifications of the permeability by dissolution processes as fluids circulate through the fracture networks and matrix. This implies that the bulk permeability of karst aquifers evolves over geological time. The emergent hierarchical, time-dependent, permeability structure makes traditional approaches for permeability prediction in karst aquifers incapable. In this study, we propose a new modelling framework for assessing the evolution and scaling of bulk permeability of karst aquifers based on multiscale DFN models. The method is exemplified using field data from the Lez karst catchment located in Montpellier, Southern France. To represent the karst network, we first generate two dimensional DFN models characterised by two simple distributions: 1) a power law for frequency distribution of fracture lengths and 2) a fractal distribution for the spatial distribution of fracture density. The parameters defining the distributions were derived from structural analysis of field data. The resultant multiscale fractal DFNs are able to capture the long-range connectivity and intriguing scaling properties of permeability associated with natural fracture systems.

By applying simple aperture models, such as power-law or lognormal distributions, the generated multiscale fractal DFNs themselves can be converted into pertinent flow models to derive network equivalent permeability. However, the qualification of the existing aperture models in natural fracture modelling across many scales is considerably questionable. In addition, the fracture aperture growth due to dissolution is essentially a highly non-linear process. The perturbation induced by aperture modification may have significant consequence on the original scaling behaviour of fracture network permeability. Considering these problems, we follow a generic scheme in driving the aperture distribution. We model aperture growth, on the basis of the initial geometry of void network defined by the multiscale DFNs, using simple growth law, where the rate of aperture change is defined by a polynomial function of the flux passing through the local evolving aperture. The scaling properties of bulk permeability can thus be investigated at specific stage during the evolution of karst networks.

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The proposed approach is a compromise proposal between pure stochastic and process-based construction of hydraulic models for assessing the bulk permeability of karst aquifers. For practical purposes, the modelling framework may provide insight into physical mechanism behind the scale effect of karst permeability demonstrated by widely variable permeability values derived from hydraulic tests across a range of scales. For theoretical purposes, the approach can be used to investigate general characteristics of karst aquifer evolution, such as the geometric phase transition, and more importantly, to reveal the substantial effects of the evolution on the scaling properties of karst networks.

Keywords: karst, carbonate, permeability, multiscale, evolution

New insights into the Cosquer art cave hydrogeological functionning (France)

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(Résumé court en français. Le résumé étendu final et la présentation seront en anglais)
La grotte Cosquer accueille et protège des peintures et gravures rupestres de plus de 31000 ans (Cal BP, Valladas et al. 2016). C'est une grotte située en bord de mer, dans le massif des Calanques de Marseille (France), au cœur des calcaires urgoniens (Barrémien, Crétacé inférieur). La grotte est uniquement accessible par plongée spéléologique, en empruntant une paléogalerie karstique aujourd'hui noyée. L'accès à la grotte pour les hommes préhistoriques a été bloqué par la remontée du niveau de la mer Méditerranée vers 10000 ans (Cal BP, Lambeck & Bard 2000). On imagine aisément que cette configuration particulière a protégé l'art paléolithique des visites de l'homme au cours des temps historiques. Toutefois, cette grotte a aussi protégé l'art en limitant la remontée du niveau marin en son sein. En effet, le niveau de l'eau dans la grotte se trouve plus bas que le niveau de la mer pourtant situé à quelques dizaines de mètres de l'autre côté du massif calcaire. Ce phénomène tout à fait singulier a été mis en évidence dès la découverte par des mesures de pression dans la grotte (Vouvé et al. 1996). La pression de l'air dans la grotte est supérieure à la pression atmosphérique et repousse le plan d'eau, sauvant ainsi naturellement plusieurs peintures et gravures situées au ras de l'eau, comme par exemple le panneau des chevaux. La surpression dans la grotte varie au cours du temps et influence la conservation de l'art. Pourtant peu de mesures ont été faites dans la grotte afin de comprendre ce phénomène. En 2014, à la demande de la DRAC, un nouveau suivi scientifique de l'environnement de la Grotte Cosquer a été mis en place par le CEREGE. Des capteurs de pression ont été installés dans l'air de la grotte, dans l'eau de la grotte, en mer et dans l'air à l'extérieur (pression atmosphérique normale), ainsi que le suivi de la source karstique côtière de Port-Miou situé à 2 km comme référence de fonctionnement du karst des calanques (Arfib & Charlier 2016).

Les résultats seront présentés pour la première fois en conférence. La première originalité de ce travail est déjà dans l'observation de cette mise en surpression. La grotte Cosquer illustre que les calcaires, malgré qu'ils soient stratifiés et fissurés, peuvent être très peu perméables. Deuxièmement, les nouvelles mesures démarrées en 2014 permettent d'établir un état des lieux, en montrant les périodes où la grotte est en surpression et la durée des périodes où l'art paléolithique se retrouve noyé. Troisièmement, le mécanisme de mise en pression est étudié en comparant les variations de pression avec la direction des vagues en mer et avec le karst de

*Speaker

référence local. Il est ainsi possible de montrer que la surpression dans la grotte dépend des vagues et ne dépasse jamais une valeur seuil maximale. Ces résultats illustrent comment le karst joue un rôle essentiel pour la conservation de notre patrimoine archéologique.

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Keywords: Art cave, conservation, overpressure, monitoring

Far and deep into the brackish groundwater of coastal karst : crossing CTD time series monitoring in submarine spring and during cave diving exploration (Port-Miou and Bestouan - SE France)

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(Résumé court en français. Le résumé étendu final et la présentation seront en anglais)
Les karsts côtiers méditerranéens sont connus pour s'être développés sous le niveau actuel de la mer durant des périodes de bas niveau marin, au quaternaire, au pliocène ou au messinien. La mer joue en effet le rôle de condition aux limites, agissant comme un niveau de base forçant les écoulements souterrains : (1) à s'enfoncer vers la profondeur lors des périodes de régression, (2) à s'adapter vers un nouvel exutoire plus haut lors des périodes de remontée du niveau marin. Il en résulte l'existence d'un réseau de conduits karstiques sous le niveau marin actuel, dont l'exutoire est aujourd'hui une ou plusieurs sources positionnées à proximité du niveau marin. Les aquifères karstiques côtiers sont par ailleurs soumis au phénomène d'intrusion saline. L'intrusion saline prend la forme d'un biseau salé, localement perturbé par des écoulements préférentiels dans des conduits karstiques. Ces écoulements préférentiels peuvent être observés : (1) de la mer vers la terre, ou (2) de la terre vers la mer.

Dans le premier cas, ces écoulements ont été décrits comme des zones favorisant l'intrusion d'eau de mer dans les terres, c'est-à-dire véhiculant l'eau de mer vers l'intérieur des terres, dans des cas d'études par exemple en Méditerranée : Croatie (Bonacci 1997) ou Grèce à Kéfalonia (Drogue 1989) ou Espagne à Moraig-Toaix (Fleury et al. 2007b), ou dans la péninsule de Floride (Xu et al. 2016).

Dans le deuxième cas, l'écoulement karstique forme une source sous-marine qui se décharge en mer (SGD) (Fleury et al. 2007a). Généralement, les conduits karstiques véhiculent alors de l'eau saumâtre, mélange entre l'eau douce infiltrée dans le bassin d'alimentation et l'eau de mer infiltrée en profondeur. La salinité est variable en fonction du débit. L'eau de mer qui participe au mélange avec l'eau douce peut être entrée dans l'aquifère soit par un conduit karstique (cas 1 précédemment cité), soit sous forme du biseau salé autour du conduit karstique profond. En amont de la source sous-marine, il existe quelques fois un conduit karstique explorable par l'homme en plongée spéléologique. Ce conduit est alors un lieu privilégié d'observation des

*Speaker

écoulements souterrains en zone côtière et d'éventuels mélanges entre eau douce et eau salée.

Le travail proposé s'intéresse à l'impact des circulations préférentielles dans les conduits karstiques en zone côtière sur la dissémination de l'intrusion saline. Le karst côtier de Cassis (SE France) est choisi comme cas d'étude. Deux sources sous-marines ont été explorées en plongée dans un conduit karstique qui se développe vers l'intérieur des terres : Port-Miou sur 2000 m de développement, et Bestouan jusqu'à 2500 m (Arfib et Douchet, 2011). Ce sont les exutoires majeurs de la basse-Provence calcaire. Lors des explorations, les plongeurs ont transporté une sonde CTD (Conductivité électrique, Température, Pression) enregistrant en continu l'évolution des paramètres le long de la plongée. Ce sont ainsi plus de 4,5 km de conduits karstiques qui ont été investigués, le long desquels les conditions de mélange entre l'eau douce et l'eau salée peuvent être étudiées. De plus, une plongée profonde à Port-Miou, à 233m sous le niveau de la mer, a permis d'explorer ces conditions de mélange en profondeur dans le karst. Ce type d'observation n'ayant jamais été réalisé jusqu'à maintenant à notre connaissance.

Ces résultats sont comparés à ceux observés sur le site observatoire de Port-Miou, où les données CTD sont enregistrées en continu depuis de nombreuses années (Arfib et Charlier 2016) à 500 mètres de l'exutoire en mer. Sur ce site, les variations de pression (ou débit) et de salinité en début de crue présentent un décalage temporel, formant une hystérèse. Ce décalage est typique d'un effet piston, c'est-à-dire la chasse d'un volume d'eau saumâtre préalablement présent dans le conduit karstique avant la crue. Ce volume, de l'ordre de 1.106 m3 est confirmé par les données enregistrées en plongée. Nous montrons ainsi que l'intrusion saline ayant lieu en profondeur génère un écoulement d'eau saumâtre dans l'aquifère sur plusieurs kilomètres. Ce n'est donc ni de l'eau douce ni de l'eau de mer qui circule dans le conduit karstique connecté à la source sous-marine. Les observations inédites faites par les plongeurs montrent que cette eau saumâtre se rencontre jusqu'à plus de 200 mètres sous le niveau de la mer.

Ce travail confirme l'existence d'écoulements préférentiels à grande profondeur sous le niveau de la mer actuelle. Les ressources en eau en zone côtière se trouvent ainsi affectées. Un suivi CTD des sources peut permettre de mettre en évidence ces phénomènes.

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Acknowledgements : This work was performed within the framework of the Port-Miou observation site, part of the KARST observatory network (www.sokarst.org) initiative from the INSU/CNRS, which aims to strengthen knowledge-sharing and promote cross-disciplinary research on karst systems.

Keywords: coastal karst, saline intrusion, water resources, in situ observation

Water tracing experiments in a quartzite karst area, Chapada Diamantina, Northeastern Brazil

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The existence of karst features and underground flow in silica-rich rocks is being increasingly recognized around the world. Well-developed quartzite karst is known from some areas of the world, notably in tropical settings such as in southern Venezuela and eastern Brazil. However, little is known about the hydrogeological behavior of these terrains. A pioneering water tracing experiment was performed in the Proterozoic quartzites of the Chapada Diamantina (Diamond Tablelands) of central-eastern Brazil, using tracers amino-G and uranine. Tracer detection was performed by four in-situ fluorometers, granular activated charcoal receptors and sampled water analysis. Hydrochemical conditions resulted in contrasting performance between tracers, with uranine providing some positive results, yielding clear breakthrough curves in some of the experiments. A preliminary assessment of flow routes and the main characteristics of groundwater dynamics in this quartzite area are provided, together with insights on the behavior of different tracers under acidic (pH=4-5) water conditions.

Keywords: Water tracing, Quartzite karst, Chapada Diamantina, Brazil

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Geological setting of the Païolive karst (Ardèche, South of France): Consequences on its genesis and vertical development.

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The southern Ardèche area is famous for its arid and deeply karstified limestone landscapes, , that attract many tourists, especially in summer. This seasonal population increase adds an important pressure on the water supply, that leads to investigation for new water resource.
The geological study of the Païolive karst, located between the Chassezac and La Baume rivers, aims at characterizing the karstic aquifer. First, the structural framework and geological cross-sections allow to localize the karstic massif in relation with the tectonic structures due to regional geodynamics. Lithostratigraphic analyses is used to distinguish reservoirs and seals formations, and to date geodynamic events that were crucial for the karst formation. Then, a geomorphological study based on upstream-downstream profiles, correlated with sedimentological observations of residual deposits, leads to : i) identify paleo-surfaces and their subsequent deformations; ii) determine the upstream sources , and iii) constrain the downstream position of each profile.

Preliminary results show that : 1) Late Jurassic to Early Cretaceous formations are slightly dipping SE and are affected by low amplitude anticline flexures oriented NE-SW, responding to a post-deposition reactivation of basement faults; 2) To the southeast, the reservoir is sealed by the listric fault bounding the tilted block of la Serre, which was activated during Oligocene rifting; 3) Neocomian formations (marly seals) was overlying - and therefore preserving - Jurassic-Early Cretaceous limestones from karstification; 4) A distinctive paleo-surface, assigned to an uptsream-downstream base-level surface, intersects different lithologies, with an upstream in the basement of the Cévennes and a downstream located across the tilted block of la Serre. This paleo-surface presents an asymptotic profile in a SE-trend, while it displays a corrugated geometry across orthogonal profiles, with a succession of ridges and gullies trending in the same way. Residual sediments deposits are found in the gullies, with detrital elements (especially granites blocs of the Finiels late Variscan intrusive). Datation of this paleo-surface is poorly constrained. However, geometrical evidences indicate that the paleo-surface was developed after Oligocene rifting. The paleo-surface is deeply incised by the Chassezac and La Baume and all their tributaries, in response to the lowering of the base-level. Consequently, the karstic network

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sinks into carbonate massif exposed at that time. However, there is no evidence of karstification below the present base level.
We discussed the origin of base-level lowering and provide evidence of a tectonic origin by long-wave uplift of the area, which occurred during the late Miocene, but prior to the Messinian base-level drop, as referenced in the neighbouring areas of Languedoc.

Keywords: karstification, paléosurface, failles, Ardèche

The Fontestorbes intermittent karst spring : New results deduced from high frequency monitoring in the karst drainage system

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The Fontestorbes karst Sp. is located near Belesta, southern France (Ariège). It is known as one of the largest intermittent springs in the World and became a classified touristic site in 1921. Numerous studies have been done on this karst spring, especially in the 70's by the French hydrogeologist A. Mangin who defined a physical model able to reproduce this intermittent flow behavior.
Since 2014, the BRGM (French Geological Survey) leads a project in partnership with Région Occitanie, Ariege and Aude Councils, and AERMC and AEAG Water Agencies, that aims at better understanding the karst groundwater resources on the Plateau de Sault. In that framework, a scientific cooperation with the Speleogical Comitee (CDS09) allowed to monitor simultaneously pressure, temperature and electrical conductivity times series at the spring and in a cave explored by CDS09. This cave, located 1200m upstream the spring ends with two sumps that show water-level fluctuations related to the intermittent flow at the spring. Besides, a simulation of the karst drainage network following the KARSYS approach, and based on the interpretation of a 3D geological model, supposes that this cave is located on the karst drainage conduit conveying water from the southern part of the catchment area to the spring.
These new results will be presented and discussed to better understand the intermittent mechanism, the karst network organization upstream the Fontestorbes Sp. and the origin of water flowing at the spring.

Keywords: karst network, intermittent spring, KARSYS, time series

*Speaker

Geological characterization and formation of a covered karstic reservoir (Urgonian limestones of the Gardon Basin, South of France) - Towards predicting the distribution and state of karstification

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Underground water supply in the south of France relies on an improved knowledge of karst reservoir architecture, a prerequisite for hydrological modeling. The Gardon (or Saint Chaptes) Basin, is a syncline affecting Mezosoic formations and filled by asymmetric, gently folded, Paleogene continental formations. The basin is crossed by the Gardon River, which supplies the alluvial table and, locally, disappears into a covered karst; downstream, several springs in the "Urgonian" limestones (Barremian reefal facies) suggest an underground flow probably related to the surface stream. The Urgonian limestone is known to constitutes a major underground water supply covered with unconformable Paleogene sediments. However, the reservoir geometry and connections are poorly known. The aim of this study is to document the architecture of the reservoir and its overburden with the following objectives: (i) Provide a 3D geological model of the reservoir for further hydrologic modeling (ii) Decipher the complex post-depositional geologic evolution of the Urgonian limestone in order to approach the intensity and distribution of karstification. The approach is based on interpretation of multichannel seismic reflection profiles acquired in the 90's, correlated with borehole data and field observations. Correlating observations and results with the regional geological setting, allows to reconstruct the successive phases of karstification and the timing of deformation in the Gardon Basin.
Preliminary results show the following points.
1) Thickness variations of the Urgonian layers are due to two erosional surfaces: one predates Late Cretaceous and the other one postdates Late Bartonian.
2) Overburden formations show a progressive unconformity over the Urgonian.
3) Northtrending normal faults are developed during Priabonian extension and remained active until Oligocene.
4) The Gardon Basin is subdivided into two sub-basins separated by a shallow structural high of Urgonian, which is consistent with the disappearance of the Gardon stream.
5) In the hangingwall of a buried major fault, the Urgonian in the eastern part of the basin is

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covered by Late Cretaceous marine marlstone and has been preserved from karstification. Finally, we propose a step-by-step geological evolution of the basin, which brings new constraints on the regional geodynamics, especially on the formation and extent of a mid-Cretaceous inversion and uplift phase which affected southern France : the "Durancian Isthmus

Keywords: karst, paleobase level

Continuous monitoring of natural fluorescence and organic content of groundwaters as a tool to characterize recharge processes and vulnerability of karst aquifers

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In karstic aquifers, changes in organic content are now commonly used to track the arrival of water from rapid infiltration (Blondel et al., 2010). Along with physico-chemical and hydrodynamic monitoring, the continuous monitoring of Total and Dissolved Organic Carbon (TOC/DOC) can thus be used to enhance our understanding of karst flows processes and karst vulnerability to pollution.
In addition to laboratory TOC analyzer, fluorescence measurements can be made to characterize the properties of the organic compounds in water (Coble, 1996). First studies dealing with fluorescence spectroscopy on karstic aquifers highlighted two distinct compounds of fluorescent organic matter, denoted humic-like and protein-like (Mudarra et al., 2011; Quiers et al., 2013). This approach however requires analyses on water samples, and is consequently limited to punctual monitoring. Other studies focused on continuous measurements of natural fluorescence by using field fluorometers, initially designed for continuous measurement of artificial dye tracers. Recent results highlight that field fluorometers can be used to measure humic-like substances, while protein-like compounds need further developments (Erostate et al., 2016). Based on such in situ monitoring, correlation between TOC/DOC and natural fluorescence data is not straightforward and show seasonal variations (Savoy, 2007; Tissier et al., 2013). Our study aims at better understanding the relationships between fluorescence, absorbance and organic content

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in karst groundwater from two karst systems with contrasted environmental contexts, the Lez spring and the Fontaine de Nîmes spring. These two sites are equipped for physico-chemical and hydrodynamic monitoring, and also with field fluorometers. Field sampling campaigns are also carried out in order to compare in situ measurements with laboratory analyses and also to sample different types of water that contribute to karstic flows to characterize the origin of the GW organic compounds.
All these data have been gathered to explore and discuss the relationship between TOC/DOC and fluorescence using samples analyses and in situ monitoring during the hydrological cycle. The first results significatively improve the understanding of recharge mechanisms in karsts which are a key element to determine the vulnerability face to pollutions and to better constrain transfer models within these media

Keywords: Natural fluorescence, Organic carbon flow, Continuous monitoring

Sensitivity analysis of a karst conduit flow and heat transport model with variable recharge and temperature using FEFLOW

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A karst spring in central Pennsylvania, USA, with noted event-scale and seasonal spring temperature variability was modeled to understand the connection between a sinking stream and the spring. Tippery Sink drains a stream with a base of about 0.08 m3 / second, which then flows to Spring Tippery which discharges 0.05-0.22 m3 / second, a connection established with dye tracer tests. Loggers installed at the sink and recorded temperature at 15-minute intervals from 2016-2017. Additional loggers also recorded rainfall and spring water level. These fields were used to construct a transient flow model between the sink and the finite element using the Finite Element Subsurface Flow Model (FEFLOW). The modeled thermal signal is highly sensitive to conductive parameters (conductivity, cross-sectional area, and tortuosity) and matrix transmissivity, but less sensitive to other parameters, such as the number of bends in a led of a fixed length. With constant recharge and transient sink temperature, a fairly good match occurred between observed and modeled spring temperature. As a result, variable sink recharge was included to produce the best possible match. As the model calibrated to a narrow range of duct and matrix parameters, it provides a greater degree of confidence in the conceptual model for the flow system, which is often a limiting factor in understanding karst aquifers.

Keywords: conduit flow, temperature tracer, sinking stream, flow modeling, springs, FEFLOW

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Setting up a high-resolution monitoring network to understand soil moisture and epikarst dynamics at 5 sites across the globe

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In many countries karst groundwater is the dominant or even the only available source of fresh water. Karstic heterogeneity induces a large spatial and temporal variability of stocks and water flows in the system providing challenging conditions for the exploration and characterization of karst processes. Up to now, most research on karst processes focussed on describing saturated zone processes and just a few studies have been investigating the dynamics of soil and epikarst processes.
In our project, we want to provide better understanding of soil and epikarst processes. For that, we plan to establish a large monitoring network that records soil moisture dynamics at a high spatial and temporal resolution at 5 karst experiments laboratories across the globe (D, ES, UK, USA, AU). These places are chosen because of their climate conditions as their represent, humid, Mediterranean, mountain, tropical and desert climate types, hence providing a large range of boundary conditions affecting karst hydrosystems.
The monitoring we want to set up, will have the purpose of measuring different soil moisture profiles in order to represent the impact of surface near karst features (variability of soil depths, etc.) on the spatiotemporal variations of soil moisture dynamic. Around 30 profiles with 3-4 soil moisture probes each and distributed over 2 clusters with contrasting land use per karst experimental laboratory sites will be implemented. To choose this locations, we are going to take into account the variables that control soil moisture as karst feature, slope, soil thickness, vegetation, soil characteristics. The selected location should allow a representation of spatiotemporal variations of soil moisture dynamic linked to karst heterogeneities. The final setup of the monitoring network and preliminary data will be presented and discussed.

Keywords: Soil, epikarst, monitoring, characterization, soil moisture

*Speaker

Preliminary results of hydrochemical and isotopic characterization of water saturated layers within the karst infiltration zone

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The Low Noise Science and Technology Underground Lab (LSBB – Laboratoire Souterrain à Bas Bruit - in Rustrel, Southeast of France) is a tunnel digged into the infiltration zone of the Fontaine de Vaucluse karst aquifer that crosses several water-flow points. Previous integrated hydro-geophysical studies (Carriere et al. 2016) realized from the surface at the Buissonnière site 30 m above the tunnel and water-flow point D leaded to a hydrogeological conceptual scheme of the site with evidence of two water saturated layers within the infiltration zone (around 15 and 50m depth). A borehole triplet (3x50m deep - 18m of distance in between) was implemented on the Buissonnière site and confirms the presence of the saturated layers into the UZ.
Within the PiKarstEau project and as a complement to the Interwells project (hydrodynamic studies of the Buissionnière site), a methodological approach was developed for the characterization of the hydrochemical and isotopical properties of the water contained in the 3 boreholes. During low yield pumping tests that were realized in 2 of the 3 boreholes, a high frequency hydrochemical, physicochemical measurements and continuous isotopic measurements have been performed. Water sampling for major ions analysis, Total Organic Carbon and stables isotopes were realized and a Picarro and a fluorimeter were used for the continuous isotopic measurements and the continuous fluorescence measurements, respectively.
Previous pumping tests provided evidence for a low connectivity and transmissivity. Pumping into one borehole seems not impacting the water table in the neighboring holes, and very little water could be retrieved from the medium before emptying the hole. During our study, no temporal variations in the hydrochemistry and fluorimetry were observed, but the 3 boreholes have different hydrochemical compositions even if they are geographically close. Isotopes measurements confirm the differences between the water from the 3 boreholes. However, they also seem to show that an interaction between the 3 boreholes may be possible. Because of the differences between the water from the 3 boreholes and the knowledge of the site geology, the environment seems to be vertically compartmented. The almost constant variations of hydrochemical parameters could also be explained by compartmentation but in our case, the low transmissivity and the very small amount of water retrieved during pumping could explain it better.

*Speaker

Keywords: karst, infiltration zone, pumping test, hydrochemistry, isotopes

Impact of atmospheric pollution deposits on the dissolved inorganic carbon fluxes in karst aquifers: evidences from 40 years old monitoring of karstic watersheds.

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Atmospheric pollutions are known to modify the soil CO2 consumption associated with the weathering of carbonate rocks. To study the long term feedbacks of atmospheric pollution on this chemical reaction, the inorganic carbon fluxes monitored from 1974 to 2006 in 5 karstic watersheds in the south of France were reinterpreted.
Looking yearly average concentrations, the [Ca +Mg] concentration increase about 7.5 μmol/L/year ($\pm$1.1). In the same time, the dissolved inorganic carbon concentration increase about 18.3 μmol/L/year ($\pm$4.8). The gap between [Mg + Ca] and HCO3, name Detla HCO3, was founded to be driven by the atmospheric pollution deposits, producing strong acids that hide the consumption of carbon from soil during the carbonate dissolution without influenced the carbonate dissolution itself. Atmospheric temperature increase is correlated with [Ca +Mg] change, whereas atmospheric pollution deposits decrease from the 70th is linked with Delta HCO3 change.
The re-interpretation of hydrochemical databases using this Delta HCO3 indicator enable to reconstruct the atmospheric pollution load on surface waters. In an indirect way, the dephasing between atmospheric loads recorded in precipitation and Delta HCO3 observed in groundwater could be a new tracer methods to estimate groundwater residence times.

*Speaker

Unveiling the ground water flow within the Ljubljanica River recharge area, Slovenia

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The recharge area of the Ljubljanica River is a 1200 km2 large complex karst system fed by autogenic and allogenic recharge. The Idrija Fault Zone (IFZ) is a dominant structure that dissects the area along a SE-NW line. The IFZ plays the role of a flow barrier and deflects the regional flow from SE-NW direction along a system of poljes and interconnecting water-cave networks. At Planinsko Polje, the underground flow springs as superficial Unica River, crosses the IFZ and sinks along several lines of ponors into the northern-most block of the system. Then, the water flows towards N and emerges at the springs of the Ljubljanica River. This part of the recharge area was the focus of our study, which is based on 3 years long records of automatic monitoring of groundwater level, water temperature and specific electric conductivity (SEC) in important springs, ponors and water active caves of the system. Many events of different scales have been recorded during that period, and several of them include temporal flooding of Planinsko Polje. The level hydrographs in the caves were analysed to build a conceptual model of the regional groundwater flow, in order to study the effect of local geometry on the recorded dynamics and to assess the unknown geometry between the observation points. A particular attention was given to inflections of the level hydrographs, which might indicate the position of potential overflow channels. Water temperature and SEC time series were used to estimate the transit times of the ground water flow along the flow lines. A distributed conduit model of the flow system has been made and tested under variate conditions, in order to verify the conceptual interpretation of the recorded data. While most of the observed system can be related to the outflow from Planinsko Polje, two points located on the southern side of the IFZ and NW from Planinsko Polje allow studying the hydrogeological role of the fault zone. The research conducted within this project has two impacts: it sheds light onto mysterious ground water flow in one of the Classical Karst aquifers and demonstrates the importance, potentials and possible shortcomings of distributed automatic monitoring in active cave systems.

Keywords: cave, groundwater, flood, water temperature, electric conductivity, Ljubljanica River, Planinsko Polje

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Abbé (Jean-Baptiste) Paramelle, 1790 - 1875, Pioneer Karst Hydrogeologist

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IIn the early 19th century when geology was becoming a science, Paramelle, a young priest in the
Department of Lot, France, went out in search of water for his thirsty congregation. His parish was located on the Causses du Quercy, where surface water was scarce. In nine years of field work he learned to determine the location and depth to groundwater. His fame spread rapidly, the bishop relieved him of parish duties, and over the next 22 years, Abbé Paramelle explored 40 of France's departments for groundwater. By his calculation, he found water in 10,000 places during his working career. When he became too old to work, he wrote a book to share his method with the public. The Art of Finding Springs, published in 1856, became a best seller. Six editions were published, and the book was translated into Spanish and German. Many hydrogeologists consider Paramelle to be France's greatest promoter of groundwater. He observed and described important aspects of karst geology before the term "karst" was used. This presentation highlights the "karst" insights of Paramelle's observational method.

Keywords: groundwater, Causses du Quercy, springs, observational method, karst, Paramelle

*Speaker

Using IDPR to characterize recharge area of karst aquifers from catchment to regional scales

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The shape and the nature of hydrographic networks on karst environments are closely linked to the infiltration capacity of geological formations. Thus, the presence or absence of a river in a favorable topographic context can be interpreted in terms of karstic aquifers recharge potential. We present the GIS built index of infiltration and runoff properties of landscape (IDPR) as an interesting tool for the characterization of the karst extension and for the further recharge estimation of such aquifers. A new version of the IDPR tool has been released over France in 2017 which spatial resolution (25 m) becomes very useful for the detection of contributive zones for karst aquifers recharge. Examples of the IDPR application at the river basin scale (Fontaine de Vaucluse) and at the regional scale (Rhone river basin) will be presented. Base flow estimation methods are used for the calibration of the IDPR index in terms of infiltration capacity, leading the IDPR index to be useful for recharge estimation.

Keywords: recharge, infiltration, base flow, rhone river basin

*Speaker

Hydrogéologie de la structure anticlinale d'Audignon (Landes, France) – Comportement karstique et intégration dans les écoulements régionaux du sud du Bassin aquitain

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Dans le sud du Bassin aquitain, les formations carbonatées se retrouvent à l'affleurement à la faveur notamment de structures anticlinales qui sont la conséquence de l'orogenèse pyrénéenne. Ces affleurements peuvent être le siège d'une karstification et constituent par ailleurs des zones d'alimentation ou d'exutoire potentiels des nappes dites profondes régionales. Parmi cette série d'antiformes, l'anticlinal d'Audignon porte à l'affleurement des formations du Cénozoïque inférieur et du Mésozoïque disposées de manière concentrique. Des travaux récents ont démontré le rôle de la karstification dans les transferts rapides d'eau depuis la surface au sein de ces aquifères qui alimentent par ailleurs des sources stratégiques pour la région dont celle du Marseillon exploitée à 6000 m3/j, et principale ressource du secteur. Le comportement karstique de la structure anticlinale engendre une vulnérabilité forte des eaux souterraines vis-à-vis des pollutions de surface, notamment celles liées aux nitrates, et des problèmes de turbidité interviennent fréquemment sur la source. Ces phénomènes ont été observés en parallèle de crues du Laudon (cours d'eau proche) dont une partie pourrait s'infiltrer pour rejoindre la résurgence. La compréhension du schéma de fonctionnement de la structure anticlinale, et de la source du Marseillon en particulier, doit permettre d'améliorer la protection de la ressource d'un point de vue quantitatif et qualitatif et de préciser le rôle de cet anticlinal en tant qu'exutoire et/ou zone de recharge des aquifères profonds.
Les travaux menés portent sur une revisite du contexte géologique conduisant notamment à la réalisation d'un modèle qui s'appuiera sur la validation des logs de forages et des cartes géologiques ainsi que sur l'interprétation et l'intégration des profils de sismique réflexion. La cohérence géométrique du modèle géologique construit sera validée via la confrontation de sa réponse gravimétrique aux données gravimétriques acquises dans le cadre du projet. Dans un second temps, l'utilisation de méthodes d'inversion gravimétrique permettra d'obtenir une distribution (sous forme de probabilités) des densités au sein des différentes couches modélisées. Le but recherché est de relier ces informations aux données de karstologie et d'hydrologie afin d'approcher une distribution de la karstification au sein des formations réservoirs. À l'issue de ce travail, une vision claire de la géométrie de la structure devra être apportée et une évaluation des

*Speaker

niveaux karstifiés pourra être approchée afin, notamment, de rendre compte de la vulnérabilité des eaux souterraines du secteur.

En parallèle, les travaux hydrogéologiques porteront sur la quantification des écoulements au travers de la réalisation de cartes piézométriques hautes eaux/basses eaux ainsi que des mesures du débit du Marseillon et du cours d'eau du Laudon (instrumentation continue). L'approche qualitative consistera en l'acquisition de données de physico-chimie de base (température, conductivité, pH, Potentiel rédox (Eh), O2 dissous), d'ions majeurs et d'isotopes (13C, 18O, 2H, Strontium) sur les sources et forages de la structure. La source du Marseillon sera également équipée d'un fluorimètre de terrrain permettant d'évaluer la réactivité naturelle de la source aux infiltrations rapides.
Les mesures réalisées et le modèle géologique seront analysés pour proposer un modèle conceptuel de fonctionnement du ou des formations aquifères de la structure. Seront précisés en particulier le rôle d'alimentation ou d'exutoire de la structure par rapport aux formations profondes ainsi qu'une estimation de la ressource renouvelable ou disponible au sein des formations. Au niveau de la source du Marseillon, l'évaluation du bassin d'alimentation et la mise en place d'indicateurs permettant de prévoir la survenue de turbidité sont attendues.

Keywords: Hydrogéologie, anticlinal, modèle géologique, gravimétrie, débitmétrie

Earth tide effect in karstic and non-karstic aquifers in the Guinea Gulf

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Abstract

While conducting long-term pumping tests in Gabon and Benin, we were surprised to observe tidal signals in boreholes located more than 20 km away from the sea.

Initially, we considered them to be Earth tide signals, to be corrected in order to improve the accuracy of the pumping test results. The approximation of these signals by a combination of sinusoids (of periods 12 and 12.42 hours respectively) works well and demonstrates that it is a tidal signal. It allows efficient compensation and elimination of this interfering signal.

This paper describes these tide effects (maximum amplitude, variation in amplitude throughout the year, phase shift, etc.) and examines the correlation between these features, the characteristics of the aquifer and the distance of the borehole from the coast. The amplitude of these signals varies very strongly from one aquifer to another (from 5 cm to 110 cm) and we have tried to exploit this variability to estimate the transmissive or capacitive properties of aquifers. The power of this aquifer study tool is limited by the quality of piezometric measurements and the difficulty to access reliable Earth tide measurements in low income countries.

The main result of these studies is to show that it is paramount to be able to distinguish three situations that do not present the same level of risk in terms of contamination of the karstic aquifer by sea water. Two of these situations have been quite widely documented: (a) Earth tides which are almost universal, but present no risk in terms of sea water intrusion and (b) ocean tides which strongly impact surface aquifers located in direct contact with the sea or an estuary (with a maximum risk of saline intrusion, especially strong in karst). A third case, little mentioned in the literature, should be added: that of ocean tides impacting confined aquifers, through periodic variations in the load on the aquifer. The risk of saline intrusion is then moderate, although this tidal effect can be very spectacular in karst aquifers, which is illustrated by a few examples.

Résumé

En réalisant des essais par pompage de longue durée au Gabon et au Benin, nous avons été surpris d'observer des signaux de marée dans des champs captant situés à plus de 20 km de la mer.

Dans un premier temps, nous avons considéré qu'il s'agissait de marées terrestres et nous les

*Speaker

avons traitées comme un parasite qu'il convenait de corriger afin de pouvoir améliorer la précision des résultats des essais par pompage. L'approximation de ces signaux par une combinaison de sinusoïdes (de périodes respectives 12 et 12.42 heures) fonctionne bien et démontre qu'il s'agit d'un signal de marée. Elle permet de procéder à une compensation efficace et d'éliminer ce signal parasite.

Mais l'amplitude de ces signaux varie très fortement d'un forage à l'autre (de 5 cm à 110 cm) et nous avons cherché à exploiter cette variabilité pour estimer les propriétés transmissives ou capacitives des aquifères. La puissance de cet outil d'étude des aquifères est limitée par la qualité des mesures piézométriques et le coût d'accès à des mesures de marée terrestre fiables. Le principal résultat de ces études est de montrer qu'il est de la plus haute importance de pouvoir distinguer trois situations qui ne présentent pas le même niveau de risque en termes de contamination de l'aquifère karstique par l'eau de mer. Deux de ces situations ont été assez largement documentées : (a) les marées terrestres qui sont quasiment universelles, mais qui ne présentent aucun risque en termes d'intrusion salie et (b) les marées océaniques qui impactent fortement les aquifères superficiels situés au contact direct de la mer ou d'un estuaire (avec un risque maximal d'intrusion saline, particulièrement fort dans le karst). Il convient d'ajouter un troisième cas, peu évoqués dans la littérature : celui des marées océaniques qui impactent des aquifères captifs, au travers de variations périodiques de la charge sur l'aquifère. Le risque d'intrusion saline est alors modéré, bien que cet effet de marée puisse être très spectaculaire dans les aquifères karstiques, ce qui est illustré par quelques exemples.

Keywords: karst, Earth tide, ocean tide, seawater intrusion

Démarche de préservation des ressources en eau souterraine pour la satisfaction des besoins futurs. Les travaux engagés sur les masses d'eau karstiques du bassin Rhône – Méditerranée.

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Dans le bassin du Rhône et de la Méditerranée, en France, 77 % de l'eau utilisée pour la production d'eau potable provient des eaux souterraines le plus souvent de meilleure qualité que les eaux de surface.
Toutefois sur de nombreux territoires du bassin et notamment sur les plateaux karstiques (qui représentent près de 40 % de la surface), on constate une évolution rapide et continue de la nature de l'occupation des sols : expansion de l'urbanisation, des zones d'activité (industrielles, artisanales ou commerciales), des infrastructures de transport, spécialisation de l'agriculture, ...
Ce développement des pressions lié à l'accroissement de la démographie et des activités économiques sur les aires de recharge d'aquifères aujourd'hui largement utilisés pour la satisfaction des besoins actuels en eau potable ou à forte potentialité pour les usages futurs, représente une menace pour la pérennité de cet usage.
Lors de l'élaboration des Schéma directeur d'aménagement et de gestion des eaux (SDAGE) valables pour 6 années (2010/2015 puis 2016-2021), il est donc apparu comme particulièrement important, conformément à ce que demande la Directive européenne cadre sur l'eau (DCE), d'identifier les ressources les plus importantes pour la satisfaction des besoins en eau potable actuels et futurs et d'organiser leur préservation sur le long terme.
Une démarche a donc été lancée sur le bassin Rhône Méditerranée (RMed), qui vise à désigner précisément les ressources stratégiques à préserver pour la production de l'eau potable actuelle et future, à définir les zones sur lesquelles sur lesquelles se constituent où sont (seront) puisées ces ressources et à proposer des dispositions de protection adaptées. Des études et des réflexions sont ainsi engagées avec les collectivités qui débouchent sur des recommandations ou des dispositions de protection à mettre en oeuvre. A ce jour près de soixante-dix masses d'eau ont donné lieu à ce type d'étude dont vingt en terrains calcaires.
Dans le résumé et la présentation proposés nous présenterons la démarche et son adaptation pour tenir compte des spécificités des aquifères karstiques.

*Speaker

Keywords: eau potable, ressources, protection, directive cadre sur l'eau

Groundwater resources exploration and sustainable management in discontinuous continental Neogene relying on a karst plateau (Mahafaly-SW Madagascar)

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The south-west of Madagascar is a semi-arid region and a hot-spot of global change. Due to advanced karstification process in the Eocene formations, in the Mahafaly plateau ($\approx$ 3600 km^2) lack of surface runoff, populations survive with the water from temporary ponds. At each drought period the humanitarian situation becomes critical and many health problems affect the population (e.g. undernutrition, water-related diseases). Many humanitarian projects around the world are in similar situations (poorly known area, limited budget and humanitarian emergency). We have chosen to develop a methodological approach for a sustainable exploitation of the groundwater resources, which can be easily repeatable in similar cases. This methodological approach combined several prospecting tools and technologies (geology, hydrogeology, hydrogeophysics, hydrochemistry and drillings). Our approach is divided in 4 phases: (1) Regional scale prospection, (2) Village scale prospection, (3) Drilling campaign, (4) groundwater resource and climate monitoring.

We identified two main groundwater resources within the same hydrosystem: a deep one (below 150m) located within the karstifed formations and a shallow one located in the near surface ($<$ 20m) within the continental Neogene sediments overlying the karst formations. Hydrochemical results from several campaigns at the hydrosystem scale highlighted the vulnerability of the deeper aquifer to saline water intrusion. Hence, the second phase focused on the shallow hydrogeological target. A piezometric survey (127 measurements) combined to high precision GPS measurements revealed a general flow in the west direction. A combination of geophysical measurements at moderate cost (262 TEMfast soundings, 2588 Slingram measurements, 35 electrical soundings) was used to investigate the complex and discontinuous geology of the recent sediments overlying the karstified formations. 6 positive boreholes and 3 wells were implemented accordingly. Despite the numerous measurements the study area remains insufficiently known. In order to prevent any over-exploitation, we installed several piezometric sensors to monitor the water resource. The hydrochemical and the isotopic campaigns were maintained during the

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(3) and (4) phases in order to further investigate the hydrogeological connection between the two aquifers.
The developed methodology was successful in this complex project and requires to be tested on other sites. This unique hydroclimatic observatory in addition to the previous multidisciplinary results will help: (i) non-governmental organization (NGO) and local institutions to prevent future water shortage in this area of Madagascar and (ii) scientists to better understand how global change will affect one of the main karst hydrosystem of the south hemisphere.

Keywords: humanitarian hydrogeology, TDEM, Slingram, electrical sounding, piezometry, karst Mahafaly plateau

Etude morphokarstique de l'hydrosystème de la Cèze

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Cette étude s'inscrit dans le cadre d'un programme de recherche sur les interactions karst/rivières réalisé par plusieurs équipes de la ZABR (Zone Atelier Bassin du Rhône) pour le compte de l'Agence de l'Eau RMC (Ecole des mines de Saint-Etienne-UMR CNRS 5600 EVS, Ecole des mines d'Alès, UMR CNRS 5023 LHENA).
La Cèze est une rivière cévenole qui conflue avec le Rhône après avoir traversé le plateau karstique urgonien de Méjannes le Clap (Gard). Le canyon de la Cèze incise ce plateau de 200 m et contrôle le niveau de base de grands systèmes karstiques dont les réseaux souterrains sont connus sur de grandes distances (Marnade, Camellié, des Fées).

La vallée en aval de ces gorges se caractérise par la présence " d'une ria pliocène " (Clauzon, 1991, Baumard, 2001) qui comble l'incision messinienne et atteint le toit de l'Urgonien à la cote - 600m NGF au droit de Bagnols-sur-Cèze (Interprétation Diastrata, 1995, in Ferry et *al.*, 1997).

L'objectif de l'étude est de mettre en évidence les grandes phases de karstification de ce plateau, de l'élaboration des paléo-surfaces d'aplanissement à la reconstitution des paléo-niveaux de base pour comprendre l'histoire polygénique de la structuration karstique du réservoir urgonien, notamment les développements des karsts profonds : karsts sous couverture des bassins tertiaires, et rôle de l'abaissement du niveau de base au Messinien.
Cette démarche permet de comprendre l'organisation de la karstification dans un continuum Cèze / canyon messinien du Rhône afin d'identifier les cibles hydrogéologiques qui s'avéreraient les plus favorables pour une exploitation future des aquifères karstiques profonds.

Keywords: Canyon de la Cèze, Karst urgonien, paléo, littoraux, incision messienne, ria pliocène, bassins continentaux, paléo, niveaux de base, géomorphologie karstique.

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The Whispering Karst

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The knowledge of karst structure and geometry is a major limit for studies of groundwater flow in karst hydro-systems. For shallow caves and conduits, geophysical methods (gravity, Electrical Resistivity Tomography, Ground Penetrating Radar among others) shows successful results in some cases. Deep caves or conduits are only discovered and mapped by speleologists. The geometry of deep karst conduits is therefore a major gap in the knowledge of the karst. And the impact of each particular cave or conduit on the water transfer could be only inferred from measurements. But such measurements are scarce as the access to the underground caves are often complicated, time consuming and sometimes dangerous.
The main purpose of the present study is to show the potential of seismology to provide new information (at least qualitative and potentially quantitative) about the main active caves or conduits during karst flooding. Floods in the karst are well known from speleologists (fast water level elevation), farmers ("blast noise") and hydrogeologists. The transfer of water in the caves leads an enhanced level of noise or vibrations due to waterfalls, rocks and always water turbulence. The ability of seismometers to measure the surface river noise at a distance of a few hundred meters has been proven in past studies (Burtin et al., 2011) but never applied to underground rivers.

For the study, seismological data from the Laboratoire Souterrain à Bas Bruit (LSBB) located in and under the Vaucluse karst (south of France) are used. First, evidence of increase of noise level during floods are presented (fig. 1). The characteristics of the underground river noise are then used to infer the origin of the signal. The available network of several seismometers allows in a first simple analyses a first location in depth and in space of the active conduits. Finally, the perspective of underground river noise for research and water management institutions are detailed.

Keywords: seismology, floods, noise, geophysic

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Karst/river interaction, elaboration of an indicator of the karst hydric state using karstic spring flows, applied to the Cèze Riv-er (Gard, France)

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Dans l'intérêt de créer un point de référence permettant de connaître l'état hydrique du système karstique dans son ensemble et dans le but de l'associer à une modélisation, un Indicateur de l'Etat Hydrique du karst (IEtHy du karst) a été établi à partir des connaissances acquises sur le fonctionnement de l'hydrosystème karstique de la Cèze. Cet indicateur permet de connaître et de qualifier si à un instant " t " le karst est plus en mesure de contribuer au débit de la rivière ou au contraire à tamponner un signal pluvieux.
Le IEtHy du karst est construit à partir des données recueillies à la source Ussel et au pluviomètre de MétéoFrance au niveau du plateau karstique de Méjannes-le-Clap (Gard, France). Les chroniques de pluie et de débits de la source couvrent deux cycles hydrologiques. Le débit de la source est obtenu à partir des enregistrements d'hauteurs d'eau issues de sondes autonomes CTD. Ces hauteurs d'eau sont converties en débits grâce à une courbe de tarage réalisée pour cette étude. Lorsqu'une précipitation est égale ou dépasse 4 mm de lame d'eau, neuf paramètres sur les pluies et l'évolution du débit de la source Ussel sont analysés afin d'obtenir l'indicateur de l'état hydrique du karst. Au total, 74 évènements ont été traités.
Finalement cet indicateur constitue une entrée pertinente pour la simulation des variations de débits dans la rivière au sein de ses gorges karstiques. Il est aussi un outil pertinent pour les acteurs locaux permettant de surveiller l'état de l'aquifère karstique et donc être une aide à la décision pour la gestion de celui-ci.

Keywords: karst, indicator, precipitation, flow, hydric state

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Karst Modelling Challenge: application of the GARDENIA rainfall-runoff model on the Milandre karst system (Jura, Switzerland)

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In the framework of the Karst Modelling Challenge (KMC), the GARDENIA numerical code is applied to simulate flow at the outlet of the Milandre cave system (JU, Switzerland). GARDENIA is a rainfall runoff hydrological model developed by the BRGM to simulated spring or river flows, as well as groundwater levels. This approach is lumped at the catchment scale, representing the main processes using interconnected reservoirs designed to illustrate soil/epikarst, vadoze zone, and
phreatic zone compartments. The model is calibrated on the 1992 - 1995 time series at an hourly time-step. Main results show that the model is able to reproduce discharge dynamics during flood as well as the recession periods with good performances. Main advantages and difficulties of such modelling approach will be discussed in comparison with other approaches carried out for the KMC.

Keywords: Karst Modelling Challenge, lumped model, calibration

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Nitrate and phosphorous evolution in surface water and groundwater across space and time scales – the example of the Jura Mountains

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The aim of this study is to explore the changes in water quality from local to large spatial scale and from short to long term periods, in order to better understand the fate and transport of pollutants. Our work focused on the analysis of nutrients in surface and groundwaters in the karstic catchment of the Loue river (_˜ 1000 km^2) in the French Jura Mountains. The hydrological behavior of this large basin is highly controlled by surface water-groundwater interactions. Recurrent algae proliferation and a scarcity of species considered to be sensitive are indices of a chronic degradation of the water quality.
A first analysis of long term evolution of nitrate over 45 yrs in surface water shows that the nitrate concentration in waters (mean value of 10 mg/l) is controlled mainly by a seasonal effect (from 2 to 40 mg/l). A long term component is also observed showing an increase of several mg/l from 70's to 90's and then a decrease from 2000 to present. This long-term evolution is correlated to the annual amount of synthetic fertilizers used in cultivated areas of the Jura Mountains. On the contrary to nitrate, phosphorous evolution shows no long-term trend. Changes are mostly controlled by several peaks often superior to 0.2 mg/l, and occurring more frequently during autumn.

A second analysis of short-term evolution was carried out at the seasonal and event-time scales comparing concentrations and fluxes at 5 gauging stations over the catchment. This analysis showed contrasted nitrate and phosphorous evolutions depending the location. High level nitrate concentrations occurred after recharge events in autumn and winter. The nitrate decrease during spring and summer reaches in some locations the detection limit. This pattern is attributed to the biomass productivity during hottest and driest months. Regarding phosphorous evolution, erratic peaks occurred after rainfalls without their amplitude being correlated with that one of the rainfalls, meaning that it originated probably from effluents from wastewater

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treatment plants.
Finally, these first results showed the spatial and temporal variability of water contamination by nutrients, highlighting the complex hydrological and ecological behaviour on the various sub-catchments. The spatio-temporal variability of anthropogenic activities associated with the complexity of transport processes and with the hydrological conditions are the key processes that explain these contrasting responses within the same hydrosystem.

Keywords: nitrogen, phosphorous, contamination, water quality, karst

Transfer process of water and solute in the unsaturated zone of chalk

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Chalk groundwater is an important source for the drinking water supply in Europe but the water quality is degraded. The transfer of contaminants from the surface to the groundwater is not fully understood. So a good understanding of the recharge and solute transfer mechanism in the unsaturated zone of chalk aquifer is important.
Chalk aquifer is a heterogeneous media of multi-porosity so it exists multi transfer processes for the water and the solutes. The objective of this study is to characterize the different kind of water resulting from the different transfer process. We would like to estimate the different transfers' velocities, the quality and also to learn the contribution of different transfer.

Our study site is a former underground quarry: Saint-Martin-le-Noeud. The quarry is located in the Paris Basin, in the cretaceous Chalk between the layer Coniacian and the layer Turonian. Two types of groundwaters are found in the quarry: the percolation (dripping water from the quarry's ceiling) and the lake (groundwater). The quarry lies at a topographic and piezometric ridge so the underground water in the quarry comes directly from the unsaturated zone. We follow 16 sites: percolation and lake across the quarry. In addition, these 16 sites are located at different depths, and their characteristics of the unsaturated zone are not the same.

The sites are equipped with probes and samplers. We have two types of measurements: the measurements in continue for several sites recording water level of lake and the rate of flow of percolation; the measurements of every two months for all the sites of several parameters (electrical conductivity, pH, temperature, water level of lake, rate of flow of percolation). We have also two types of samples of percolation and lake: the sampling in high frequency (every 84h) for 3 sites and the sampling of every two months for all the sites. Then, the samples are analyzed in the laboratory for different parameters: major ions, pesticides, trace ions, etc. So we have the time-series of the quality and the quantity of the groundwater. The quality and the quantity will also be compared between the sites. This is a spatio-temporal study.
The results show that it exist a significant variation between the sites in quality and also in hydrodynamics. For example, the nitrate concentration of percolation varies from 10 ppm to 140 ppm. The concentration of DEA (degradation product of Atrazine) of percolation is lower than the detection limit in several sites when the concentration of percolation in other sites is higher than 10μg/L. And the hydrodynamics vary also between the sites. In most of the site, the

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percolation stops during the dry season. However, there are several sites that the percolation is non-stop all year long. The beginning time of lake level's rising is also different between the sites with a maximum difference of 5 months. The geochemical parameters will be studied with the hydrodynamic of the sites in order to better understand and to characterize the different transfer processes.

Keywords: transfer, unsaturated zone

Fault and karstification: extrapolation from case study of Saint-Clément fault, Languedoc, France.

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In northern Montpellier area, southern France, most of the groundwater resources are located in carbonate and karstic aquifers. These carbonate reservoirs are crossed by a NE-SW faults family that control the karstification and the flow in subsoil. We focus our research on faults structure and on the consequences for karst characteristics and flows alongside these faults.
Saint-Clément fault is a 15 kilometers fault where we focalize the main part of our investigation. Our study is based on a multi-method approach that used different tools. Indeed, in addition to the geological fieldwork, we make use of data from Electrical Resistivity Tomography (ERT), aerial picture analysis and artificial flow tracing.

First, we highlight that Saint-Clément fault plane is quite large (10 meters thick) and mostly composed of impervious material like gouge and smear clay. Moreover, we measure a strong vertical offset (about 500 meters), which links Berriasian limestones, NW, to Valanginian marls, SE. Thus, Saint-Clément fault has an impermeable behavior for transversal flows. Consequently, this structure pushes to a longitudinal groundwater flow that can contribute to the karst development. Furthermore, the systematic presence of karstic loss at the thalwegs/fault intersections permits us to realize some artificial flow tracing to confirm this theory. Indeed we show the existence of a very well connected karstic network along the fault plane. In this way, we demonstrate that Saint-Clément fault is a drainage axis with good groundwater productivity.
Finally, thanks to investigations on others faults, we suggest that structural and karstic characteristics of Saint-Clément fault can be spread to others NE-SW faults in northern Montpellier carbonate.

Keywords: Saint, Clément, fault, karst

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Simulation of multiple-peaked skewed breakthrough curves with the new open-source program OM-MADE.

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Multiple-peaked skewed breakthrough curves (BTCs) have been reported in several tracer tests
realised in karstic environments (Dewaide et al., 2017; Goldscheider et al., 2008). Multiple-peaks are often interpreted as an effect of the presence of auxiliary conduits that divert the solute from the main channel before transport it back to it (Goldscheider et al., 2008; Perrin and Luetscher, 2008; Smart and Ford, 1982), which is a common configuration in anastomotic karstic systems (Smart and Ford, 1982).
The skewed aspect of BTCs is mainly attributed to storage or immobile water zones (Bencala, 1983; Goldscheider, 2015; Hubbard et al., 1982), even if alternative processes are also proposed (e.g., adsorption-desorption, large molecular diffusion, ...).
and Leij, 2012). Existing codes allow us to model one-dimensional transport occurring in one single
flow zone coupled or not with storage zone (OTIS (Runkel, 1998)), or to compute the results of a dualadvective-dispersive equation modelling of the system (Field and Leij, 2012). But in the case of the Furfooz karstic system, the hypothesis was made of a system combining two advective flow zones and one storage zone (Dewaide et al., 2017), with configuration changes along the flow.
In that purpose, we developed OM-MADE, a new open-source program that allows to simulate onedimensional solute transport in multiple exchanging conduits and storage zones. OM-MADE is based on the resolution of classical mass conservation equations. It uses a fractional approach: a temporal explicit resolution scheme and a spatial Lax-Wendroff scheme are used to solve advection, while dispersion is solved with an implicit approach. OM-MADE allows to simulate various configurations: each zone can be a storage or a mobile zone exchanging or not with the other ones, solute lateral inflows or outflows are considered, as well as first-order decay process. The system is discretised along the flow into several reaches of constant parameters.
OM-MADE has been validated against analytical and existing numerical solutions. It is also successfully demonstrated on one tracer test realised in the karstic system of Furfooz. It will soon be available on Github for a free use by the community.
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Keywords: tracer tests, breakthrough curves, program, one dimensional transport, modelling

Hydrogeological characterization of the lukewarm springs in Kistapolca (South Hungary)

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Considerable part of Hungary's thermal water resources is hosted by carbonate rocks. Owing to the favourable geological and geothermal conditions many of these reservoirs are characterized by natural thermal water discharge, usually at the boundary of outcropping carbonates and adjacent sedimentary basins. The Villány thermal karst area is situated in the southern part of Hungary. The karst aquifer consists of Mesozoic carbonates. The outcropping carbonates and their subsurface continuation covered by younger sediments in the adjacent basin basement form a thick (up to 1700 m) karst reservoir.

Since the current hydrogeological system has an artificially influenced discharge, because of water abstraction by wells, the main focus was on the characterization of the natural discharge of the system. Natural discharge phenomena such as springs are telltales of their parent groundwater flow systems and the processes acting along the flow paths. Only one natural spring is known from the Villány region in Kistapolca. There is a lukewarm (20 ∘C) lake in this little village which is fed by several lukewarm springs (24 ∘C). These springs were intensely researched and captured in the 1960s, but since then there is no record available, not even in the spring cadastre. In July 2017, a continuous measuring device (dataqua) was installed in the main spring outlet in order to continuously record the water level, temperature and electrical conductivity changes. According to the springs' temperature and the personal communication with local people the water is a mixed water, so a deep thermal and a local cold component can be supposed. Therefore the springs have a crucial role in the characterization of mixing and the temporal variability of mixing ratio. Since Kistapolca is located in the vicinity of several hypogenic caves (Beremend, Nagyharsány) these results may contribute to the understanding of the cave formation processes i.e. mixing corrosion.
The research was supported by the National Research, Development and Innovation Office – NKFIH, PD116227 project.

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Keywords: thermal water, spring, mixing

Comprehensive hydrogeological study of a hypogenic cave in South Hungary

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The hypogenic cave of Beremend is located in the Villány karst area (South Hungary). This cave is characterized by thermal water-related phenomena: tectonically controlled maze-like pattern, morphological features such as spherical niches, and typical minerals such as huntite, aragonite and typical forms of calcite such as cave popcorns (Takács-Bolner, 1985; Takács-Bolner in Székely, 2003; Vigassy et al., 2010). The deepest part of the cave is still underwater even today, filled by lukewarm karst water (20 ∘C). This region consists of outcropping Mesozoic carbonates and their subsurface continuation in the adjacent basin basement covered by younger sediments. However, due to the complex tectonic settings, small basement outcropping carbonate hills (e.g. Beremend, Siklós) can be found in the sedimentary basin in the South as well. The Beremend cave is located in one of those small carbonate hills. The formation of the cave and its peculiar minerals can be evaluated only if the groundwater flow pattern and its thermal and geochemical characteristics are revealed. The aim of the present study is to perform a regional and a local scale hydraulic study based on measured archival well data. This is supplemented by geochemical study, using natural tracers to identify different fluid components and the mixing processes. Moreover, the flow net and the temperature distribution were reconstructed by a regional-scale numerical simulation. The comprehensive hydraulic–geochemical–numerical study of the hypogenic cave of Beremend could give a plausible conceptual model of its formation.
The research was supported by the National Research, Development and Innovation Office – NKFIH, PD116227 project.

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Keywords: hypogenic, cave, natural tracer, numerical simulation

Karstic processes evolution in the Risle river, their impacts on surface water/groundwater interaction, river flow loss dynamics study and impacts on groundwater

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The Risle river, in its middle portion, is frequently affected by episodes of major sinkholes development; indeed, in the last decade or so, two major sinkholes developed in the river bed leading to crisis situation with a complete river loss in the underlying groundwater and a dried up river course over distances of several kilometers downstream during the summer season. This resulted in major modifications in hydrogeological and in surface – groundwater interaction processes, with major consequences on water quality, water uses and water dependent ecosystems. To understand this phenomenon, its impact both on surface-groundwater interaction processes and on aquatic ecosystems and to improve crisis management, a multi-parameter monitoring program has been set up, in order to acquire the necessary data and knowledge and develop proper tools to best manage these situations. Several monitoring networks were implemented involving several partners. The work carried out in this project notably included setting up monitoring networks for groundwater level, water river level, differential flow in rivers, temperature and conductivity surveys, springs yield, ecosystem surveys (fishes, macroinvertebrates, vegetation) as well as modelling surface, karst and groundwater flow...

Results obtained were numerous including river loss impacts on fishes, macroinvertebrates and vegetation and population recovery rates. The dynamics of local hydrogeological processes are assessed and linked to the consequences on the ecosystems habitats and on water use.

Inverse modelling using an analytical solution of the diffusive wave equation helped assessing for lateral flows during flood events, quantifying spatio-temporal variability for surface water

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and groundwater exchanges. It also highlighted the important role of the karstic zones both on storage and on river flood peak attenuation processes, thereby protecting downstream villages against floods.
Finally an approach using transfer model based on computing the convolution integral of up to several signals allowed building the first functional scheme of this karst system.

Keywords: surface/groundwater interactions, karst, river loss, sinkholes

Physical and hydrological meaning of the spectral information from hydrodynamic signals at karst springs

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Physics-based modeling of karst systems remains almost impossible without enough accurate information about the inner physical characteristics. Usually, the only available hydrodynamic information is the flow rate at the karst outlet. Numerous works in the past decades have used and proven the usefulness of time-series analysis and spectral techniques applied to spring flow, precipitations or even physico-chemical parameters, for interpreting karst hydrological functioning. However, identifying or interpreting the karst systems physical features that control statistical or spectral characteristics of spring flow variations is still challenging, not to say sometimes controversial. The main objective of this work is to determine how the statistical and spectral characteristics of the hydrodynamic signal at karst springs can be related to inner physical and hydraulic properties.

In order to address this issue, we undertake an empirical approach based on the use of both distributed and physics-based models, and on synthetic systems responses. The first step of the research is to conduct a sensitivity analysis of time-series/spectral methods to karst hydraulic and physical properties. For this purpose, forward modeling of flow through several simple, constrained and synthetic cases in response to precipitations is undertaken. It allows us to quantify how the statistical and spectral characteristics of flow at the outlet are sensitive to changes (i) in conduit geometries, and (ii) in hydraulic parameters of the system (matrix/conduit exchange rate, matrix hydraulic conductivity and storativity).

The flow differential equations resolved by MARTHE, a computer code developed by the BRGM, allows karst conduits modeling. From signal processing on simulated spring responses, we hope to determine if specific frequencies are always modified, thanks to Fourier series and multi-resolution analysis. We also hope to quantify which parameters are the most variable with auto-correlation analysis: first results seem to show higher variations due to conduit conductivity than the ones due to matrix/conduit exchange rate. Future steps will be using another computer code, based on double-continuum approach and allowing turbulent conduit flow, and modeling a natural system.

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Keywords: Spring flow modeling, Time, seried analysis, Spectral characteristics, Statistical characteristics

1. New developments in exploring the saturated zone of karst aquifers: Applications to the Quercy region (Southern France)

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In a previous work, we showed at laboratory and field scales that we can estimate water storage and residence time in the epikarst from seasonal seismic properties variations. In this study, we extend our work to the saturated zone and use the seismic signature of water mobility within the saturated porous carbonates to map heterogeneities such as karstic conduits, a task generally impossible to achieve with traditional geophysical methods.
We present first the results at Le Ressel test site located in the Quercy region (Southwest of France). The location of the 100-meter deep conduit is known and piezometers reaching the drain are available. Time-lapse seismic surveys found a signal dimming with seasonal variations above the conduit; it is easier to detect during the dry season. Downhole measurements indicate that the variations could be linked to changing water mixing conditions in the volume surrounding the conduit.
Following this result, the Conseil Départemental du Lot decided to apply the methodology to the Font Vincent case. This karstic spring supplies drinking water to several communities but does not comply with protection regulations. It is necessary to relocate the water intake to a less vulnerable position by setting a well to intercept the conduit. The seismic amplitudes map identified several targets, which are currently evaluated using new speleological discoveries posterior to the geophysical survey.

Keywords: karst, saturated zone, water mobility, geophysics

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Development of a Freshwater Lens Assessment Protocol for Karst Islands

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Karst Islands like those found in the Philippine Archipelago present extreme challenges for stakeholders to manage their water resources in a sustainable manner. Anthropogenic Climate Change, land development, point source pollution and increased population have all combined to alter the water balance on these fragile islands. Karst features, shallow depth to groundwater and the potential for dissolution, contribute greatly to these challenges. Combined, these factors pose an array of complex research challenges. A field reconnaissance, and semi-structured interviews were completed on Bantayan Island in 2016. Drawing upon current groundwater characterization practices the research posits a novel approach for these hydrogeologic environs. With the application of the Freshwater Lens Assessment Protocol (FLAP) credible output for the characterization of the islands groundwater resources will be determined and integrated into an Adaptive Water Resource Management framework, empowering stakeholders to make informed decisions on sustainable abstraction strategies.

Keywords: Karst, Water, Climate, Hydrogeologic, Sustainable

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Combining distributed numerical modelling and signal decomposition techniques to study internal discharges of a karst catchment in Ireland

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Karstic aquifers represent 25% of the water resources worldwide, and are vulnerable to pollution, especially in regard of the high-flow velocities in the conduits. Therefore, comprehension of those systems and the study of their vulnerability is a major stake in the management of the water resource. In particular, the understanding of the different internal dynamics and flow patterns is important when it comes to flow modelling or contaminant transport modelling. The challenge of distributed modelling approaches to represent karst groundwater systems is to deal with the high spatial heterogeneity of karst aquifers. Among the different numerical modelling approaches, coupled continuum pipe flow (CCPF) models (also called "hybrid models") enable to simulate flow in the conduit /fracture/ matrix domains (Ghasemizadeh et al., 2012). However, the building and calibration on actual study sites is long and complex, necessitating 3d geological models and a thorough knowledge of the catchment. Signal analysis methods, especially wavelet analysis and multiresolution decomposition techniques have shown some potential in understanding the behaviour of the system, as the signal from input (rainfall) to output (spring discharge) undergoes some successive filtering and this transformation gives information about its functioning.

This research aims to apply conjointly numerical modelling and signal analysis techniques (Fourier and multiresolution) on a small karst catchment in Ireland. We used Modflow with the UnStructured Grid (USG) and Connected Linear Networks (CLN) modules developed by USGS (Panday et al., 2013) falling in line with previous works from CAVE conduit flow module to Modflow CFP (Kiraly, 1998; Liedl et al., 2003; Shoemaker et al., 2005). We applied multiresolution analysis on the spring discharge and we compared scale-components extracted from spring discharge by wavelet multiresolution analysis with internal flows of the distributed model extracted from different flow paths (direct infiltration, diffuse infiltration, sub catchments). This approach allowed the identification of internal dynamics of the karst catchment and a better understanding of the functioning of the system.

Keywords: multiresolution, wavelets, coupled continuum pipe flow model

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Regional scale geochemical characterization of the Villány thermal karst area (South Hungary)

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Considerable part of Hungary's thermal water resources is hosted by carbonate rocks. The Villány thermal karst area is situated in the southern part of Hungary. The karst aquifer is build-up of Mesozoic carbonates. The outcropping carbonates (i.e. the Villány Hills) and their subsurface continuation covered by young sediments in the adjacent basin basement form a thick (up to 1700 m) karst reservoir.

The Villány thermal karst area is the cradle of thermal water abstraction since Hungary's first thermal well was constructed in this region, in the city of Harkány, by Vilmos Zsigmondy in 1866. The long tradition of thermal karst water utilization is mainly focused on balneology. The thermal waters of Harkány have a unique geochemical component, the carbonyl sulphide (COS), which was firstly described from that location by Károly Than in 1867. Several hypothesis exist explaining the origin of this component. Csicsák-Gondár-Majoros (2008) related it to sulphide ores while Scheuer (2012) suggested that active tectonics induced mantle fluid contribution could be its source.

The aim of the present study to set up a detailed, regional scale geochemical study to get an overview about the region and to investigate the occurrence of sulphuric components. Preliminary results show the data from Harkány are different from the others, i.e. these thermal fluids seem to be unique and different in the region, which can be caused either by fluid contribution from other, non-karstic reservoirs or by local effects. The latter was investigated by a local scale geochemical study, focusing on the region of Harkány.

Keywords: thermal water, geochemistry, sulphur water

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Radionuclides in groundwater flow systems – case studies from karst aquifers in Hungary

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Uranium, radium and radon are usually found in groundwater. Using these radionuclides is a novel approach to characterize fluids of groundwater flow systems and understand mixing processes. Particularly, in regional discharge areas, where different order flow systems convey waters with different temperature, composition and redox-state to the discharge zone. Radium and uranium are redox-sensitive parameters, which causes fractionation along groundwater flow paths. Discharging waters of regional flow systems are characterized by elevated total dissolved solid content (TDS), temperature, reducing conditions, and therefore with negligible uranium content. Whereas local flow systems have lower TDS and temperature and represent oxidizing environments, and therefore their radium content is low. Due to the short transit time, radon may appear in local systems' discharge, where its source is the soil zone. However, our studies revealed the importance of FeOOH precipitates as local radon sources throughout the adsorption of radium, which is transported by the thermal waters of regional flow systems. These precipitates can form either by direct oxidizing of thermal waters at the discharge zone, or by mixing of waters with different redox state. Therefore elevated radon content often occurs in regional discharge areas as well. Owing to the geographical and geological settings, there are many karst reservoirs in Hungary, which consist of two parts, an uncovered karst and its subsurface continuation covered by young sediments in the adjacent basin basement, as a covered karst. Due to the interaction of karst waters and fluids from the sedimentary cover, there are processes, which facilitate the enrichment of radionuclides. Such cases occur e.g. in the vicinity of hydrocarbon reservoirs, where the strong reducing conditions are coupled with elevated radium concentrations. Since 2016 the measurement of radioactivity of springs and wells is compulsory in groundwater monitoring in thos cases, when they are used for drinking water supply. In our study we present case studies from Hungary, where the understanding of groundwater flow systems helped to explain the occurrence of radionuclides in karst aquifers. This study was supported by the ÚNKP-17-4 New National Excellence Program of the Ministry of Human Capacities.

Keywords: radionuclides, flow system, monitoring

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Imaging in a Model the Flow Networks generated by Harmonic Pumping Tests in a Karstic Field (Lez Aquifer, France)

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Identifying flow paths within karstic fields remains a complex task because of the high dependency of the hydraulic responses to the relative locations between the observation boreholes and the karstic conduits and interconnected fractures that control the main flows of the hydrosystem. In this context, harmonic pumping is a new investigation tool that permits to inform on the flow paths connectivity between the boreholes. We have shown that the amplitude and phase offset values in the periodic responses of a hydrosystem to a harmonic pumping test characterize three different type of flow behavior between the measurement boreholes and the pumping borehole: a direct connectivity response (conduit flow), an indirect connectivity (conduit and short matrix flows), and an absence of connectivity (matrix).

When the hydraulic responses to study are numerous and complex, the interpretation of the flow paths requires an inverse modeling. Therefore, we have recently developed a Cellular Automata-based Deterministic Inversion (CADI) approach that permits to infer the spatial distribution of field hydraulic conductivities in a structurally constrained model. This method distributes hydraulic conductivities along linear structures (i.e. karst conduits) and iteratively modifies the structural geometry of this conduits network to progressively match the observed responses to the modeled ones. As a result, this method produces a conductivity model that is composed of a discrete conduit network embedded in the background matrix, capable of producing the same flow behavior as the investigated hydrologic system.
We applied the CADI approach in order to reproduce, in a model, the amplitude and phase offset values of a set of periodic responses generated from harmonic pumping tests conducted in different boreholes at the Terrieu karstic field site (Southern France). This association of oscillatory responses with the CADI method provides an interpretation of the flow paths within the field in a geologically realistic pattern of conduits. This method is therefore of considerable value towards an enhanced imagery of karstic fields in a distributed model for a better water management in this type of aquifer.

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Keywords: Oscillatory signal, Karstic network, Inverse problem, Hydraulic imagery

Hydraulic Analysis of Harmonic Pumping Tests for Identifying the Conduits Networks in a Karstic Aquifer

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In a karstic field, the flow paths are very complex as they globally follow the conduit network. The drawdown responses to a pumping test at constant rate in this type of aquifer are highly variable spatially and difficult to interpret. Furthermore, a constant-rate pumping tends to mobilize matrix diffusive flows and, thus, the conduit flows become 'blurred'.

Harmonic pumping tests represent a new investigation method for characterizing the subsurface groundwater flows. They have several advantages compared to a constant-rate pumping (i.e. more signal possibilities, extracting the signal in the responses, possibility of closed loop investigation).

In the case of a karstic field investigation, several works have shown that a harmonic pumping test allows a better characterization of the local field hydraulic properties. We show in our recent works that interpreting the responses from a harmonic pumping test permit to go further in the conduit network characterization by delineating a connectivity degree between measurement points. We have studied the amplitude and phase offset values in the responses to a harmonic pumping test in a theoretical synthetic modeling case in order to define an interpretation method for the responses. According to the amplitude and phase offset values in a response, relative to the pumping signal, we have distinguished three different type of responses to be interpreted: a direct connectivity response (conduit flow), an indirect connectivity (conduit and short matrix flows), and an absence of connectivity.

We have applied this interpretation method on a true field responses (from a karstic field in Southern France). Firstly we have stated that the whole set of field responses appears to be coherent toward the observation that have been made in the theoretical case. Then, by comparing the periodic responses between them and with the pumping signal, we could interpret and delineate easily and quickly the main flow paths, through the degree of connectivity between each measurement point. We believe that harmonic pumping investigation will soon become of first interest for subsurface flows characterization. The responses interpretation method that we propose allows a simple and quick comprehension of the principal flow paths, without necessary

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a need of calculation or modeling.

Keywords: Heterogeneity, Aquifer characterization, Conduit network

Le Pôle Karst : un outil au service des milieux et rivières karstiques jurassiens

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La Haute-Chaîne, les plateaux, les faisceaux, les structures plissées des Avant-Monts et du Jura alsacien sont des composantes de la chaîne jurassienne qui sont toutes marquées par l'empreinte du karst. Cette karstification n'est évidemment pas uniforme à l'échelle du massif mais chacune de ces unités est plus ou moins impactée par les morphologies du karst qui conditionnent une forte susceptibilité aux contaminations. À ces paramètres structurels de vulnérabilité se greffent des problématiques plus conjoncturelles puisque depuis quelques années certains des grands hydrosystèmes karstiques du massif connaissent des dysfonctionnements écologiques majeurs. La Loue, le Doubs Franco-Suisse, le Dessoubre, la Bienne, la Haute rivière d'Ain, aucune des grandes artères de ce territoire n'a été épargnée par des altérations hydro-écologiques qui se traduisent notamment par des mortalités piscicoles de grandes ampleurs.
C'est dans une perspective de meilleure connaissance et corolairement de meilleure préservation de ces hydrosystèmes que le Pôle Karst a été initié. Après une première phase de préfiguration du projet (2015/2016), le Pôle a engagé pleinement ses actions en début d'année 2017 avec comme objectifs (i) l'amélioration de la structuration et de la visibilité des données et connaissances produites (notamment par les acteurs du monde de la recherche) aux niveaux régional et infrarégional, (ii) la fédération d'un réseau de partenaires pour répondre aux problématiques que posent la gestion de ces hydrosystèmes, (iii) l'accompagnement (technique et scientifique) des acteurs du territoire dans leurs démarches.
L'objectif est en premier lieu de témoigner des nombreuses actions qui soutiennent ces perspectives mais aussi de proposer, un an et demi après le lancement officiel des actions, un premier retour d'expérience sur ce dispositif unique en France.

Keywords: Connaissance, Partage, Accompagnement, Hydrosystèmes karstiques, Massif du Jura (France)

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Carbon exports and landscape evolution in the Vadu Crişului karst basin of Transylvania, Romania

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The epigenic conduit system connecting meteoric recharge entering Bătrânului Cave on the Zece Hotare karst plateau to spring discharge arising from Vadu Crișului Cave along the Crișul Repede River provides one glimpse into karst processes and landscape evolution occurring in the Pădurea Craiului Mountains of Transylvania. This investigation considers field chemistry, discrete samples, and continuous monitoring data collected between October 2016 and December 2017 to quantitatively evaluate the net export of dissolved inorganic carbon (DIC), particulate inorganic carbon (PIC), total suspended sediments (TSS), and dissolved inorganic carbon (DOC). Contributions of PIC and DOC in karst groundwater are often unaccounted for in carbon budgets.

Direct meteoric recharge accounts for 4 to 13% of observed discharge; most recharge enters the karst basin through infiltration into dolines and epikarst on the karst plateau, which results in stable water chemistry at Vadu Crișului. The annual flux of DIC from this karst basin is from 1.37x105 to 1.64 x105 kg/yr. The annual flux of carbon increases by 12 to 22% when considering added contributions of DOC.

Storm events do have a significant impact on mechanical and chemical processes operating in the karst basin; the addition of PIC and TSS flux increase landscape erosion rates by 1.1 to 1.2% and 7.9 to 8.3%, respectively, above the denudation rate computed by DIC alone (36.5–56.9 mm/ka). This illustrates the contributions of mechanical erosion in karst landscapes, particularly in high discharge conditions, when the flux of suspended sediments outpaces dissolved solutes.

Keywords: particulate inorganic carbon, dissolved organic carbon, mass balance, total suspended sediments, Pădurea Craiului

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Variability of the water stock dynamics in karst: insights from geophysics

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Strong and sharp variations of geological properties such as porosity or permeability induce in complex hydrosystems a significant heterogeneity in terms of hydrogeological conductivity, storage capacity or transmissivity. Those structural heterogeneities are challenging to take into account for both scientist and groundwater resources management, while their impact on groundwater transfer and storage might be significant in karsts. Karst heterogeneities prevent the comparison and moreover the combination of data representative of different scales: for example borehole water level can generally not be used directly to interpret spring flow dynamic. The complexity of the geological structures hosting hydrosystems also impacts the temporal variability of groundwater transfer and storage. Indeed, karst hydrosystems present a characteristic non linear relation between the precipitations and the discharge at the outlets with threshold effects and a large variability of groundwater transit times. We apply here geophysical methods with an original configuration at a specific site where the presence of an underground gallery offers us the singular opportunity to acquire data in depth and at the surface above the tunnel. Those new observations are analysed to deepen the understanding of the hydrosystem heterogeneity impacts on water tranfer and storage processes. For that purpose we focus on the complementarity of a 2D electrical resistivity tomography and time-lapse micro-gravity experiments for describing the subsurface heterogeneity and its impact on the functioning of a karst hydrosystem located on the Larzac plateau in the south of France. The collected data set allows a characterization of the groundwater storage dynamic spatial variability at a scale of a few hundred meters.

Keywords: Water storage, Gravimetry, ERT

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Impact of rainfall events on the sulfate variability of a complex gypsum-carbonate karst spring

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Especially in alpine regions, karst springs are an important source of drinking water but also highly vulnerable to contamination, particularly after rainfall events. Rapid infiltration of surface water occurs in karst aquifers because of a significant conduit development and in addition contaminants can easily enter the karst network through swallow holes, dolines or fissures. Especially during flood events water exchanges may occur between the karst conduits itself and the adjacent matrix.
This study addresses a complex gypsum-carbonate karst setting in the Lechquellen Mountains in Vorarlberg, Austria where limestone and dolomitic rocks are underlain by the Raibl Group. In this case, a usually stable flux of sulfate originating from gypsum deposits within the Raibl Group was being mixed with variable flow of carbonatic karst freshwater. For this particular case, an almost constant bicarbonate concentration was observed during a rainfall event, while the sulfate concentration showed a significant decrease during this flood event. Because discharge increased by 32% while the sulfate concentration decreased by 65%, this behavior cannot be explained by a simple dilution effect.

During stable low-flow conditions, the main flow paths are located within the Raibl Group and this sulfate-rich water contributes a large portion to the spring discharge. During high-flow conditions, the gradients reverse. In this case, the head within the main conduits is greater than the head of the surrounding matrix and causes a water flow from the conduits to the matrix. Therefore, more water from the overlying carbonatic layers contributes to the discharge of the spring while the percentage of the contribution of the sulfate water from the Raibl Group decreases.
The variations of the sulfate concentration during a flood event could be demonstrated in this study. We developed a conceptual model for the spring behavior and showed that the reason for the decrease of the sulfate concentration after rain events is not only a dilution effect but also a conduit-matrix interaction and an interaction between the sulfate-rich layers from the Raibl Group and the overlying carbonatic rocks.

Keywords: karst groundwater, sulfate variability, conduit, matrix interaction, Raibl Group

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Relation karst-rivière : intérêt du suivi continu de la chlorophylle

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La relation entre le karst de restitution et les eaux de surface est un élément primordial de la gestion des captages d'eau potable en zone karstique. Elle peut être étudiée avec des approches classiques en hydrogéologie que sont les essais de pompages et les suivis physico-chimiques. Ces méthodes peuvent s'avérer caduques à caractériser les relations entre les masses d'eau lorsque les variations de niveaux dans les conduits restent faibles, et que le système karstique possède un fort pouvoir tampon, notamment sur le pH et la température.
La caractérisation des transferts de masse doit donc chercher à s'appuyer sur l'étude d'un paramètre présentant un signal caractéristique pour l'une des masses d'eau et un bruit de fond quasi nulle pour l'autre. La chlorophylle répond à ce postulat, et à ce titre, son suivi en continu permet d'étudier les transferts de masse rivière-karst et les risques d'inversac. Des sondes compactes Hyperion ont été testées dans un système constitué d'une source (drain principal) et d'un forage implanté sur le système annexe au drain (SAD). La limite de détection est de 0,025 μg/L. Les courbes enregistrées au pas de temps de 1 minute permettent de caractériser les échanges dans le temps et en terme de concentrations dans les compartiments du karst. Les données enregistrées montrent des réponses différentes entre le conduit et le SAD, en accord avec les résultats de traçages.
Les enseignements tirés de ce suivi permettent de déterminer les capacités de production en complétant les tests de pompage par une approche qualitative, pour des captages implantés sur des karsts de restitution en plaine alluviale. Un suivi en continu permettrait en outre de caractériser les périodes de risques d'inversac pour lesquels des traitements plus poussés seraient ponctuellement nécessaires.

Keywords: karst, rivière, chlorophylle, gestion de la ressource

*Speaker

CARACTÉRISATION D'UN HYDROSYSTÈME KARSTIQUE PAR UNE APPROCHE PLURIDISCIPLINAIRE : LE CAS DES CALCAIRES DU BARROIS

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Les aquifères karstiques constituent une ressource incontournable pour l'alimentation en eau potable, mais restent un défi posé aux gestionnaires comme aux hydrogéologues du fait de la complexité de leur caractérisation ainsi que de leur sensibilité potentielle aux contaminations et crues éclair. La caractérisation des hydrosystèmes karstiques est classiquement basée sur le suivi hydrochimique et hydrodynamique des exutoires, dont la réponse est sensée intégrer l'ensemble du comportement du bassin. Cette méthodologie est inadaptée au cas de systèmes compartimentés en sous-bassins hydrogéologiques situés en tête de bassin hydrologique. L'installation d'un centre de stockage de déchets radioactifs en couche géologique profonde (projet Cigéo) dont les installations de surface sont implantées au sein d'un système hydrogéologique karstifié en tête de bassin versant (calcaires du Barrois) a ainsi nécessité le développement d'une méthodologie pluridisciplinaire originale et dédiée afin de comprendre la dynamique des écoulements et d'évaluer les stocks au sein de cette formation.
Sur ce site d'environ 50 km2, la réalisation de plus de 100 forages a permis d'établir un modèle géologique numérique. L'inspection vidéo des ouvrages a ensuite offert une reconnaissance de la fracturation (peu exprimée en surface) et des drains karstiques (non accessibles par le réseau spéléologique). L'analyse des chroniques piézométriques relevées en forage et des chroniques de débit des cours d'eau aux exutoires a permis de définir des groupes de points de mesure aux fonctionnements statistiquement similaires. Ces données ont été interprétées en regard de la fracturation et des niveaux de karstification préférentiels synthétisés dans le modèle géologique. Enfin, la réalisation de sondages par Résonance Magnétique des Protons (RMP) a permis de quantifier les teneurs en eau dans les différents horizons géologiques.

Cette analyse pluridisciplinaire a permis de préciser les principales caractéristiques de l'hydrodynamique locale et d'aboutir à un modèle conceptuel de l'aquifère des calcaires du Barrois au droit du site Cigéo. Cet hydrosystème pourrait ainsi être décrit comme un système hydrologique présentant ainsi des drains développés sur les inter-bancs calcaires et associés à un réseau de fractures périglaciaires en proche sub-surface. Sa perméabilité matricielle est faible.

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Cette structure conditionne le comportement hydrodynamique du système. La réponse piézométrique au droit des forages suivis est globalement rapide, attestant de la bonne transmissivité du réseau de fracture et de drains. Les effets de seuils observés sur les chroniques piézométriques ont pu être liés à la structure du réseau de drainage et à la présence de niveaux semi-perméables stratifiant l'aquifère(fractures et karstification). Les faibles teneurs en eau RMP confortent la mise en évidence d'un aquifère peu capacitif.

Le modèle hydrogéologique conceptuel des calcaires du Barrois pose la question de la vulnérabilité de cet aquifère karstique au changement climatique. La pluviométrie actuelle relativement constante sur l'année (moyenne 100 mm/mois) sur ce site à la limite entre Meuse et Haute-Marne permet de soutenir un couvert végétal important (forêts et activités agricoles). La faible capacité de stockage de l'aquifère du Barrois laisse supposer une vulnérabilité importante de ce couvert végétal à des périodes de sécheresse prolongées.

Keywords: karst, fracturation, piezometric monitoring, RMP

Influence of karsts on the radon production and migration: experimental data and numerical modelling (Fourbanne site, French Jura Mountains)

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Radon (222Rn) is a naturally occurring radioactive gas with a 3.82-day half-life, originating from the decay of 226Ra in the solid grains of soils and rocks. It can accumulate in confined environments, such as buildings and has been recognized as a carcinogenic gas (IARC, 1988). Radon risk management requires identifying areas where the radon concentration is expected to exceed the relevant national reference level in a significant number of buildings (Council Directive 2013/59/EURATOM).
A national map of the geogenic radon potential was elaborated in France by the Institute for Radiological Protection and Nuclear Safety (IRSN) in 2010. However, the results of this mapping showed the necessity to enhance knowledge on the influence of some local geological factors on the radon production and migration, such as karstic structures, at a regional scale. Indeed, karsts are very permeable geological environments and can contribute to radon transfer to the surface by gas movements in their underground cavities, fractures and other typical structures as sinkholes. The aim of this study is to characterize and to model the radon production and transport in a karstic system in order to evaluate the potential influence of such geological contexts on the radon levels in the unsaturated soils.

A karstic area formed in Secondary carbonate sedimentary rocks and located in the French Jura Mountains, where a significant amount of indoor radon levels higher than 300 Bq.m-3 are observed, was selected as field study area. The physical and radon source properties of the unsaturated soils have been characterized (radium activity, permeability etc.). The radon level fluctuations in time and space in the karstic system (caves and soil-air) have been continuously monitored during one year. Those fluctuations have been correlated with meteorological and hydrogeological time-series data. Moreover, some single-time data have also been measured to characterize the spatial variability, on the area, of the radon activity concentration in soils and the radon exhalation rate at the soil surface and to test the potential impact of karstic structures

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(faults, sinkholes) on this variability.

These experimental data allowed calibrating a new model of radon transport from the caves to the soil surface that has been developed using the Brinkman approach. In this approach, the transition from the fluid (caves) to the porous (soil) medium is achieved through a continuous spatial variation of properties. This model is based on the TOUGH2Rn software developed at IRSN (Saadi et al., 2014) which can handle finite volume numerical problems of non-isothermal, two phases, five-component flow and transport in porous media. The total flux term in the mass balance equations is assumed to result from advection and diffusion, and it calculated according to Darcy and Fick laws. The code calculates radon production by emanation from soil-radium. The goal of the numerical modelling was to explain the conditions leading to very high radon concentrations in soils and to understand the phenomena involved in the transport of radon in the karstic system.

Keywords: Radon, natural radioactivity, transport in porous medium

Speleogenesis of some deep and long caves and karst springs in Croatia

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In the last twenty five years due to the technical inovations, the results of caving and speleodiving are much more comprehensive and complete. The greatest results are the ones gathered from caving in deep vertical, long horizontal caves and diving the deep karst springs worldwide as well as in the Dinaric Karst in Croatia.
Vertical caves are indicators of a stronger tectonic activity and their genesis is connected to the primary and secondary tectonics. Three of the caves are deeper than 1000 meters and the deepest one is 1432 meters (Lukina jama) and the longest one (Kita Gacesina) is longer than 34 kilometers (depth near 800 meters) and the whole cave system could be very soon longer than 60 kilometers. The constant presence of groundwater i.e. karst springs in those caves indicate the certain neotectonic and neohydrogeological activity of the region. This points to the speleogenesis of the hypogenetic type, which is not so common in Croatia.
Even the experts in speleogenesis in Croatian karst could not predict the existance of karst springs deeper than 100, 150, 200 or 250 meters in Croatia. New speleodiving researches in the springs of rivers Una, Sinjac, Gacka, Kupa, Krnjeza, Krka, Krupa, Zagorska Mrežnica, Dubanac etc. present new data about the tectonic and hydrogeological structure of the certain karst areas in Croatia. The longest submerged sea cave springs (Vrulja Zecica, Vrulja Modric) are today longer than 3 and half kilometers.

Keywords: Karst, Caves, Springs, Speleogenesis, Dinaric karst, Croatia

*Speaker

A predictive machine learning-based model for groundwater flooding in lowland karst

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This research has developed a Support Vector machine based model of a lowland karst network in order to assess groundwater flooding in the area in response to combinations of extreme rainfall and tidal events. The study has focused on a lowland karst network in the west of Ireland fed by allogenic runoff from low permeability Devonian mountains and discharges into a bay below mean sea level. The temporal dynamics of localised groundwater-surface water interactions have been studied for several years to yield information about the nature of the hydraulic connections beneath the ground. From this a deterministic hydraulic / hydrological distributed pipe network model of the system has been developed. This model predicts the outflow from the main spring into the sea (which had not been possible to measure continuously). In response to severe flooding events in November 2009 and December 2015, this current research has now characterised the hydrogeology of whole karst network by carrying out lagged correlations between historical flooded volume and rainfall as well as tidal amplitude to investigate the impact of these two main drivers on flooding in the area. The relationships were then incorporated into a machine learning approach (Support Vector Regression) to develop a predictive model for groundwater flooding based upon lagged rainfall and tidal amplitude inputs. The model has been used to hind-predict the extent of flooding the lowland karst area over the past 50 years, back to periods before monitoring had started. It has also been used to evaluate the inherently non-stationary behaviour of the flooding in the karst system, suggesting that the extent of flooding is related to the synchronicity of heavy rainfall and perigean (i.e. maximum) spring tides. This knowledge can be used to make more reliable flood management predictions and mitigation strategies in the future in order to help to protect local communities.

Keywords: lowland karst, support vector machine, groundwater flooding, tide

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Karst Modelling Challenge - semi-distributed pipe network and reservoir model (Ireland)

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This paper details the progress made on the Karst Modelling Challenge (KMC) by the team from Trinity College Dublin (TCD), Ireland. The KMC was set up by Pierre-Yves Jeannin (SISKA) in 2016 with the aim of identifying the most effective approach for modelling karst aquifers in different situations. As such, competing teams have been given access to the same rainfall-discharge measurements from the Milandre cave stream catchment in Switzerland and asked to model the aquifer behaviour using their own preferred approach. The Milandre catchment is approximately 10 km2 large, receiving only autogenic recharge and discharges at the Saivu spring. Time series of precipitation, spring discharge and air temperature at hourly time steps over a 2.5 year period (1993-1995) have been supplied against which the model has been calibrated. The first phase of the KMC (reported on here) is to model only the rainfall-discharge relationship, evaluating the model's performance using the Kling-Gupta Efficiency (KGE) criteria for comparison against the other teams. The TCD team's approach has been to develop a hydraulic / hydrological semi-distributed pipe network model of the karst aquifer system. This model has been built using Infoworks ICM version 6.5 (Innovyze software). This software package is designed for management of urban drainage networks and incorporates the Hydroworks modelling engine. The model simulates the hydraulic behaviour of a pipe network under varying conditions of rainfall, land use, population, inflows, etc. and so is capable of modelling the hydraulic conditions in both open channel and pressurised flow channels. It is therefore considered to be a suitable approach for modelling a well-developed karst conduit network such as that of the Milandre test catchment. The model represents the main conduit flow system in the Milandre karst aquifer as a network of pipes (representing conduits) as well as tanks to provide additional storage linked to specific geological attributes. Diffuse autogenic recharge has been incorporated into the model using a conceptual epikarst fracture system represented by sub-catchments draining into the main conduit system via permeable pipes. This was achieved using a combination of runoff-routing model, Groundwater Infiltration Module (GIM) and use of SUDS (Sustainable Urban Drainage) applications in the Infoworks modelling suite. The rainfall falling on a subcatchment is first subjected to evapotranspiration losses and initial wetting and storage losses. The water was then routed down through the soil into the conceptual epikarst fracture system which was represented by pipes with permeable characteristics (with flow calculated via Darcy's Law), which then link to the main open conduits.

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Keywords: karst modeling challenge, pipe network, Infoworks

Interpretation of long-tailed breakthrough curves from tracer tests in karst aquifer systems

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Understanding and predicting contaminant transport is of major importance for groundwater protection, particularly in karst areas. Karst aquifers are important drinking water resources but highly vulnerable to contamination. Contaminants are transported rapidly through the network of conduits which causes a fast response at the springs and a rapid deterioration of the water quality. At the same time, contaminants are retarded in immobile zones and are subsequently transported as the concentration in the conduit, i.e. the mobile zone, decreases. This might generate a long-lasting low-level contamination. This behavior is expressed by the steep rising limb and the long-tailed falling limb of tracer breakthrough curves which is an often-observed phenomenon in karst systems and cannot be quantified by the conventional advection-dispersion equation (ADE). We examined examples from a sub-tropical karst system in Northern Vietnam and an alpine karst system in Austria under humid climate where we observed distinctive long-tailed breakthrough curves of the conservative tracers. We present several modeling approaches: (i) ADE with Dirac injection, (ii) ADE with multiple pulse injection (MPI), (iii) two-region non-equilibrium model (2RNE) and (iv) continuous time random walk approach (CTRW). The MPI approach is suitable to determine transport parameters along individual conduit sections if intermediate monitoring points are available. The 2RNE makes it possible to quantify exchange processes with immobile fluid regions. In particular, CTRW is a promising approach, as it requires a lower number of fit parameters.

Keywords: long tailed breakthrough curve, advection dispersion equation, two region non equilibrium model

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Hydrogeological framework for a safe and sustainable water supply system in the Dong Van Karst Plateau UNESCO Global Geopark, Vietnam

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The Dong Van Karst Plateau is the first UNESCO Global Geopark in Vietnam, located in the northernmost part of the country. Since its designation as Geopark in 2010, the number of tourists in the region has increased an now exceeds 500,000 per year. The freshwater demand has increased accordingly, but due to the extremely intense karstification and steep topography, water availability is limited. Furthermore, agricultural land use and the absence of adequate wastewater treatment, along with the high vulnerability of the karst system, represents a challenge in terms of groundwater quality. Since 2013, a new water supply system is being designed and implemented, using energy-efficient, adapted technologies. In parallel, detailed hydrogeological investigations have been carried out as a basis for sustainable water supply in terms of water quantity and water quality, using a comprehensive approach that is transferable to other remote, mountainous and subtropical or tropical karst systems. Numerous tracer tests made it possible to delineate karst spring catchments and determine relevant transport parameters. In the major cave system feeding the designated water abstraction structure, mean flow velocities increase from 183 m/h in dry season to 1043 m/h in wet season. Microbiological sampling and analysis revealed that 40 % of the samples taken at springs connected to swallow holes show *E. coli* levels $>$ 2000 MPI/100 mL, while springs not connected to a swallow hole display lower contamination levels. Continuous monitoring of particle-size distribution and β-D-glucuronidase was established as a novel method of microbial water-quality monitoring at karst springs and revealed diurnal fluctuations, probably related to land-use activities in the allogenic catchment. These findings helped to locate suitable freshwater sources, to identify contamination sources, and to set the basis for a safe and sustainable water supply system in a subtropical karst region.

Keywords: freshwater supply, subtropical karst, tracer tests, water, quality monitoring, microbiology

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The Functional significance of the hyporheic zone in karst water system

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3620 groundwater systems are registered in karst area in South China. The groundwater system discharges as subterranean river or spring, providing domestic drinking water, industrial and irrigation water for numerous of cities and villages, and supporting the unique underground ecosystem. Under the impact of human activities and climate change, most of the groundwater systems suffer from flow reducing or drying and face the problem of water deterioration. This kind of problem can be viewed from two sides. Firstly, the deterioration of water is caused by direct or specific human activities. It can be improved by controlled the activities, such as pollution sources. Secondly, the water environment degrades quietly, representing by disappearance of original aquatic plant and then trigging problems such as microorganism outburst, water temperature rising, and turbidity increasing, resulting in the loss of groundwater ecological functions. The occurrence and development of the latter problem in karst area have more uncertainty, and the solved measures will be more complicated. The outlet of underground river or spring usually forms karst pool or lake with a certain area, which is not only the location of water resources development and utilization but also carrying significant ecosystem value. Meanwhile, the outlet usually overlaps with the river hyporheic zone (HZ). Therefore, the outlet of underground river or spring is a HZ of groundwater and surface water. Originally, the HZ is a zone with high active biogeochemistry process, which is the important healthy symbol of groundwater, surface water, and aquatic biological environment. If the interaction function of HZ weakens or loss, the health status of groundwater and surface water will be decreased.
Even though the concept of karst hyporheic zone was already raised by researcher in recent years, it was only aimed at the interaction function of karst conduit water and the matrix. The interaction process between karst conduit and surface water and the hydrochemistry process and the biology function are poorly understood. Scientific issues, such as how the karst hyporheic zone forms in karst water system in South China and what roles it plays in improving or deteriorating the water environment are never involved. Taking a typical karst basin in South China, Wuming covered karst basin as the case, the environment function of karst hyporheic zone was studied by auto-monitoring and sampling analysis of hydrology and hydrochemistry, by identifying the key community of aquatic ecosystem, and by comparing carbon cycle in different media and hyporheic zones. The objective is to know the environment function of karst hyporheic zone, to understand the role it plays in improving or deteriorating water environment and aquatic ecosystem, and finally to provide scientific evidence for policy-making of unified management in groundwater and surface water system.

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Based on the characteristic of flow and discharge of karst groundwater in South China, the concept of karst cave hyporheic zone (CHZ) is defined. The cave hyporheic zone is defined as the site or zone where the conduit flow and other types of water are interacting. Breaking the limitation of original concept, this concept focus issues of how it changes and what is the effect of groundwater after it interacting with other types of water. The concept develops and enriches the scope of karst hyporheic zone.

The types of cave hyporheic zone are classified. According to the karst development and the hydrodynamic condition, the cave hyporheic zone is classified as four types: spring hyporheic zone, sinkhole hyporheic zone, window hyporheic zone, and conduit hyporheic zone. Of which, spring hyporheic zone and window hyporheic zone are the most common and important. The characteristic of each types of hyporheic zone was analyzed.

The hydrogeochemistry process and the main community of aquatic organism in spring hyporheic zone and window hyporheic zone, and the interaction and feedback between them are understood. The hydrochemical features show a significant gradient in horizontal direction in spring hyporheic zone, while there is vertical direction of gradient in window hyporheic zone. After passing through the HZ, the content of NO3- decreases as 6.5%-90.9%, indicating that HZ has a good degradation capacity of contaminant. The aquatic macrophyte in CHZ has a good function of water purification performance, but it is easily disturbed, resulting in evolution or vanish. In general, the diversity index of plankton is low in CHZ, and the structures, evenness, and the dominant species in different CHZ are different. Also, the seasonal variations of those indexes are significant, indicating the vulnerability and specificity of CHZ. The species and abundance of plankton in the karst groundwater outlet and in the CHZ are different, and the structures and dominant species change, suggesting the CHZ is an active bioreactor.
The reason of cave hyporheic zone deterioration is mostly attributed to the interaction between groundwater and surface water. When the spring HZ and river HZ overlaps, water environment is more easily degeneration. Lingshui is the representative of this kind of HZ. The reason is water quality in surface river usually worse than that in karst groundwater. Even though the vanish of submerged plant would not cause the destroy of aquatic organism food chain in a short time, the water environment and aquatic ecosystem will be changed acutely if the restricted condition of water environment factors are changed. The water quality can be improved by groundwater quickly updating, but the healthy aquatic ecosystem would not be recovered due to the degradation of HZ functions.

Keywords: cave hyporheic zone, conduit flow, karst spring, aquatic ecosystem, carbon cycle

Analysis of the flow recessions of the main outlet of the Dyr karst (Tebessa – Algeria)

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In this paper, we present the results of a characterization study of the hydraulic behavior of the Maastrichtian karst system of the Dyr perched syncline that is situated in the north of the Algerian territory and constitutes the north horst of the Tebessa subsidence basin. The processing tool of treatment is the application of the method of analysis of the flow recession curves of the main outlet; we are only interested in the decreasing part of the unitarian hydrogram with which we will analyze:

- The recession, during which the infiltration influences the draining of the reservoir;
- Drying up, which starts at the moment when the flow of infiltration becomes zero.

According to the Maillet model, the draining of under karst system bathed will thus be described and the various physical and structural parameters of its flow will be determined. The treatment with this method of functional approach, unitarian hydrograms relating to the flow rate of the spring Ain Zerga over a period nine hydrological cycles (2002/2003 to 2010/2011) revealed us that this karst system is characterized by a very complex structure and hydraulic behavior. This complexity is certainly due to the hierarchy of voids and the considerable irregularity of the temporal distribution of the water inflow by precipitation.

The functioning of the under system infiltration is marked by an infiltration always slow despite the irregular change of the climatic conditions in this zone of study. The duration of water infiltration for recharging the bathed zone is 06 till 12 days. The bathed karst under system is characterized by a rather rapid draining probably due to a karstification developed in this zone. Its groundwater reserves are quite important and its flow regime is influenced by the losses of load upstream of the main outlet and the intensification of pumping at the deep wells installed in this under system. According to the Mangin classification, the Maastricitian aquifer system of Dyr is effectively karst (K $<$ 0.5) and complex with large geometry and numerous subsystems.

Keywords: Karst, Hydraulic behavior, Recession curves, Flow rates, Ain Zerga spring, Dyr Syncline,

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La dynamique du CO2 dans le continuum atmosphère-sol-épikarst et son influence sur le potentiel de karstification des eaux épikarstiques : application au site de la Grotte de Lascaux (Montignac, France).

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Ces travaux avaient pour objectifs de comprendre la dynamique du CO2 dans le continuum atmosphère-sol-épikarst du site de la Grotte de Lascaux et d'en évaluer l'impact sur le marquage hydrogéochimique des eaux épikarstiques. A ces fins, une parcelle expérimentale a été instrumentée à proximité de la cavité. Cette dernière permet l'enregistrement en continu des paramètres hydroclimatiques et des teneurs en CO2 mais aussi l'analyse du δ13CCO2 de l'air à différentes profondeurs dans le sol et l'épikarst. Les flux de CO2 émanant des sols y sont aussi enregistrés. La cavité de Lascaux donne quant à elle accès à une fenêtre d'observation sur les écoulements non pérennes provenant de l'épikarst sus-jacent (6 m d'épaisseur). Des prélèvements hebdomadaires permettant la détermination des équilibres calco-carboniques des eaux mais aussi du δ13CCMTD y sont effectués tout comme le suivi en continu des débits et des paramètres physico-chimiques de l'eau. Les teneurs en CO2 relevées dans les sols soulignent la saisonnalité de la production biogénique mais aussi une différence de production selon le faciès pédologiques et les propriétés physico-chimiques. Les calcisols comportent des concentrations de 0.5 à 3.9%, bien supérieures à celles des brunisols acides (0.1 à 1.8%). Les flux ascendants de CO2 mesurés montrent quant à eux une évolution saisonnière avec des valeurs maximales (25 g.m-2.j-1) en été et en automne et des minimales en hiver et au printemps (6 g.m-2.j-1). Ces flux diminuent à l'échelle de l'épisode pluvieux suite à l'augmentation de la teneur en eau du sol qui agit comme un " couvercle " et limite la perte de CO2 en direction de l'atmosphère. De la même façon, des processus saisonniers d'accumulation du CO2 (hiver et printemps) et de vidange du CO2 vers l'atmosphère (été et automne) sont observés sous l'effet de la variation de la teneur en eau de l'épikarst. Ces processus expliquent les concentrations en CO2 très variables (0.6 à 6%) enregistrées dans l'épikarst superficiel (0 à 3 m de profondeur) et concomitantes avec celles du δ13CCO2 (-22.1 à -24.5). Le phénomène d'accumulation du CO2 permet alors d'expliquer la présence de teneurs en CO2 plus importantes dans l'épikarst que dans la zone de production principale : le sol. Plus en profondeur, un stock de CO2 différencié est mis en évidence. Cette zone de l'épikarst n'étant que ponctuellement mise en relation avec l'épikarst superficiel sous l'effet

*Speaker

du gradient thermique, les teneurs en CO2 enregistrées (4% à 6%) et les valeurs de δ13CCO2 mesurées (-22.5) n'y sont que peu variables. Du point de vue de la variabilité interannuelle, les teneurs en CO2 dans les différents compartiments du continuum montrent une évolution dictée par le caractère synchrone ou non des phases de production intense et de forte saturation en eau du sol. Ainsi, les années 2015 et 2016 montrent des teneurs en CO2 plus importantes qu'en 2017, année au cours de laquelle la période de production importante n'a pas coïncidé avec une période de forte saturation en eau du sol. Il est alors conclu que la variation de la teneur en eau ainsi que la configuration " pédo-géologique " sont des composantes majeures du cycle du CO2 dans l'épikarst comme le montre le schéma conceptuel produit au cours de ces travaux. La mise en parallèle avec l'évolution de la chimie des eaux en sortie de ce même épikarst apporte des éléments de compréhension quant à l'acquisition du potentiel de karstification. En effet, au cours des cycles hydrogéologiques étudiés, l'évolution saisonnière de la minéralisation carbonatée calcique des eaux est très bien expliquée par l'évolution des teneurs en CO2 dans l'épikarst (PCO2 à saturation vis-à-vis de la calcite similaires à la PCO2 de l'air de l'épikarst). De plus, la présence de deux compartiments de CO2 différents dans l'épikarst permet d'expliquer la variabilité du marquage chimique des eaux (PCO2 à saturation et δ13CCMTD) à l'exutoire en fonction des conditions d'écoulement. Ainsi, lors des épisodes de crue, la participation importante d'eaux ayant transité rapidement dans l'épikarst à travers les zones de fracturation est soulignée par des valeurs de PCO2sat analogues à la PCO2 de l'air de l'épikarst superficiel. A l'inverse, des eaux de zones plus capacitives (réserve épikarstique) participant à l'écoulement en période de débit de base et de tarissement ont un marquage chimique hérité de leur long temps de transfert dans l'épikarst plus profond dans lequel règnent des conditions de PCO2 de l'air différentes. La comparaison de ces équilibres calco-carboniques selon les années montre des variations interannuelles concordantes avec celles des teneurs en CO2 dans l'épikarst. Ceci montre l'importance de prendre en compte l'évolution de la dynamique du CO2 dans l'épikarst et indirectement des paramètres hydroclimatiques tels que la pluie, la température et l'évapotranspiration lorsque l'on s'intéresse au potentiel de karstification des eaux entrant dans le système karstique. Il serait donc intéressant de pouvoir dans un futur proche, estimer l'impact des changements climatiques sur l'acquisition du potentiel de karstification des eaux.

Keywords: Dioxyde de Carbone, Karst, Epikarst, Monitoring en continu, Hydrogéochimie, Lascaux

First results of the semi-distributed VarKarst simulation model at the Milandre test site, Switzerland

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With increasing availability of data and computational resources, a wide range of karst simulation models have become available. Those models were designed for different purposes like hypothesis testing, water management, contamination risk assessment, or assessment of the impact of climate or land use changes on karst systems. Consequently, they differ strongly in terms of their structure, data requirements and simulation output, ranging from simple bucket models driven by precipitation only and providing a single time series of karst system discharge, to highly complex distributed models driven by spatially and temporally variable meteorological forcing to provide 2 or 3 dimensional grids of groundwater levels and flow.
The aim of the karst modelling challenge is the application of a wide range of available karst models at the same test site (Milandre test site, Switzerland). The models will be tested for their performance and prediction reliability under varying data availability and spatial information in order to derive recommendations for future model applications.
This contribution presents the first results of the semi-distributed VarKarst model driven by only precipitation and temperature to simulate the combined discharge of the three springs discharge the test site. Although the model provides a high performance concerning different efficiency criteria (Nash Sutcliffe, Kling Gupta, etc.), sensitivity analysis indicates high parameter uncertainty. Hence, with the currently provided data, the model is most probably prone to over-parameterization. This finding is in accordance with previous applications of the model showing that it provides most reliable precision when discharge and hydrochemical information are combined within the model calibration procedure.

Keywords: karst modelling, model comparison, karst modelling challenge

*Speaker

Karst and deep geological repositories for radioactive waste – the regulatory perspective

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Radioactive waste will be stored in Switzerland in deep geological repositories. Currently, the site selection process revealed few favourite sites in northern Switzerland. Mesozoic claystones at depth of several hundreds of meters are considered as host rock.
Karstification of the host rock does not play a key role for the evaluation of possible repository sites and many aspects of repository construction and operation are similar to other underground constructions (mines, traffic tunnels). However, the long-term performance (many thousands of years) might be affected, because the host rock is sandwiched between carbonate rocks. Furhermore, when overlying carbonate rocks have to be penetrated during construction and operation of access infrastructure (shafts, tunnels, ramps), some specific challenges arise: possible water or mud inflows should not deteriorate the host rock, and nuclear safety issues have to be considered.
This presentation highlights aspects of rocks prone to karstification in the regulators view of radioactive waste disposal and outlines briefly the current stage of the ongoing site selection process.

Keywords: nuclear waste, geological repository

*Speaker

Rôle d'un karst andin tropical (Alto Mayo, Pérou) dans la dynamique de production de matériel dissous vers l'Amazone – Analyse du fonctionnement hydrogéologique et des flux associés

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Dans le domaine andin du bassin amazonien, les zones karstiques ont un rôle prépondérant sur la géochimie du fleuve Amazone et sur la consommation de CO2 liée aux processus d'altération malgré la faible surface qu'elles couvrent (< 1% du bassin de l'Amazone). Le Pérou concentre près de 90% de ces zones karstiques andin qui s'étagent des sommets de la cordillère (à plus de 5000 m d'altitude) jusqu'au piedmont amazonien (400 m) dans une grande variété d'écosystèmes tropicaux. Bien que ces zones représentent une source majeure de matières dissoutes exportées par l'Amazone, elles n'ont jamais été étudiées à l'échelle de l'aquifère karstique. Des reconnaissances récentes, réalisées dans le cadre d'un projet conjoint SO HYBAM – LMI PALEOTRACES, ont révélé l'existence de sources karstiques majeures sur le piedmont amazonien du Pérou (débits d'étiage 19 m3s-1). Afin d'identifier les facteurs de contrôle des dynamiques de production et de transfert de matières dissoutes depuis le domaine carbonaté jusqu'à l'Amazone, le fonctionnement hydrogéologique des aquifères du massif karstique de l'Alto Mayo, situé sur le versant oriental des Andes du Nord Pérou, a été analysé. Les trois principales sources karstiques du massif ont été équipées de sondes CTD (Conductivity, Température and Depth) et des jaugeages périodiques ont été réalisés afin d'évaluer leur débit. Un prélèvement bimensuel a été effectué pour l'analyse des paramètres géochimiques (éléments majeurs et en trace, Carbone Organique Total et isotopes stables de l'eau). La variabilité temporelle des débits et des concentrations a été calculée par le rapport entre l'écart-type et le moyen mensuel en pourcentage. La principale source de ce massif (Río Negro, débit moyen = 25 m3s-1) présente une faible variabilité du débit au cours du cycle hydrologique (variabilité temporal des débits de 12%) et une faible réponse impulsionnelle aux précipitations qui indiquent un fort amortissement du signal

*Speaker

par le système karstique. Une faible réactivité hydrologique aux précipitations est également observée sur la source du Río Aguas Claras (variabilité temporal des débits de 20%). La source du Río Tío Yacu présente quant à elles une réponse impulsionnelle plus marquée ainsi qu'une variabilité hydrologique plus élevée (variabilité temporal des débits de 32%). La signature chimique des eaux souterraines de l'ensemble des sources est fortement dominée par l'altération des carbonates (Ca2+ et HCO3-) mais affiche une variabilité relativement faible au cours du cycle hydrologique (5%, 10% et 6% pour les résurgences du Rio Negro, Aguas Claras et Tio Yacu respectivement) avec indice de saturation par rapport à la calcite entre -0.6 à 0.6. Ces premiers résultats indiquent que la dynamique de production de matériel dissous, dans les sources du massif karstique du l'Alto Mayo, est contrôlée principalement par la variabilité des débits malgré l'hétérogénéité des comportements hydrodynamiques. Ce comportement "chemostasie" a été observé dans nombreux contextes à l'échelle globale et à des échelles spatiales très contrastés, pouvant être attribué à l'hypothèse que les fluides approchent rapidement de l'équilibre chimique. En conséquence, nos résultats caractérisent la sensibilité de l'altération des carbonates, aux variabilités hydroclimatiques dans les milieux andins tropicaux.

Keywords: karst andin tropical, hydrochimie, bassin amazonien

Karst Modelling Challenge – A first comparison of various models for assessing the hydrological response of a karst aquifer

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The idea of the Karst Modelling Challenge (KMC) is to invite various modellers to apply their tools to the same data set in order to compare approaches and results, and finally to discuss advantages and disadvantages of the respective approaches.
The Milandre test-site (Switzerland) is used because of the high knowledge of its hydrogeological behaviour, including a large set of data: meteorological, spring discharge, cave heads and discharge rates, borehole heads, and physico-chemical data (chemistry, stable isotopes, radon, CO2).

KMC is supposed to continue over several years with an increasing degree of complexity in the modelling of the selected test-site. The first step, which is ongoing from 2016 to 2018 is dedicated to the "hydrological response", i.e. to the relation between precipitation and spring discharge.

Fifteen groups from all over the world have announced their interest during the last Eurokarst Conference at Neuchâtel in 2016. Four groups have provided results until summer 2017 and at least four other groups announced their intention to provide results by the end of 2017.

For this first step, time series for 1993 and 1994 of precipitation (P), air temperature (Tair) and total discharge rate (Qtot) have been provided to each group with an hourly time-step.

Various questions arose along the modelling work, already leading to interesting discussions:

- Evaluation criteria of the results provided by the respective models

- Effect of the time step

- Data required by the respective models (only P, Tair, Qtot) or more (e.g. catchment area, PET...)

The comparison of the respective models will consider:

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- The performance of the model to the given data set, which is used for calibration

- The performance of the model on a complimentary data set (validation)

- The data requirement for the respective models

- The necessary effort deployed for making the modelling work

- The availability of the modelling tool for any other group.

This list is not exhaustive. Other aspects will probably appear along the challenge.

A large discussion will be opened and a paper will present the main results of this comparison and discussions.
Each model will be presented at Eurokarst 2018 and this talk will introduce the discussion at the end of the presentations.

Keywords: Karst Modelling Challenge, Recharge, simulation

The effect of drought and wet year on the Bibi –Talkhone karstic spring in the southwest of Iran

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The pabdeh karstic anticline is placed in the Zagros Mountan Range in the northeast of Khuzestan province, in the southwest Iran. The pabdeh anticline which bears a significant karstic aquifer is a double plunging asymmetrical anticline trends corresponding to general pattern of the Zagros Structural Belt. The Pabdeh anticline has transversely bisected by the Taluk tectonic vally which created by Balaroud sinisteral strike slip fault. The Bibitalkhone karst spring emerges in the left bank of this valley with an average annual discharge of 2 m3/s and this is the only source for different usage of inhabitants in the area. Drought is a part of climatic condition in the area and occurs as a result of the lack of precipitation. In recent years, the lack of local precipitation and the incidence of consecutive droughts in the study area has raised concerns about the sustainability of the quality and quantity of groundwater resources. This study carried out to investigate the relationship between precipitation and potential quantity and quality of groundwater resource in the study area during the period 2004-2014. To achieve this purpose, indexes such as standard precipitation index(SPI), stream flow drought index (SDI) and groundwater drought index(GRI), were determined and 2005-2006 water year as the wet period, 2011-2012 water year as drought and water year 2013-2014 as normal year were considered. The spring hydrograph was used to determine monthly and yearly water table drawdown and recession coefficient (α) and this coefficient was taken into account to calculate dynamic storage volume of the aquifer. The results show that the discharge of the Bibi Talkhone springs, is affected by indexes (SPI), (SDI) and (GRI), without interrupt time and hydrochemical data such as EC and Cl ion as well as the diagrams indicate qualitative impact of the spring from the wet and dry events.

Keywords: Karst, spring, groundwater, drought, wet, index, Bibitalkhone

*Speaker

Karst characteristics in arid regions: case study in Shotori Mountains, Iran

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Karst characteristics in arid regions are distinct from geomorphology, hydrogeology and hydrogeochemistry point of views. Shotori mountains are located in east of Tabas in east-central of Iran. This region is a very arid region in Iran such that its annual rainfall is about 50 mm. In this karstic terrain, sinkhole, poljes, closed depression and other important geomorphological features are absent while bare rocks are frequent. There is no sensible difference between Qmax and Qmin in karst springs. In addition, the recession curves include one gentle slope. Moreover, although the lithology in this karst area is limestone and dolomite but in most karst springs the dominant ions are chloride and sodium.

Keywords: arid region, karst development, shotori mountains

*Speaker

Dye tracing as an effective method in the catchment area studies: Case study: Dimeh Spring, Iran

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The application of dye tracers for investigation of karst systems is a relatively accurate method that's usually done after the geological and hydrogeological studies. However, in some cases, these studies cannot reach a definitive answer. For example, after three tracing tests in the Zarab Anticline (which located southwest of Iran), It was found that karst groundwater flow in the three different directions. In addition, the tracer was not detected in any of the tests at Dimeh Spring. Therefore, the fourth stage of dye tracing of the Zardkooh and Bahlesh Anticlines are on the agenda. We will use the uranine dye for Zardkooh and rodamine dye for Bahlesh Anticline.

Keywords: Dye tracing, Dimeh Spring, Zarab Anticline

*Speaker

Groundwater vulnerability assessment in the Strategic Greek Karst Aquifer of Damasi Titanos using QGIS PaPRIKa plugin

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In Greece, groundwater is an almost ubiquitous source of fresh water and covers about 60% of the water demand. Indisputably, preserving groundwater reserves is of outmost importance to support economic activities (food, tourism, industry, energy) as well as to ensure human health and ecosystems. Karst aquifers cover approximately 35% of the Greek terrain and dominate in the central and western part of Greece. Many large cities of Greece are completely or partially dependent on drinking water from karst aquifers. In Thessaly, the karst aquifer of Damasi Titanos constitute the main water supply source for the cities of Larissa and Tyrnavos with total population about 175000 habitants. Additionally, numerous wells are exploiting the karst aquifer so as to supply water for the local agricultural and livestock activities. The karst system consists of Triassic-Jurassic marbles covering an area of 350 km2. It is recharged from directly infiltrating precipitation and percolation water from the Titarisios river. Three main springs named Mati, Agia Anna and Amygdalia discharge the aquifer system. Although the strategic role of the aquifer for water supply sustainability in the region it is under intense anthropogenic pressures and constant threat of pollution. Vulnerability maps constitute a useful tool in the fight against groundwater pollution. Therefore, in this paper we focus on vulnerability mapping of Damasi Titanos karst aquifer using the PaPRIKa method. PaPRIKa is an intrinsic vulnerability mapping method for the protection of karst aquifers based on four criteria: protection, reservoir, infiltration and karstification. It was developed in 2005 by a French research team headed by the BRGM. In 2017, the UMR EMMAH developed an open access GIS toolbox to standardize the application of the method. Therefore, the QGIS PaPRIKa plugin was used to elaborate the various hydrogeological data and finally to produce the vulnerability map. The final vulnerability map can be used from stakeholders in order to prevent groundwater quality deterioration of the aquifer as well as to delineate protection zones of water supply sources such as springs and wells.

Keywords: Greece' Vulnerability' Groundwater' QGIS' PaPRIKa

*Speaker

Karren above Custonaci (Sicily, Italy)

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The extremely interesting karst of the Capo San Vito area in western Sicily displays the majority of the distinct characteristics of the three-dimensional landscape: karst surfaces, caves, unique water trickling systems, and maritime development. By the sea as well as higher in the hinterland, the surface is mostly karren-like. This part of the planned study of the formation of the entire rock surface of this karst presents the results of studying the slope karren above Custonaci. They reveal the development of karren from subsoil karren and the characteristic formation of the karst surface in this area and on this rock.

Keywords: karren, karstification, karst geology, rock relief, Sicily

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Evolution of the physico-chemical response of a binary karst aquifer during a hydrological year (Planinsko Polje, SW Slovenia)

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Monitoring physico-chemical characteristics of water is one of the most effective methods commonly used in hydrogeology. Karst aquifers are prone to rapidly respond to rainfall events, and water characteristics can change very quickly throughout a short interval. Measuring changing parameters, such as electrical conductivity, temperature and water level/discharge in short intervals (e.g. hourly or shorter) and in various points of the karst system (springs, ponors, underground streams), including precipitation is very suitable to better understand the system functioning. Active monitoring was performed during last hydrological year in the recharge area of two karst springs on the outskirts of the Planinsko Polje (SW Slovenia). Data loggers, measuring water level, temperature and electrical conductivity in 30-minute intervals were installed at two main springs, three small springs, four ponors, one surface stream and five caves with a water flow. In addition, two rain-gauges were installed to measure precipitation at the same time interval. The main goal was to see how this complex karst system reacts during dry and wet periods. To supplement the results of data loggers, periodical analyses of chemical and microbiological parameters were conducted. Based on the analyses and comparison of measured data, the influence of different types of recharge and relations between inflows from various parts of the catchment and their contributions to discharges of springs were assessed.

Keywords: Karst aquifer, water monitoring, cave, spring, ponor, Slovenia

*Speaker

Assessing hydrochemical interactions between humic-rich stream and shallow karst aquifer using natural tracers (Tuhala karst system, N Estonia)

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Diverse shallow karst aquifers contribute approximately a third of consumed domestic groundwater in Estonia. Due to its geographical location and climatic conditions, mires are widespread in Estonia, forming the headwaters for numerous humic-rich rivers. Such streams are frequently sinking on the karst aquifer outcrops. In this study we combine hydrodynamic and hydrochemical data to assess interactions of the humic-rich Tuhala River and the Tuhala karst system hosted by the shallow Nabala-Rakvere aquifer, a locally important groundwater resource in Harju County, Northern Estonia. Hydrodynamics, major ion chemistry, stable isotopes and humic substances were observed in a total of 15 surface- and groundwater monitoring points covering the study area throughout the period of October 2016 – October 2017. The collected data was assessed by coupling time-series analysis, multivariate statistics and end-member mixing model. Humic substances combined with selected major ions and stable isotopes proved to be effective in characterizing the mixing of the humic-rich streamwater with the groundwater within the shallow karst aquifer during low, medium and high flow conditions. The results suggest that the karst system, previously considered to be fed primarily by the allogenic humic-rich water of the Tuhala River, may receive a significant contribution of autogenic recharge from the adjacent shallow Nabala-Rakvere aquifer. In addition to the perennially linked springs and wells, particular monitoring points may gain a hydraulic connection to the karst system depending on the hydrological conditions.

Keywords: groundwater/surface water interactions, shallow karst aquifer, natural tracers, end member mixing model

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Lithological and structural controls of cave development on Kornati Islands, Croatia and introduction of of EU project "Center of excellence -Cerovačke caves"

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Kornati Islands archipelago encompasses 91 carbonate islands and islet situated in the central part of eastern Adriatic coast in Croatia. They are predominantly composed of deformed Upper Cretaceous to Eocene pre-orogenic carbonates and stretch parallel with the coast in NW-SE, i.e. Dinaric direction.In order to contribute to the knowledge of the speleogenesis of the Kornati Islands caves, 45 caves (42 pits and 3 caves) have been identified and analysed during a three year research project of cave inventarization. In this research we aim to identify if the "inception horizon" exist and to connect cave forming to lithological or chemical deviation from the predominant carbonate facies within the surrounding sequence or to structural and tectonic elements. Geological structures above and within the caves were measured. Petrographic analysis of geological samples taken in the cave and on the surface were done in order to determinate inception horizons and how they influence cave geometry. Based on collected data a GIS analysis on cave density, distribution, vertical position has been performed. Spatial analysis of the cave distribution show higher density of the in the west coast of Kornati islands between 1 and 60 m a.s.l. while some of the cave extend below sea-level up to 45 m of depth. Based on the hydrological characteristics nine caves have no water and 36 caves are partially (22 anchialine caves) or completely submerged (10 sea caves). Analyses of the cave passage orientation indicate that most of the analysed caves are dissolution caves with dominant NW-SE orientation. This reveals dominant influence of neotectonic stress related to the Adria microplate underthrusting the Southern Alps. The intensive folding of the Islands and several identified faults caused development of secondary porosity that significantly influenced speleogenisis of Kornati islands caves. Results show existence of a favourable structures, unrelated to today's surface topography, where a more intensive dissolution processes have occurred. This sequence extends approximately 60 m a.s.l. and 50 m below today's sea level. This karstification processes probably began along expansion fracture in zone of axial surface and subvertical bedding planes. In April 2018 the EU project "Center of excellence - Cerovačke caves; sustainable management of natural heritage and karst underground" (MIS code: KK.06.1.2.01.0011 Competitiveness and Cohesion operational programme 2014-2020, Theme 62C) started. The main goal of the project is to improve sustainable use of natural heritage, primarily in Nature park Velebit with focus

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on Cerovačke caves (Upper and Lower Cerovačke caves). It is the first project in Croatia where a such funds are available for restoration of show-caves and multidisciplinary cave research.

Keywords: spelegenesis, inception theory, caves, kars, Croatia

CLASSIFICATION OF CARBONATE AQUIFERS BASED ON HYDROGRAPH ANALYSIS

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Carbonate aquifers are traditionally considered as karst systems based on lithological characteristics. Little effort has been made to quantitatively distinguish between developed karst systems and poorly karstified or fractured carbonate aquifers. At the same time, there is an inconsistency in the application of modelling techniques in karst hydrogeology. While most carbonate systems are proven to manifest karstic hydraulic behaviour, equivalent porous medium models are extensively used for simulating hydrodynamic and transport processes.
It is crucial to determine the hydraulic behaviour of strongly heterogeneous systems in order to select the most appropriate investigation techniques and modelling approaches.

Dolomite aquifers represent an ambiguous group of carbonate rocks. While classical karstic landforms such as sinkholes or dry valleys might be present, there is often a lack of well-developed hierarchical underground conduit networks. Although often considered as karst aquifers, many dolomite aquifers behave as fissured hydrogeological systems

Spring and well hydrographs contain important information about the hydraulic behaviour and geometric characteristics of karst aquifers. This study provides an overview of quantitative classification of carbonate rocks based on hydrograph analysis. Analytical formulae have been developed to describe baseflow recession of various types of hydrogeological systems. The analytical formulae provided in this study establish links between conduit geometry, aquifer properties and hydrograph recession coefficients, and describe the spatial and temporal variations of spring discharge and of the water table measured in monitoring bores.

The proposed method is demonstrated through the application of field data. Several test sites including limestone and dolomite aquifers have been studied through systematic spring discharge and piezometric level monitoring. Hydrograph analysis of several flood peaks of each data series was undertaken to determine aquifer characteristics and to classify hydraulic behaviour. The results of hydrograph analysis were verified through field observations.
The proposed quantitative classification method provides crucial information about the hydraulic functioning of carbonate hydrogeologial systems, and facilitates the selection of adequate investigation and modelling techniques.

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Keywords: karst, hydrograph analysis, dolomite, classification

Application of in situ experimental results in the problem of evolving precipitates in thermal water systems

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Biological and chemical precipitates cause a lot of problem during thermal water usage in wells and also in geothermal systems. The clogging effect of these precipitates decreases the efficiency of the production. These precipitates are also prevalent in karst areas, e.g. in springs and caves. Therefore, the understanding of their natural occurrences can help us to recognize the processes which form them artificially.
In this study, two different kind of scales of Hungarian geothermal systems were analysed by stereo microscope, scanning electron microscope, X-ray powder diffraction, inductively coupled plasma mass spectrometry and gamma spectroscopy. They were compared to the results of *in situ* experiments, executed in Buda Thermal Karst, Hungary. One *in situ* experiment was made in flowing thermal water, while the other in quasi stagnant thermal water.

The scale formed in a tube showed similar crystal morphology as the precipitate in naturally flowing thermal water. They both had remarkable radioactivity after a short time. The other scale is different from the precipitates of the *in situ* experiments, both morphologically and chemically. The different location and quantity of scales in the two geothermal systems was found to be because of the different aquatic chemistry, revealed by geochemical modelling.
The research was supported by the NK 101356 OTKA research grant and by the European Union and the State of Hungary, co-financed by the European Regional Development Fund in the project of GINOP-2.3.2.-15-2016-00009 'ICER'.

Keywords: biological precipitate, chemical precipitate, in situ experiment, thermal water, geothermal system

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In-situ experimental study of chemical and biogeochemical precipitates of a flowing thermal water

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Chemical and biogeochemical precipitates are common phenomena in karst areas, usually occurring together, especially in thermal springs, thermal water wells and caves. The complexity of natural systems makes it challenging to measure and consider every parameter and governing factor. Because of that, such a system cannot be modelled in a laboratory experiment. *In situ* experiments can be key tools in overcoming these problems.
Buda Thermal Karst in Hungary is an active hypogenic karst system where ongoing chemical, biological precipitation and dissolution processes can be studied near the surface. The two main precipitates of the system are carbonates and iron-oxyhydroxides, identified as biogeochemical precipitates. Apart from their microbiological, mineralogical and microchemical characteristics, we know less about their formation, age and governing factors of their evolution.

To answer these questions, a 12-week-long *in situ* experiment was carried out in an artificially controlled natural system. It means that thermal water was pumped with constant volume discharge (_˜ 12 l/min) into a trapezoid canal. Beside temporal changes of discharge, the effects of daily and seasonal variations of air parameters could be also excluded because the experiment was made in a tunnel with relatively constant air (compared to the outside air) parameters in the course of the year.

For designing the experiment, a 1-day-long experiment was executed to assess the changes of main physicochemical parameters (temperature, electrical conductivity, pH, dissolved oxygen

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content, concentration of Ca2+ and HCO3-) of the flowing water and to identify the main driving forces of these changes. Measurements were compared to the results of a reactive transport model.

During the 12-week-long experiment, the formation of the precipitates was studied in a 130-m-long canal, on glass slides, put into the water at key distances from the discharge point. The precipitates were examined after 6 and 12 weeks by stereo microscope, transmitted light microscope, scanning electron microscope and X-ray powder diffraction. Parallelly the water parameters were also measured along the flow path.

Intense red coloured biogeochemical precipitate formed close to the discharge, while further away light red, then yellowish white calcite with two different morphologies, rhombohedral and dendritic. The boundary between the biogeochemical and chemical precipitates shifted in time.

The evolution of calcite precipitate parallel with the composition of water and changes of calcite crystals depending on time and distance could be followed.
The research was supported by the NK 101356 OTKA research grant and by the European Union and the State of Hungary, co-financed by the European Regional Development Fund in the project of GINOP-2.3.2.-15-2016-00009 'ICER'.

Keywords: calcite, biogeochemical precipitate, flowing water, thermal water, in situ experiment

Karst-specific contaminant occurrence in Swiss groundwater resources

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Karst aquifers are known to be more vulnerable to contamination than other aquifer types. The occurrence of contaminants in karst groundwater, however, also depends on their behavior in the environment and the according land-use. Data from the NAQUA National Groundwater Monitoring were processed in order to assess the quality status of karst groundwater resources in Switzerland, and to obtain information about the determining factors responsible for the occurrence of contaminant residues. Karst spring monitoring represents about 20% of the total groundwater monitoring, corresponding to the spatial distribution of karst landscape on the Swiss territory.

Statistical analysis performed for monitoring results over a 10-years period and at more than 500 stations revealed a significantly different situation for karst aquifers with respect to other, i.e. unconsolidated and fissured, aquifer types. Substances of concern – as pesticides, VOC, or nitrate – where detected in karst environments at less monitoring stations and generally in lower maximum concentrations. This appears, at first glance, contradictory to the high karst vulnerability but is consistent with non-karst catchments, and especially unconsolidated aquifers, being characterized to a much higher degree by agricultural land-use. Karst catchments, in contrary, are mainly located in less intensively used alpine and peri-alpine regions.

Comparing karst systems of differing system vulnerabilities indicates stations in moderately productive aquifers being more frequently affected by a basic load of persistent substances, such as nitrate and pesticide metabolites, than karst aquifers of high productivity, the latter reaching their maximum concentrations of diverse kinds of contaminants during individual samplings at high water situations. This dynamics in contaminant occurrence is related to the prevalent duality of rapid and slow flow components inherent to such vulnerable systems, also corroborated by microbiological monitoring results.

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The findings of this overall evaluation are consistent with contrasting vulnerabilities and land-use characteristics of the monitored catchments, with land-use being the dominant factor for groundwater quality status in many cases. They are also the consequence of the nature of karst aquifers and the related monitoring device, i.e. at springs as the outlet of the whole aquifer system. Specific requirements are thus necessary for karst groundwater monitoring and subsequent resource management with respect to sound data collection and conclusive data analyses, including the need to distinguish between the vulnerability of groundwater and its risk to contamination.

Keywords: vulnerability, contaminant, NAQUA, groundwater quality

HYDROCHEMICAL AND ISOTOPIC CHARACTERIZATION OF KARSTIC AQUIFER IN THE REGION OF TEBESSA NORTHEAST – ALGERIA -

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In this work, we present results of the hydrogeological, hydrochemical and isotopic studies on groundwater samples from the karstic aquifer in the region of Tebessa, Northeast Algeria. Groundwater from karst aquifers is among the world's most important sources of drinking water supplies, and the hydrochemical characteristics of karst water are affected by both natural environment and human activity.
The study area is characterized by a semi-arid climate, with a very hot and dry summer and very cold and humid winter.

The karstic aquifer system that characterizes this study area is drained by a number of sources, the most important of which are those of Youkous, Ain Troubia, El Megalib, Gaagaa and Ain Sari which are located in different altitudes and spaced fairly large distances. The karst system has a complex functioning.
The hydrochemical data (major ion geochemistry) indicate that these groundwaters are characterized by the dominance a Ca-HCO3-SO4 and Ca-Cl-SO4 water types. The main factors controlling the groundwater composition and its seasonal variations are geology, because of the presence of different carbonate formations, additionally elevation, and the rate of karst development. Using stable isotope analysis data, δ18O and δ2H relationships show that all waters are meteoric in origin.

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Keywords: Hydrochemistry, Isotopic, Karstic aquifer, Tebessa, Algeria

Mise en œuvre d'un outil intégratif permettant la quantification et la spatialisation des apports azotés influençant un captage d'alimentation en eau potable – Approche à l'échelle de l'hydrosystème karstique des Sources du Toulon (Périgueux, France)

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L'ion nitrate (NO3-), la forme la plus persistante et mobile de l'azote (N) dans les eaux de surface et souterraines, a causé la dégradation de la qualité des aquifères karstiques depuis plusieurs décennies. L'azote apportée à la surface des hydrosystèmes karstiques peut provenir de différentes sources ponctuelles ou diffuses, et s'infiltrer à travers les formes exokarstiques présentes en surface. La compréhension de l'origine des nitrates dans l'eau est un préalable obligatoire à une meilleure gestion et protection des aquifères. Les dépôts atmosphériques, les fertilisants organiques ou inorganiques ainsi que les rejets d'assainissement sont autant de sources d'azote qu'on peut retrouver à l'exutoire des systèmes karstiques. L'objectif de ce travail est de quantifier et de spatialiser les différents apports azotés à l'échelle d'un hydrosystème karstique, et les comparer avec les concentrations en nitrates mesurées à l'exutoire.
Un suivi haute résolution des débits et des concentrations en nitrates est réalisé à l'exutoire de l'hydrosystème, permettant de quantifier les flux d'azote en sortie. En parallèle la quantification des différents apports azotés en surface est réalisé à partir des informations recueillies auprès de différents organismes (chambre d'Agriculture de la Dordogne, Service d'Assainissement du Grand Périgueux), et à partir des mesures réalisées sur le terrain (prélèvements hebdomadaires sur les retombées humides, prélèvements en sortie de station d'assainissement individuelle). Sur chaque source d'azote, un coefficient d'atténuation est attribué pour prendre en compte les processus biogéochimiques dans le sol et les transferts entre le sol et la zone saturée de l'aquifère (type de source d'azote, type de sol, processus de recharge). Enfin, la somme de chaque apport est comparée avec les concentrations en azote mesurées à l'exutoire.

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En parallèle de cette quantification globale à l'échelle de l'hydrosystème, une deuxième étape de spatialisation de ces différents apports est mise en œuvre à partir du développement d'un outil intégratif sous Système d'Information Géographique (ArcGis). Cette spatialisation est réalisée sur l'ensemble du bassin d'alimentation des Sources du Toulon, en découpant le la zone d'étude en 5697 mailles de 1 hectare. Cet outil permet ainsi pour chaque maille d'estimer les apports annuels à la zone saturée de l'aquifère en kg/ha/an.
L'outil développé dans ce travail apporte de nouvelles pistes pour une meilleure compréhension des apports d'azote influençant un captage d'alimentation en eau potable, et permet d'esquisser un premier bilan de matière à l'échelle d'un hydrosystème karstique.

Keywords: Karst, azote, infiltration, spatialisation, quantification

Identification des conditions d'écoulement dans la zone non saturée et dans la zone saturée de l'aquifère karstique - Apport du Carbone 13-CMTD dans l'interprétation des équilibres calco-carboniques

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L'aquifère karstique est séparé en plusieurs horizons, du sommet à la base : l'épikarst, la zone non saturée et la zone saturée. L'horizon le plus superficiel, l'épikarst, est localisé proche du sol. Le sol correspond à la zone de production du CO2. Pendant son transit de l'épikarst jusqu'à l'exutoire d'un système karstique, une eau peut s'écouler dans différentes conditions (fractures de la zone de transmission, zone transmissive de la zone noyée, zone capacitive de la zone noyée). Différentes signatures géochimiques sont alors enregistrées dans les sources karstiques. L'objectif de ce travail est de proposer une méthodologie pour caractériser les conditions d'écoulement de l'eau dans les différents compartiments du karst, et ainsi de préciser le fonctionnement des aquifères karstiques. Pour cela, une méthode basée sur la pression partielle de CO2 (PCO2) et sur l'indice de saturation vis-à-vis de la calcite (ISc) est utilisée en parallèle de l'analyse de la distribution des fréquences de conductivité électrique. En complément, le carbone 13 du carbone minéral total dissous (δ13C-CMTD) est utilisé pour évaluer le marquage géochimique des eaux par le CO2 dans les différents compartimentsdu karst. Cette méthodologie est appliquée sur 6 systèmes karstiques localisés proche des Sources du Toulon en Dordogne (France).
6 sources karstiques sont sujets à un suivi géochimique entre Février 2014 et Octobre 2017. Ces sources sont représentatives des différentes horizonss de l'aquifère karstique (zone non saturée, zone noyée libre, zone noyée captive). Les paramètres des équilibres calco-carboniques (PCO2 ; ISc) sont calculés à partir des mesures effectuées *in-situ* (température, pH, conductivité électrique, oxygène dissous) et des analyses réalisées en laboratoire (ions majeurs, δ13C-CMTD). La pression partielle de CO2 à saturation (PCO2sat) est également estimé. Elle correspond à la PCO2 de l'eau calculée pour un ISc égale à zéro.

A partir de ces données, l'analyse de la distribution des fréquences de conductivité électrique permet d'évaluer l'étalement des conductivités le long des plages de variation et de calculer le poids de chaque mode par rapport à l'étalement total. Pour chaque source, le mode principal est mis en évidence, caractérisant le type d'eau moyen qui émergent à l'exutoire.

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La visualisation dans un graphique –logPCO2 ; ISc, permet d'identifier les différentes conditions d'écoulement de l'eau dans qui émergent aux différents points de mesure. Les eaux peuvent être sur-saturées, sous-saturéees, ou à l'équilibre vis-à-vis de la calcite, et peuvent posséder différentes concentrations en CO2. Pour chaque source, une droite modèle est établie à partir des points situés dans le mode principal mis en évidence dans l'analyse de la distribution des fréquences de conductivité électrique. Cette droite caractérise le type d'eau moyen qui émerge à l'exutoire lorsque le système n'est plus influencé par les précipitations. Une PCO2satmodèle est attribuée à chaque source karstique étudiée. Les capacités d'infiltration de chaque système sont évaluées en calculant l'écart entre la PCO2sat modèle et les PCO2sat des eaux participant à la recharge (Infiltration diffuse ou concentrée). Ces eaux sont rapidement transportées vers l'exutoire, causant un déséquilibre dans les équilibres calco-carboniques. Cette perturbation se manifeste par une diminution notable de l'ISc. Plus cet écart est important, plus le système karstique possède la capacité à drainer les eaux rapidement depuis la surface, augmentant la vulnérabilité vis-à-vis du transport des contaminants.

L'apport δ13C-CMTD dans la compréhension des équilibres calco-carboniques fournit des informations sur le marquage géochimique des eaux par le CO2. Il permet de mieux identifier les eaux drainées depuis la surface qui possèdent un signal appauvri en δ13C-CMTD, et de les relier à des conditions d'écoulement spécifiques.
La méthode appliquée dans ce travail permet une meilleure caractérisation du fonctionnement des aquifères karstiques. Elle permet de traiter la capacité des systèmes karstiques à faire transiter des eaux sous-saturées lors des périodes de recharge (ISc négatif). Elle permet également de classer les systèmes karstiques en fonction de leur capacité d'infiltration. L'ensemble des résultats est à remettre dans le contexte hydrogéologique de chaque système, et donne des informations sur l'épaisseur de la zone noyée et de la zone non saturée. Ce travail, facilement reproductible sur d'autres systèmes, permet d'améliorer les connaissances sur les modèles conceptuels de fonctionnement des aquifères karstiques.

Keywords: Karst, infiltration, Indice de saturation vis, à, vis de la calcite, Pression partielle de CO2, δ13C, CMTD, zone non saturée, zone saturée.

Evaluation de la dynamique et des origines des nitrates dans un aquifère karstique multicouche en utilisant un suivi haute-résolution, et les isotopes des nitrates (δ15N-NO3 ; δ18O-NO3)

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En bordure Nord du Bassin aquitain, l'aquifère karstique des sources du Toulon est une ressource en eau stratégique pour l'agglomération de Périgueux. Ces sources possèdent un débit moyen de 450 L/s. Elles sont le siège d'une alimentation multiréservoirs issue des aquifères multicouches du Jurassique supérieur et du Crétacé supérieur. Malgré la qualité satisfaisante de cette ressource en eau, certains paramètres sont les témoins d'une contamination anthropiques. Les rejets domestiques et l'agriculture présents en amont des sources du Toulon sont vecteurs de contaminations diffuses et concentrées. Les propriétés karstiques du bassin d'alimentation rendent la ressource en eau plus vulnérable. Cette étude a pour objectifs d'évaluer la dynamique des nitrates au sein de l'aquifère karstique à partir d'un suivi haute-résolution et des isotopes des nitrates. Cette approche est couplée à une approche spatiale, permettant d'identifier les sources des apports azotées.
Les isotopes des nitrates (δ15N-NO3, δ18O-NO3) sont analysés à l'exutoire de l'hydrosystème. En complément, plusieurs paramètres sont mesurés en continu permettant une analyse plus précise des variations géochimiques (Débits, pH, Conductivité électrique, Température, Oxygène dissous, Turbidité, Nitrates, Carbone organique). Enfin, un suivi des compositions isotopiques (δ15N-NO3, δ18O-NO3), est réalisé dans différentes conditions hydrologiques, sur les eaux superficielles et souterraines de la zone d'étude.

Les relations entre les concentrations en nitrates et carbone organique dissous permettent la distinction d'arrivée de plusieurs masses d'eau à l'exutoire du système : (i) les eaux issues de la zone saturée de l'aquifère, présentant uniquement une augmentation des concentrations en nitrates ; (ii) les eaux issues de la zone non saturée de l'aquifère présentant des augmentations de concentrations synchrones en nitrates et carbone organique. Les compositions isotopes de l'azote caractérisent une contamination étendue à l'ensemble du bassin karstique, présentant plusieurs origines (agriculture, rejets domestiques). A l'exutoire du système karstique, l'ensemble

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de ces compositions isotopiques sont mesurées, témoignant de l'apport de différentes zones d'infiltration.
Les premiers résultats permettent la réalisation d'un modèle conceptuel basé sur les relations entre les réponses des nitrates à une source karstique et les facteurs environnementaux (conditions hydrologiques, fonctionnalité du système karstique). Ce travail innovant est intéressant dans une optique de protection de la ressource en eau et pourrait être appliqué sur d'autres hydrosystèmes complexes aux enjeux similaires.

Keywords: Karst, nitrates, carbone organique dissous, isotopes, infiltration, approche spatiale.

Evaluation de la dynamique et des origines de la turbidité dans un aquifère karstique multicouche en utilisant la distribution de taille et la nature des particules en suspension associées aux variations géochimiques

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En milieu karstique, l'apparition de particules en suspension à l'exutoire dégrade de façon récurrente la qualité de l'eau. Le transport et les origines de ces particules alimentent les questionnements scientifiques depuis plusieurs décennies. Les sources du Toulon sont une ressource en eau stratégique pour l'agglomération de Périgueux. Ces sources possèdent un débit moyen de 450 L.s-1, et sont le siège d'une alimentation multiréservoirs issue des aquifères multicouches du Jurassique supérieur et du Crétacé supérieur. Malgré la qualité satisfaisante de cette ressource en eau, la turbidité la dégrade de façon récurrente. Certains évènements rares forcent même l'arrêt de l'exploitation. Ce travail a pour objectif d'évaluer la nature et les modalités de transport des particules en suspension dans l'aquifère en lien avec la vulnérabilité de la ressource en eau.
Un suivi innovant, basé sur le couplage d'analyses granulométriques et morphométriques permettant d'identifier la nature des particules en suspension, est réalisée à l'exutoire du système karstique. En complément, un suivi haute résolution est réalisé sur certains traceurs de l'infiltration (nitrates, carbone organique dissous, bactériologie).

Les résultats mettent en évidence plusieurs types de turbidité qui transitent dans le système karstique sur un épisode de crue. Les particules minérales, plus grossières, sont associées à des phénomènes de remobilisation des sédiments déposés au sein du système karstique. Les particules organiques, plus fines, sont associées à des processus d'infiltration rapides. Elles sont concordantes à l'arrivées d'eaux d'origine superficielle, plus concentrées en traceurs de l'infiltration (nitrates, bactériologie, carbone organique dissous).

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Ce travail apporte une nouvelle méthodologie pour la caractérisation du fonctionnement des aquifères karstiques. La turbidité, associée à la nature des particules en suspension transportées, est un paramètre pertinent pour la détermination des transferts de pression et des transferts de masse qui opèrent au sein des systèmes karstiques.

Keywords: Turbidité, infiltration, distributions granulométriques, minéralogie, bactériologie, matières en suspension

Spatialization of runoff indicators on karstic basins : application in the Cévennes-Causses area (France)

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The use of hydrological models for flood forecasting on karstic catchments implies having some information regarding the spatialization of runoff over the basin. Mapping the spatial variability of runoff during flood and recession periods is a challenge, specifically in karstic areas where zones characterized by a high infiltration rate can generate high runoff coefficient during exceptional rainfall events. Karstic areas covering almost 1/3 of France, it is useful to develop a methodology to map runoff karstic zones at a national scale.

The aim of our work is to assess on a test basin, the ability of a geomorphological index to localize contributive areas from karstic zones during floods. Our approach uses the index of development and persistence of the river network, IDPR (Gay et al., 2016), as a proxy of infiltration/runoff areas. This index is computed by comparing the topographic thalweg network with the natural hydrographic network. It is available as a 25m spatial resolution grid over France. The test site is the Tarn basin at Millau in south France (2200 km^2), characterized by hard-rock areas in the upstream zone (Cévennes) and by karstic areas in the intermediate and downstream ones (Causses). Daily streamflow time series were collected for 13 gauging stations over the past 30 years. Total discharge values (Qt) were separated into baseflow component (Qb) and flood component (Qf) using the BFI method.

First results show a good correlation between the Qf/Qt ratio computed with interannual mean

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data, and the mean and median IDPR of each sub-basin. The IDPR could thus be an interesting approach to map runoff indicators characterizing notably highly contributive karstic zones during flood periods. A sensitivity analysis is also performed on parameters of this relationships, in order to assess the influence of i) information aggregation (catchments surface), and ii) hydrograph separation model. Our results give interesting perspectives on the regionalization of the method.

Reference:

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

Keywords: Karst, flood, runoff, IDPR, Tarn

Karstogenesis modelling of a regional Mediterranean aquifer (Lez, France)

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For the last few millions years, the aquifer of Lez (Montpellier, France) has been developed in a Mediterranean setting. However, several evidences show that other previous karstification stages affected this aquifer. The problem is to weight the impact of each of these stages on the present-day karst network. For example, the Messinian crisis is considered as mainly driving the architecture of the karst conduits, but how to quantify its impact compared to the ones of the previous and following stages? In order to provide quantitative arguments and elements of responses to these questions, a numerical modelling of diagenetic overprints (using an in-house TOTAL S.A. modelling toolbox) has been applied.
This study shows that the main conduits of the present-day karstic network were created during the early karstification stages, and then used again during the Messinian. A preferential karstic area, located at the top of the Jurassic layer (jurassic epikarst), developed during the earliest period of karstification (late Jurassic). The karstification during the Messinian crisis emphasized and increased the dissolution in this superficial zone, but also created a new and deeper karstic network.
Combining both the observation on field with a numerical modelling of successive periods of karstification, this study is a former to have been realized at the regional aquifer scale. These firsts results are promising and incite to be done on more successive phases of karstification.

Keywords: Karst, Genesis, Mediterranean, Numerical modelling, Lez

*Speaker

Geological controls of the Sierra de las Nieves karst aquifer (Málaga, Spain)

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The Sierra de las Nieves karst massif is a high relief Mediterranean karst aquifer where fracturing, bedding and folding have conditioned the speleogenesis of a well-developed network of karst conduits. The aquifer is formed by a sequence of carbonate rocks (dolestones, limestones and carbonate breccia) from the Triassic to the Cenozoic. By the development of a three-dimensional model of the karst aquifer the relationships of the three factors are analyzed and the areas more susceptible for karstification are identified. This has implication in the mathematical model of water flow and transport of contaminants as well as vulnerability mapping.

Keywords: 3D, karstification, mapping, vulnerability

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Karst and vegetation: biodiversity and geo-botany in the Sierra de las Nieves karst aquifer (Málaga, Spain)

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The Sierra de las Nieves karst system is a high relief Mediterranean karst with an ample range of altitudes: from the base level of the system at río Grande Spring (450 m a.s.l.) to the maximum altitude at the Torrecilla peak (1919 m a.s.l.). From a geologic point of view, the Sierra de las Nieves aquifer is part of the Nieves Unit which is composed by a Triassic to early Miocene succession largely made up of carbonate formations. From base to top, the Triassic series comprises dolostones, alternating marls, marly limestones, and micritic limestones. The Jurassic–Palaeogene sequence is dominated by cherty limestones, nodular limestone, marly limestones, and marls. The succession of the Nieves Unit is capped by continental carbonate breccias. These terrains host a large botanical diversity. In fact the Sierra de las Nieves shows a wide range of vegetation with a high degree of biological interest such as *Abies pinsapo, Quercus alpestris*, *Juniperus Sabina, Berberis hispanica, Ulex baeticus, Pinus halepensis*, *Pino silvestre* and *Quercus faginea,* among others. Also, there is an interesting vegetation related with karst depressions, potholes, caves and karst springs. In this sense it is of interest to study the interaction between karst and vegetation. Every vegetal species grows in soil with different composition, pH or humidity degree. For this reason, we observe spatial variations in the species or botanic associations in relation with karst features. In this work, we propose a first cartography of some vegetal species related with the main lithologies. For this, we have used supervised and unsupervised classification methods using remote sensing data.

Keywords: geo, botany, epikarst, biodiversity, mapping

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Delimitation of a Geopark proposal as a hydrogeological reserve in a coastal-karstic system located southwestern Playa del Carmen, Quintana Roo, Mexico.

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Playa del Carmen is the city with the higher rate of increased population growth in Latin America in the last 20 years, is located in southeastern Mexico in the region of the Caribbean. Currently Gets the supply of drinking water from the aquifer, in an area located to the West of the city, which it has not any legal protection yet, increasing the risk of pollution due to its karstic nature and to the expansion of the urban spot. The town of Playa del Carmen has 225,000 inhabitants. The City has a thin freshwater lens of the karstic aquifer ($<$ 30 m thick). This aquifer also provides water to the services sector and to the groundwater-dependent ecosystems. In order to preserve the unique source of fresh water for the population, ecosystems and the services sector, it has been proposed the creation of a geopark (GP) which preserve geological, cultural richness, environmental services and quality of the region's water. A polygon of 35 km2 was selected to the southwest of the city. This area is located upstream of the city, characterized by the absence of industrial activity and the presence of a large dissolution conduits system of approximately 43,856 meters mapped, where some semi flooded caves reach up to 35 m wide by 20 m high. The geological and biodiversity richness present in this area has been of vital importance to the preservation of the Jaguar and for the Paleoclimatology, so it has been able to rebuild the climates of the past through the stalactites and stalagmites, as well as the understanding of the Mayan civilization over time and the ecosystem connectivity. This Geopark proposal is the first to be developed in the Yucatan Peninsula which involves biodiversity, water and geological preservation.

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Keywords: Geopark, Hydrogeological Reserve, Coastal, Karst System, Protection, Semi, Flooded Caves, Yucatan Peninsula

Morphogenèse récente de la marge cévenole, nouveaux apports quantitatifs

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L'âge de formation des morphologies de la marge cévenole, à l'instar des gorges du Tarn ou de l'Hérault est discuté depuis plus d'un siècle. Cette étude s'inscrit dans cette démarche et, par l'apport de nouvelles contraintes temporelles précise, et parfois questionne, les derniers modèles morphogénétiques. Les datations absolues complétées par l'analyse du paléomagnétisme des argiles piégées dans les karsts indiquent qu'une grande partie de la morphologie observée actuellement s'est formée durant le Quaternaire.
La convergence des résultats de la modélisation numérique, de la géo-morphométrie et des datations éclaire le rôle important de l'érosion dans cette morphogenèse avec des taux d'incision de l'ordre de 0,1 mm.an-1 durant le Plio-Quaternaire.
Le rebond induit par l'érosion explique la moitié du taux de surrection observé impliquant le rôle d'un ou plusieurs autres processus. De part son emprise régionale, le rebond isostatique permet l'extrapolation des résultats obtenus dans cette étude aux régions limitrophes : les grands Causses et les Cévennes.

*Speaker

Réseau de Métiers CNRS "Milieux Souterrains et Karsts"

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Présentation

La communauté scientifique française travaillant sur les milieux souterrains au sens large ou les karsts n'est pas fortement fédérée. Il existe plusieurs Services d'Observations et Observatoires locaux ou nationaux pour la partie scientifique (OZCAR, SNO Karst etc.) mais pour ce qui est de la partie terrain il y a peu d'échanges.

Tous les domaines de recherche ayant pour objet ou moyen d'études les milieux souterrains sont amenés à utiliser des outils communs et des techniques communes. Le projet de mettre en place un réseau de métier " Milieux Souterrains et Karsts " permettrait de rassembler toutes les personnes travaillant sur tous les milieux souterrains sans restrictions, qu'ils soient naturels ou artificiels, pénétrables ou non, karstiques ou pas.

Nous souhaitons, à travers ce réseau de métiers CNRS, partager et échanger les connaissances techniques et pratiques des personnels de recherche ayant besoin d'étudier, d'accéder ou de travailler dans des sites souterrains pour y réaliser des observations, y prélever du matériel ou instrumenter des sites.

D'autre part, ces milieux nécessitent des techniques spécifiques et des matériels résistants pour travailler, ainsi que des compétences humaines particulières et un matériel personnel adapté pour pratiquer en toute sécurité. Ce réseau de métiers pourrait accompagner les personnels vers de la formation technique à la progression souterraine.

Enfin, un élargissement des techniques et matériels à d'autres milieux d'accès complexes serait envisagé ultérieurement.

Objectifs

Les objectifs du réseau de métiers CNRS " Milieux Souterrains et Karsts " sont les suivants

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:

- Fédérer la communauté de scientifiques travaillant sur et autour des milieux souterrains ;

- Mutualiser les connaissances et échanger sur les pratiques ou les matériels ;

- Réaliser une veille technique et technologique sur les matériels de mesures et les moyens de prélèvements ;

- Recenser et tester les instruments de mesures *in situ* ;

- Sensibiliser et former les personnels à la sécurité lors des missions de terrain ;

- Organiser des actions de formations thématiques sur des techniques spécifiques (instrumentations, imageries, topographies, moyens d'accès au milieu...) ;

- Animer, coordonner et piloter des ateliers thématiques ;

- Tenir à jour un vivier d'experts et de compétences associées ;

- Valoriser des actions de développements techniques adaptés aux milieux souterrains ;

- Echanger également avec les personnels travaillant sur des milieux complexes extérieurs.

Activités

Le réseau de métiers CNRS " Milieux Souterrains et Karsts " met en œuvre et soutient les activités suivantes :

- Des formations sur la progression dans les milieux souterrains et sur les techniques d'études ou de prélèvements ;

- Des groupes de travail autour des matériels et techniques les plus adaptés pour réaliser des mesures particulières ou des prélèvements ;

- La rédaction de documentations pratiques et techniques ;

- La diffusion d'informations pratiques sur les milieux souterrains au travers d'ouvrages, de publications ou de communications ;

Organisation

Le réseau de métiers CNRS " Milieux Souterrains et Karsts " est animé par un comité de pilotage (CoPil) constitué de 8 à 10 membres pour une durée de 4 ans, mandats renouvelables une fois. Trois membres sont désignés au sein de ce comité de pilotage pour constituer le Bureau comprenant un responsable du réseau, un référent formation et un coordinateur budget.

Les membres du CoPil sont chargés de mission auprès du CNRS sur la base de leur fonction au sein de ce CoPil.

La vocation principale du réseau est l'échange, le partage, la formation, la diffusion d'informations autour des milieux souterrains et des milieux complexes.

Contact

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Keywords: Réseau de Métiers, Techniques d'instrumentation, Milieux souterrains

Visual KARSYS – a web-tool for the documentation of karst aquifers

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Groundwater management in karst regions is still a challenge in various parts of the world due to the lack of understanding and of dedicated tools. Existing knowledge about geology and hydrology are usually not synthetized in an optimal way, making difficult to produce a clear conceptual model of the karst flow systems, showing the geometry of the aquifer, the catchment boundaries and the main flowpaths. Such conceptual models are however essential for application (groundwater well boring, assessing karst related hazards in underground construction, etc.), and/or for designing further investigations on site (geophysics, dye tracing tests, etc.). SISKA developed a pragmatic and 3D-based approach – KARSYS – for the documentation of karst aquifer. This approach provides a conceptual model of aquifers and flows. KARSYS helps decision makers, engineers and hydrogeologists to get a pragmatic and consensual information in order to take the best decisions regarding groundwater management. As the application of KARSYS deals with several software packages and requires a long training, SISKA is now developing Visual KARSYS, which is a web-tool for the users to apply KARSYS by themselves through an intuitive web-based interface.
Visual KARSYS adresses two types of users: modelers and end-users. Visual KARSYS will guide modelers through the KARSYS's steps and will provide them essential tools to establish their own karst aquifer models by using their own data set. Visual KARSYS will also include a dedicated module to end-users (e.g. water authorities), who could view and interrogate the data/results produced by Visual KARSYS via a 3D-Web viewer.

The talk intends to present the concepts and the architecture of the Visual KARSYS web-tool and the related fields of application.

The Visual KARSYS project is supported by the grant for Innovation and Technologic development from the Swiss Federal Office for Environment.
Visual KARSYS may be reached at visualkarsys.isska.ch - feel free to try it!

Keywords: Karst, 3D models, groundwater management, web, service

*Speaker

Karst Modelling Challenge – A semi distributed model for assessing the recharge of the Milandre karst aquifer (JU, Switzerland)

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A semi-distributed model has been developed for assessing groundwater recharge in lowland karst areas (Malard A, Thesis in preparation). In such environments of low relief contrasts, land-uses are expected to be more significant for recharge than those related to relief. The distribution of forests, cultivated land and urban areas are therefore taken into account. The model also addresses the relations between vegetation, soils and epikarst as they significantly govern the groundwater recharge.
The model has been developed within EXCEL® and Python as a succession of embedded and cascading reservoirs that reflect properties of ground covers (interception) and of the karst aquifer (infiltration, storage and evaporation). The model is designed for working at an hourly time step. The catchment area is divided in sub-catchments for which the size, land-use and reservoir parameters are calibrated. It assumes the catchment area is known and the model inputs are equivalent precipitations (Peq, i.e. rainfalls and snowmelt) and evapotranspiration (PET).

PET is taken from meteorological station. Over each sub-catchment Peq is obtained via a routing model (MINERVE©) which makes it possible to krigging different meteorological stations in the surrounding area and to compute snow and melting processes depending on surface temperature (T) and raw precipitation (P). P and T are both obtained from meteorological stations.

Peq is transferred to four interception reservoirs: forest, cultivated lands, no-covered soils (i.e. rocky areas) and urbanized areas. Once the storage capacity of the interception reservoir is exceeded the overflow activates and the water infiltrates toward the upper and the lower reservoirs (i.e. two interdependent reservoirs reflecting the tandem soil/epikarst). Each reservoir show two outlets: one for the concentrated percolation through enlarged karst features and the second for the diffuse infiltration through smaller cracks. Depending on the water level, remaining PET may also be retrieved from the reservoirs. Downstream these reservoirs, water flows through the conduits. Along the course, an exchanger makes it possible for the water to be stored (resp. to be released) in/from the low permeability volume depending on hydraulic-head differences. Finally, the signal should reproduce the aquifer discharge.
In the frame of the Karst Modelling Challenge, this model has been applied to the Milandre

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karst aquifer at hourly time step for the years 1992 to 1994 using basic meteorological parameters (P, T and PET). Details and results of the simulation will be discussed and compared to other simulation results which have been performed in the frame of the Karst Modelling Challenge.

Keywords: Karst Modelling Challenge, Semi distributed model, Recharge, Milandre, Jura, Switzerland

Assessing seasonal and low-flow groundwater storage of karst aquifers in Switzerland

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Hydrogeological systems transform recharge into discharge thereby storing water during a certain time. The intra-annual, i.e. seasonal, storage variation volume of a given system can be estimated by comparing the water inflow and outflow components. Hydrological regimes of four well-documented karst aquifers from different contexts in Switzerland (Tabular Jura, Folded Jura, Helvetic Alps and Central Alps) have been simulated using a semi-distributed hydrological model. For each system, computed recharge is compared to the observed discharge in order to assess volume variations of the storage within the aquifer. Resulting simulations provided seasonal storage variations globally ranging between values of 40'000 and 70'000 m3/km2 (i.e. 40 to 70 mm) depending on the system. The maximal computed value was 160'000 m3/km2 for an anthropogenically modified system. With the exception of this extreme value, storage represents 3 to 10% of the groundwater recharge for these zones. It is assumed to take place mainly in the soil and epikarst, as well as in the periodically flooded conduits of the epiphreatic zone. Karst flow systems of relative great extension without temporary overflow springs, and where the perennial spring shows a restricted discharge capacity are expected to include the largest storage variation volume.
Already with the only four test sites simulated allowed for extrapolating values to the whole Swiss territory in order to provide a benchmark at this scale. Considering that karst environments in Switzerland nearly cover 7'500 km2, the expected storage variation volume may range between 0.3 and 0.5 km3, (max. 1 km3), i.e. a few percent of the annual recharge of karst aquifers (6.6 to 11.9 km3).

Regarding low-flow storage (i.e. the water released after the aquifer is no longer recharged), results show that it represents 20'000 to 50'000 m3/km2 (20 to 50 mm) which may be distributed in soil and epikarst (_˜50%) and in the phreatic zone (_˜25% in the conduits and _˜25% in the low permeable volume of the phreatic zone). At the scale of Switzerland, the total estimated low-flow storage ranges between 0.2 and 0.4 km3. Uncertainties remain large on these assessments as low-flow spring measurements are not always accurate, and also because the occurrence of real prolonged periods without any recharge are extremely rare, especially for karst systems of relative great extension.

Assessing storage processes in karst aquifers still remains a difficult task because the number of adequate test-sites for this type of study is limited and because both baseflow and overflow

*Speaker

springs are often not well monitored. However, results appear to be consistent as they are (i) comparable from one aquifer to another and (ii) consistent with the physical characteristics of the aquifer, i.e. with measurements of water storage in the epikarst as well as in the epiphreatic zone.
These aspects should be further refined regarding perspectives of climate change. In the coming decades, Swiss hydro-climatic regimes are supposed to move to a more pluvial regime than actually. Spatial distribution and aggregate state (snow vs. rainfall) of the precipitation will significantly differ and global temperature will rise by at least 2∘C. In this view, expected changes in groundwater recharge and storage in karst aquifer depending on hydro-climatic regimes will be discussed.

Keywords: storage, Karst aquifer, Switzerland, climate changes, groundwater recharge

Detailed water quality monitoring at various points of the Krásnohorská Cave system (Slovakia)

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Krásnohorská Cave system is a part of the Slovenský kras Mts. / Silická planina karstic plateau built by Triassic limestones. The cave itself is 1,550m long, formed by a huge underground stream that can be followed in more than 400m long corridor. Here, only two smaller visible side inlets to the stream are found until the whole stream disappears in a long siphon. On the opposite side it appears on the ground surface as a Buzgó karstic spring (5.3 to 1,355.8 L/s discharge). Although the Krásnohorská Cave system seems to be an efficient drainage element of the limestone plateau, two other (but smaller) karstic springs are situated within a distance of 200m, with yet unknown karstic network behind them. 150m deep hydrogeological borehole RHV-4, exploited as drinking water source for the neighbouring village, is situated just in front of the Krásnohorská Cave entrance. Both side inlets of the major underground stream, its start and end points (siphon and spring at the cave entrance), smaller side springs and the borehole were regularly sampled for basic chemistry, δ18O, δ2H and tritium content in the period of June 2015 – June 2016. Approximate weekly samplings here were accompanied by precipitation sampling in the same extent, but in two weeks interval. Although many features of the different water sources in the Krásnohorská Cave system were similar, it seems that one part is influenced by dissolved sulphates of geogenic origin, probably in Lower Triassic shales. Water isotopic composition of one smaller karstic spring differs from what was observed at all other monitored sites, and mean isotopic composition of precipitation is even more different what points to the snowmelt origin of groundwater here.

Keywords: water quality monitoring, basic chemistry time series, tritium, stable isotopes

*Speaker

Modeling the global change impacts on the Lez karst aquifer

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The Lez karst system, located just north of Montpellier, is a major Cretaceous and Jurassic limestone karstic aquifer that supplies drinking water to 340 000 inhabitants of metropolitan Montpellier. The present water management scheme allows pumping at higher rates than the natural spring discharge during low-flow conditions, while supplying a minimum discharge rate into the Lez river for ecological purposes, and reducing flood hazards via rainfall storage in autumn.
Lez spring water is currently tapped by four pumping units consisting of two submerged pumps connected in series and operating at variable speed with an output of 600 to 1 000 l/s. These pumps are located in three of the four vertical boreholes that intercept the main karst conduit. The mean pumping abstraction rate-currently 1080 l/s or 34 Mm3/year-is sufficient to supply drinking water for a permanent population of around 340 000 inhabitants. The Lez spring system is one of the largest temporary groundwater abstraction systems in the world, similar to the Figeh karst system, which supplies water for the city of Damas [Lamoreaux *et al.* 1989].
Semi distributed lumped model has been used to characterize the regime of the karst aquifer subjected to extensive pumping. The systemic approach uses a transfer model that is based on computing the convolution integral of up to several signals, e.g., efficient rainfall, pumping, to simulate flow rates and groundwater levels in both the karst conduit and the carbonate matrix at the aquifer outlet and in several parts of the catchment area. The model is a semi-distributed lumped model which simulates the hydrological response of the different hydrologic compartments of the karst system. Groundwater is abstracted near the system's major outlet at a higher rate than the low-water spring discharge, thereby mobilizing stored groundwater during low-water periods ('active management'). The model's results are very satisfactory, especially for the karst system outlet, where the water levels are particularly well reproduced. The model can also simulate the natural, i.e., non-pumping, state of the karst system and thereby estimate the impact of active management on the water resource. It has been used to simulate several scenarios of pumping under present and future (2045-2065) climate. It is useful in order to determine the sustainable pumping rate allowing to respect the authorized drawdown and pumps elevation

Keywords: global change, pumping, modelling, lumped model, time series, active management

*Speaker

Monitoring and preliminary analysis of the natural responses recorded in a poorly accessible streambed spring located at a fluviokarstic gorge in Southern Spain

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An adequate understanding of the inherent hydrological complexity found in carbonate aquifers is a prerequisite for implementing sustainable water management strategies. In this sense, analysis of natural responses (hydrodynamic, hydrothermal and hydrochemical) of karst springs, as well as the interpretation of isotopes variations in groundwater are well-established tools to provide insights into the hydrogeological functioning of the aquifers they drain. However, a suitable monitoring of natural responses in poorly accessible streambed springs are often difficult to establish due to the interaction between surface water and groundwater flowing through carbonate aquifers. In such contexts, an acceptable knowledge of the hydrological settings prior to the placement of the corresponding facilities and devices is essential to effectively obtain single and/or continuous records of the natural responses during different hydrological conditions.
This work presents the preliminary hydrogeological dataset collected during one year in the Charco del Moro spring (Southern Spain), an outlet that emerges at the bottom of a partially flooded gorge (20 - 200 m depth and 2 km length), eroded by the Guadiaro River streamflow. This spring constitutes the largest discharge point in the region, draining groundwater from norther nearby carbonate outcrops.

Probes for continuous (hourly) measurements of electrical conductivity, water temperature and turbidity were directly installed within the outflowing cave, placed 4 m deep from the water surface, using an adjustable stainless steel box as mooring structure and with the support of scuba divers. A water pump coupled on an auto-sampler was simultaneously installed for tak-

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ing water samples. In addition to water quality equipment, 2 low-cost water level dataloggers were installed upstream and downstream, respectively, from the spring and their hourly records were afterwards converted into continuous record of discharge, using their corresponding rating curves.
Results displayed a hydrogeological behavior clearly influenced by precipitation events. Significant and rapidly decreases in mineralization (up to _˜200 μS/cm) and water temperature values were recorded during recharge period, simultaneously to rises in turbidity and spring discharge (up to 10 - 12 m3/s few days after rainfall episodes). In contrast, at low water conditions, mineralization and temperature showed slow increase coinciding with the minimum values of turbidity and discharge (0.4 m3/s). This variability reflects a high degree of heterogeneity in the duality of groundwater flow and storage dynamics, which is typical of clearly karst conduit flow systems.

Keywords: Fluviokarstic, Gorge, Hydrochemical, Devices

SIMPLIFIED VARKARST SEMI-DISTRIBUTED MODEL APPLIED IN VILLANUEVA DEL ROSARIO KARST SYSTEM (MÁLAGA, SPAIN)

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Numerical modelling approaches constitute well-established tools for advancing in the understanding of groundwater dynamics and they support water management, involving both drinking water supplies and ecosystems protection. In the case of karst aquifers, their hydrogeological heterogeneity and complexity determine require adapted simulation routines. In this study, a simplified version of the semi-distributed VarKarst model was applied to jointly simulate spring discharge and piezometric variations in a tectonically complex and mountainous karst system located at Southern Spain. To evaluate the new approach, simulated spring outflows have been compared with springflows derived from a previous application of the original VarKarst model. Scatter correlation yields a Pearson coefficient (R2) of 0.8854. Furthermore, the modified approach includes new equations from which the piezometric level variations, in a borehole located 1,165 m eastward from the spring, have been calculated. 12 months of simultaneous records of spring discharge and water level variations were used in the calibration procedure. The R2 and the root mean squared error (RMSE) results obtained of groundwater level were 0.8535 and 3.07 m, respectively. We conclude that the simplified VarKarst numerical code can provide realistic hydrodynamic results in the karst system concerning both discharge and groundwater level dynamics. This capacity of simulation will help to reduce uncertainty in model routines and it might open new perspectives for a better evaluation and management of water resources.

Keywords: Karst (carbonate) aquifer, semi, distributed modeling, VarKarst, hydrodynamic simulation

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Karst hydrogeology of the UK Chalk aquifer and implications for groundwater protection

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In the UK, the Chalk provides a large proportion of national groundwater resources. High aquifer transmissivity has been attributed to solutional enhancement of fractures, and the Chalk has been traditionally considered to be a "fissured" rather than "karstic" aquifer. The Chalk is generally managed and protected using standard hydrogeological approaches and equivalent porous medium models. However, karst features have been documented for many decades, and an ongoing collaborative knowledge exchange initiative involving academics, regulators, the water industry, planners, cavers and hydrogeological consultants has collated knowledge and data on karst in the Chalk. This has revealed that small-scale surface karst features (stream sinks and dolines) are more common in the English Chalk than was previously thought, and also that there is some cave development. Caves are exposed within the base of stream sinks; caves have been intercepted during quarrying and the construction of wells and adits; and caves with features indicating karstic origins are present in coastal areas. However, Chalk caves in England are not common or extensive, and therefore it is particularly difficult to investigate subsurface karst. Groundwater protection is particularly challenging because the Chalk is extremely heterogeneous, and although much groundwater flow is through preferential flowpaths, the locations of these are very difficult to identify. Tracer tests have demonstrated rapid groundwater flow through the unsaturated zone and the saturated zone; both via stream sinks, and in areas where there are no surface karst features. Recent tracer tests have demonstrated rapid flow to abstraction boreholes. Many Chalk abstractions are impacted by nitrate and pesticide pollution, and determining the pollutant sources is difficult due to the high aquifer heterogeneity. Data on Chalk karst will be presented, and methods of delineating source protection zones, and determining where to focus catchment management measures to reduce nitrate and pesticide pollution in these types of carbonate aquifer will be discussed.

*Speaker

Keywords: Chalk, Groundwater protection, tracer test

Understanding flooding in Planinsko Polje (Slovenia)

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Planinsko Polje belongs to the Ljubljanica River recharge area (Slovenia) and is considered as a locus-typicus of karst poljes due to its large variety of geomorphological and hydrological processes. Flooding in the polje occurs often after abundant rainfall and/or snowmelt and forms an intermittent lake that can persist for several weeks. Human settlements around the polje have been traditionally positioned above the level of the most severe floods. However, most of the polje neighbouring villages expanded during the last decades to areas endangered by large flood events. As an example, floods of February 2014 were the highest in the last 80 years and created an over 10.3 km2 large intermittent lake with a maximum water level of 8.26 m recorded at the gauging station. The lake remained for almost two months and flooded two villages, causing important damages to the infrastructures. In addition, a recent study has shown that prevailing humid climate of mid-Holocene (8000-5000 BP) might have caused more severe floods in several Slovenian karst poljes, making them a potential threat for the neighbouring settlements under changing climatic conditions. This shows that current knowledge of the main factors controlling polje flooding is still insufficient and that further research is needed. This work aims to identify and evaluate the impact of the factors controlling the flooding in Planinsko Polje. To do so, continuous monitoring of water level, electrical conductivity and temperature was established at the main springs, ponors and water active caves located around the polje. Data analysis was combined with several groundwater models of different complexities. The models attempt to reproduce the behaviour of the polje from the simplest to the most complex observed processes under various hydrogeological conditions. Results improve the current understanding of flooding in Planinsko Polje and show the importance of combining direct measurements with numerical modelling. The approach has the potential to be applied on other poljes having the same flooding problematic.

Keywords: Polje, flood, karst aquifer, groundwater modelling, monitoring, Slovenia

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Karst Modelling Challenge: lumped model contribution

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In the framework of the Karst Modelling Challenge proposed by Jeannin & Malard, we propose a rainfall - discharge modelling contribution using the modelling platform KarstMod from the french SNO Karst.

Keywords: karst modelling challenge, karstmod

*Speaker

Natural and artificial tracers to assess slow groundwater flow in an auxiliary karst system (lake of Fontaine de Rivîre, Belgium)

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The lake of Fontaine de Rivîre is an auxiliary karst system in the Frasnian limestones of the Ourthe valley in Belgium. Its particular confinement was studied by conjunctional use of natural responses and single point dilution tracer test, with an injection of 41 g of uranine on 22nd March 2017. The tracer test was monitored during one year using fluorometers, water and charcoal samplings at 5 points in the lake and 6 points at the surface (no connection having been established outside). A slow flow (in the order of magnitude of 1 m/h) of the lake could be observed and some mixing processes identified. The dilution of the tracer along the year indicates a average discharge of only 0.16 l/s. This low discharge is com-patible with the high confinement of the lake also proved by its high homogeneity and stability (temperature, chemistry). However the fluctuations of level are ap-parently not compatible with this renewal and especially with the low rate of dilu-tion of the tracer observed during winter in the lake. This can thus be explained by pressure transfers from the surroundings, without necessarily high fluxes of water. The delays for the responses have also been quantified by cross-correlations for the whole period of monitoring from 2007 to 2018.

Keywords: dilution test, uranine, active charcoal, natural tracer, karst flow, climate

*Speaker

Field constraints and procedures in fluorescent dye tracing

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Tracer tests using fluorescent dyes must be addressed according to the intended level of information: geographical, hydrogeological or related to contaminants (but the reliability of the results has to be estimated prior, or eventually after, the test. The modern tests rely on the use of spectrofluorometric analyses at the end, but most of the errors often come from inadequate or wrong procedures, even mistakes, at the early sampling stage, and there is not yet a unique or recognized method. Some pros and cons of the four main sampling techniques are here discussed and compared, based on past experience: in-situ data sampling with field fluorometers, manual water sampling, sequenced sampling with automatic samplers, and passive sampling with granular active charcoal. Their ability to fulfill various field and experimental constraints, individually or in combination, is then evaluated.

Keywords: tracer test, fluorescent dye, sampling, errors, fluorometry

*Speaker

Creation of karst system model as a result of complex aquifer monitoring (example on Beljanica karst area- Eastern Serbia)

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Generally, it's difficult to define the hydraulic and physical parameter of carbonate rocks such as karst. Even when the many of different investigations are applied, in the case of karst terrain, the results can not be completely sure and accurate. Usually it's not possible to verify the obtained values or to determine which part of the karst channels are active or not (eg, filled with clay or calcite).
The scope of this paper is to corelate the measurements of spring discharge with some physico-chemical and isotopes data of the springs that drain Beljanica massif and to merge them into the 3D model of karst channels, which means to observe the results of the upper zone of the karst aquifer (recharege zone), such as sinkholes, pits and the caves and research in constantly saturated active part of the karst aquifer to the drainage area.
The purpose of this paper is the reconstruction and modeling of complex karst aquifers characteristics. For construction and interpretation of the model, besides the considerable field work, quality and powerful programs (such as ArcGIS) were used, that made possible performance of the spatial, quantitative and qualitative analysis of speleogenesis, as well as functioning of karst conduit.

Keywords: karst, groundwater, monitoring, model, hydrochemistry, isotopes

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Applicability and sensitivity analysis of four vulnerability assessment methods to the Yucatan karst, Mexico

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Vulnerability maps are valuable tools for the development of protection strategies and sustainable use of karst water resources. Despite several methods are currently available, subjectivity for karst vulnerability assessment leads into contradictory results when different models are applied over the same area. Agreement between methodologies could vary depending on given vulnerability rates, weighting factors and considerations of karst features behaviour, thus creating difficulties in determining a method to be applied on a specific karst area. The Yucatan karst aquifer presents unique hydro-geological characteristics contrasting against those areas where most of the actual karst vulnerability methods were developed and tested. Actual pollution scenarios in Yucatan stress the necessity to evaluate vulnerability and promote protection measures. Four methods, RISKE, KARSTIC, DRISTPI and The Slovene Approach were applied for the Yucatan karst for source intrinsic vulnerability. Agreement between final maps was evaluated according to their match on vulnerability rates when they overlap; intrinsic features influencing such match and divergent factors were highlighted. Additionally, layer removal sensitivity analysis was performed in order to determine intrinsic factors and their influence in a regional basis. The present work aims to determine if existent vulnerability methods display a congruent vulnerability scenario according to regional characteristics or if adaptations for such methods is necessary.

Keywords: Yucatan, Mexico, Vulnerability, DRISTPI, KARSTIC, RISKE

*Speaker

A two dimensional terrain and pipe network model of a lowland karst catchment in the west of Ireland

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The karst of the south Galway lowlands in western Ireland is underlain by highly permeable epikarst with a well-developed conduit and cave system dispersed throughout the catchment. The area is also known to be underlain by more ancient paleo-karst which may also interact with the shallow epikarst and conduit systems providing alternative discharge methods. The outlet for the catchment is through a submarine groundwater discharge (a series of springs located at the intertidal zone of the bay) at Kinvara Bay. Discharge from these springs occurs intertidally and as such, their flow rates cannot be measured using traditional methods. The flooding which occurs annually in the majority of the ephemeral lakes (turlough basins) across the catchment is mainly due to insufficient capacity of the underground karst system to take increased flows following excessive precipitation events, causing the conduit-type network to surcharge. A model of the karst network has been previously developed using a pipe network to represent conduits with turloughs represented as ponds (Gill et al., 2013a; Gill et al., 2013b, McCormach et al., 2014). The model has been used to predict the groundwater discharge to the coast at Kinvara via the main Kinvara West spring. This current study involves utilising LiDAR data for the catchment in combination with the existing pipe network model to produce 2D models of the catchment. The pipe network model has been linked to the 2D terrain surface of the landscape and groundwater flooding from the karst has been calibrated against recorded stage data for a number of turloughs. This has enabled flood estimation to take place beyond the time period for which calibration data are available. Overland flood routing has been matched to the mapped flood extents of recent extreme flood events (2009 & 2015) and various scenarios have been simulated.

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Keywords: 2D, karst, pipe network

Karstic Water potential based on the Geological view in the North East of Iran

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Karstification is an important geological process in carbonate rocks. It modifies the rock properties and creates positive (for example reservoir potential) or negative aspects (geological hazards) for the human life. One important aspect of the karsts is the water storage potential. Karstic water is very important particularly in arid and semi – arid areas, thus applying different methods of karstic water recovery is improving. Basically, five main geological parameters control the karstification including, lithology, climate, geomorphology, hydrogeology and tectonic setting (those can be classified into twenty smaller classes). The influence of these five parameters (and the other 25 sub classes) are determined in different areas of the country (Iran). These parameters show different levels of importance thus they are evaluated and combined in the next step. This evaluation and combination (weighting) is carried out based on the statistical analysis that is named the AHP method. This method is very useful for the geologists in quantifying the qualitative geological parameters. Different grades of karstification potential are attributed to the regions and eventually, the susceptive locations in karstification are defined and graded based on their potential. The study is carried out by the Geological Survey of Iran. A few number of wells are drilled in important locations based on the geoelectrical and field studies for testing the validity of the theoretical studies in the initial stage of the project. The results show that the determined high potential locations in theoretical studies are compatible to the karstic features and karstic water in different depths which improves the possibility of attaining higher volumes of water in these areas.

Keywords: karst, hydrogeology, water resource, groundwater, karstic water

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Assessment of Empirical and Analytical Methods for Estimation of Water Inflow rate into the Zagros Tunnel in Karstic Area, Kermanshah, Iran

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Presence of groundwater flow and surface water flow are among negative factors in construction of underground tunnels. Determining of the groundwater inflow rates into the tunnel is necessary for confronting of environmental problems and decreasing the risk of tunnel instabilities and falling. In this paper, the amount of inflow waters into the section 2 of Zagros tunnel, West Iran, have been estimated using analytical and Empirical methods. The results compared to the measured actual data of inflow water into the tunnel in different sections by consideration the abilities of the methods in prediction. It was revealed that the confidences of analytical and empirical methods are 14% and 69%, respectively. The results show that the hydraulic conductivities of the rock masses, as one of the key parameter in these methods, has an enormous effect on the accuracy of the predictions. Geological condition, hydrogeological properties of faulted and fractured zones, development of karst in the formations and the type of hydraulic conductivity test procedure could be caused to obtaining the incorrect hydraulic conductivity values and unreliable prediction of water inflow to the tunnel. The high ambiguities appear in fractured zones and cavities with high hydraulic conductivities. Analytical and Empirical methods that are generally used to estimate water inflow in to the tunnels are including simplifying assumptions such as homogeneous and isotropic porous medium and the karst development is not considered in the formations of tunnel route.

Keywords: Water inflow rate, Analytical and empirical methods, Zagros tunnel, Kermanshah

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Unravelling the hydrodynamics behavior of karst systems through comparative hydrology

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The hydrodynamics of karst aquifer depend largely on its strong heterogeneity which controls the flow signal of karstic springs. While there is much research in karst hydrology that focusses on local and catchment scales, comparative knowledge about the hydrodynamic behaviour of karst systems in different regions of the world and the understanding to parameterise karstification in ungauged basins remains limited. Finding an accurate descriptor of aquifer heterogeneity, its variation across different scales and regions of the world is still an open question in karst research.

Springs enter undoubtedly well into the study of dynamic nature of karst aquifers because their flow behaviour reflects an integration of processes of what is happening within the entire karst groundwater basin. The characteristic behaviour of springs can be evaluated with global methods such as recession analysis that may provide quantitative information about the degree of karstification. Such quantitative measure would be of high value to compare karst spring behaviour at different catchment across the globe and reveal important information on factors that control the variability among karst systems under different climatic and physiographic conditions.

This poster will present an overview of available data set, initial approach to the analysis, prospect methods and an outlook to the future applications of outcomes of this research.

Keywords: discharge, comparative hydrology, recession analysis

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Estimation of recharge in karst aquifer using improved evapotranspiration monitoring thanks to remote sensing data

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Evapotranspiration (ET) is a fundamental variable of the hydrological cycle. Estimation of ET at regional scale from remote sensing data provides spatially distributed information that can improve ground water assessment.
In particular, remote sensing can provide information on vegetation phenology which is strongly related to the capacity of vegetation to extract water from the ground over long period of time. We tested the interest of including such information in the modelling of the stream flow at the outlet of a karst system.

The test site is the impluvium of Fontaine de Vaucluse karst aquifer, located in the South-East France. The spring is the only outlet of a 1162 km^2 catchment area. The hydrologic regime of the system is described using the Karst Recharge Model (Ollivier et al., submitted) based on the assumption that karst recharge is mainly controlled by climate and surface and sub-surface catchment heterogeneities. We have developed a semi-distributed model based on lumped structure in order to compute water transfer thought the karst aquifer. In the original version, the epikarst is represented as simple buckets with known water holding capacity (spatially variable as a function of soil type) and a simple water balance is performed to compute drainage from rain and evapotranspiration. The latter is computed using the reference ET based on the Penman-Monteith equation (ET-PM).
In the present work we replace ET-PM by a new calculation (ET-RS) accounting for the amount of vegetation through a vegetation index derived from MODIS data (Kc-ETref). The rain regime is also accounted for better describe the impact of evaporation from the superficial soil layers. The new ET assessment based on ET-RS yields more consistent ET temporal dynamics than ET-PM-based approach. The calculated discharge was also improved (Nash Index rises from 0.58 to 0.69).

Keywords: Evapotranspiration, remote sensing, semi, distributed model, karst aquifer recharge

*Speaker

PaPRIKa toolbox : a standardization of karst aquifers vulnerability mapping

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Karst aquifers are highly heterogeneous in terms of their surface and subsurface features and hydrodynamics. Karst aquifer vulnerability assessment is therefore challenging and requires specific mapping methods. PaPRIKa is a commonly-used vulnerability assessment method. PaPRIKa vulnerability maps are based on a combination of factors related to the protection of the aquifer (P), the characteristics of the reservoir (R), infiltration features (I), and karst network maturity (Ka). We developed a QGIS plugin toolbox that makes it possible to use spatial analysis to compute the PaPRIKa vulnerability index of an aquifer. This toolbox thus standardizes the application of the PaPRIKa method, saves time, and prevents user omissions. The toolbox also makes it easy for the user to test combinations of different factors so as to submit the most relevant vulnerability map to groundwater managers and decision-makers.

Keywords: PaPRIKa toolbox, QGIS, vulnerability mapping, arst aquifer

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Complex pollutant transfer in fractured and karstified chalk aquifer systems in Eastern Normandy, France

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Chalk aquifer systems often display dual or triple porosity textures leading to complex flowfields, not easily detected through regular groundwater level measuring campaigns which most of the time use available unevenly distributed wells opened at different depths. This often can biased groundwater flow interpretation and lead to partially erroneous flowfields or piezometric maps. This is a real problem when dealing with pollution migration, as finding pollution sources, predicting plume evolution or pollutant concentration trends and setting up corrective measures to protect water resources.
This paper intends to discuss complex pollution transfer in two chalk aquifer valleys in eastern Normandy where pollutants do not seem to only follow flowlines shown on available groundwater level maps; indeed, divergent pollutant transfer also take place along fractured axes and karst developments which can often be associated to geological discontinuities, as was already highlighted through model calibration processes in the Avre river catchment.

In the Commerce valley case, a rare emerging pollutant, N-nitrosomopholine, was discovered to migrate in two opposite directions from a single source point identified in the upper Valley: indeed, this pollutant was both found south and downstream in the fractured and porous aquifer, and way up north in a karst channel system used for drinking water purposes, in what was thought to be a completely different watershed.

In the Iton valley case, the pollutants are volatile organohalogenated compounds (VOH) which are widespread in Normandy and often stem from historical industrial pollutions. Several potential VOH sources were identified in industrial areas in the valley south from contaminated drinking water wells; yet the groundwater flow map suggest an eastern origin for the pollution source...
This situation often encountered in the chalk aquifer systems of eastern Normandy makes it difficult to establish "cause to effect" links between pollution sources and contaminated drinking water wells. To tackle this problem and clarify flowline interpretation, a multi-parameter approach based on geological and hydrogeological criteria has been developed; it is discussed in this paper.

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Keywords: Pollution, Pollutant transfer, karsts, aquifers systems, groundwater

A field abacus for the estimation of saturation index with respect to calcite

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In limestone karst environment, Saturation Index with respect to calcite (SIc), and equilibrium CO2 partial pressure (Pco2eq) are major parameters used in characterizing an aquifer. Water saturation or under-saturation with respect to calcite indicates the ability of the water to precipitate or dissolve limestone. Thus, SIc is necessary in considering the ongoing behavior of the water. However, to date, a handy tool that can provide immediate estimations of SIc *in-situ* is still a pressing concern.
From the calcite equilibrium equations, it is possible to express SIc as a function of measured field parameters. These equations are summarized to provide an abacus based on the SIc=f(Pco2eq) reference frame, hence called SIc-Abacus. This abacus helps to estimate SIc and Pco2 values from direct field measurements such as pH and bicarbonate. Thus, providing a tool that can be easily used on field.
This article focuses on the construction of the SIc-Abacus and the equations behind. The abacus is built from spreadsheet software. Assumptions made to simplify the equation are presented and their impacts on estimated value of SIc are discussed.

Keywords: Saturation, Bicarbonate, CO2

*Speaker

Model validation: confronting MODFLOW CFP to sandbox experimental results

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This work is focused on validating the MODFLOW CFP M1 model developed by the U.S. Geological Survey for simulating groundwater flow in karst aquifers. The model validation process is important to build confidence for using the model. We were interested in quantifying to what extent the model can accurately simulate groundwater flow in karst conduit and surrounding porous media. The model validation was done using results of lab experiments. A sandbox lab device was developed to understand three-dimensional groundwater flow in a confined karst aquifer with a conduit in the middle of the aquifer. Thirteen lab experiments were performed. Hydraulic heads and flow rates of the conduit and surrounding sand were measured. We used three experimental results to calibrate the roughness of the conduit, hydraulic conductivity of the sand surrounding the conduit, and a coefficient used by MODFLOW CFP M1 for simulating the flow exchange. Using the calibrated model, we evaluated the estimated errors (the difference between model simulations and the corresponding data) along with the 95% confidence intervals for the true error. The errors were calculated for flow rates at the inflow and outflow of the sandbox and the heads in the porous media. The confidence intervals consider measurement error, model calibration error, parameter uncertainty, and propagation of the measurement error in the boundary conditions. The results of model calibration and validation showed that the magnitude of the error was highly correlated with the magnitude of measured flow exchange, indicating that MODFLOW CFP M1 cannot adequately capture the physics of the flow exchange. Therefore, MODFLOW CFP M1 is valid when the flow exchange is small but invalid otherwise for this sandbox experiment.

Keywords: Uncertainty, MODFLOW CFP, exchange flow, aquifers

*Speaker

Approche interdisciplinaire pour la quantification du potentiel de soutien d'étiage des zones humides au cours d'eau – Application à la tourbière de Frasne (Doubs, France)

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Il est important de quantifier la capacité de stockage et de restitution d'eau des zones humides de tête de bassin versant pour évaluer leur capacité de soutien d'étiage des petits cours d'eau. En contexte de changement climatique, une telle contribution peut s'avérer cruciale pour les rivières et fleuves situés à l'aval. La quantification du soutien d'étiage nécessite une approche interdisciplinaire et un développement méthodologique afin de mieux comprendre les interactions cours d'eau/zone humide/eau souterraine et réduire les incertitudes. Le projet s'appuie sur des méthodes de mesures de terrain (pédologie, géophysique, imagerie aéroportée, hydrologie, hydrogéologie et géochimie) et sur la modélisation pour évaluer la capacité de soutien d'étiage des zones humides (bilan hydrologique, propriétés hydrodynamiques) en fonction du contexte climatique, géologique (ex. karstique), géomorphologique (ex. héritage glaciaire) et des activités anthropiques associées.
Cette méthodologie interdisciplinaire sera mise en œuvre sur plusieurs sites de zones humides dont la tourbière de Frasne (Doubs, France) en domaine karstique à héritage glaciaire. Sur ce site, la quantification du soutien d'étiage nécessitera de : 1) " boucler " de manière précise les bilans hydrique et hydrologique du site en identifiant et quantifiant les sources d'apport localisées ou diffuses (ex. pluie, ruisseau, résurgence-émergence, aquifère dont drainance...) et d'export (ex. évapotranspiration, surverse, infiltration, pertes karstiques...) ; 2) caractériser en 3D la géométrie (parfois variable dans le temps) de la zone humide et ses propriétés hydrodynamiques (ex. perméabilité, porosité...). L'accent sera plus particulièrement mis sur la caractérisation de deux interfaces : 1) l'interface tourbière/versant-encaissant pour estimer les apports et les pertes diffuses (ou cachées) liés à des écoulements souterrains ; 2) l'interface catotelme/acrotelme pour déterminer les propriétés hydrodynamiques de la zone hydrauliquement dynamique de la tourbière.
À terme, l'objectif vise à proposer : (1) des indicateurs simples à destination des gestionnaires (ex : guides technique ou méthodologique) pour évaluer la fonction de soutien d'étiage des zones humides ; (2) des arguments dédiés à leur protection à destination des élus et du grand public (ex : plaquettes de vulgarisation ou d'information). Ces travaux constituent un préalable indispensable pour une meilleure caractérisation, voire une quantification économique, du service " soutien d'étiage ".

*Speaker

Keywords: Bilan hydrologique, indicateur, soutien d'étiage, tête de bassin versant, zone humide

A parsimonious distributed model (KARSTFLOW) for simulating rain-discharge in the Karst Modelling Challenge (KMC)

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KARSTFLOW is not a software package but the name given to a mathematical model for simulating transient water flow in high-relief karst aquifers. This parsimonious model is described and adapted to the rain-discharge simulation of the Karst Modelling Challenge (KMC). The model assumes data scarcity and then a parsimonious approach is required to model the system to ensure that the level of complexity of the model was commensurate with the amount, type and quality of the available data. Parsimony also requires the model to include the minimum essential components that account adequately for the data, which in this and similar cases are the functional dualities of the karst system: duality in recharge (diffuse and preferential), duality in flow (slow flow across the rock matrix via fractures and fast flow along conduits) and duality in discharge (slow flow and fast flow after recharge events). The methodology, which is completely general and can be used for similar aquifers, is illustrated by application to tthe karst aquifer in the Milandre groundwater catchment in Switzerland.

Keywords: Rainfall, discharge, mathematical modeling, lumped models, distributed models

*Speaker

Fractal analysis of karst landscapes: the case of Sierra de las Nieves (Málaga, Spain)

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Since the introduction of fractal geometry, there has been increasing evidence of the universality of fractal forms in nature. Fractal analysis has been used for evaluating the roughness of both natural surfaces and engineered surfaces. In this work, we use a high-resolution digital elevation model to conduct a fractal analysis of topographic surface roughness for a high-relief karst system for which the local fractal dimension is calculated for each pixel using a moving window rather than a global (or unique) fractal dimension for the whole area. Roughness is quantified by the local variogram of altitudes. We found that the fractal dimension is not related to slope and that a fractal dimension of 2.3, suggested as an upper limit of topographic surface roughness based on arguments of surface fragility, is also a practical limit for fractal dimensions of karst terrains. The map of roughness described by the local fractal dimension can be used on its own or together with other information (slope map, hypsometric curve, slope orientation map, etc.) for terrain segmentation that could assist in quantitative terrain analysis and in geomorphological interpretation and mapping, as well as ecological studies of karst terrains and in predicting the multi-scale dynamics of landform processes. We also analyse the spatial patterns of local fractal dimensions of the roughness of landscapes. The methodology is applied to the high-relief Mediterranean karst of the Sierra de las Nieves in Southern Spain where two different areas of karst evolution and development have been identified.

Keywords: Fractal dimension, roughness, slope, karst depressions

*Speaker

Epikarst mapping by remote sensing: application to Sierra de las Nieves (Málaga, Spain)

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The epikarst, as the most surficial part of a karstic massif, has a strong influence on the spatiotemporal variability of recharge and the hydrodynamic functioning of many karst aquifers. It plays an important role for the temporary storage of water and delays its transit towards the springs; it also constitutes the main dissolution area of the karstic system and retains and scatters pollutants. In the Mediterranean morphoclimatic zone, the average thickness of a well-developed epikarst has been established around ten meters thick, but the patterns that determine its degree of development and its spatial distribution are still little known. In addition, direct field observation is difficult due to the fact that good outcropping conditions are restricted to particular locations. In this sense, remote sensing provides a complete view of the whole area, with spectral resolutions that reveal variability features. These in turn can define image textures which can be related to the development of the epikarst. This research aims to contribute to the understanding and mapping of the spatial variability of epikarst thickness by using a procedure that integrates satellite images and field observations. The proposed methodology has been applied to the Sierra de las Nieves karstic aquifer (Málaga, southern Spain). In order to validate this procedure, results from several geophysical surveys, including seismic refraction and electrical resistivity tomography, as well as field work have been employed. Epikarst mapping by remote sensing could be used to improve recharge estimations and in the development of mathematical models and vulnerability maps for karst systems.

Keywords: Epikarst, Remote Sensing, Numerical classification

*Speaker

DETECTION AND ANALYSIS OF SINKHOLES THROUGH INTEGRATION OF FIELD SURVEYS AND SEMI-AUTOMATED TECHNIQUES

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Sinkholes are among the most typical landforms of karst terrains. They may originate from a simple downward process, through dissolution of carbonate rocks, or through rapid, sometimes catastrophic, collapse, due to the presence of an underground void or cavity, from where the instability may eventually reach the ground surface. These two extremes imply a great variety in both vulnerability of man-made structures, and effects on the population, which make the analysis of sinkholes extremely important to society. In this contribution we present an integration of techniques to detect, classify and analyze sinkholes, aimed at contributing to the evaluation of sinkhole susceptibility and hazard. The methodology used will be illustrated by means of a variety of examples from the karst of Apulia, south-eastern Italy.

Keywords: sinkholes, susceptibility, hazard

*Speaker

GROUNDWATER RESOURCES IN THE APULIAN KARST: FIRST OUTCOMES OF A PROJECT DEDICATED TO MONITORING THE DEEP WATER TABLE

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The deepest cave in Apulia, an almost entirely karst region in south-eastern Italy, is recently being the object of a dedicated project, aimed at evaluating the quality and quantity of the groundwater resources. The cave system, located in one of the most remarkable karst landforms in the region (the polje of Canale di Pirro), reaches the water table at depth of -264 meters, with diving explorations that brought the total depth of the cave down to -324 meters. This contributions illustrates the preliminary activities carried out during the project, with a particular focus on geology, morphology and structural geology of the cave system and surrounding areas, together with hydrogeological research and chemical analyses of the groundwater

Keywords: cave, water, hydrogeology, exploration

*Speaker

Combining dissolved gas, gravity and hydrodynamic measurements in a spatially distributed conceptual model of the Durzon karst systems (South of France).

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Karst aquifers are known as spatially heterogeneous media with temporal and scale dependent relationships between recharge and flows. For these reasons, scale is a major concern when studying karst hydro-systems. In this context, this work focuses on the use of three distinct tools, each characterizing a different scale dependent process to better constrain a conceptual model of flow and transport in a karst systems:

Dissolved gas is used to characterize residence times and recharge processes. They are usually measured at spring to represent the whole karst system.

Ground-based gravity measurements are used to estimate the variations of the groundwater mass balance. They are representative of an intermediate scale (_˜ 100 m).

Underground river flow are used to characterize vadose zone hydrodynamics. In-situ hydrodynamic measurements are generally representative of a local scale.

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Scales (both temporal and spatial) are also one major concern when studying karst hydro-systems. As karst hydro-systems are spatially heterogeneous with temporal non-linear relation between rainfall and spring flow.

The study area is the Durzon karst system in the Larzac plateau, south of France. We recorded:

- Time series of dissolved gas at the main spring during more than 2 years with both low and high spring discharge (fig. 1)

- Time series of gravity during more than 4 years (fig. 2)

- Time series of underground river flow during more than 2 years at a depth of ¯˜ 120 m (fig. 3)

These three main data-set are unique due to the type of data (long time series of gravity and dissolved gas in a karst area), and to the spatial distribution of the monitoring in the same karst system. The three data-set are first detailed within the geological and climate context. Then a conceptual model is presented, constrained by the available measurements. In the conclusion, the perspectives towards data assimilation in numerical models are presented.

Keywords: dissolved gas, gravimetry, Larzac

Multidisciplinary approach for the characterisation of regional aquifers and the sustainable management of groundwater resources: case studies of the Milk River Aquifer (Canada-USA) and the Thau karstic aquifer (France)

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Characterisation of regional aquifers can be challenging due to data and information fragmentation, non-natural jurisdictional boundaries and the numerous stakeholders involved over a large area. Yet, a comprehensive portrait of the aquifer system is required to fully understand its global dynamics and assess the conditions required for the sustainable management of groundwater resources.
A multidisciplinary approach is needed to fully assess regional aquifer systems. Examples of such an approach are presented through two case studies: The Milk River transboundary aquifer (Canada-USA) and the Thau karstic aquifer (France). Both of these regional groundwater resources are in a challenging context of intensive groundwater use with strong economical stakes and concerns about the sustainable management of the resource.

*Speaker

The multidisciplinary approach involves an initial stage of gathering and evaluation of pre-existing data over the study area to harmonise and unify geological, hydrogeological and geochemical datasets. This step indicates the locations of less-documented areas and shows how to complete the dataset with new key information and data through focused field work.

The next step of the approach is the development of a 3D geological model of the aquifer system. This first model forms the basis of the regional study by providing indications on hydrogeological implications of the system and sound definition of its natural limits. During the development of this first model, hydrogeological and hydrogeochemical studies are carried out at the system scale. These studies include the definition of groundwater flow patterns, identification of recharge and discharge areas, location of active and low-flow areas, groundwater types and residence time and a groundwater balance Results of these investigations are then integrated and combined into a conceptual hydrogeological model of the system. Thus the conceptual model describes the functioning of the aquifer system based on geological, hydrogeological and geochemical evidences.

This conceptual model is then tested and validated with a numerical groundwater flow model, using the previously developed 3D geological model as a basis. The numerical groundwater flow model quantitatively integrates all available information about the aquifer and is considered as a tool to quantitatively answer specific questions that have been raised during the development of the conceptual model. Groundwater flow models can help refine the understanding of the regional groundwater flow system and verify the plausibility of the previously developed conceptual model. The numerical model is also used to assess and quantify the change in the water budget components and simulate the impact of different past and future groundwater use scenarios.

Altogether, these series of regional models support the formulation of recommendations for the sustainable management of groundwater resources following the natural limits of the aquifer system. Finally, this workflow implies that stakeholders of various jurisdictions (municipal, regional, federal/provincial) encompassed by the aquifer limits, should be involved from the early stages of the study.
Thus, this approach provides a common scientifically-based knowledge of the aquifer and is a prerequisite to groundwater management and informed decision. The case studies presented illustrate a sound approach based on scientific tools to allow the proper assessment of regional aquifer systems and support groundwater management at the aquifer scale.

Keywords: regional study, multidisciplinary approach, sustainability, management

Influence of recharge scenarios on karst contamination risk: field experiments and integrated methodology

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The hydraulic conductivity and storage capacity of the unsaturated zone and the amount of recharge are the main parameters controlling the ability of contaminants to migrate from the soil surface to the saturated zone of an aquifer, i.e. to an active conduit network in a karst system.
Within the scope of groundwater vulnerability methods, recharge is often taken into account based only on mean annual values of meteorological data (precipitation, ETP, runoff), and rather addresses diffuse infiltration. Within karst aquifers, the existence of concentrated infiltration points (e.g. at swallow holes) must be considered to correctly differentiate crucial contrasts in groundwater recharge. The protective function of the unsaturated zone can be dramatically reduced or nullified if the recharge rate overcomes the storage capacity of the geological layers. Moreover, the behavior of karst aquifers often implies the contribution of freshly infiltrated water to aquifer recharge, and spring discharge respectively, following each significant rainfall event. This requires shorter recharge periods (e.g. a few days) to be considered rather than annual data.

Besides the distribution of natural diffuse or concentrated recharge, human hazards can also locally create recharge by themselves, decreasing the protection capacity of the unsaturated zone and thereby increasing the risk of contamination.
The approach presented aims at better defining the influence of long and short term meteoric recharge as well as determining the influence of man-induced recharge linked to various hazards. Artificial tracer experiments performed at different field sites were used to simulate diverse recharge scenarios and proved to be an adequate tool to better understand some mechanisms leading to karst groundwater quality degradation. This approach contributes to some recent development of groundwater protection tools, such as karst vulnerability mapping and contamination risk assessment.

Keywords: Recharge, Tracer testing, Contamination, Risk assessment

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Local Wisdom-Based Karst Springs Management in Playen District, Gunungkidul Regency, Indonesia

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Karst springs is the main water supply for residents in Playen District, Gunungkidul Regency. Given that another source of surface rivers do not have the quality and availability of large quantities and the utilization of underground rivers that are only channeled at some locations, leads the karst springs in the Playen District becomes a very important to fulfill the water needs of the surrounding residents. The condition in Gunungkidul which has arid and dry surfaces, thin soil, and the largest reservoir of water present in the epicarst and underground-ground-rivers lead it to the most convenient alternative water supply. Nevertheless, water supply has a certain limitations and certain management so that it can be consumed in the long term. In the case of Playen District, utilization of karst springs by residents in Playen has been done for a long time and done uniquely, with localized approaches such as the use of myths to mark the water supply, the presence of prohibitions and collective work which performed routinely every specific date. This local wisdom has been passed down by the Playen community from generation to generation, so that the water supply there can be sustained until today. In this research, the method used in obtaining information on the management of karst springs is In-depth interview on the key person who manages the water supply. For the purpose of plotting locations and mapping, GIS is being used. Based on the results of inventory of water supply management based on local wisdom in the District Playen, this approach can be directed and applied in other Districts in Gunungkidul Regency. Considering that it can maintain both quality and quantity of water supply in the long terms.

Keywords: karst springs, local wisdom, water management

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Hydrochemical characterization of a complex mediterranean karstic system to improve the regional management of the groundwater resources (Thau lagoon area, Montpellier, France)

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Groundwater in coastal area is a strategic resource but undergoes high pressure due to important human activities of these areas. An example of the complex management of such system is given by the karstic hydrosystem of the Thau basin,which is a strategic resource for drinking water, spa activities as well as shellfish aquaculture. In this aquifer, groundwater originates from 3 different naturally sources: 1) cold karstic waters, 2) warm and mineralized thermal waters, and 3) marine waters (Thau lagoon and seawater).
This karstic and thermal aquifer underwent several flow inversion events (known as an "inversac" process) in the past decades, during which the seawater flows into the aquifer causing an adverse impact on water quality and consequently on the economic activities depending on this resource. Therefore, a deep understanding of the regional hydrosystem under both natural and inversac conditions is required to better protect the groundwater resources.

In this context, the "Dem'Eaux Thau" project aims to characterize and model the Thau hydrosystem in order to develop tools for groundwater resources management allowing decision-makers to take on the challenges of this region. The present study covers the hydrogeochemical part of the project through the valorisation of existing geochemical data (major and trace elements, stable isotopes, REE...) and the collection of new data (noble gases, CFC/SF6, isotopes of B, Li, Sr) in strategic locations representative of each component of the system (surficial and deep karst, springs and thermal boreholes). In addition, a new exploratory well has been drilled in the study area, providing new insights of the functioning mode of the regional thermal reservoir.

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Combined with geological and hydrogeological parts of the project, this hydrogeochemical study constitutes the basis of a comprehensive conceptual model of the hydrosystem and support the development of a future groundwater management tool for this strategic regional resource.

An assessment of karst aquifer prospective by the salt dilution method

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One of the main challenges of a hydrogeological research of heterogeneous karst terrains is an aquifer parametrization. There are numerous techniques for an assessment of porosity and karstification of carbonate rocks in the zone of tested borehole, such as: pumping test, slug test, Lugeon test, packer test, borehole televiewer, caliper logging and electromagnetic induction logging. Besides these methods there is possibility for an application of hydrochemical techniques for an assessment of borehole prospect for groundwater abstraction. The salt dilution method, which has long been used in hydrology and in tracing of subterranean flows, could find wider application in borehole testing. This method is based on injection of salt into a borehole and continuous measurement of a groundwater electrical conductivity. Minor changes of an initial electrical conductivity (i.e. TDS) after injection of a certain amount of salt indicate better prospective of the borehole for a groundwater abstraction, and a higher increase of TDS indicates the opposite. This method have been applied to the borehole which is drilled through the karstified limestone in Lješanska Nahija (Montenegro). Obtained results which is discussed in this paper could be useful for the future improvement of this method that has potential for a wider application in karst hydrogeology.

Keywords: salt dilution, borehole, test, karst aquifer

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Geochemical insight on the weathering processes in a Mediterranean karstic watershed.

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The eastern Mediterranean region is under an arid to semiarid climate and is suffering from water scarcity. Lebanon has important resources of water and has 13 perennial rivers with 5 karstic sources of 1st magnitude. The study area (Kadisha - Abou Ali watershed) is a karstic watershed of 491 km2 area. It extends from sea level to 3000m on the western flank of the Lebanon Mont, thus leading to a sharp climatic stratification. The catchment is dominated by Mesozoic carbonate sediments along with basaltic outcrops in its upstream.
In order to better understand the weathering and the hydrological processes, water samples were collected throughout the seasons. Physicochemical characterization as well as C-, H-, O-, and Sr- isotope ratios of the water were established and the dissolved species were analyzed.

The alkalinity is poorly affected by the hydrological regime of the seasonal variability. Furthermore, the pattern of the 87Sr/86Sr ratio, fluctuating between 0.7072 and 0.7081 and co-varying with the Ca/Sr molar ratio (from 399 to 889), indicates a well-defined marine carbonate dissolution. In addition, the isotopic composition of the dissolved inorganic carbon ranges from -15.4 to -7.4 . Lightest values are mainly found in areas having the highest anthropogenic impact, and likely associated to biological respiration, the vast majority of the catchment, including karstic springs at high altitude (> 1600m), are nevertheless characterized by biologically-mediated carbonate dissolution. Moreover, temperature loggers installed at the river's springs show contrasted behaviors. At Rachiine Spring (low altitude) it ranges from 10.3 to 15.8 ∘C, with a significant decrease triggered by the snowmelt and characteristic diurnal cycle, whereas Kadisha Spring (high altitude) shows a more buffered temperature (7.1 to 7.9 ∘C).
In conclusion, the studied watershed corresponds to a typical East Mediterranean karstic system. The influence of sea spray and other minor lithologies (basalts) will nevertheless be quantified as long with the anthropogenic influence.

Keywords: Karst, weathering, carbonates, Mediterranean, Lebanon.

*Speaker

A flood pulse triggered temporal and spatial dynamics of water quality in a binary karst aquifer: example from SW Slovenia

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Water quality assessment is often a driving factor for monitoring selected natural tracers within or at the margin of karst aquifers. After abundant rainfall and/or snowmelt events the dynamics of various parameters is often highly heterogeneous. Particularly binary karst aquifers show both temporal and spatial variability of individual parameters. This study focuses on a selected flood pulse in mid-September 2017 caused by intense precipitation event following a several months long droughty period. The ponors of the Rak and Pivka Rivers, two cave streams of the Planinska Jama and two springs (Unica and Malenščica) belonging to the same aquifer system have been observed. We continuously monitored precipitation, water level, electrical conductivity and temperature. Altogether 108 samples have been taken in one month for selected chemical and microbiological parameters' analyses. The results enabled assessing the origin of water, the transit times through the underground karst system, as well as the behaviour of different subcatchments. A better insight of occurrence and fate of contaminants has also been obtained. In addition, the results showed that during flood pulse sinking rivers represent an important concentrated input of contaminated water into the highly permeable conduits of a karst aquifer and onwards towards karst springs triggering low water quality. The findings are important to better understand the character of karst systems variability in space and time. Water source managers can use this information to predict eventual water contamination dynamics and establish appropriate water quality and protection measures. The gained results could further be used in modelling approaches to envisage aquifer hydraulic responses and related water quality.

Keywords: karst groundwater, flood pulse, water monitoring, hydrologic variability, water protection.

*Speaker

Impacts of human activities on subterranean ecosystems - macroecological and conservation perspective

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Due to difficult accessibility, subterranean ecosystems – where light does not penetrate – are rich in endemic biodiversity with different morpho-physiological adaptations and constitute one of the most poorly known and unprotected natural resources of our planet.
The infiltration of contaminants to the subterranean ecosystems is fast, making them excessively vulnerable to impacts of pollution. Despite worldwide recognition of the importance of subterranean ecosystems as the most important sources of freshwater for human consumption and also recognized as critically endangered, initiatives like the EU Water Framework Directive or the Groundwater Directive, stress the need to achieve a good physicochemical status of groundwater, neglecting its endemic biodiversity.

Animal species richness below the ground plays a key role in regulating the whole suite of ecosystem functions directly related to groundwater dependent ecosystems, as springs and rivers. A complete evaluation of the condition of subterranean ecosystems should consider not only abiotic parameters but also their biological components. Furthermore, the fact that terrestrial subterranean ecosystems are intimately linked with the groundwater cycle is also neglected and scientific information concerning the effect of pollution in these ecosystems is needed for their protection.
We are generate a framework for future ecological assessment of subterranean ecosystems, ensuring its sustainability. As far as the subterranean species may be more sensitive to chemical pollutants than surface species, ecological quality criteria based on responses of surface organisms are clearly insufficient to protect subterranean ecosystems.

Keywords: biodiversity, karst, groundwater, conservation, risk assessment

*Speaker

Laminar and turbulent discrete-continuum approach: MODFLOW-2005 Conduit Flow Process

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We applied the discrete conduit-continuum approach Modflow-2005 Conduit Flow Process Mode 1 with some adaptations and enhancements like Conduit Associate Drainable Storage (CADS, Reimann et al. 2014). The field situation is considered by selected simplified conceptual representations, which are investigated by numerical simulations in combination with inverse parameter estimation techniques. The most suitable conceptual model is further investigated by a refined numerical model that considers the field situation with increased complexity. Finally, our experience is critically evaluated regarding effort, data demand and computational costs.

Keywords: Karst Modelling Challenge, Recharge, Model comparison

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Bayesian inversion of karstic conduit position using posterior population expansion

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The posterior population expansion (Popex) is a new technique that was developed to invert discrete parameter fields using a given prior distribution [Jäggli et al, 2016]. The main characteristics of this approach is that it allows dealing with categorical variables such as the presence or absence of a conduit. Solving an inverse problem in such discrete cases is difficult because the misfit function between the data and the model results is not varying continuously as a function of the conduit position. Most standard approaches based on derivatives or covariances to estimate the sensitivity of the misfit to the parameters are inefficient in such cases. Popex instead is based on two simple ideas. One should first use conditional probabilities instead of covariances to deal properly with the categorical information. Then, one should use the whole ensemble of models to learn about the relation between the misfit and the unknown parameter to progressively generate new candidates that are more probable to fit the data. The details of this approach have been presented in a previous paper [Jäggli et al, 2016].
In this presentation, we will describe the general principles of this approach and illustrate its application in a karstic system. The case study is based on the field site operated by the University of Poitiers in France. Many pumping tests have been conducted in this karstified and confined aquifer [Bodin et al. 2012]. To model the site, we use the direct sampling multiple point statistics algorithm to generate an ensemble of plausible karstic conduits geometries, and a finite element flow simulator to model the flow responses to pumping. We show that one of the main advantages of Popex is that it allows to integrate prior information about the geometry of the karstic conduits in the inversion procedure. We also show that it is more effective than existing Markov Chain Monte-Carlo approaches while it estimates accurately the level of uncertainty. This is a very important aspect as soon as those models are applied to produce hydrogeological forecasts. However, even if Popex is much faster than previous techniques, the proposed method still requires significant computing resources.

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Keywords: Inverse technique, Numerical modelling, Geostatistics

A double medium approach to simulate groundwater level variations in a fissured karst aquifer

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Karst aquifers are known for their complex flow mechanisms produced by a high spatial heterogeneity of voids distribution. This study aims at confirming and enhancing the understanding of these flow mechanisms in a fissured karst aquifer using flow simulation with a double medium approach. Groundwater level (GWL) variations of the studied site (a topographic hill of 17 km^2 located in Burgundy, France) are hourly monitored through 18 boreholes, 3 karstic resurgences and the outlet river discharge of the catchment basin (40 km^2). The Gerke & Van Genuchten double porosity model is implemented in the METIS code and used to simulate GWL variations with a matrix and a fracture medium. Model parameters are calibrated by fitting simulated fracture medium GWL to measured GWL for four boreholes which are representative of the topographic hill hydrodynamic. The double medium approach succeeds in reproducing measured fast GWL responses after recharge events, which are not reproduced by a single medium approach. Investigating the model parameters impact on simulated GWL variations and the exchange flow between the two media allows for to conceptualizeing the physical structure and the hydrodynamic mechanisms of the studied fissured karst aquifer. A parameters spatial organisation is observed and indicates areas of higher fracture density producing rapid GWL responses in contrast to lower fracture density areas producing slower and higher GWL responses. Fracture medium hydraulic parameters and the exchange parameter, controlling the matrix/fracture interface properties, are the most influent parameters on simulated fracture medium GWL and the exchanged flow between matrix and fracture medium during a recharge event. Finally, this study shows the Gerke and Van Genuchten double porous medium validity for simulation of groundwater level in a fissured karst aquifer.

Keywords: Hydrogeology, Modelling, Karst aquifers, Double medium approach, Groundwater level simulations

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Limits in Using Multiresolution Analysis to Forecast Turbidity by Neural Networks. Case study on the Yport Basin (Normandie-France)

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25% of the world population drinking water comes from karst aquifers. The comprehension and the protection of these aquifers appear thus as crucial.
In *Normandie* (North-West of France), the highly karstified chalk aquifer is the principal exploited aquifer. For example the *Yport* pumping well fed by a karst aquifer provides half of *Le Havre* conurbation (236 000 inhabitants) tap water. Due to the karstification, connections between surface water and underground water induce turbidity occurrences that decrease the water quality. Due to the karst aquifer, the processes inducing turbidity peaks are difficult to apprehend because of both the non-linearity of the rainfall/turbidity relation and the multiplicity of variables and phenomena.

In this context the aim of this work is to predict turbidity peaks in order to help pumping well managers to decrease the impact of turbidity on water treatment. The database consists in hourly rainfalls coming from six rain gauges, located in the alimentation basin since 2009, and hourly turbidity, measured in the karst drain of Yport, since 1993. Because of the lack of accurate physical description of the karst system (for example no rating curve is available), the systemic paradigm is chosen to achieve prediction using black box models: neural networks models are chosen.

In previous works, the prediction of turbidity at 12h lead time and 24 hours lead time was studied using 16 models: two kinds of neural networks architectures: the multilayer perceptron, and an improve multilayer perceptron devoted to a better consideration of the evapotranspiration process (called as two branches model). Both kinds of architectures were designed in the

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framework of recurrent models and non-recurrent models (feed-forward). These previous works highlighted that the feed-forward multilayer perceptron is better to predict turbidity peaks when feed-forward two-branches model is better to predict 100 NTU threshold surpassing.

In this context, the present paper addresses the application of the multiresolution analysis to decompose the turbidity on several time scales in order to better consider various phenomena at various time scales. The stakes of causality and temporal translation invariance as well as the way to better couple neural network design and multiresolution analysis is discussed in order to better represent slow and fast dynamics modeling.
The results show that the coupling of neural networks and multiresolution decomposition allows improving the turbidity prediction only for recurrent models.

Keywords: Turbidity, Neural Networks, Forecasting, Multiresolution, Yport basin

Applying a novel set of methods to improve hydrograph separation in Irish karst aquifers

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Karst aquifers are highly heterogeneous systems that are characterised by multi-scale temporal and spatial hydrologic behaviour. Different permeabilities in the conduit, fissured and matrix domain translate a given rainfall input into these systems into two flow components, i.e. a slow Darcian flow vs. fast turbulent flow, to which is referred as "duality of groundwater flow".
Quantifying both flow components is a perquisite for the understanding and modelling of groundwater recharge, flow and discharge dynamics in karst aquifers. To distinguish between fast and slow flow component, hydrograph decomposition has been applied on spring discharge (Forkasiewicz and Paloc, 1967; Padilla et al., 1994) or well head time series (Kovács et al., 2015; Shevenell, 1996). Based on the principles of recession analysis in surface hydrology, also the time-discharge or time-head response of karst hydrographs can be decomposed into at least two segments, i.e. a flood and a baseflow component, representing the average fast and the slow response of the aquifer following a rain event.

This research aims to differentiate slow components in three different Irish karst aquifers combining long- and short-term high-resolution field data, in order to improve pipe network modelling techniques. The methods comprise a set of traditional and novel techniques to decompose well and spring hydrographs, namely a) frequency analysis (Fast Fourier Transform and wavelet analysis) (Labat et al., 2000; Torrence and Compo, 1998), b) digital filtering (Chapman, 1999), c) numerical baseflow separation (Kovács and Perrochet, 2008; Kovács et al., 2015; Kovács et al., 2005), and d) end-member mixing analysis (EMMA) using stable isotopes (18O, 2H) in conjunction with major ions and silica (Fritz et al., 1976; Laudon and Slaymaker, 1997).
This approach has enabled time-frequency components of wavelets (a) to be linked to the more physically meaningful results derived from methods b) to d), in order to better relate time-frequency and time-amplitude signals to Darcian and turbulent groundwater flow, which is expected to significantly improve current pipe network modelling techniques.

Keywords: baseflow separation, stable isotopes, signal analysis, time series, karst, Ireland

*Speaker

KARST LIMESTONE CAVES IN NORTH INDIA : AN AID TO INFER THE CLIMATIC CHANGES OF THE AREA

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The preserved and well exhibited karst limestone caves around Dehradun are exposed over an area of about 20Km2. The area meets all the necessary and adequate conditions for karst development such as availability of limestone, bedding structure, rich in rainfall of about 200cm / year, thick vegetation cover with evergreen multi canopied forests, and high temperatures favoring the development of organisms and high diversity in biology, accelerating chemical interactions and emitting much CO2 as feedstock for the karstification. The percolating vadose water containing dissolved CaCO3 gets the first chance of evaporation and reaches the roof of the cavern in the form of droplets. These droplets stick to the roof for a while, get evaporated and, therefore, deposit small granules of CaCO3 which are fixed with the roof and naturally hang from the ceiling towards the floor in the form of stalactites and from the floor towards ceiling in the form of stalagmites. These structures are well preserved in the limestone karst caves. There are six interconnected caverns in the form of caves, each of which is about 100 to 500m in length. By the side of these caves, naturally occurring sulfur spring exists. This sulfur spring spa which has many medicinal properties such as the ability to eradicate skin diseases together with adjoining karst limestone landscape / caves and ecology represents a unique scenery and draws thousands of tourists from different parts of country and abroad every year. The local authorities and the Indian Tourist Development Corporation, Government of India, are promoting the spot as a big attraction centre for the tourists.

Keywords: karstification, mining, sulfur spring, vadose water, warming

*Speaker

Revision of karst vulnerability assessment to address the protective effect in a quantitative manner

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The Swiss Water Protection Ordinance requires vulnerability assessment as the appropriate approach for delineating groundwater protection zones in karst terrains. For this objective, a vulnerability method specifically dedicated to karst groundwater has been developed in Switzerland 20 years ago, based on the mapping parameters of epikarst, protective cover, infiltration conditions and karst network. This methodology is currently under revision taking into consideration practical experience in groundwater protection zoning and integrating recent karst research findings. It will be adjusted to a more comprehensive origin-pathway-target approach, with the protective effect of the above parameters assessed and summarized in a quantitative manner.
In particular, transient water storage in soil, subsoil and epikarst – known to play an essential role in relation to the vulnerability of many karst systems – provides prolonged residence times for potential attenuation of non-persistent contaminants, mainly with regard to fecal microorganisms. Such attenuation can be expressed as reduced recovery of the potential pollutant while passing through the system, defined in terms of a number of protection units. A protection unit then corresponds to the smallest class that can be attributed to a mapping parameter. The sum of protection units, finally, describes the overall protective effect between the catchment surface and the karst spring.

The presented approach is to provide a better quantitative basis for the classification of the vulnerability assessment criteria, with classes yielding a similar degree of protection. Mapping results thus become more comprehensible and comparable. It is believed – in conjunction with some adaptation in the Swiss legislation for reducing land-use conflicts – making protection zoning in karst catchments more meaningful and easier to implement.

Keywords: Vulnerability, Protection effect, Quantitative approach, Karst groundwater, Switzerland

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Artificial tracer tests interpretation for karstic system using transfer function approach

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A karstic formation consists in a three-dimensional hydrological system which involves horizontal and vertical, diphasic or saturated water transfers characterised by a large range of velocity. These subsurface flow processes correspond to various water pathways through fractured, fissured, and underground streams or conduits leading to a nonlinear and non stationary global behaviour of the karstic system.
An efficient way of investigation of a karstic system behaviour consists in the injection of artificial tracer at loss points and in careful analysis of the Residence Time Distribution (RTD) derived from the concentration curves measured at one or several outlet of the karstic system.

Advection-Dispersion Equation model have been widely used for interpreting RTD curves. Nonetheless, the physical significance can be questionnable when it represents flow process in karstic system on several kilometers distance. Here, we propose to study karstic system using process engineering tools : Laplace-transform transfer function of the RTD. Considering karstic systems as chemical reactors, we shows that the introduction of a transfer function approach constitutes an efficient way to describe dispersive phenomenon. Also, karstic system can be modeled as a chemical reactor including plug flow, mixing and recirculation.

Several karstic systems have been studied basefor artificial tracer tests interpretation using transfer function approach. Results shows multiple improvement :

1 - Transfer function parameters constitute a new way to classify karstic systems depending on their hydro dispersive behaviour.

2 - In some case, transfer function parameters seem to be independent from hydrologic conditions, as the variation remains small. So this approach appears to be robust as the validity limits of the transfer function are clearly defined.
3 - This is offering a new way to deal with pollution scenarii tests.

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Keywords: karstic systems, artificial tracer tests, transfer function

Jurassic Carbonate Aquifer – The Most Valuable Fresh Water Resource at the Horn of Africa

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The eastern part of the Horn of Africa (Somalia, Ethiopia) is one of the very rare African regions that are characterised by the prevalence of karstified rocks and karstic aquifers. Its major aquifers are formed in Jurassic limestones and dominantly evaporitic rocks of the Eocene age, both of the platform type and resulting from the Tethys Sea regression. Even though mostly saline or highly mineralised (TDS mostly $>$ 3000 ppm), waters from Eocene evaporitic rocks are broadly used as they represent the sole resource in the easternmost part of the Horn (northeast Somalia). In contrast, groundwater discharging from the Jurassic karst aquifer is commonly fresh and of very good quality. Unfortunately, the Jurassic aquifer has limited extension, with main outcrops located along both sides of the border between Somalia and Ethiopia.
Borama is the largest town in Somalia that utilises the Jurassic aquifer. It is located just 20 km from the Ethiopian border. Today Borama has some 150,000 residents, of which only are connected to the waterworks' pipeline. The main source is in the nearby village of Dhamuuq, where the initial karstic spring has been tapped out, followed by several boreholes that were subsequently drilled from the year 2000 to date. Their depths vary between 64 and 120 m. The total discharge is 27 l/s, which, together with 6 l/s of tapped spring water, makes for a total of 33 l/s available for drinking water supply. Despite the relatively small capacity, there is clear evidence of over-extraction. It was indicated that the water table has depleted by some 13 m during the period 2006-2012 (2 m/year), mostly as a result of limited aquifer distribution and erratic rainfall. The water quality is regularly controlled and no treatment is applied (not even chlorination).

Jijiga is the largest town in Ethiopia that taps and utilises the same Middle Jurassic (Doggerian) aquifer. The city is also close to the border, and is currently one of the major dwellings in the Somali State Province of Ethiopia. However, this aquifer cannot be viewed as fully transboundary, because its outcrops are even not continual and connected. The Jijiga well field is located near the city in the alluvial plain of the Jarer River. In the 1970s, several wells were drilled to the total depth of 70m. They have very high specific yields (0.6-2.6 l/s per m' of drawdown). Recent drilling (2009) confirmed the existence of groundwater table at the average depth of 70m, while the total drilling depth of most wells is 130m. It is noteworthy that the

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drilling depth has doubled in comparison with that of the 1970s; nevertheless, based on performed pumping tests, they still yield a good amount of water (specific yield of 1 l/s per m' of drawdown). The tested water has a low level of mineralisation (TDS is regularly lower than 1000 ppm).
Although limited in distribution and groundwater storage, this aquifer can be further developed at many locations where it is linked to overlying alluviums. Constructing underground dams across riverbeds of many present temporary streams and storing the water for longer period of year in the upstream alluvium's sections may also contribute to larger and longer recharge of Jurassic aquifers.

Keywords: karst aquifer, fresh waters, limestone, Jurassic, Horn of Africa

Sources, sinks and role of drip water solutes at Yarrangobilly Caves, SE Australia

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The trace element records of speleothem archives reflect the cave dripwater chemistry. Correctly translating the significance of hydrochemical variations of cave dripwater allows a wider application of speleothems as paleoenvironmental records. However, the dripwater chemical composition at the stalactite tip reflects a contribution from different endmembers and processes; therefore it is necessary to study the different sources, pathways and processes that occur as water migrates through the atmosphere-soil-karst system. Here we present high resolution aerosol, rainfall d18O and drip-water datasets within the Yarrangobilly Caves system, in the Snowy Mountains, south-eastern (SE) Australia. Analysis of aerosol samples above the caves reveals the atmosphere supplies a suite of elements from automobile emissions, windblown soil, smoke, secondary sulfate and aged sea salt sources. A simple characterisation of element mobility through the soil profile was examined through assessing soil enrichment factors relative to the bedrock for a suite of elements. We then applied a mass balance model to quantitatively partition the contribution of individual elements into the marine aerosol, atmospheric (non-sea salt), bedrock, and residual sources.
Based on the d18O, trace element and drip rate data, we identified that the flow pathway to the monitored drip sites was fracture flow from a well-mixed ventilated pocket reservoir in the epikarst. Using drip-water Cl, Mg/Ca and Sr/Ca ratios, we identified that dilution and reduced prior calcite precipitation (PCP) controlled the drip-water chemistry during the La Niña/wet years whereas enhanced PCP was observed during the El Niño and dry periods (Tadros et al., 2016). Furthermore, during warmer than average temperatures, we observed a flow path change through the epikarst using bedrock and dripwater Mg/Ca and Sr/Ca ratios and based on Ca concentrations and temperature anomalies we identified that CO2 is a major driver of limestone dissolution. We also applied principle component analysis, a statistical method, to clarify the main processes controlling how the dripwater chemistry evolves over time. We identified three important geochemical processes control the dripwater chemistry: (1) recharge, (ii) biochemical weathering, and (iii) K-fixation. In order to correctly evaluate the use of trace elements as paleoclimate proxies in speleothem studies, we discuss the importance of atmospheric and end-member measurements in SE Australia and globally.

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*Speaker

eastern Australia, Hydrol. Earth Syst. Sci., 20, 4625-4640, doi:10.5194/hess-20-4625-2016, 2016.

Keywords: Trace elements, cave drip water, long term monitoring, SE Australia

Hydraulic assessment of a large lacustrine ecosystem at the interface of unconfined and confined carbonates

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The different hydraulic behaviour and conceptual flow field of confined and unconfined carbonate regions applying the topography-driven regional groundwater flow theory were already outlined and presented for adjoining confined and unconfined cases (Mádl-Szönyi & Tóth 2015, Mádl-Szönyi et al. 2017). In this paper, the hydraulic position of the largest lacustrine ecosystem in Central Europe, the Lake Balaton, Hungary, was examined by hydraulic data analysis and numerical simulation. Hydraulic conditions of the Lake Balaton were not studied previously in the context of the surrounding groundwater flow systems.
North of the lake, the unconfined or semi-confined part of the Transdanubian Range is mainly built up of Triassic and Early Jurassic carbonates, which are the main aquifer in this region. There are only some clayey–marly aquitards in the 1–4 km thick carbonate sequence in this area. The carbonates are poorly karstified and they are influenced by faults and folds (Haas 2012). South of the lake, Triassic carbonates are confined by several-kilometres-thick siliciclastic sediments.

Tomographic potential maps, pressure vs. elevation profiles were constructed for revealing the horizontal and vertical groundwater flow components. Groundwater flow is dominantly lateral in carbonates due to the higher hydraulic conductivity of carbonates compared to siliciclastic formations. In the elevated parts (above 250 m asl), recharge areas were determined and the groundwater discharged at the lower elevations (below 150 m asl). The hydrostratigraphy and the geometry of units modify the flow pattern, e.g. a folded structure efficiently restricted the through-flow and a low-permeability thrust-fault caused a head drop of 10–30 m at the footwall.

The regional-scale numerical simulation and hydraulic data assessment could disclose the asymmetric flow pattern caused by different topographic setting of the unconfined and confined parts, the hydraulic regimes in the broader vicinity of the Lake Balaton, and also the groundwater discharge in the Lake Balaton, which can be considered as a groundwater-dependent ecosystem.

Haas J (ed) 2012: Geology of Hungary. Springer Verlag Berlin; Heidelberg, p. 236

Mádl-Szönyi J & Tóth Á 2015: Basin-scale conceptual groundwater flow model for an unconfined and confined thick carbonate region. Hydrogeology Journal 23/7, 1359–1380.
Mádl-Szönyi J, Czauner B, Iván V, Tóth Á, Simon Sz, Erőss A, Bodor P, Havril T, Boncz L,

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Söreg V 2017: Confined carbonates–Regional scale hydraulic interaction or isolation? Marine and Petroleum Geology

Keywords: gravity, driven regional groundwater flow, Lake Balaton, Hungary, ecosystem, hydraulic data analysis

Optimization of high-resolution monitoring of water nutrients in karstic environment using a PLSR calibration model of a UV-VIS spectrometer

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Degradation of surface water and groundwater quality is a major concern in terms of environmental impact and public health problems. In order to perform monitoring of water quality variations at efficient cost, implementation of a continuous high-resolution monitoring by an automatic sensor could be relevant, notably in karstic catchments. The UV-visible spectrometer (s::can) allows reliability and accuracy monitoring of certain nutrients parameters coupled with a limited maintenance. A global factory calibration for NO3, TOC, turbidity and LDO, designed by the supplier on the basis of a surface water dataset, is programmed by default on the spectrometer. All the range of chemical characteristics of the surface water dataset is not supplied by the probe manufacturer and its representativeness of the karstic domain is questionable, as such environment showed high turbidity in waters, known to perturb data acquisition.
The purpose of this study is to test the suitability of spectroscopy to measure parameters proposed by the factory manufacturer (NO3, TOC, LDO, Turbidity) as well as other parameters as TP (total phosphorous) and PO4 in waters in karstic environment. The spectrometer was installed successively in the French Jura Mountains at two stations at the Loue spring and then at the Loue river at the edge of at the purely karstic watershed, in order to test the monitoring of groundwater and surface water respectively. For calibration, water were sampled for chemical analysis of NO3, TOC, TP, PO4 at a frequency of 1 to 4 days and continuous measurements of LDO and Turbidity were recorded by multiparameter probes (MS5,Hydrolab, OTT), calibrated manually on the field. We developed a calibration model based on the partial least squares regression method applied on the absorption spectra, in order to (1) evaluate the relevance of the factory "calibration", comparing results given by the factory and those obtained by our approach, (2) assess if the implementation of wavelengths selection and the correction of turbidity could improve calibration performance and (3) assess the suitability of the non-programmed factory parameters as TP and PO4.

First results for groundwater are satisfactory. For NO3, factory calibration shows very good performance as well as our calibration model. But for TOC, LDO and turbidity, our calibration improves significantly the dynamics and the amplitude of the parameter estimation in comparison to the factory calibration. However, for TOC and turbidity, although our calibration satisfactorily reproduces the global dynamics, it does not always succeed in estimating the amplitude of some peaks. Regarding TP and PO4, results showed that our approach is able to

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track main TP and PO4 peaks, but with a less correlation than previous parameters.
These results showed that our new calibration approach is able to reproduce several key chemical parameters of water quality at a high frequency time step, given interesting perspective for monitoring groundwater and surface waters in karstic basins.

Keywords: water quality, spectrometer, metrology, karst, Jura, nutrient, high, resolution monitoring

Nature, Origin and Transfers of suspended particles matters (Mineral, Organic, and Biological) in karst hydrosystems: A New Methodological Approach by Morphogranulometry

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For a better knowledge of karst dynamics, one challenge consists in the characterization by in-situ measurements of the nature, the origin and the transfer of suspended particles matter (SPM) in a karst network. Tracer methods and transfers analysis are parts of the main tools in hydrogeology but few methods cover such requirements and among them, the methodology using the shape of particles deserves to be developed.
Indeed, morphometry of particles is widely used in sedimentology to identify different sedimentary stocks, source-to-sink transport and sedimentation mechanisms. Currently, morphometry analyses are carried out by scanning electron microscope coupled to image analysis to measure various size and shape descriptors on particles like flatness, elongation, circularity, sphericity, bluntness, fractal dimension. However, complexity and time of analysis are the main limitations of this technique for a long-term monitoring of SPM transfers.

Here we present an experimental morphometric approach using a morphogranulometer (a CCD camera coupled to a peristaltic pump). The camera takes pictures while the sample is circulating through a flow cell, leading to the analysis of numerous particles in a short time. The image analysis provides size and shape information discriminating various particles stocks according to their nature and origin by statistical analyses.

Lab calibration measurements were carried out on standard samples of particles commonly found in natural waters. The size and morphological distributions of the different mineral (clay, sand, oxides etc), biologic (microalgae, pollen, etc) and organic (peat, coal, soil organic matter, etc) samples are found statistically independent and can be discriminated on a 3D graph. Now, we would like to present environmental results: on field in situ measurements were carried out at the sink and the spring of the Norville karstic network in Normandy. We also conducted punctual multi-tracers tests by injecting particles well defined by the morphogranulometer (clays, sand, microalgae, flour, etc) at different hydrological conditions to compare with the previous

*Speaker

tests made on site using chemical tracers (Duran 2015) and statistical investigations of transport processes (Fournier 2008).
The results show the promising ability of the morphogranulometer to trace the transfers of particles inside a simple sink-spring network. Such a development offers great perspectives to use the method for the characterisation of other karstic hydrosystems.

Keywords: particles, tracers, transfers, shape, image analysis, morphometry, karst

Groundwater vulnerability mapping of karst aquifers in Greece using the COP method, remote sensing and GIS techniques

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T The COP method used for the assessment of intrinsic groundwater vulnerability and remote sensing were applied in two different karstic systems in Greece, namely the "Ksiromero" system and the "Ziria" karst system. The "Ksiromero" system, a karstified evaporate system, occupies an area of 146 km2. It is located in West Greece and it is mostly covered by highly karstified Triassic carbonate breccias. The "Ziria" karst system occupies an area of 198 km2 and is located at the Northern part of Peloponnese in South Greece. It is a mountainous area, covered mostly by highly karstified carbonate rocks. It is characterized by the absence of permanent streams and the existence of shallow holes and dolines. Large springs drain both of the systems. Remote sensing techniques (free available DSMs) were used for the detection and qualification of the karst depressions. With the use of GIS tools vulnerability maps have been finally produced, highlighting the different degrees of intrinsic vulnerability in the each karst system and the differences between the two systems.

Keywords: groundwater vulnerability mapping, karst aquifer, COP method, Remote sensing

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Hydrogeology of Dévoluy karstic sytem : new insights with dye tracing and rainfall-discharge model

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The Dévoluy is an important karstic massif of the Southern Pre-Alps (France). Its geological structure is dominated by an important layer of limestone of the upper Cretaceous (up to 600m of power locally) constituting an unused carbonate aquifer with a potential groundwater resource. Downstream of the system, a hydroelectric development consisting of a reservoir lake (Sautet lake) and a dam is being operated by Electricité De France (EDF) for more than 50 years. In order to follow the feeding of the lake, long flow ratetime series of the main springs of the massif are available.In the early years of 2010, a study program led by the French Federation of Speleology was started in collaboration with EDF. This study has two main goals : 1) First, anticipate the feeding of Lac du Sautet in order to better manage hydroelectric installations, 2) Second, to improve knowledge about this important regional groundwater resource (volume, recharge, low water regimes, flood regimes, etc.) in order to be ready for sustainable exploitation in the event of insufficient resources currently exploited.Quantitative tracing experiments were re-launched, as well as physico-chemical monitoring of the outlets and the waterlevel in the karst. We show in this poster the main results acquired to date and their integration in a rainfall-discharge modeling approach. We have chosen a "reservoir type" model which, despite its simplicity, allows to make interesting interpretations.

Keywords: Dévoluy, French Alps, Regional Study, Tracer testing, Water Ressources, Karst Water Management, RainfFall, discharge modelization

*Speaker

Estimation of confined karst aquifer parameters via tide-induced head changes in a coastal observation well

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Abstract: It is known that the water table levels in coastal karst aquifers fluctuate due to the tidal effect, and the tidal periodic changes of groundwater level in coastal karst aquifers contain some important hydrogeological information. In this study, we are concerned with a confined karst aquifer in the coastal areas with a constant hydraulic recharge rate landward boundary and tidal periodic fluctuation at the seaward boundary which can be represented as the superposition of several sinusoidal waves with different amplitudes and frequencies. The analytical solution in the form of Fourier series is derived based on the method of separation of variables, and then an effective method based on matrix pencil method (Hua and Sarkar, 1990) and linear least squares is developed from analyzing the tide-induced well-water-level data at the inland observation well to determine the coastal karst aquifer parameters (hydraulic transmissivity, storage coefficient) as well as the tidal characteristics (amplitudes, frequencies). Some parameter values are adopted to generate the observed data in the hypothetical case based on the analytical solution, and then the synthetic observed data is analyzed to demonstrate the usefulness and limitation of the proposed method.
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*Speaker

Carbonate Reservoir Fields: karst features recognition and modeling

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Karst features, formed in a very wide range of different contexts and mechanisms from subaerial exposure at and below unconformity surfaces to the burial environment, strongly affect, in different way, giant oil/gas fields of Eni portfolio. We can mention Carboniferous oil fields in the Pre-Caspian Basin, Cretaceous Middle East oil fields, Cretaceous gas fields in the Mediterranean offshore, Eocene gas field in the Venezuelan offshore and Cretaceous oil fields in the on-shore of Southern Italy.
Karst features represent, for some aspects, a problem in the oil/gas industry, because they jeopardize the safe drilling of the wells with sudden huge mud losses, but can also represent an opportunity as they drastically increase the reservoir characteristics. However, the estimation of the vertical and horizontal extension of these features and their impact on storage and flow capacity of the reservoirs is very uncertain. In fact, the direct observation and understanding of these features, relies mainly on few cored intervals to be extended/extrapolated, at field scale, based on the calibrated interpretation of the Image Logs. Seismic attributes 3D volumes, like Continuity/Coherency, can be very useful to guess the spatial variation/intensity/presence of these events. However, seismic attributes are strongly affected by their resolution generally able to recognize only very large-scale features.

For these reasons, the modeling of karst-affected carbonate reservoirs represents a very challenging task for reservoir geologists. Quarry outcrops, analogues of oil field, can be utilized for a better understanding of the distribution of small-to-middle scale karst features and get insights about their spatial distribution then used for the creation of small-scale 3D synthetic models.

However, the 3D reservoir geological models used in oil & gas industry have to comply with a minimized cells number to make the CPU time of the following numerical simulations feasible. Therefore, cell dimensions are bound to be quite large, especially in giant fields, where they generally range from 100 to 200 meters in XY directions, making the upscaling of karst properties an additional difficult task. To face this issue, different methods for the proper description of the dynamic behavior of karst features can be considered, from the usual approaches to the "Stokes-Brinkman" approach able to describe free-flow and flow in porous media using a single equation.

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Keywords: karst, oil/gas fields

LiDar Scanning on Notches in Karst Towers in Kinta Valley, West Malaysia

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Karst notches are often found in coastal karst environments and have been used widely as indicators of sea-level changes and tide behavior. A number of cliffs on tower karst in Kinta Valley, Peninsular Malaysia have preserved the terrestrial version of this geomorphological feature. These features are believed to be formed by dissolution of the cliffs by pond waters located at the foothills, often in dolines. The aim of this study is to measure the height of these multi-level notches and examine their morphologies. Terrestrial LiDAR (TLS) has been used to accurately measure the height and depth of these indentations. Profiles of these notches between 43.3 m above mean sea level (present ground level) to 73 m show a combination of shallow and deep cuttings with depths range from 0.6 m to 7.0 m. Many of the original notches have been modified or eliminated by dissolution or rock collapse. However, the remaining notches are helpful indicators of previous ground levels and comparison with coastal notch models shows the possible process of fluctuations of the pond levels during their formation.

Keywords: LiDar, tropical karst

*Speaker

Carbon Sequestration in Epikarst based on Hydrocherm-discharge methods: Case study of Kakap Springs, Gunungsewu Karst, Indonesia

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Kakap spring is one of the important springs in Eastern parst of Gunungsewu karst. This study aim to determine the carbon sequestration and carbon temporal variation in epikarst. The study used three parameters , i.e. alkalinity, specific conductivity (SPC) and discharge of Kakap Spring. Titration in the field was performed to measure HCO3- and Ca2+. The study was conducted by monitoring the (SPC) and water level for 1 year in 30 minutes interval basis. The result reveals that Kakap Spring varies in carbon sequestration. Carbon sequestration recorded at 42.57 – 105,325.14 mg/s with the average 19,461.79 mg/s. This varies of Carbon squestration depend on seasonal variation. Carbon sequestration in wet season influenced by discharge. Whereas in dry season es affected by the vegetation carbon uptake activity.

Keywords: Carbon Sequestration, Epikarst, Hydrocherm, discharge methods

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Transportion of suspended particles and heavy metal ions in karst groundwater during rainstorm events: a study of Yaji Spring, SouthChina

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karst aquifer has special hydrodynamic and hydrochemical properties, which has important influence on the transport of particulates and heavy metals in groundwater. The S31 spring was sampled at short time intervals through periods of storm discharge, we studied the source of suspended particles in water and the transport process, discussed the dynamic process and its effect on metal elements.
The results show that the particles in the karst underground river have two main sources: surface source and underground source.In karst peak cluster depression area, The particles of spring are derived from surface carrying by the overland flow of karst peaks (mainly in fine - medium grain, high proportion and long duration), or form the overland flow of depressions (the main source of coarse grains, smaller proportion, earliest discharge and short tail) or from the sediments resuspension in the karst conduit and fissure (mainly fine grained, with the highest proportion and duration).

The breakthrough curve of S31 spring is divided into four different phases, with different sources of particulate matter: overland flow of depression with coarse particle - overland flow of karst peaks –transition section - groundwater matrix flow with mainly fine particles.

Metal concentrations track with larger particles (such as 10 um, 20 um particulate matter) which is mainly from surface suggesting that the metal transport is mainly by adsorption onto larger suspended particulates which are mobilized during storm flow.
The rainfall is an important condition for the transport of particles, and the larger particles ($>$ 5um) are affected obviously by hydrodynamic, which maybe from the surface. The smaller particles ($<$ 5um) are not significantly affected by hydrodynamic, and are from karst fissures and have weak relationship with heavy metals.

Keywords: karst spring, suspended particles, heavy metal ionsrainstorm events

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Dissolution process: when does the process start?

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Dissolution process is important for the development of carbonate reservoirs that are important for storage water and hydrocarbons, fundamental resources for the economy of our planet. Dissolution process is a complex phenomenon governed by several factors as like lithology, porosity, stress orientation, environmental conditions, pre-existing network of fractures. Traditionally, in the field on karstology (Forti, 2007), water circulation is commonly thought to be related to extensional structures (as faults and joints) assuming that these features are more favorable to water circulation. In fact the fault zone have a high permeability only in the early stages of the movement but shortly the process of recrystallization and reprecipitation reduce the permeability greatly within them. In this context, features formed in a compressional setting have never been taken into consideration thinking that in compressional structures is not possible any circulation of water and that therefore there is no fluid-rock interaction. Instead the few studies(Alsharhan & Sadd 2000) on this topic are showing the opposite. The focus of the research is to investigate the starting point of the dissolution and the micro mechanisms that lead to the formation of the caves. The research is focused on understanding when a structure reduce or enhance porosity/permeability. Then the research follows two different paths: 1. Macroscopical analysis 2. Microscopical analysis. The macroscopic analyzes consist of a structural geological reconstruction carring out in a karst area in South Italy. A detailed study of the relationships between tectonic and dissolution was conducted. In addition to this we have carried on chemical and petrographic analysis using SEM, FTIR, and XRD. These analyzes are helping us to carachterize the porosity and permeability near these structures. Despite to the common thought, where there is a presence of clay minerals, the dissolution/precipitation process can begin.Interesting early correlations between tectonic structures, mineralogy and dissolution have been founded. We present the first results of the field and chemical/petrographic analysis carried out. Recently, fluid-rock interactions and their impact on carbonate rocks is becoming very important as a consequence of a progressive deterioration of the quantity and quality of the groundwater

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Keywords: dissolution, clay minerals, stylolite

*Speaker

GIS based applied regulatory approach for covered karst aquifer management; a cases from west of Iran

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In Iran, a rapidly growing rate of drilling of deep water wells has been witnessed during the last two decades. Water extracted via these wells is mainly consumed for agricultural purposes. This process has put an enormous pressure on the alluvial groundwater resources, which as a result, these resources can no longer provide enough water for defined purposes. Deepening water wells into covered karst aquifers was, then, taken into action. Regardless the fact that exploitation from karst aquifers is only allowed for supplying water for drinking purposes, illegal karst water extraction have been acted upon by a considerable number of farmers and other water-demanding industries. In Iran, lack of proper legislation to stop illegal groundwater extractors is the main reason why these resources have been severely depleted during the last few decades. Absence of proper monitoring infrastructures is another reason fueling uncontrolled karst water exploitation. This study has aimed at proposing an applicable procedure by which it could be possible to reveal zones of covered karst aquifers that are highly endangered by uncontrolled water exploitation. To achieve the main goal of this research, various hydrology and hydrogeology methods have been used. Islam Abad, Zahab, Kangavar (all in Kermanshah province), and Razan-Kabudar Ahang (in Hamadan province) plains were evaluated and compared. Results shows that wherever a greater number of extraction wells have penetrated into covered karst formations, utilizing water from those wells were enhanced and discharge rates of neighbor springs, on the contrary, were dramatically decreased or in some cases it caused completely drain out of the springs. In sever conditions, sinkhole incidents may occur. The method introduced and followed in this study has been presented for the first time by the authors of this article, and it can be used as a practical tool in order to control drillings within covered karst areas and to effectively manage and retain sustainable karst water supplement for allowed usages.

Keywords: Covered karst, GIS, over, exploitation, karst aquifer management, Iran

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New insights into the Cosquer art cave hydrogeological functionning (France)

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Key words : Art cave, conservation, overpressure, monitoring

The Cosquer cave supports and protects some paleolithic paintings and engravings, dated to more than 31,000 years (Cal BP, Valladas et al. 2016). It's a coastal cave, located in the Calanques massif, near Marseille in south of France. This area is well-known for its karstic landscape, in the white urgonian limestones (Barremian, early cretaceous). Nowadays, the cave has no water-free entrance. The only way to access to the cave is to dive to a submarine entrance giving access to a karst conduit connected with the non-flooded part of the cave (Figure 1). During paleolithic times, the seawater level was lower (down to 135 m). The access to the cave to the paleolithic men was flooded by the Mediterranean Sea rise around 10,000 years (Cal BP, Lambeck & Bard 2000). This specific location of the cave offered a protected area for the conservation of the rock art: no man entrance during the historical time, climatic and environmental steady conditions. Moreover, the karst also protected the rock art because it limited the sea-level rise within the cave. Indeed, the water level inside the Cosquer cave is lower than the sea-level, although only a tens of meters of limestones separate the cave to the sea. Obviously, the cave is a confined environment and is an interesting case-study to understand the impact of permeability contrasts between open karst features and the surrounding matrix. The aims of this work are: (1) to present a first long pressure time series ever recorded in the Cosquer cave, (2) to show which phenomena control the water level variation inside the cave, in order to answer to the following questions: when, how high and why the water level varies in the cave?

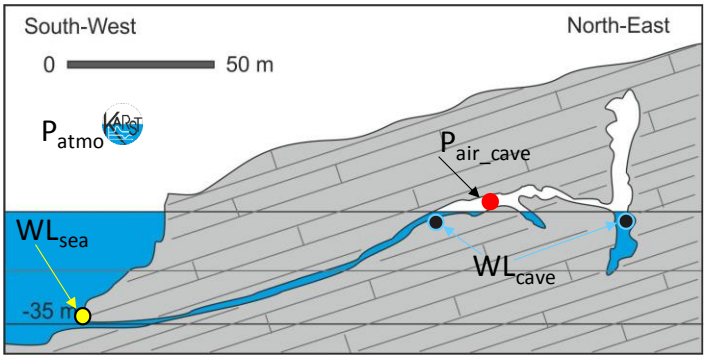

Figure 1 : Schematic cross-section of the Cosquer cave, in the Calanques National Park, Marseille, France. Automatic pressure sensors have been installed: (1) in the sea in front of the submarine entrance (WL_{sea}), (2) inside the cave in two pools (WL_{cave}) and in the air (P_{air_cave}), (3) in the air outside the cave (P_{atmo}) at the Port-Miou observatory (SNO Karst) located 5 km eastward from the cave.

This unexpected low water level in the cave was shown since the first pressure measurements following the discovery (Vouvé et al. 1996). The air pressure in the cave is higher than the atmospheric pressure outside the cave. This air overpressure pushes down the water level and

avoids the water to rise on paintings and engravings located close to the sea-level, e.g. the horse panel. The air overpressure changes over the year and influences the art conservation. However, few measurements have been done to study this phenomenon. In 2014, on request of the regional agency of cultural affairs in charge of the study and conservation of the Cosquer cave (DRAC PACA, France), the CEREGE laboratory started a new scientific survey of the hydrogeological functionning of the cave. Pressure sensors have been installed in-situ, with a 5 minutes time-step recording, inside the cave in the air and in the water, in the sea, and in the air outside the cave (Figure 1). Pressure is converted to fresh or salted water column. We also beneficiated from the measurements done at the Port-Miou observatory (SNO Karst) located 5 km eastward from the cave, that gives access to pressure data and that can be used as reference for the hydrological states of the karst aquifers in the area (Arfib & Charlier 2016).

Figure 2: The water level inside the Cosquer cave at three hydrologic periods: a) 04/10/2014, the water level is low, the air pressure inside the cave is high; b) 24/08/2017, the water level is high, the bottom of the horses' panel is flooded; c) 27/09/2017, the water level is very high, the air pressure in the cave decreased close to the outside atmospheric pressure.

The three years of data show that the cave air pressure is always higher than the normal atmospheric pressure. The air overpressure ranges between a few centimeters to 1.2 m. Water level in the cave is the same in the several pools. It varies at the annual scale up to 1.2m, correlated with the air overpressure variations. Taking the horses' panel as a reference art rock in the cave, the paintings are usually out of water (Figure 2a), but can be partially flooded from 1 to 3 months depending on the year, during summer and early autumn (Figure 2b,c). Water level (or air pressure) varies at several scales. Daily, the sea tide is transferred within the coastal cave, but the water level variation is limited by the cave air volume. This clearly confirms that the cave behaves as a confined medium. At the annual scale, short events have a very high impact, decreasing the water level in the cave to more than 1 meter in a few hours. In this case, the water level decrease is mainly due to an equivalent increase of air overpressure. We showed that these events are generated by waves outside the cave. Waves can transfer air through the limestone massif by karst or cracks usually flooded. When flooded the submarine karst path are limited to water transfer and the cave remains confined. The karst massif can be conceptualized with a vadose zone with very low permeability, and a saturated zone below the mean sea-level where karst network is open (Figure 3). Karst network geometry should be special and connected with the waves properties in order to allow the air to flow only in one way from the sea to the cave. As a first step of the further work still needed, we showed that the overpressure events are linked with direction and height of the waves.

This study shows that karst environment plays an essential role in the conservation of our archeological natural heritage. Permeability in a karst massif can be highly heterogeneous at various scales; we show that even at the scale of a karst cave the permeability could be contrasted, e.g. very low in the vadose zone and high in the saturated zone in the Cosquer cave.

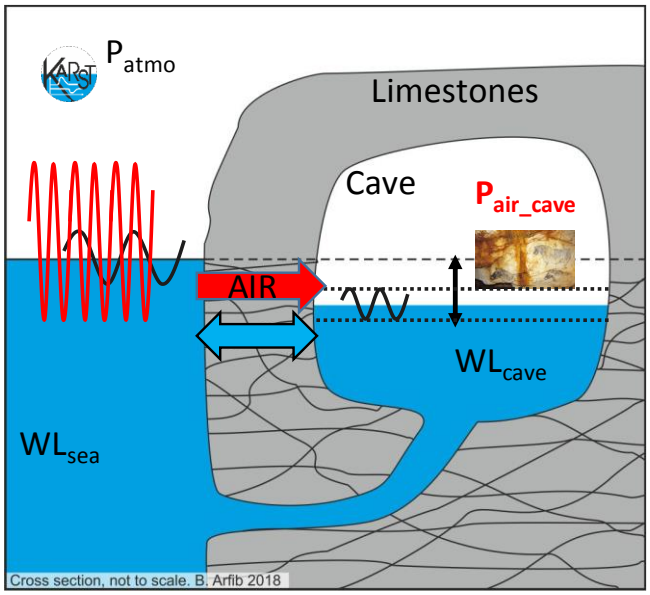

Figure 3: Conceptual cross-section of the Cosquer karst functionning. The cave is partly confined. Tide variations propagate inside the cave but are lower than the sea-tide (black curve). Specific waves height and direction (red curve) inject air inside the cave and generate an air overpressure that decreases the water level inside the cave.

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Acknowledgements :

This work has been possible thanks to the partnership between the DRAC – SRA (Service Régional de l'Archéologie, France) and the laboratory CEREGE. The authors would like to thank: (1) Mr. Xavier Delestre (SRA) for his support in this study, (2) Mr. Claude Vella and Mr. Pierre Rochette (CEREGE) for their help on the field, (3) the Immadras team, Mr. Eric Lesomptier the ship captain, and the divers Anne Delhomme and Fabrice Dudenhofer.

This work beneficiated of data recorded in the Port-Miou observation site, part of the KARST observatory network (www.sokarst.org) initiative from the INSU/CNRS, which aims to strengthen knowledge-sharing and promote cross-disciplinary research on karst systems.

Far and deep into the brackish groundwater of coastal karst: crossing CTD time series monitoring in submarine spring and during cave diving exploration (Port-Miou and Bestouan - SE France)

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Key words : coastal karst, saline intrusion, water resources, in-situ observation, cave diving

Extended abstract

Mediterranean coastal karsts are known to exist below the current sea level. They were initiated or enlarged when the sea level was lower, mainly during the quaternary, pliocene or messinian periods. Indeed, the sea acts as a boundary condition in the aquifer, imposing a base level that forces the groundwater to: 1) flow deeper during recession times, or 2) find a new outlet at a higher elevation during transgression when the sea level rises. The karst network is now submerged, and the Mediterranean coastal karst aquifers discharge usually in point source in springs close to the sea level. Moreover, coastal karstic aquifers are encroached by saline intrusion. Saline intrusion has the shape of a saltwater wedge, locally modified by preferential flow in karst conduits.
Submarine karst conduits open to the sea are connected in a network of pipes where fresh or brackish or seawater can flow. These preferential groundwater flows can discharge from inland to the sea, or from the sea to the continent. This latter flow direction has been described in several case studies: Croatia (Bonacci 1997), Greece in Kefalonia (Drogue 1989), Spain in Moraig-Toaix (Fleury et al. 2007b), or in Florida peninsula (Xu et al. 2016), but the usual observation is submarine groundwater discharge (SGD) to the sea (Fleury et al. 2007a).
SGD to the sea at springs is usually brackish, with a varying salinity correlated to the groundwater flow rate. The brackish water comes from a mixing between the fresh groundwater recharged in the catchment area, and the seawater intruded at depth within the aquifer (called hereafter salt groundwater). The karst conduits allowing preferential flows play a major role in the saline intrusion mechanism. The deep salt groundwater that mixes with the fresh groundwater can flow by two ways (Figure 1): i) the main karst conduit connected to the submarine spring cross the saline intrusion wedge, and then diffuse flow from the matrix (salt groundwater) to the conduit (initially fresh groundwater) occurs (Figure 1a), or ii) the salt groundwater flows through karst conduits connected with the fresh groundwater karst network (Figure 1b). These two conceptual model of salt and fresh groundwater mixing are still very difficult to observe since in-situ data are often limited to well observation, that are not necessarily representative of the aquifer behavior in karstic environment. In situ measurements at spring are usually the only observation available. In order to go insight into the saline intrusion observation in karst aquifer, we decided to record salinity, temperature and depth (CTD) time series during cave diving exploration in large, long and deep karst conduit. Indeed, when karst conduits connected to a submarine spring are large enough to be explored by cave divers, the in-situ CTD time series recorded at the spring over time can be compared to the spatial variation of saline intrusion within the conduit. It's also a way to explore the places where salt and fresh water mix inland within the aquifer (see the two conceptual models in Figure 1).

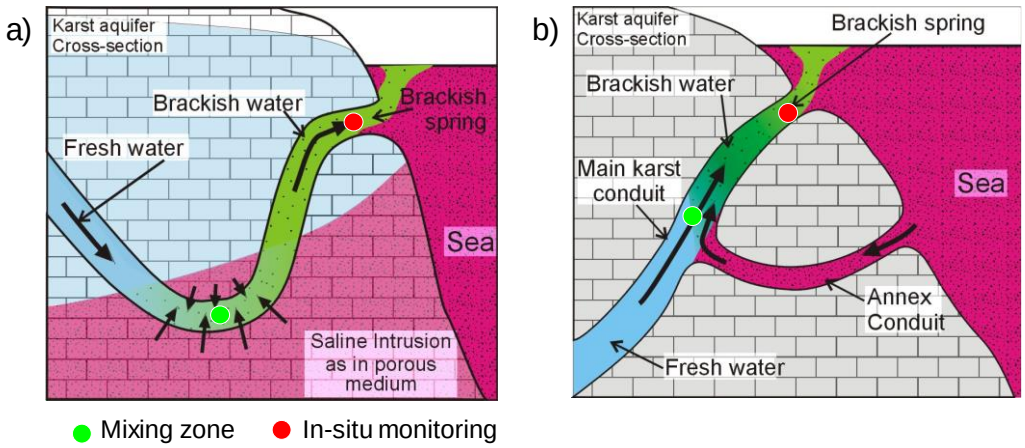

Figure 1: Conceptual cross-section of a coastal karst aquifer. a) Saline intrusion as in porous medium, with a saltwater wedge crossed by a karst conduit connected to the submarine spring. b) Saline intrusion by seawater preferential flow path in the karst conduit ("annex conduit") connected to the main karst conduit discharging at the submarine brackish spring.

The case study proposed is located in south-east of France, near Marseille (Figure 2 & 3). It's the Port-Miou regional aquifer, draining a large part of the Low Provence, and discharging to the sea in two main karstic submarine springs: Port-Miou and Bestouan. This case study is included in the French network of observation of karst (SNO Karst). The two submarine springs have been explored by cave divers and are each connected to a large karst conduit: 2000m long for Port-Miou and 2500m long for Bestouan (Arfib et Douchet, 2011). During several dives, cave divers transported a CTD probe, giving access to the observation of the mixing between fresh and salt groundwater. Moreover, two very deep dives in the Port-Miou karst, at -233m below the sea level, gave the in-situ observation of the saline intrusion in depth. To our knowledge, this kind of in-situ deep observation in the karst network has never been done until now.

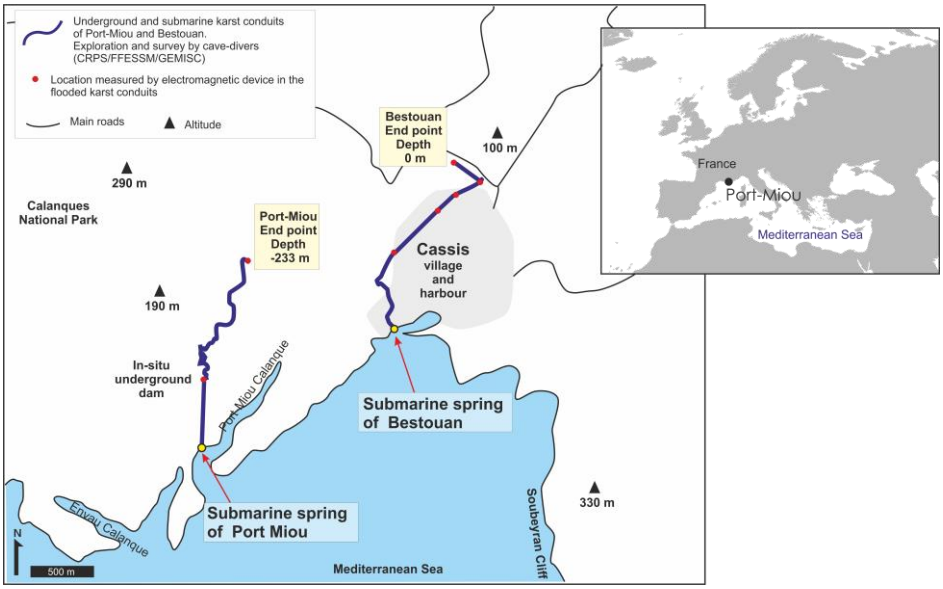

Figure 2: Location of the Bestouan and Port-Miou submarine karst conduits explored by cave-divers in the Port-Miou coastal aquifer (Cassis, France), from the springs up to 2000 m inland.

These results are compared with the CTD time series recorded at the Port-Miou underground laboratory (Figure 3), located 500 m inland from the submarine spring (Arfib and Charlier

2016). So we have a data base of two in-situ time series, that we will call hereafter: cave diver CTD measurements (spatial variation along the karst conduit), and spring CTD measurements (time variation in one point of observation, at the underground laboratory). Spring CTD measurements show that for each flood (related to rainfall in the recharge area), discharge and salinity variations are correlated, with a variable time lag, that draws a hysteresis plot on discharge VS salinity scatter plot. This time lag is a typical piston effect, i.e. the flush of the brackish pre-event water stored in the karst conduit and moving from inland to the sea. It constitutes a volume around 1.10^6 m^3, confirmed by the data recorded during the cave diving. We show that the seawater intrusion occurs upstream the 2000 m long karst conduit explored from the Port-Miou submarine spring. The salt and fresh groundwater mixing in depth generates a brackish groundwater flow in the aquifer over several kilometers, flowing in the main karst conduit connected to the spring. The original new observations in depth show that the brackish water is still present at the deepest point reached, at -233m below the sea level.
This work shows that preferential deep flow in karst conduit exists below the current sea level down to several hundreds meters deep that may impact the groundwater salinity. Groundwater resources in coastal zones are then restricted in the sea-shore and inland in the deep part of the aquifer. A CTD in-situ monitoring of submarine springs can help to forecast the saline intrusion.

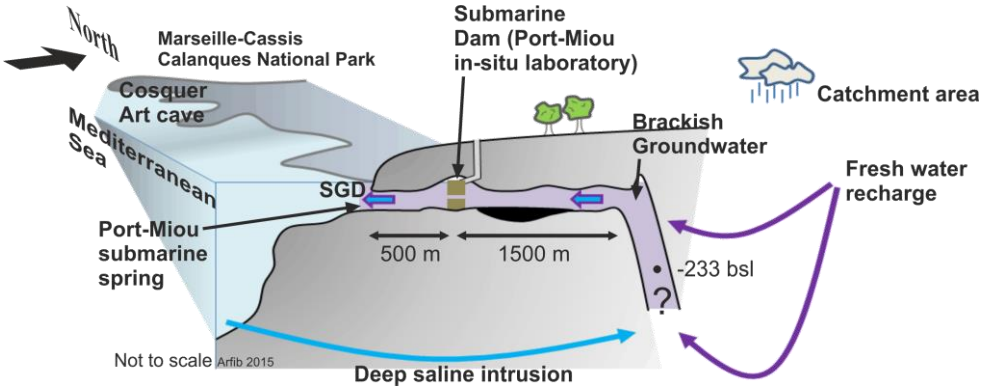

Figure 3: Schematic 3D view around the Port-Miou karst conduit

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Acknowledgements : This work was performed within the framework of the Port-Miou observation site, part of the KARST observatory network (www.sokarst.org) initiative from the INSU/CNRS, which aims to strengthen knowledge-sharing and promote cross-disciplinary research on karst systems. We also thank the Conservatoire du Littoral, the Calanques National Park and the Cassis city for the access authorization to the Port-Miou in-situ underground laboratory.

Crédit photos : Stéphan GIRARD

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Eurokarst is the European bi-annual conference on the Hydrogeology of Karst and Carbonate Reservoirs. The 2018 edition will be organized in Besançon, France, from 2 to 6 July, in the historic buildings of “Espace Grammont” in the town center of Besançon.

The annual assembly of the Karst Commission of the International Association of Hydrogeology will as in 2016 be held during the Eurokarst conference.