

**KG@B 2015**  
**International Conference on**  
**Groundwater in Karst**  
**20 - 26 June 2015**  
**University of Birmingham**  
*John Gunn and Ian Fairchild, convenors*



**PROGRAMME & ABSTRACTS**

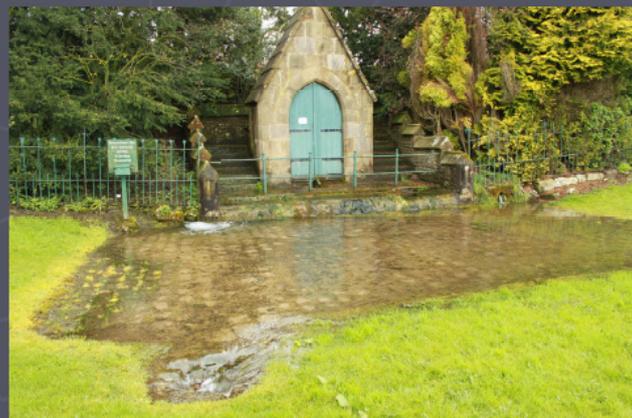


**UNIVERSITY OF BIRMINGHAM**



**British Geological Survey**

NATURAL ENVIRONMENT RESEARCH COUNCIL



## CONTENTS

	PAGE
<b>Foreword and Acknowledgements</b>	<b>2</b>
<b>International Scientific Committee</b>	<b>4</b>
<b>Conference Programme</b>	<b>5</b>
<b>Abstracts of Oral Presentations listed alphabetically by presenting author (first author is presenting author unless shown otherwise)</b>	<b>10</b>
<b>Abstracts of Poster Presentations listed alphabetically by presenting author (first author is presenting author unless shown otherwise)</b>	<b>70</b>

### COVER DETAILS

Map of British carbonate karst environments (prepared by Tony Waltham)

Bottom left: Bogg Hall Rising, a large spring discharging from Jurassic carbonates in Yorkshire. The flooded conduit beyond has been dived to a depth of 18m and part of the flow is thought to be from a stream that sinks some 1500m away (photo by Steve Worthington; for more information and a survey see [http://ukcaving.com/wiki/index.php?title=Bogg\\_Hall\\_Cave](http://ukcaving.com/wiki/index.php?title=Bogg_Hall_Cave)).

Bottom right: "Brindley's Well", an ephemeral spring in the centre of Wormhill hamlet, that is fed by water perched on the Lower Miller's Dale Lava, one of two significant lava beds in the Carboniferous limestones of north Derbyshire. The well has a memorial to James Brindley, a nationally famous engineer and designer of canals, who was born nearby. (photo by John Gunn)

## **Foreword and Acknowledgements**

Carbonate rocks present a particular challenge to hydrogeologists as the major groundwater flux is through an integrated network of dissolutionally enlarged channels that discharge via discrete springs. The channels span a very wide aperture range: the smallest are little more than micro-fractures or pathways through the rock matrix but at the other end of the spectrum (and commonly in the same rock mass) channels may grow to dimensions where they can be explored by humans and are called caves. Groundwater transmission through the smaller channels that are commonly intersected by boreholes is very slow and has often been analysed using equivalent porous media models although the limitations of such models are increasingly recognised. At the other end of the spectrum (and commonly in the same rock mass) flow through the larger conduits is analogous to ‘a surface stream with a roof’ and may be amenable to analysis by models devised for urban pipe networks. Regrettably, hydrogeologists have too often focussed on the extreme ends of the spectrum, with those carbonates possessing large and spectacular landforms regarded as “karst” whereas carbonates with little surface expression commonly, but incorrectly labelled as “non-karstic”. This can lead to failures in resource management.

Britain is remarkable for the variety of carbonate rocks that crop out in a small geographical area. They range in age and type from Quaternary freshwater carbonates, through Cenozoic, Mesozoic and Paleozoic limestones and dolostones, to Proterozoic metacarbonates. All near surface British carbonates are soluble and groundwater is commonly discharged from them at springs fed by dissolutionally enlarged conduits, thereby meeting one internationally accepted definition of karst. Hence, it is very appropriate that Britain, and Birmingham as Britain's second largest city, hosts this International Conference on Groundwater in Karst. The meeting will consider the full range of carbonate groundwater systems and will also have an interdisciplinary approach to understanding karst in its fullest sense.

The conference has been structured around four key themes:

### **1. Lithological, structural & stratigraphical influences on karst groundwaters**

Karst is a special environment in which the major groundwater flux is through an integrated network of dissolutionally enlarged channels that discharge via discrete springs. The channels span a very wide aperture range; the smallest are little more than micro-fractures or pathways through the rock matrix but at the other end of the spectrum (and commonly in the same rock mass) channels may grow to dimensions where they can be explored by humans and are called caves. The relationships between matrix, channels and conduits in a carbonate rock mass are a product of recharge and rock lithology, stratigraphy and structure and exploration of these relationships is a key theme of the conference.

### **2. Modelling karst groundwater systems**

Water transfer through the smaller channels that are commonly intersected by boreholes is very slow and has often been analysed using equivalent porous media models although the limitations of such models are increasingly recognised. At the other end of the spectrum (and commonly in the same rock mass) the channels may grow to dimensions where they can be explored by humans (caves) through which water flow is analogous to ‘a surface stream with a roof’ and may be amenable to analysis by models devised for urban pipe networks. The development of holistic and realistic models for water movement and storage in karst is a second key theme of the conference.

### **3. The ecology of karst groundwaters**

The direct, and often rapid connections between surface water and groundwater in karst have given rise to distinctive groundwater ecosystems that have only recently been subject to detailed study and this forms a third theme for the conference. In the past there has been a tendency for those approaching this topic from an ecological background to meet separately from those trained as hydrogeologists and the convenors hope that the conference will allow greater interchange between the two disciplines.

### **4. Human-karst groundwater interactions**

It is well known that karst groundwater systems are of global importance to humans both as direct sources of potable water and as the source of many rivers. Hence, a fourth theme will consider human-karst groundwater interactions, a wide area that includes water resource assessment, groundwater protection, mineral extraction and infrastructure development.

Following receipt of abstracts it became clear that there was scope for an additional theme on two important techniques used in investigating karst groundwaters:

### **5. Isotopes and water tracing**

In organising the meeting we have been keen to encourage more discussion than is commonly the case at meetings where there is only time for a brief question after each talk. To that end we have allocated only 15 minutes for each speaker (30 minutes for each of the four keynotes) but have followed each block of talks with a 15-minute discussion session during which questions can be addressed to any of the speakers from the session and which will hopefully allow some matters to be discussed in greater detail.

Birmingham enjoys a central location in England and we have been able to arrange single day excursions to each of the countries three main carbonate lithologies. These trips will focus on differences and similarities between and within each area. An afternoon field excursion will visit a fourth carbonate lithology which is notable for a complete absence of mention of any karst features in the published literature. There will also be two specialist workshops on water chemistry and on fluorescence and a workshop to enable karst groundwater ecologists to discuss key questions that face their subject area.

The symposium is sponsored by the International Association of Hydrogeologists through its Karst Commission, the International Speleological Union through its Commission on Karst Hydrogeology and Speleogenesis and the International Geographical Union through its Karst Commission. Within the UK the conference is also sponsored by the British Cave Research Association, the British Geological Survey, the Hydrogeology Group of the Geological Society of London and the IAH GB Chapter.

We are grateful to our colleagues on the International Scientific Committee for their support and particularly to Tim Atkinson, Andy Farrant and Lou Maurice for organising field excursions and to Chris Bradley and Steve Worthington for running Workshops. Thomas Carney, Marian Jordan, Kate Newton and Jamie Peart of the University of Birmingham are thanked for providing administrative support.

John Gunn and Ian Fairchild (convenors)

## **International Scientific Committee**

- Bartolome Andreo (University of Malaga, Spain)
- Tim Atkinson (University College London)
- Augusto Auler (Brazilian Karst Research Institute)
- Chris Bradley (University of Birmingham)
- Andy Farrant (British Geological Survey)
- Derek Ford (McMaster University, Canada)
- Paul Hardwick (RPS Planning & Development, UK)
- Andreas Hartmann (University of Freiburg, Germany)
- Nico Goldscheider (Karlsruhe Institute of Technology, Germany)
- Jiang Guanghui (Institute of Karst Geology, Guilin, China)
- Pierre-Yves Jeannin (SISKA, Swiss Institute for Speleology and Karstology)
- Neven Kresic (AMEC Environment and Infrastructure, Inc., United States)
- Alexander Klimchouk (Ukrainian Institute of Speleology and Karstology)
- Lou Maurice (British Geological Survey)
- Simon Neale (Natural Resources Wales, UK)
- Art Palmer (State University of New York, United States)
- Anne Robertson (University of Roehampton, UK)
- Geary Schindel (Edwards Aquifer Authority, United States)
- Rob Ward (British Geological Survey, UK)
- Paul Williams (University of Auckland, New Zealand)
- Paul Wood (Loughborough University, UK)
- Steve Worthington (Worthington Groundwater, Canada)

**Draft Programme (as of 3rd June 2015)**  
(subject to change as some speakers have not yet obtained a travel visa)

**Saturday June 20<sup>th</sup> 09:00-17:00.**

Workshop for consultants and professionals: *Groundwater in Carbonate Rocks*

**Sunday June 21<sup>st</sup>**

08:15 - 20:30: Fieldtrip: *Groundwater in Cretaceous Carbonates*

16:00 - 21:00: Registration and (from 18:30) Welcome Reception

**Monday June 22<sup>nd</sup> 08:30 - 19:30 Avon Lounge & Lecture Theatre, University Centre**

08:30 - 09:00: Registration

**09:00 - 10:45: SESSION CHAIR - PROFESSOR IAN FAIRCHILD**

09:00 - 09:10: Welcome from University and IAH

09:10 - 09:30: Prof John Gunn: *British carbonate karst environments*

**Conference theme 1: Lithological, structural & stratigraphical influences on karst groundwaters**

09:30 - 10:00: *Keynote Lecture by Dr Pierre-Yves Jeannin*

10:00 - 10:45

Farrant, A.R.	Stressed out: determining preferential flow pathways in karstic aquifers from cave survey data
Auler, A.S.	Paragenetic initiation and later overprint in cave passages: a review from Brazil
Klimchouk, A.	Functional organization and lithostratigraphic control of a large hypogene cave system in the Precambrian carbonates, NE Brazil

10:45 - 11:15 Refreshment break in the lounge outside the lecture theatre

**11:15 - 13:10 : SESSION CHAIR - DR IRA SASOWSKY**

11:15 - 12:45

Gautrey, S.J.,	Relative importance of lithologic, stratigraphic and structural controls of karst conduit development at the Victor Diamond Mine, James Bay Lowlands, Ontario, Canada
Hunt, B.B.	Influence of faulting and relay ramp structures on groundwater flow in the Karstic Edwards and Trinity Aquifers, Central Texas, USA
Myroie J.E.	Fresh-Water Lens Dissolution: The Lack of Strong Lithologic and Structural Control in a Laminar and Transitional Flow System
Palmer, A.N.	Duration and Significance of Vadose Perching in Karst: Mammoth Cave Region, USA
Petrus, K	Influence of layering on the formation and growth of dissolution pipes in karst systems
Raeisi, E.	Parameters controlling the general groundwater flow of the carbonate karst aquifers in the Zagros Simply Folded Belt

12:45 - 13:10 Questions for morning session authors and discussion on Theme 1

13:10 - 14:00 Buffet lunch in lounge outside the lecture theatre

## 14:00 - 16:00 : SESSION CHAIR - DR CHRIS BRADLEY

### Conference theme 2: Modelling Karst Groundwater Systems

14:00 - 14:30: *Keynote Lecture by Dr Andreas Hartmann:*

*Modelling karst hydrology - a balance of available information and model complexity*

14:30 - 15:45

Kordilla, J.	Approaches for modelling of flow and transport in unsaturated fractured aquifers - from catchment to pore scale
Kovacs, A.	What can we learn from hydrograph analysis? Theory and examples
Dewaide, L.	Double-peaked breakthrough curves: from field data to laboratory analogue tests. A study case in the Dinant area (South of Belgium)
Dubois, C.	Hydrogeological modelling and upscaling of weathered karst aquifer by a distributed porosity approach
Johannet, A.	Neural networks modelling for long-term prediction of Albarine river discharge for various scenarios of global change (Ain basis - southern France)

15:45 - 16:00 Questions for authors and discussion on Theme 2

16:00 - 16:30 Refreshment break in lounge outside the lecture theatre

## 16:30 - 18:15 : SESSION CHAIR - DR STEVE WORTHINGTON

16:30 - 18:00

McCormack, T.	Quantification of submarine/intertidal groundwater discharge from a lowland karst catchment
Streetly, H.R.	A water resource management tool for the Cotswolds Oolitic Limestone aquifers: Using the EA's MODFLOW/4R approach to regional groundwater modelling in a complex karstic system
Oehlmann, S.	Reducing the ambiguity of karst aquifer models by pattern matching of flow and transport on catchment scale
Zhdanov, S.V.	Thermodynamic and kinetic modelling groundwater - carbonate rocks interactions for karst terrain Izhora plateau, Russian Federation
Giese, M.	Significance of parameters and processes for the evaluation of large scale tests in karst aquifers with numerical hybrid models
Reimann, T.	Determination of controlling parameters for hydrodynamic and physicochemical signatures of karst aquifers by distributed parameter hybrid models

18:00 - 18:15 Questions for authors and discussion on Theme 2

**18:30 - 19:30 Business Meeting of IAH Karst Commission in the Avon Lounge**

**Tuesday June 23<sup>rd</sup> 09:00 - 14:00 Avon Lounge & Lecture Theatre, University Centre**

## 09:00 - 10:30 : SESSION CHAIR - PROFESSOR NICO GOLDSCHIEDER

### Conference theme 2: Modelling Karst Groundwater Systems

09:00 - 10:15

Andreo, B.	Monitoring natural responses of karst springs water to characterize the hydrogeological functioning of Sierra de Jarastepar-Alto del Conio aquifer (S. Spain)
Fiorillo, F.	Long-term trend and fluctuations of karst spring discharge in central-southern Italy
Gill, L.W.	Use of stable isotopes to characterise the hydrogeology of a lowland karst aquifer
Malik, P.	Recession curve analysis and water temperature vs. discharge relationship of karstic springs on the northern rim of the Silicka Planina Plateau (Slovakia)
Paiva, I.	The characterization of karst hydrological functioning based on spring responses analysis

10:15 - 10:30 Questions for authors and concluding discussion on Theme 2

10:30 - 11:00 Refreshment break outside the lecture theatre

## 11:00 - 13:10 : SESSION CHAIR - PROFESSOR JOHN GUNN

### Conference theme 3: The ecology of karst groundwaters

11:00 - 11:30 *Keynote Lecture by Prof Dr Christian Griebler*

*Key drivers and major limitations of microbial growth and carbon cycling in natural and stressed groundwater ecosystems*

11:30 - 12:45

Di Lorenzo, T	Is metabolism a key factor in determining groundwater copepod sensitivity to pollutants?
Galassi, D.M.P	Monitoring karstic springs: the role of groundwater meiofauna as indicators of aquifer hydrodynamics
Malard, F.	Multi-causality & spatial non-stationarity in the determinants of groundwater biodiversity patterns in Europe
Maurice, L.	The invertebrate ecology of Chalk groundwaters
Weitowitz, D.C.	Towards a new typology of subterranean habitats: Defining geohabitats for groundwater ecosystem investigations

12:45 - 12:55 Questions for authors and discussion on Theme 3

12:55 - 13:10 Posters (each presenter will have a 2-minute slot to introduce their paper and the posters will be displayed outside the lecture theatre in the lunch area)

Cifoni, M.,	A protocol for a development, reproduction and population growth test with freshwater copepods
Fiasca, B.,	The EC-AQUALIFE Project in Italy: state of the art and future prospects
Knight, L.R.F.D	The aquatic invertebrate fauna of the Ogof Draenen cave system in South Wales
Knight, L.R.F.D.	Auto-ecological studies on <i>Niphargus glenniei</i> (Spooner, 1952) and <i>Niphargus aquilex</i> (Schiodte, 1855)
Robertson, A.L.	Groundwater flooding: Responses of groundwater ecosystems to an extreme recharge event.
Stubbington, R.	Density and richness estimates of invertebrates at the surface water - groundwater interface reflect the pump sampling method used
Wood, P.	Groundwater and macroinvertebrate recovery on the River Lathkill (Derbyshire) following supra-seasonal drought

13:10 - 14:00 Buffet lunch and poster viewing outside the lecture theatre

**Tuesday June 23<sup>rd</sup> 14:00 - 17:30**

Free-time or one of:

- Workshop on modelling carbonate chemistry (pre-booking required; meet Ian Fairchild in Avon lounge at 13:55)
- Workshop on groundwater fluorescence (pre-booking required, meet Chris Bradley in Avon lounge at 13:55)
- Workshop on carbonate groundwater ecology (meet Paul Wood in Avon lounge at 13:55)
- Field excursion to historic underground limestone quarry workings and canals near Dudley (pre-booked participants, departs 2 p.m. sharp from East Entrance - see separate joining instructions)

**Tuesday June 23<sup>rd</sup> 19:00 for 19.30 dinner**

Conference dinner, Noble Room, 3<sup>rd</sup> floor Staff House,

with illustrated after-dinner talk by **Professor Derek Ford:**

*Karst and karst aquifers in the Northwest Territories of Canada: A Review.*

**09:00 - 10:45 : SESSION CHAIR - DR AUGUSTO AULER**

**Conference theme 4: Human-Karst Groundwater Interactions**

09:00 - 09:30 Keynote lecture by Prof Dr Nico Goldscheider

*A holistic perspective of karst systems, their services for humanity, and human impacts on karst*

09:30 - 10:30

Blum, P.	Agriculture impact on nitrate concentrations in karst aquifers in Ireland
Mellander, P.-E.	Groundwater vulnerability assessment of an agricultural karst landscape
Bajtos, P.	Environmental and emergency risks induced by mining in gypsum karst area (spisska Nova Ves, Slovakia)
Cowell, D.W.	Induced karst features in the drawdown zone of an open pit diamond mine in Ontario's James Bay Lowland, Canada

10:30 - 10:45 Questions for authors and discussion on Theme 4

10:45 - 11:15 Refreshment break outside the lecture theatre

**11:15 - 13:10 : SESSION CHAIR - DR ART PALMER**

11:15 - 12:30

Schindel, G.	Strategies for the response to hazardous materials releases in Karst
Buckley, R.	Use of a 'lines of evidence' approach for Source Protection Zone delineation in the Corallian Limestone Aquifer of North Yorkshire
Streetly, M.J.	Use of transient soil moisture balances and simple 1-D stores for investigating and protecting groundwater resources
Cook, S.	Regional groundwater modelling of the Brighton and Worthing Chalk aquifer to both investigate the impacts of groundwater abstraction on surface water flows and to predict and optimise the source reliable output from public water supply source.
David, P.-Y.	Participatory tool to improve knowledge, management and protection of the karstic chalk aquifer system in Eastern Normandy

12:30 - 12:45 Questions for authors and discussion on Theme 4

12:45 - 13:10 Posters (each presenter will have a 2-minute slot to introduce their paper and the posters will be displayed outside the lecture theatre in the lunch area)

Chemseddine, F	Vulnerability of urbanisation in karst areas (Northeast Algeria)
Chemseddine, F	Characterisation of the main Karst aquifers of the Tezbent Plateau, Tebessa Region, Northeast Algeria, based on hydrogeochemical and isotopic data
Coxon, C	Microbial quality of Irish karst springs: implications for management of water supplies
Crow, A	Mapping Groundwater Flooding in the Republic of Ireland
Farr, G	The Great Spring, South Wales UK: updating a Source Protection Zone in a complex karst aquifer
Hartmann, A.	A database to assess impacts of land use and climate change on Europe's karst regions
Herms, I	Isotopic and hydrogeochemical characterization of karst aquifer in the Port del Comte (Lerida, Spain).
Jeannin, P-Y	Assessment of annual resources in Swiss karst aquifers
Jebreen H	Hydrochemistry and effect of karst on spring water in the Soreq catchment, Ramallah, West Bank
Khamis, K	Monitoring water quality using a through-flow fluorescence sensor
Krajnc, B.	Cave air dynamics and drip water geochemistry in Pisani rov-Postojna cave (Slovenia)
Venturieri, E.M.	An applicable model for karst in Gambier limestone in order to improve the water management in Mount Gambier region, southeast South Australia.

13:10 - 14:00 Buffet lunch and poster viewing outside the lecture theatre

## 14:00 - 15:45 SESSION CHAIR - PROFESSOR CATHERINE COXON

14:00 - 15:30

Karami, G.H.	Investigation of presence or lack of hydraulic connection between Emam-Gheise karst spring and water wells of Shahreza, Iran
Jiang, G.	Utilization of rainwater harvesting in bare karst areas for domestic use and ecological restoration
Liu, H.	The response of Heilongtan spring to the 2010-2012 consecutive droughts of Yunnan Province, China
Zhu, Y	Optimization of Groundwater for urban water supply and energy use in karst areas
Schomburgk, S.	Representation of karst units in the Aquifer Reference System of France - BDLISA: challenges of small-scale mapping
Schmidt, S.	Evaluation of rapid recharge processes and spring source vulnerability of karst aquifers in semi-arid environments based on high-resolution monitoring

15:30 - 15:45 Questions for authors and concluding discussion on Theme 4

15:45 - 16:15 Refreshment break outside the lecture theatre

## 16:15 - 18:15 : SESSION CHAIR - PROFESSOR TIM ATKINSON

### Conference theme 5: Isotopes and water tracing

16:15 - 18:00

Jeelani, G	Estimating the sources of recharge to karst spring flows in a snow and glacierized catchment, western Himalaya (India)
Muhammad, F.	Chemical and isotope characteristic of the surface water in Karst dominated area of Kinta Valley, Malaysia
Yonge, C.J.	Stable isotope comparison of two major karst valley systems in the Canadian Rockies
Ender, A.,	In-cave tracer tests during dry and wet season with spatial resolution of transport parameters in a tropical karst aquifer
Goeppert, N.	Advances in colloid and particle tracing with applications in karst hydrogeology
Liu, Z.	Hydrologically-driven variations in the karst-related carbon sink fluxes: insights from high-resolution monitoring of three karst catchments in Southwest China
Poulain, A.	Complex hydrogeological dynamic of the Lomme Karst System (Belgium) characterized by high resolution monitoring and tracer tests

18:00 - 18:15 Questions for authors and concluding discussion on Theme 5

18:15 - 18:30 **Formal close of meeting and presentation of 'Young Karst Researcher' awards**  
(followed by briefing session for those attending the field trips)

**Thursday June 25<sup>th</sup> 08:15 - 20:30:** Fieldtrip: *Groundwater in Jurassic carbonates*

**Friday June 26<sup>th</sup> 08:15 - 20:30:** Fieldtrip: *Groundwater in Carboniferous carbonates*

## **Abstracts of Oral Presentations**

**listed alphabetically by presenting author**

**(first author is presenting author unless shown otherwise)**

# Monitoring natural responses of karst springs water to characterize the hydrogeological functioning of Sierra de Jarastepar-Alto del Conio aquifer (S Spain)

De la Torre, B., Mudarra, M. and **Andreo, B\***.

\*presenting author

andreo@uma.es

Department of Geology and Centre of Hydrogeology at the University of Malaga (CEHIUMA), Malaga, 29071, Spain.

Analysis of natural responses of karst springs provides information on the behavior of the systems they drain and on the hydrogeological heterogeneity of the aquifer. In this research, detailed monitoring and analysis of natural responses have been performed on the springs draining the Sierra de Jarastepar-Alto del Conio carbonate aquifer (province of Malaga, southern Spain), which highlights the considerable heterogeneity existing in this area, with different pattern of hydrogeological functioning. This aquifer (30km<sup>2</sup> of surface area) presents a complex geological structure, which includes rocks belonging two tectonic units of the Betic Cordillera: Jurassic dolostones and limestones of the External Zone and Triassic dolostones of the Internal Zone. The latter appears southward in a narrow and elongated NE- SW outcrop. The Sierra de Jarastepar-Alto del Conio aquifer is mainly drained by springs located at the south: Fuente Grande (419 m a.s.l.), Huertos de Alpandei (562 m a.s.l.), Charco de Faraján (600 m a.s.l.), Zúa (605 m a.s.l.) and Pozancón (665 m a.s.l.). Last point corresponds to a shaft 40 m deep, where piezometric level is accessible and even outflowing under high water conditions. These springs have been monitored with data logger devices, providing an hourly record of discharge, water temperature and electrical conductivity during one year. Thus, springs located in the External Zone (Fuente Grande and, specially, Pozancón) respond rapidly (several hours) to precipitation events, with sharp, significant increases in discharge rates and water mineralization (conduit flow system). During the main recharge periods, Pozancón spring also shows falls in water mineralization. In addition, the high degree of hierarchisation of karst conduits provokes a decrease in water temperature in both outflow points.

In contrast, springs situated at the southern border of Internal Zone outcrops (Zúa, Huertos de Alpandei and Charco de Faraján) have an intermediate-low degree of hierarchization of conduits, which means that their hydrodynamic, hydrothermal and hydrochemical responses present some inertia. Furthermore, systems drained by these springs exhibit irregular hydrogeological behaviour to precipitation events, ranging from small increases in water flow, clearly lagged respect to rainfall (Huertos de Alpandei), to relatively rapid and significant rises in discharge rates (Zúa). Additionally, these springs may also display slightly and lagged dilutions or sharp decrease in water mineralization and temperature, depending on the volume of recharge.

Therefore, different sectors of the Sierra de Jarastepar-Alto del Conio aquifer show distinct hydrogeological functioning, in an area geologically complex, although under similar climatic conditions, which highlight the heterogeneity of karst media and the importance of adequate investigations for groundwater management and protection in karst areas.

## **Paragenetic initiation and later overprint in cave passages: a review from Brazil**

**Auler, A.S.**

[aauler@gmail.com](mailto:aauler@gmail.com), Instituto do Carste, Brazil

Cave morphological studies in many karst areas developed in cratonic settings in Brazil reveal an abundance of paragenetic features, both primary (i.e. linked to the original cave generation process) and secondary (later overprint into an existing cave passage). Paragenetic processes are favoured due to a combination of low relief and low hydraulic gradients (and thus low groundwater flow velocities) and an abundance of fine-grained soil-derived sediments due to high weathering rates in a tropical environment.

Soil infilling and paragenetic development is characteristic of early stages of cave generation but also occur later in the development of already drained cave passages due to sediment input during dry paleoclimate intervals.

Low uplift rates promote long term permanence of a given cave passage within the phreatic zone, favouring paragenetic development before the water table is reached. At the same time, abundant sediment infilling episodes related to pluvial events during dry past climate phases favour infilling of already existing cave passages and thus reestablishment of temporary paragenetic processes.

Thus, two unrelated but concomitant processes (low uplift rates and palaeoclimate phases), act together in providing a favourable scenario for paragenetic processes in caves. Non paragenetic caves such as floodwater mazes can be overprinted, and massive sediment deposits may be retained within the caves, masking the majority of cave passages, resulting in a complex suite of morphological features and sedimentary facies that make difficult to establish the relative role of primary and later paragenetic processes.

## **Environmental and emergency risks induced by mining in gypsum karst area (Spišská Nová Ves, Slovakia)**

<sup>1</sup>Bajtoš, P., <sup>2</sup>Malík, P.

<sup>1</sup>peter.bajtos@geology.sk, State Geological Institute of Dionyz Stur, Slovakia

<sup>2</sup> State Geological Institute of Dionyz Stur, Slovakia

Geological assessment of mining influence on the environment in gypsum karst terrain, located in inhabited area of the Spišská Nová Ves (Slovakia), reveals not only environmental risks, but also emergency risks for local people.

Gypsum/anhydrite bodies – parts of upper Permian sedimentary strata of the gemericum tectonic unit (inner part of the Western Carpathians) - are exploited here since 1856 and the Maria mine is still operating. However, around the mentioned gypsum/anhydrite mine also other abandoned mines (Cu, U-Mo) exist, partially catching Permian evaporite bodies. In these mines, relatively extensive caverns, filled with residuum and water at depths of 30 – 140 m below ground surface were found. Presence of these karst features complicates mining due to hazard of water inrushes into mine workings, and also induces surface collapse/subsidence features.

Monitoring of mining impacts on the abiotic environment, performed here since 2007, involves both engineering geological, hydrogeological and geochemical observations. Its results show that: 1) total area of surface collapses above the Maria mine due to undermining have enlarged from 10,910 m<sup>2</sup> in 2004 to 22,170 m<sup>2</sup> in 2011 and their extent always increases; 2) flux of sulphate anions dissolved in mine water of the Maria mine and abandoned copper mine reaches 500 – 650 kg/d and 30 – 160 kg/d respectively, as consequence of gypsum dissolution in volume of approximately 100 m<sup>3</sup> and 15 m<sup>3</sup> annually and 3) surface water quality is locally worsened by mine water outflows with elevated concentrations of sulphate anions, arsenic, antimony and copper.

Sudden surface collapses due to undermining of karstified zones in gypsum bodies already imposed damages of local infrastructure in studied area. Most serious collapse event occurred in 1975, when inrush from gypsum cavern in copper mine induced subsidence of surface with main road in the populated area. Sudden mine water outflows (outrushes) from copper mine occurred in 2008. These were brought through gypsum karst feature in dewatering adit and caused local flood waves which damaged local infrastructure.

Ongoing gypsum karstification, intensified by drainage effect of mines, evokes emergency risk for local population due to possible origin of sudden surface collapses or mine water outrushes. Cessation of springs, captured and used for drinking water supply, together with deterioration of groundwater and surface water quality, can be considered as main environmental risks. For successful risk management of the area, a comprehensive study of karst processes has to be done, followed by detailed risk assessment.

## Agriculture impact on nitrate concentrations in karst aquifers in Ireland

<sup>1</sup>Blum, P, <sup>1,2</sup>Huebsch, M, <sup>2</sup>Horan, B., <sup>1</sup>Butscher, C., <sup>1</sup>Goldscheider, N., <sup>3</sup>Jordan, P., Hennessy, D., <sup>2</sup>Richard, K.G., <sup>2</sup>Grant, J. & <sup>2</sup>Fenton, O.

<sup>1</sup> philipp.blum@kit.edu, Karlsruhe Institute of Technology (KIT), Germany

<sup>2</sup> Teagasc - The Agriculture and Food Development Authority, Ireland

<sup>3</sup> University of Ulster, Northern Ireland

High nitrate ( $\text{NO}_3^-$ ) concentrations in groundwater contribute significantly to eutrophication of surface waters, can impact drinking water quality and therefore might have severe consequences for human health. Elevated nitrate levels typically correlate with intensive agriculture due to increased nitrogen (N) applications on the surface. Karst aquifers in Ireland are extremely vulnerable due to the low denitrification capacity in high permeability soils and aquifers. Hence, the objective of the present study is to comprehensively investigate the impact of agronomic practices of two dairy farms on spatial and temporal nitrate concentrations in karst aquifers in Ireland.

Below one dairy farm nitrate concentrations in 11 wells were intensively monitored as well as paddock-specific farm management practices during the study period of 11 years (2002-2011). Here, a multiple linear regression with automatic variable selection was applied for the statistical analysis. Four scenarios were created to compare paddock specific changes to borehole locations while using topographic and hydrogeological assumptions of a tracer test and a geoelectric survey performed on site. The results showed that site specific characteristics such as soil and epikarst zone thicknesses, local weather conditions such as rainfall and soil moisture deficit (SMD) and agronomic practices all influenced nitrate concentrations in the groundwater. In particular, the results demonstrated that agronomic practices became increasingly important after a time lag of 1 to 2 years and that the following introduced agronomic practices such as reductions in inorganic fertilizer application, changing the timing of slurry application, the relocation of a dairy soiled water irrigator to a less vulnerable area and the implementation of minimum cultivation reseeding instead of ploughing, led to reduced nitrate concentrations in the studied aquifer.

Furthermore, on a second farm the response of high rainfall events on nitrate concentrations were intensively studied to elucidate the key controlling factors, which cause mobilisation and/or dilution of nitrate concentrations in such karst systems. To study these nitrate responses temporal high-resolution data of nitrate using a spectrophotometric sensor and discharge in a karst spring were evaluated. Based on these analyses various hypotheses could be formulated and tested on this site and compared with other international case studies. The outcome of this comparison showed that the key controlling factors for mobilisation and/or dilution are hydrological conditions and in particular, nutrient source and hydraulic pathways in relation to land use and karstification. Finally, the outcomes of this study can be used to guide and provide practical advice for all involved stakeholders.

# Use of a 'lines of evidence' approach for Source Protection Zone delineation in the Corallian Limestone Aquifer of North Yorkshire

---

**Buckley, R. and Howlett, P. R.**

joint presenters

[ruth.buckley@environment-agency.gov.uk](mailto:ruth.buckley@environment-agency.gov.uk) , Environment Agency, England

[paul.howlett@rhdhv.com](mailto:paul.howlett@rhdhv.com) , Royal HaskoningDHV, England

The town of Scarborough in north east England is solely reliant for its drinking water supply on three groundwater abstractions from the karstic Corallian Limestone aquifer. Existing Source Protection Zones for these abstractions were designed in the 1990's using finite difference modelling and took no account of the known karstic nature of the aquifer. New Source Protection Zones have been designed using a novel 'lines of evidence' approach. Information from a variety of sources including current speleological investigation, tracer tests, spring morphology and new interpretations of pumping test data has been used. Inception along bedding planes and vertical linkage by a limited number of small faults is proposed as a mechanism for karstic development in the aquifer.

The newly designed zones include the surface water catchment of an upland river system which is influent to the aquifer, but exclude large sections of outcrop where karstic development is not expected. The local authority has adopted the zones into their local development planning guidance and it is expected that the zones will be refined as more evidence comes to light.

In a contrasting project new Source Protection Zones have been developed for public water supply abstractions in the nearby Yorkshire Chalk aquifer. There is evidence of very fast flow paths to some of the abstractions but the Chalk is also known to have a large degree of primary porosity. Data from an existing regional finite difference model has been post-processed using the *flowsorce* package to produce defensible model-based zones.

**Regional groundwater modelling of the Brighton and Worthing Chalk aquifer to both investigate the impacts of groundwater abstraction on surface water flows and to predict and optimise the source reliable output from public water supply sources.**

**Cook, S.<sup>1</sup>, Packman, M.J.<sup>2</sup>, Witterick, W.<sup>3</sup>, Hunt, D.<sup>4</sup>, Power, T.<sup>3</sup> & Soley, R.W.N<sup>3</sup>**

<sup>1</sup>(simon.cook@amecfw.com), Amec Foster Wheeler (Environment and Infrastructure), UK

<sup>2</sup> Southern Water Services Limited, UK

<sup>3</sup> Amec Foster Wheeler (Environment and Infrastructure), UK

<sup>4</sup> Atkins (Water and Environment), UK

A regional groundwater model of the coastal karstic Brighton and Worthing Chalk aquifer in South East England has been developed to maximize public supply abstraction whilst minimizing ecological impacts and the risk of saline intrusion. The karstic Newmarket Valley is located in the east of the Brighton Chalk Block, to the west of Lewes. The valley is of strategic importance for water supply and supports the highly ephemeral Lewes Winterbourne. The Brighton Chalk Block also supports some thirteen public water supply groundwater abstractions in a relatively small area [of which the Newmarket Valley contains four groundwater sources with an average combined output of ~21Ml/d]. Through the National Environment Programme, ecological and hydrogeological data collation and analysis has guided the development of conceptual and numerical models of the semi-karstic flow system which underpin the assessment of the impact of groundwater abstractions on surface water flows and ecology.

In parallel, the resultant groundwater model has been refined and enhanced to be able to accurately model pumped water levels within the well field of the karstic aquifer. To enable a better representation of aquifer complexity, enhancements to the MODFLOW-USG code have been developed, including the simulation of level dependant variations in hydraulic conductivity. Support for unstructured grids (USG) has also been added to the 4R runoff-recharge code. Public supply wells and abstractions from laterally extensive shaft and adit systems which intersect karstic features have been simulated using the Connected Linear Network functionality of MODFLOW-USG. When coupled with local grid refinement, this enables regional scale heads to be downscaled to pumped source water levels, incorporating both planned changes in abstraction rates within the simulation and the automatic adjustment of modelled abstraction rates as a function of simulated coastal fluxes to limit saline intrusion risks. These techniques could be applied to other regional scale models to explore alternative source abstraction management strategies and in order to optimise source reliable output from the aquifer as a whole. The use of Connect Linear Networks could also be used to model known karstic conduit features within an equivalent porous medium model. Stochastic recharge time series representing both historic and projected future severe droughts have been applied to the model with a view to supporting resilient water resource investment and management plans.

# **Induced Karst Features in the Drawdown Zone of an Open Pit Diamond Mine in Ontario's James Bay Lowland, Canada.**

<sup>1</sup>Cowell, D.W., <sup>2</sup>Gautrey, S.J., and <sup>3</sup>Steinback, B.J.

<sup>1</sup> [dcowell@amtelecom.net](mailto:dcowell@amtelecom.net), Daryl W. Cowell & Associates Inc., Canada

<sup>2</sup> Amec Foster Wheeler, Canada

<sup>3</sup> De Beers Canada Inc., Canada

A series of diamond-bearing kimberlite pipes were emplaced through Silurian carbonates during the Jurassic Period. One of these pipes is currently being mined using open pit methods requiring groundwater depressurization. The mine lies immediately south of the Attawapiskat River within an extensive peatland complex. Mining was initiated in 2007 and within a year of the commencement of dewatering a number of surface features began to appear including “dry ponds” located within bog/fen tracks and collapse-style sinkholes.

An active Holocene karst terrain lies approximately 5 to 10 km east of the mine site. This terrain was investigated by the lead author in 1977 who described a zone of fluvio-karst features along the Attawapiskat River and an inland bio-karst zone within the peatland. Karst drainage was initiated during the mid to late Holocene following emergence of the land base from the Tyrrell Sea and the development of a hydraulic gradient by river down-cutting.

A total of 20 potential karst features have been observed within the drawdown zone of the mine. These include 10 dry ponds within pond complexes and lacking closed depressions; 6 closed depressions located outside of pond complexes; and 4 closed depressions located within pond complexes and fed by erosional peat-based channels. Closed depressions mostly appear as collapse features 4 to 7 m across with abrupt walls and torn muskeg mats. At least two of the closed depressions with dry ponds were also found to have secondary sinkholes believed to have formed after the initiation of karst drainage at the site

Paleokarst features are abundant in the area as demonstrated in the pit, quarries, and building excavations. The rapid appearance of collapse-type sinkhole features is considered due to the presence of paleokarst cavities at the bedrock/sediment/peat interface. Collapse occurs as soon as depressurization commences in the bedrock. Dry ponds without sinkholes are considered to be related to proximity to bedrock and not paleokarst cavities.

Peat materials have a capacity to absorb water and thus impacts to the peatland ecosystem at individual dry ponds and at collapse-type closed depressions without ponds are considered limited. Detailed piezometer investigations and evidence from the Holocene karst indicate that peatland drainage in these situations is limited to a zone of approximately 30 m.

Sinkholes draining a sequence of ponds via surface channels and initiating secondary sinkholes are considered to have the greatest potential to impact peatland waters and mitigation measures are offered for these features. It is expected that rising groundwater levels post mine closure (~ 2019) will re-flood the features. A couple of features could continue to operate post closure by optimizing hydraulic gradients toward the major rivers.

## **Microbial quality of Irish karst springs: implications for management of water supplies**

<sup>1</sup>Coxon, C.E. & <sup>2</sup>Hickey, C.

<sup>1</sup>cecaxon@tcd.ie, School of Natural Sciences, Trinity College Dublin, Ireland

<sup>2</sup> Geological Survey of Ireland, Dublin, Ireland

Karst water quality is a topic of particular concern in Ireland because the predominant bedrock aquifer type is Carboniferous limestone, with karst aquifers dominated by conduit flow occurring extensively in the western limestone lowlands. In this region, the combination of shallow soils, point recharge (via dolines and swallow holes) and rapid conduit flow provides inadequate attenuation of faecal microorganisms, and contamination results from both animal sources (including badly stored animal manures and slurries, farmyard runoff and landspreading of animal waste in vulnerable situations) and human sources (primarily septic tank systems that are poorly constructed or located in unsuitable situations).

The unpredictability of borehole yields in these conduit-dominated karst aquifers means that drinking water supplies are often obtained from karst springs. The raw water quality of these springs is generally poor, with pulses of bacterial contamination often resulting in counts of >100 faecal coliforms per 100 ml. This is a concern from the public health viewpoint in relation to both untreated private domestic supplies and inadequately treated public supplies. Very considerable improvements in water treatment in recent years have greatly decreased the detection rate of faecal bacteria in treated groundwaters used for public supply in Ireland. However, bacterial problems remain in some smaller private supplies due to inadequate chlorination, with presence of verotoxin-producing *E. coli* (VTEC) being a growing concern. There have also been problems even in larger public supplies with the protozoan parasite *Cryptosporidium*, due to the fact that its oocysts are resistant to chlorination and require more complex treatment methods.

This issue is illustrated with examples from County Roscommon, which obtains approximately 85% of its drinking water supplies from groundwater, largely from karst aquifers. Outbreaks of cryptosporidiosis in this region were traced to several large karst springs used for public water supply, and over 20,000 people were obliged to boil drinking water for extended periods during 2013 and 2014. Smaller private water supplies schemes from karst springs in the county also have poor raw water quality and potentially inadequate treatment. The response by the water supply authorities to the cryptosporidiosis problem has focussed primarily on the provision of treatment facilities capable of removing *Cryptosporidium* spores. However, there is also a need to improve raw water quality by groundwater protection measures. This has long been recognised by both the Geological Survey of Ireland (GSI) and the Environmental Protection Agency (EPA), who have carried out vulnerability mapping and identified zones of contribution of the karst springs. The EPA are currently supporting the development of Water Safety Plans for public water supplies, while the Geological Survey of Ireland are currently working with the National Federation of Group Water Schemes to develop zones of contribution for these community water supplies, and in Roscommon this work focuses on supplies from karst springs.

# Participatory tool to improve knowledge, management and protection of the karstic chalk aquifer system in Eastern Normandy

<sup>1</sup>David, P.-Y., <sup>2</sup>Pennequin, D.

<sup>1</sup> py.david@brgm.fr, BRGM, France, <sup>2</sup> BRGM, France

In Eastern Normandy, karst generates natural collapse structures at the ground surface (locally called « bétoires ») which constitute entrance points for surface water into the chalk aquifer system. During intense rainfall episodes, sinkholes represent preferential transport vectors for suspended solids (SS) coming from erosion processes, as well as for pollutants issued from plant healthcare products, such as fertilizers and pesticides. Sinkholes are also sometimes, either deliberately or accidentally, outlet points for drained agricultural land, road wastewater networks and wastewater treatment plants. Karst channels connected to the sinkholes, rapidly transfer particles and pollutants to the chalk aquifer system and thereby to the catchments used for drinking water purpose. Furthermore, sinkholes geometry and down flow (yield) vary over time. In addition, new sinkholes are generated each year.

In 2008 the Seine Normandie Water Agency, the three Upper-Normandy Councils, in partnership with BRGM decided to develop a data base to store karst characteristics and transfer processes affecting the Normandy chalk aquifer system. Stored data notably include information about exokarst (sinkholes), karstic springs and karst conduit connections highlighted by tracing experiments. After a 4-year program of intensive work of consulting historical archives and carrying out field investigations, about 15 000 sinkholes and 2425 karst connections highlighted by tracer tests were identified and introduced into the data base.

This work was initiated and carried out by BRGM, but it is now taken forward in a participatory way involving all water and basin stakeholders, as well as organizations and even, more generally, the civil society. A participatory tool has been developed for that purpose, including Websites interfaces through which data can be introduced into the data base and retrieved from it in different ways (GIS format, consulting files, ...) free of charge.

Today this tool allows for sharing knowledge collected by local authorities and the various communities in charge of water resources management and drinking water supply, wastewater treatment, flood forecast, catchment water management and road maintenance among others. It also provides opportunities to update data according to field evolution.

More specifically, this tool helps improving the understanding of the operating processes affecting the karst network thereby allowing for better management and protection of the chalk aquifer system preventing from quality degradation (turbidity, nitrates, pesticides, ...) and ensuring safe drinking water production. Examples of uses include active water resources management, delineating safety perimeters and protection zones (against agricultural pollution) around drinking water catchments.

In addition, the collected data greatly enhanced understanding of the effects of lithology, geological structures and stratigraphy on karst developments in the chalk aquifer system as well as on the exokarst spatial distributions. Along this line for example, a preliminary GIS analysis already showed a strong correlation between, on the one hand, sinkhole density patterns and, on the other hand, both thickness of superficial formations and proximity to surface water drainage axes. Finally, this data also brought out tracer test anomalies and showed fallacious results stressing the need to adapt tracer tests configuration to the geologic context.

## **Double-peaked breakthrough curves: from field data to laboratory analogue tests. A study case in the Dinant area (South of Belgium).**

<sup>1</sup>Dewaide, L., <sup>2</sup>Gervais, C., <sup>2</sup>Rochez, G. & <sup>2</sup>Hallet, V.

<sup>1</sup>lorraine.dewaide@unamur.be, University of Namur, Belgium

<sup>2</sup> University of Namur, Belgium

Carboniferous carbonates outcropping in the Dinant area (South of Belgium) are intensely karstified. In particular, in Furfooz (6 kms SE of Dinant), an interesting karstic system is developed along the Lesse river. The Lesse is partially infiltrating through a sinkhole (*Trou des Nutons*) and is re-emerging 1200 m downstream at a resurgence called the *Trou de La Loutre*. The specificity of this underground system is the existence, on the flow path, of an important volume of standing water (the *Puits des Vaux* lake).

In order to understand and to characterize the hydrogeology of the active system, tracer-tests were performed in various flow conditions. Breakthrough curves (BTC) obtained via the different tests show similarities, particularly in the existence of a double peak downstream the *Puits des Vaux* lake. The appearance of a double peak means that the tracer cloud separates in two. Interpretation of the BTCs, along with field observations and monitoring of various parameters (temperature, conductivity and water level), suggests that the dual peak is due to the presence of the lake on the tracer route.

This hypothesis cannot be verified on the field. Indeed, the lake can only be explored by scuba diving and the divers's report is not valuable because the access and the visibility are very poor. Therefore, it was decided to build a laboratory analog that could reproduce BTCs similar to the experimental ones. Geometric and dynamic similarity between the scale model and the real system was established so that the analog could be considered as representative. Two major postulates are tested within the analog. First, a segregation of the solute due to hydrodynamic process that causes two flows to coexist within the lake: a quick and advective flow on the one hand, and on the other hand a flow spreading slowly through the lake volume; second, a physical separation of the tracer, meaning that a double conduit should exist within the lake or bypassing it.

Results of the different scenarios were matched to the field BTCs and helped us to rethink our conceptualization of the field reality. Moreover, thanks to the establishment of a conceptual model, modelization could be performed on the field BTCs. The modelization tool used is the OTIS program (One-dimensional Transport with Inflow and Storage) that supposes the existence of a storage zone along the main flow zone in which solute can be temporarily caught causing retardation under specific conditions. OTIS, considered as an adequate tool to model solute transport in karst conduits, allows to dimension karst conduits and to estimate the main transport parameters.

Field results and laboratory analog results will be exposed during this presentation. Main conclusions and conceptual model will be presented while the modelling tool and results will be introduced.

## Is metabolism a key factor in determining groundwater copepod sensitivity to pollutants?

<sup>1</sup>Di Lorenzo, T., <sup>2</sup>Cifoni, M., <sup>3</sup>Di Marzio, W.D., <sup>4</sup>Cannicci, S., <sup>1</sup>Baratti, M. & <sup>2</sup>Galassi, D.M.P.

<sup>1</sup> [tiziana.dilorenzo@ise.cnr.it](mailto:tiziana.dilorenzo@ise.cnr.it) Istituto per lo Studio degli Ecosistemi - CNR, Via Madonna del Piano 10, 50019, Sesto Fiorentino, Firenze, Italy

<sup>2</sup>Department of Life, Health and Environmental Sciences, University of L'Aquila, Via Vetoio, Coppito, 67100 L'Aquila, Italy

<sup>3</sup>Programa de Investigación en Ecotoxicología, Departamento de Ciencias Básicas, Universidad Nacional de Luján - Comisión Nacional de Investigaciones Científicas y Técnicas CONICET, Argentina

<sup>4</sup>Department of Biology, University of Florence, Via Madonna del Piano 6, 50019 Sesto Fiorentino, Italy

Groundwater is a relatively stable and predictable environment, characterized by permanent darkness, constant temperature and physico-chemical parameters, reasonably foreseeable flow rates and scarcity of organic matter. Among the adaptations that groundwater-dwelling species (the so-called stygobionts) have evolved to cope with the groundwater environment, one of the more striking is the low metabolic rate. However, this physiological adaptation may turn in a disadvantage when the conditions of the groundwater ecosystems suddenly change.

The metabolic rates of two species of Cyclopoida Cyclopidae, the stygobiotic copepod *Diacyclops belgicus* and the non-stygobiotic *Eucyclops serrulatus*, co-occurring in the same alluvial aquifer in Tuscany, were measured. The metabolic rate of *D. belgicus* was significantly lower than that of the epigeal *E. serrulatus*, irrespective of the ontogenetic stage. In *D. belgicus* the rates of oxygen consumption apparently did not change systematically with body mass for the adult stage but scaled isometrically for the juveniles. Conversely, the epigeal *E. serrulatus* showed an allometric relationship between oxygen consumption and body mass for both adult and juvenile stages.

Under acute (96 h) exposures, the epigeal *E. serrulatus* proved to be remarkably more tolerant than the hypogean *D. belgicus*, at both juvenile and adult stages, to pollutants that are more and more often found in groundwater worldwide, namely chloroform, ammonium, the herbicide Imazamox and a mixtures of ammonium and Imazamox. However, considering the two species separately, the more metabolically active juvenile stages were more sensitive than adults, indicating that other variables, such as the maturity of detoxifying mechanisms or the thinness of juvenile exoskeleton, may play a role in determining the sensitivity to toxicants, at least in copepod species.

These results showed that the low metabolic rates of the stygobiotic species may entail an inability to cope with toxicants, rendering them more sensitive to pollutants than their, more metabolically active, epigeal relatives. These outcomes thus arises the question whether metabolism is to be intended a key factor in determining copepod sensitivity to pollutants.

# Hydrogeological modeling and upscaling of weathered karst aquifer by a distributed porosity approach

<sup>1</sup>Dubois, C., <sup>2</sup>Goderniaux, P., <sup>3</sup>Deceuster, J. & <sup>2</sup>Kaufmann, Olivier.

<sup>1</sup>caroline.dubois@umons.ac.be, University of Mons, Department of Geology and Applied Geology, Belgium

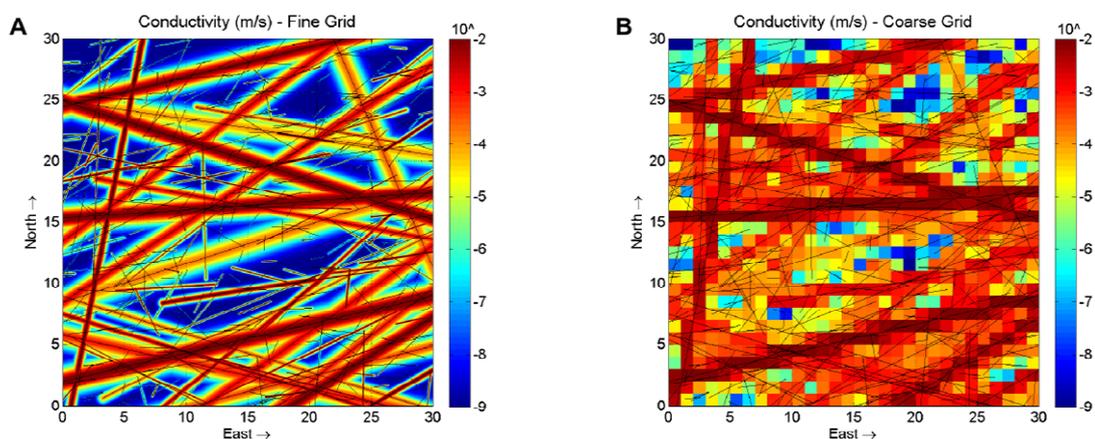
<sup>2</sup> University of Mons, Department of Geology and Applied Geology, Belgium

<sup>3</sup> Engineering Department, CFESA, Belgium

‘Ghost-rock’ karst aquifer has recently been highlighted. In this particular type of aquifer, the karst is not expressed as open conduits but consists in zones where the limestone is weathered. The in-situ weathering of limestone leaves a soft porous material called ‘alterite’.

The hydro-mechanical properties of this material differs significantly from those of the host rock: the weathering enhances the storage capacity and the conductivity of the rock. This type of weathered karst aquifer has never been studied from a hydrogeological point of view. In this study, we present a modelling approach derived from the common Equivalent Porous Medium (EPM) approach but including the spatial distribution of hydrogeological properties through the weathered features, from the hard rock to the alterite, according to a weathering index. Unlike the Discrete Fracture Network (DFN) approaches, which enable to take into account a very limited number of fractures, this new approach allows creating models including thousands of weathered features.

As the properties of the alterite develop at a centimeter scale, it is necessary to perform an upscaling to run simulation over large models (Figure 1). Therefore, an upscaling method was developed, taking into account the anisotropy of the weathered features. Synthetic models are built, upscaled and different hydrogeological simulations are run to validate the method. This methodology is finally validated on a real case study: the modeling of the dewatering drainage flow of an exploited quarry in a weathered karst aquifer in Belgium.



**Figure 1: Conductivity grids of a weathered features network (30m x 30m). (A) Grid with centimetric mesh; (B) Upscaled grid with metric mesh.**

# **In-cave tracer tests during dry and wet season with spatial resolution of transport parameters in a tropical karst aquifer**

**Ender, A., Goeppert, N. & Goldscheider, N.**

anna.ender@kit.edu

Karlsruhe Institute of Technology, Institute of Applied Geosciences, Germany

In many karst regions in South East Asia, the population suffers from water shortage. The tropical climate with its distinct dry and wet seasons, broad deforestation, the strong karstification, the oftentimes poor water quality of karst springs due to agricultural activities and the lack of waste water treatment exacerbate the living conditions of the local population. Therefore, it is essential to research tropical karst aquifers and how the extremely variable hydrologic conditions impact their behavior and water quality, to be able to develop adjusted and sustainable groundwater management strategies.

The Dong Van Karst area in Northern Vietnam is located in one of the poorest and remotest regions in the country. The KaWaTech project intends to improve the situation by capturing water from karst springs and water caves to supply the villages in the region. The research presented here focuses on the investigation of the hydrological variability of relevant karst springs. In this context, tracer tests were conducted in a karst system consisting of a sinking stream, several connected water caves and karst springs during the dry and rainy season. The cave system is composed of four already explored caves, Male 1 to 4, with small parts in between that are yet unexplored owing to phreatic passages. The river Ma Le runs through all four water caves to emerge at two springs (Male 4 and Seo Ho 1) about one kilometer further downstream. Uranine was injected into the sinking stream at the cave entrance of Male 1 and samples were taken in the two caves Male 2 and 3 and at the springs. We achieved a spatial resolution of flow velocities and transport parameters in four individual sections of this conduit system for low and high flow conditions, by using the breakthrough curves from one section as input function for the subsequent downstream section in the CXTFIT simulations.

The mean flow velocity between Male 1 and the spring Male 4 was four times higher in the rainy season (398 m/h) than in the dry season (98 m/h). Using the conventional approach of an impulse injection in Male 1 yields a maximum flow velocity between Male 1 and Male 3 of 1368 m/h in the rainy season. But with the spatial resolution achieved with the multiple pulse approach, it amounts to 637 m/h between Male 2 and Male 3, lower by a factor two. Furthermore, the multiple pulse approach reveals significant differences in dispersivity between the caves undetectable with the conventional approach. With 15 m, dispersivity is found to be highest between Male 2 and 3 during the rainy season, while dropping off to 5 m upstream and 3 m downstream from that section. The conventional approach would have wrongly yielded a relatively constant dispersivity of around 7 m for the whole cave system.

By spatially resolving transport parameters, we were able to identify sections that differ in behavior, due to pools, sumps or phreatic zones. We could also show that dispersivity is highest in the middle section of the cave system and that it does not increase with distance to the injection point. Such detailed information provides a valuable basis for the potential use and protection of this karst water resource for drinking water supply.

## **Stressed out: determining preferential flow pathways in karstic aquifers from cave survey data**

**Farrant, A.R**

arf@bgs.ac.uk, British Geological Survey, UK

Groundwater flow in karstified carbonate rocks is usually determined by secondary dissolutional permeability developed along fractures and stratigraphic discontinuities. Conduits are often developed at the intersection of these discontinuities. Modelling of cave inception suggests flow pathways are strongly influenced by the initial fracture aperture. Thus the structure of the evolving karst aquifer is determined by the initial geological setting at the time of conduit inception. Consequently, the plan pattern of caves provides evidence for which fracture sets are most favorable for conduit inception. An analysis of cave survey data across the UK provides evidence for preferred flow directions along certain joint orientations. This yields insights into the role of fractures in speleogenesis and their influence on determining the subsequent evolution of the aquifer and groundwater flow pathways. The same principles also apply in less well karstified fracture-dominated carbonate groundwater systems such as the Jurassic oolites and the Upper Cretaceous Chalk. This has implications for modelling groundwater flow pathways and determining Source Protection Zones (SPZ) in carbonate aquifers.

# Long-term trend and fluctuations of karst spring discharge in central-southern Italy

<sup>1</sup>Fiorillo F., <sup>2</sup>Petitta M., <sup>3</sup>Preziosi E., <sup>4</sup>Rusi S., <sup>1</sup>Esposito L. & <sup>5</sup>Tallini M.

<sup>1</sup> [francesco.fiorillo@unisannio.it](mailto:francesco.fiorillo@unisannio.it), Dip. Scienze e Tecnologie, University of Sannio, Italy

<sup>2</sup> Dip. di Scienze della Terra, University “La Sapienza”, Rome, Italy

<sup>3</sup> CNR-IRSA, National Research Council-Water Research Institute, Rome, Italy

<sup>4</sup> Dip. Ingegneria e Geologia, University “G. d’Annunzio”, Chieti, Italy

<sup>5</sup> Dip. Ingegneria Civile, Edile-Architettura e Ambientale, University of L’Aquila, Italy

The central-southern Apennine is characterized by high ridges formed by carbonate sequences, mainly of Mesozoic age. These mountains represent wide aquifers, limited along the border by low-permeability deposits, as argillaceous pre-orogenic sequences, flysch formations of Miocene, alluvial deposits, etc., whose act as aquicludes and favour the outcrop of large karst springs.

High rainfall rates and snowmelt significantly affect the recharge regime, while wide endorheic areas have a significant role in recharge processes. As a result, recharge can reach values higher than 1000 mm/year. The karst spring of Apennine chain are largely exploited for the human consumption since the Roman Times and currently feed some tens of millions inhabitants with tap water of high quality. Most of them are typical basal karst springs, fed by huge aquifers and are characterized by a steady rate during the year with modest seasonal variability.

However, the effects of climate changes are being strongly perceived in central and southern Italy as in the rest of the Mediterranean basin, and groundwater is obviously also affected. Thanks to long discharge measurements, we analyze the discharge time series of some main karst springs in the region evaluating the trends and fluctuations, also in relation to rainfall regime, on a yearly time scale; the role of the North Atlantic Oscillation has also been considered. Trends and fluctuations have been highlighted by n-years moving average and transforming the time series by the Rescaled Adjusted Partial Sum. The results show that a drop in the discharge has occurred since 1987, with reductions ranging from 15 up to 30 %, although this negative trend is now possibly attenuating or even reversing. As a final remark, the spring discharge of the large karst aquifers in central-southern Italy can be assumed as a robust indicator for climate changes as it integrates the effects of precipitation and temperature variation in time and space.

# **Karst and karst aquifers in the Northwest Territories of Canada: A Review.**

**Ford, D C**

Emeritus Professor of Geography and Earth Sciences,  
McMaster University, ON L8S 4K1, Canada.

[dford@mcmaster.ca](mailto:dford@mcmaster.ca)

There are thousands of square km of karstically drained terrain between Lats. 60°-68° N in the Northwest Territories of Canada. The host rocks are Paleozoic in age, diagenetically mature, primarily dolomites and limestones but with extensive gypsum/anhydrite and frequent underlying salt in sabkha or clastic facies. They outcrop in three distinct structural settings:- (i) interior low plateaus dipping gently westward from the edge of the Canadian Shield, succeeded by (ii) the Franklin Mountains, a narrow belt of sharper cuesta topography lying east of the Mackenzie River, formed by overthrusting from the west and rising to ~1000 m above sea level; (3) west of the River, the Canyon Ranges of the Mackenzie Mountains are a broader complex of thrust and fold structures rising to 2000+ m asl. Most of the Territories were covered by the Laurentide continental ice sheet or by coalescent valley glaciers but parts of the northwest escaped all glaciations due to aridity. The modern climate is sub-arctic to arctic continental, mean annual temperatures ranging from -2<sup>0</sup> to -15° C or lower , precipitation from ~250 to ~750 mm with a marked summer maximum as rain. Permafrost is 'sporadic' at the southern limits, becoming 'widespread but discontinuous' further north, technically 'continuous' above 400 - 600 m asl everywhere. Most of the area is uninhabited.

On behalf of the Territorial government the author has reviewed the (sparse) documentation on karst and karst waters, interpreted the aerial photography, and investigated more than thirty sites on the ground. This paper will summarize the highlights of a dozen of them selected from the different structural settings, placing emphasis on the wide variety of form and behaviour that is to be found - and concluding with illustrations of the effects of climate warming that is now impacting the Territories very strongly.

## Monitoring karstic springs: the role of groundwater meiofauna as indicators of aquifer hydrodynamics

<sup>1</sup>Galassi, D.M.P., <sup>1</sup>Fiasca, B., <sup>2</sup>Di Lorenzo, T.

<sup>1</sup> [dianamariapaola.galassi@univaq.it](mailto:dianamariapaola.galassi@univaq.it) University of L'Aquila, Department of Life, Health & Environmental Sciences, 67100 L'Aquila, Italy

<sup>2</sup> Institute of Ecosystem Study - CNR - National Research Council of Italy, Via Madonna del Piano 10, 50019 Sesto Fiorentino, Florence, Italy

Stygobites, obligate groundwater-dwellers, either drifted from the karstic discontinuities of the carbonate bedrock or stranded in the alluvial aquitards, inhabit spring habitats. In natural springs and springs used for drinking purposes, the hydrological setting of the aquifers, their hydrodynamics, the preferential flowpaths, or changes in flowpaths, are among the major determinants of the fine-scale distribution of stygobites.

The spatial and temporal distribution of stygobiotic crustaceans (by selecting Crustacea Copepoda as a target group) in four large karstic springs in central Italy were analysed in order to assess: (i) their sensitivity to different flowpaths in the same aquifer; (ii) their role as hydrological tracers in spring systems fed by groundwater of different origin; (iii) their potential in detecting severe changes in aquifer discharge triggered by natural catastrophic events; (iv) the relationships between stygobiotic assemblages in drift samplings and the aquifer discharge regime in springs kept for drinking purposes.

Our study showed that (1) stygobiotic copepod species are sensitive to aquifer flowpaths, since we collected different species at the discharge sites of different hydrological flowpaths in the same aquifer; (2) two spring units belonging to the same spring system harboured two highly different assemblages of stygobiotic copepod species, indicating a different origin of the groundwater feeding the two springs: stygobiotic populations can maintain the “memory” of their native habitats, likely due to low aptitude for dispersal and may serve as hydrological tracers of groundwater origin; (3) an earthquake-triggered increase in discharge of a karstic aquifer in central Italy determined drastic changes in stygobiotic species abundances at the spring outlets, indicating that catastrophic events strongly altering aquifer discharge are mirrored by differences in species composition and abundance found at the spring outlets; (4) finally, a spring used as drinking water supply harboured stygobiotic copepod assemblages varying according to aquifer discharge regime, with increase in abundances during the low-discharge period of the aquifer indicating that stygobiotic species likely inhabit the capacitive systems of the aquifer rather than the conductive ones. These patterns together indicate that karstic aquifer hydrodynamics dictates stygobiotic species composition and abundances at the spring outlets.

# **Relative importance of lithologic, stratigraphic and structural controls on karst conduit development at the Victor Diamond Mine, James Bay Lowlands, Ontario, Canada.**

<sup>1</sup>Gautrey, S.J., <sup>2</sup>Rummel, P., <sup>3</sup>Cowell, D.W., <sup>3</sup> and <sup>2</sup>Steinback, B.J.

<sup>1</sup> [simon.gautrey@amecfw.com](mailto:simon.gautrey@amecfw.com), Amec Foster Wheeler, Canada

<sup>2</sup> De Beers Canada Inc., Canada

<sup>3</sup> Daryl W. Cowell & Associates Inc., Canada

The Victor Diamond Mine is located in the James Bay Lowlands approximately 90 km west of the coastal community of Attawapiskat. Mining is proceeding with open pit methods at a kimberlite pipe intruded through a 270 m thick sequence of Ordovician and Silurian sedimentary bedrock deposited in a large stable intracratonic basin. Like many stable basins in the glaciated areas, the topography is flat, and there is little opportunity for visual examination of the bedrock; however, after eight years of excavation, the mine is approximately 140 m deep, providing a unique window on the karst features of the region.

The Silurian bedrock exposed at the mine is predominately limestone from several flat-lying formations. The stability of the intracratonic basin means the Silurian bedrock has never undergone significant burial and uplift, which when combined with a lack of dolomitization, has preserved much of the original porosity. Evidence from the mine indicates that karst conduits have developed through a combination of exploiting the original porosity and new conduit development along stratigraphic contacts or planes of structural weakness where no original porosity existed. As such, the karst conduit development is influenced by the original lithology (including porosity), stratigraphy and structure of the bedrock.

Regional geophysical mapping has revealed a pattern of shallow bedrock valleys that are now buried beneath a plain of late Quaternary silts deposited in the area after the retreat of glaciers. The original hydrologic system that discharged to these former bedrock valleys is now choked by deposits of silt and is defunct. The new hydrologic system is immature and directs groundwater flow towards rivers established in last few thousand years, but the flat terrain ensures that groundwater gradients are low, and discharge from karst springs provides very little information on the importance of the former karst network. Dewatering at the mine is significant and has reactivated parts of the paleokarst system, which offers a unique opportunity to evaluate the relative importance of lithologic, stratigraphic or structural controls on karst development through an assessment of drawdown around the mine.

This presentation will show examples of the types of karst features found at the mine and their association with lithologic, stratigraphic and structural controls. The presentation will assess the relative importance of each control on karst conduit development as revealed by the aquifer response to dewatering.

# **Significance of parameters and processes for the evaluation of large scale tests in karst aquifers with numerical hybrid models**

<sup>1</sup>Giese, M., <sup>2</sup>Reimann, T., <sup>2</sup>Liedl, R., <sup>3</sup>Maréchal, J.C., <sup>1</sup>Geyer, T., & <sup>1</sup>Sauter, M.

<sup>1</sup>mgiese@gwdg.de, Geoscientific Centre, University of Göttingen, Göttingen, Germany

<sup>2</sup>Institute for Groundwater Management, TU Dresden, Dresden, Germany

<sup>3</sup>Bureau de Recherches Géologiques et Minières (BRGM) - D3E/NRE, Montpellier, France

Flow patterns in karst aquifers are complex as a result of the large contrast in hydraulic parameters between the conduits and the permeable fractured matrix. Hydraulic parameters may differ by several orders of magnitude from local to catchment scale. Therefore, karst aquifer characterization is still a challenge and requires the application of different characterization techniques in order to deal with large-scale heterogeneities, mainly introduced by karstification processes. The analysis of spring responses, a frequently used method, reveals integral information about geometrical and physical properties, which can be used to build lumped parameter models. The drawback of lumped parameter models is the strong simplification of the flow dynamics of karst aquifer systems. These models are able to represent the ‘global signal’ but they are not able to represent the flow on different scales. Traditional hydrogeological techniques, e.g. small-scale hydraulic borehole tests, are used to characterize the hydraulic parameters on ‘local-scale’. Hence the results represent the permeability in the vicinity of the wellbore but normally fail to characterize the system heterogeneity on catchment scale. One approach to deal with the scale problem is the application of large scale experiments such as pumping tests in karst aquifer systems. Due to the water abstraction directly from the conduit system, such large-scale experiments cover both scales and, therefore, the spatial scale of dominant karst aquifer heterogeneities.

The numerical hybrid modeling approach MODFLOW-2005 Conduit Flow Process Mode1 (CFPM1), recently expanded by the addition of further hydraulic features like conduit associated drainable storage, can be employed to simulate large scale pumping tests. CFPM1 couples a discrete conduit network to a groundwater continuum and allows the systematic analysis of different aquifer parameters on the drawdown behavior.

During water abstraction the drawdown curves show different flow characteristics. These characteristics can be transferred to certain flow patterns, individually representing a characteristic scale or feature of the karst aquifer system. For example, linear flow represents the conduit network whereas radial flow, usually occurring at late times, represents the global response of the aquifer. The transition period between the inner boundary conditions of the conduit system (conduit storage and skin effect) and linear flow represents the period where two porosities tend to an equilibrium condition of pressure. This period can be used to characterize the interaction between the fissured matrix and the conduit system. This contribution demonstrates the general functioning of CFPM1 and provides an overview about the analysis of large scale pumping tests. Effects and significance of hydraulic processes, for example turbulent flow conditions or conduit network structure, are discussed. Results of an extensive study of the behavior of flow in idealized model domains are used to characterize the flow conditions and the hydraulic parameters of a mixed flow karst system (Cent-Fonts, France).

# Use of stable isotopes to characterise the hydrogeology of a lowland karst aquifer

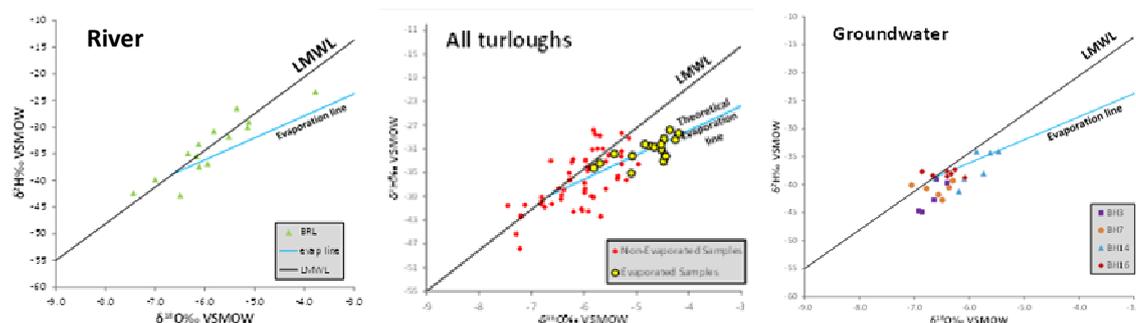
<sup>1</sup>Gill, L.W., <sup>2</sup>McCormack, T., & <sup>2</sup>Johnston, P.M.

<sup>1</sup>laurence.gill@tcd.ie, Trinity College Dublin, Ireland

<sup>2</sup> Trinity College Dublin, Ireland

The binary karst area of south Galway in the west of Ireland provides an intriguing setting for hydrogeological studies due to its low-lying nature whereby the main spring from this area discharges slightly below mean sea level at the coast. This low-lying landscape provides unique karstic hydrogeological signatures in the form of fluctuating water levels of intermittently flooded topographic depressions - temporary lakes known as *turloughs*. This close interaction between groundwater and surface water makes the catchment an interesting study area for the use of stable isotopes to attempt to fractionate the origin of turlough water between autogenic diffuse/epikarst sources or directly from allogenic river/conduit inputs, from which the hydrogeological controls on the aquifer can be more fully elucidated.

Water quality samples were collected across a three year period from the turloughs, wells in the karst and allogenic river recharge and analysed for their <sup>18</sup>O, <sup>2</sup>H and <sup>13</sup>C isotopic signatures. These data revealed that the <sup>18</sup>δ signature of water becomes slightly enriched as it moves through the catchment due to frequent evaporative interaction with the atmosphere. More specifically the groundwater samples exhibited the least influence from evaporation, rivers showed minor evaporation while the turloughs showed the highest evaporation (Fig. 1). Overall however, the effect of evaporation within the catchment is quite minor. Within the turloughs, evaporation was mainly picked up during the summer when the turlough water levels were low. The isotopic patterns within the turloughs also confirmed the findings of alkalinity measurements which suggested some contribution to the turloughs from their surrounding epikarst over a flooded period. Indeed, a more diffuse recharge operating turlough (not fed by main river-fed conduits) showed only slightly more depleted isotopic signatures than the average groundwater value, confirming it as a groundwater fed turlough.



**Figure 1.** Delta-plots showing Local Meteoric Water Line (LMWL) and theoretical evaporation line overlaid on isotopic data for river, turlough and groundwater samples.

Finally, the use of <sup>13</sup>C isotopes in this catchment to quantify the diffuse flow contribution into the main network proved to be impractical due to the interaction between surface and groundwater in this lowland aquifer: as well as becoming enriched from bedrock contact, <sup>13</sup>C also experiences enrichment from exposure to the atmosphere.

## **A holistic perspective on karst systems, their services for humanity, and human impacts on karst**

**Goldscheider, N**

Karlsruhe Institute of Technology (KIT), Institute of Applied Geosciences, Division of Hydrogeology, Karlsruhe, Germany  
[goldscheider@kit.edu](mailto:goldscheider@kit.edu)

This keynote lecture presents a holistic perspective on karst systems and highlights their value for humanity as well as human impacts on karst, with a focus on groundwater resources and their vulnerability to contamination and overexploitation. Recent research examples are used to illustrate different aspects of this complex of themes, and recommendations for the integrated management of karst resources are formulated.

Karst terrains contain valuable resources and provide various ecosystem services for humanity, such as freshwater for drinking and agricultural use, thermal and mineral water for bathing and energy production, limestone for aggregate, cement and a large variety of industrial and pharmaceutical purposes, and soils for agricultural use. Karst terrains also host a large biodiversity both at the surface and in the underground, and karst processes act as a sink for anthropogenic CO<sub>2</sub> and thus help to mitigate climate change.

At the same time, karst systems are particularly vulnerable to human impacts, ranging from soil erosion to groundwater contamination. All these karst resources and services are intimately interconnected, and so are the vulnerabilities and impact pathways: Impacts on individual elements of the vulnerable karst ecosystem can have unexpected impacts on other elements or even the entire ecosystem. Therefore, the utilization and exploitation of karst resources require wise management approaches that consider these complex interdependencies.

Water is arguably the most valuable and vulnerable karst system resource for humanity. Water is also the key driver of karst processes and the agent connecting all other karst resources, karst ecosystem services, vulnerabilities and impact pathways. In karst terrains, surface and groundwater resources are closely interconnected.

Severe impacts on karst groundwater quality can be observed in some urban areas. A case study from Jordan illustrates the complex interrelations between human impacts on karst groundwater and the utilization of water from karst springs for urban freshwater supply. Another example from Jordan demonstrates the feasibility of Managed Aquifer Recharge (MAR) in karst areas as a way to mitigate hydrologic extremes and overcome water shortage during dry periods, but also highlights the possible ecological side effects.

As a conclusion, the sustainable management and protection of karst resources and services requires a holistic approach including surface and groundwater protection, the prevention of soil erosion and the preservation of surface and subsurface biodiversity.

# Advances in colloid and particle tracing with applications in karst hydrogeology

<sup>1</sup>Goeppert, N. & <sup>2</sup>Goldscheider, N.

<sup>1</sup>nadine.goeppert@kit.edu, Karlsruhe Institute of Technology (KIT), Germany

<sup>2</sup> Karlsruhe Institute of Technology (KIT), Germany

The transport of colloids and (nano-) particles in the subsurface is of major concern to drinking water quality due to introduction of viruses, bacteria, protozoans, and colloid- or nano-sized industry materials, and potentially toxic mobile mineral colloids. Karst aquifers are important fresh water resources and at the same time highly vulnerable to contamination, which can easily enter the aquifer via thin soils or swallow holes, and may be rapidly transported in the conduit network. In rural and alpine karst areas, microbial contamination from agricultural land use often leads to transient severe groundwater quality problems. Fecal and pathogenic bacteria in karst groundwater are often associated with suspended sediment particles which in turn underscores the importance of colloid and particle groundwater tracing methods.

We present the results of different methods and approaches for colloid and particle groundwater tracing using polystyrene microspheres, and natural sediment particles in comparison with a conservative solute tracer. Instrumental advancements in the field of particle detection make it possible to use natural sediments as inexpensive, toxicologically safe and valuable particle tracers that deliver detailed transport parameters for a whole range of particle sizes. First results from an alpine epikarst research site are presented and potential further developments and applications of this promising technique are discussed.

## **Dynamics of microbial communities and functions in natural and stressed groundwater ecosystems – key drivers and major limitations**

**Griebler, C**

Helmholtz Zentrum München, Institute of Groundwater Ecology, Ingolstaedter Landstrasse 1, D-85764 Neuherberg/Munich, Germany, +49 89 3187 2564, [christian.griebler@helmholtz-muenchen.de](mailto:christian.griebler@helmholtz-muenchen.de)

Today groundwater ecosystems face multiple impacts, mainly from anthropogenic activities. It is hypothesized that groundwater ecosystems are specifically sensitive and vulnerable to impacts. Why do we think so? One idea is that systems of low productivity have a low potential to withstand disturbances. My talk will focus on different types of disturbances to groundwater ecosystems, i.e. (1) transient hydraulic conditions, (2) overload or (3) depletion of organic matter, or (4) a combination of these, and will show how microbial communities may react, having a close but separate look at microbes living attached to surfaces and those being suspended in groundwater. Moreover, I will try to link the resistance and resilience of groundwater ecosystems with respect to different disturbances to their microbial carrying capacity. Attention will be paid on bottom-up and top-down controls involved. Key drivers and major limitations that govern the dynamics of groundwater microbial communities are discussed.

## **British Carbonate Karst Environments**

**Gunn, J**

j.gunn.1@bham.ac.uk

Limestone Research Group, School of Geography, Earth & Environmental Sciences, University of Birmingham, Birmingham B15 2TT, UK.

There is nowhere else on earth where there is a greater temporal range of carbonate rock outcrops in such a small geographical area as in Great Britain. They comprise Quaternary freshwater carbonates, limestones and dolostones of Cretaceous, Jurassic, Permian, Carboniferous, Devonian, Silurian, Ordovician and Cambrian ages and Cambrian to Neoproterozoic metacarbonates. Geographically they extend from the southern coast of Devon to the northern coast of Scotland (about 900 km) and from the tip of western Wales to the Cliffs of Dover in the east (about 450 km). One commonly accepted definition of karst is that it is "an integrated mass transfer system in soluble rocks with a permeability structure dominated by conduits dissolved from the rock and organised to facilitate the circulation of fluids" (Klimchouk & Ford, 2000, p.46). All near surface British carbonates meet this definition because they are soluble and groundwater is commonly discharged from them at springs fed by dissolutionally enlarged conduits. An important corollary to the definition is that "Whether karst is expressed at the surface is not relevant" (Klimchouk & Ford, 2000, p.46). This point has been missed by some British hydrogeologists who have classed those carbonates where there are prominent surface landforms, and especially where there are caves, as being 'karstic' whereas other carbonates (most notably those of Jurassic and Cretaceous age) which have few caves have commonly but erroneously been classed 'en masse' as 'non-karstic' or, at best as 'weakly karstic'. This has led to a failure to recognise the marked spatial heterogeneity within all of the large carbonate outcrops such that in some parts of the Cretaceous chalk, commonly regarded as being non-karstic, groundwater has been shown to move rapidly over long distances in dissolutionally enlarged conduits whereas in some parts of the Carboniferous limestones of Derbyshire, commonly regarded as being highly karstic, groundwater velocities may be two orders of magnitude slower. However, none of the unconfined carbonate groundwater systems behave as porous media for transport. It is argued that the main influences on the pattern of groundwater movement are recharge (concentrated recharge from sinking streams and dolines almost always enters integrated conduit systems with rapid groundwater velocities), lithostratigraphy (particularly presence of inception horizons) and structure.

## **Modelling karst hydrology - a balance of available information and model complexity**

**Hartmann, A**

[andreas.hartmann@hydrology.uni-freiburg.de](mailto:andreas.hartmann@hydrology.uni-freiburg.de)

Institute of Earth and Environmental Sciences, University of Freiburg (Germany)

Climate simulations project a strong increase in temperature and a decrease of precipitation in many karst regions in the world over the next decades. Despite this potentially bleak future, few studies specifically quantify the impact of climate change on karst water resources.

This presentation will explore different conceptual models of karst systems and how they can be translated into numerical models of varying complexity. This goes along with varying data requirements and depths of process representation that limit the applicability of current karst models. Methods to evaluate those limitations of current karst models will be shown and methods to adapt and improve our models will be elaborated.

# **Influence of Faulting and Relay Ramp Structures on Groundwater Flow in the Karstic Edwards and Trinity Aquifers, Central Texas, USA**

<sup>1</sup>Hunt, B.B., <sup>1</sup>Smith, B.A., <sup>1</sup>Andrews, A.A., <sup>2</sup>Wierman, D.A., <sup>3</sup>Broun, A.S., & <sup>4</sup>Gary, M.O.

<sup>1</sup>[brianh@bseacd.org](mailto:brianh@bseacd.org), Barton Springs/Edwards Aquifer Conservation District, Austin, TX, USA

<sup>2</sup> Meadows Center for Water and the Environment, San Marcos, TX, USA

<sup>3</sup> Hays-Trinity Groundwater Conservation District, Dripping Springs, TX, USA

<sup>4</sup> Edwards Aquifer Authority, San Antonio, USA

The Cretaceous-age Edwards and Middle Trinity Aquifers of central Texas are critical groundwater resources for human and ecological needs. These two major karst aquifers are stratigraphically stacked (Edwards over Trinity) and structurally juxtaposed (normal faulting) in the Balcones Fault Zone. Studies have long recognized the importance of faulting on the development of the karstic Edwards Aquifer. However, the influence of these structures on groundwater flow is unclear as groundwater flow appears to cross some faults, but not others. This study combines structural and hydrological data to help characterize the potential influence of faults and relay ramps on groundwater flow within the karstic Edwards and Middle Trinity Aquifers.

Detailed structure contour maps of the study area were created from a geologic database (n=380) comprised of primarily geophysical and driller's logs. The data were then contoured in Surfer® (Kriging) with no faults. Structure contour surfaces revealed detailed structural geometries including linear zones of steep gradients (interpreted as faults) with northeast dipping zones of low gradients (interpreted to be ramps) between faults. Hydrologic data (heads, dye trace, geochemistry) were overlaid onto the structure contour maps in GIS. Results for the Middle Trinity Aquifer suggest relay ramps provide a mechanism for lateral continuity of geologic units and therefore groundwater flow from the Hill Country (recharge area) eastward into the Balcones Fault Zone. Faults with significant displacement (>100 m) can provide a barrier to groundwater flow by the juxtaposition of contrasting permeabilities, yet flow continues across faults where they have relatively minor displacement, or where permeable units are juxtaposed with other permeable units. In the Barton Springs segment of the Edwards Aquifer the primary flow path defined by dye tracing and heads is coincident with a relay ramp dipping to the northeast.

This work addresses the lateral continuity (intra-aquifer flow) of these two karst aquifer systems, which has importance for conceptual models and ultimately resource management. A recent water-development controversy from a company proposing to pump a large volume of groundwater from the Middle Trinity Aquifer in the Balcones Fault Zone underscores the issue. Structures that influence groundwater flow will also influence the anisotropy of impacts (drawdown) due to significant pumping.

## **Lithological, structural & stratigraphical influences on karst groundwaters**

**Jeannin, P-Y**

pierre-yves.jeannin@isska.ch,  
SISKA - Swiss Institute for Speleology and Karst Studies, Switzerland

Can the position of the main flow-paths in a karst massif be predicted? Addressing this question will help to delineate water catchment areas, to protect groundwater from potential pollution and to find adequate locations for extracting water. Limestone aquifers may be fissured or karstified, how can the difference be defined and where is the limit within a limestone massif? These questions can be addressed by considering karst genesis. Karst development from early conditions to maturity depends mainly on voids (permeability), and on flow and dissolution processes. Dissolution is known to depend on flow, which depends on permeability, which depends on dissolution once karstification is started (feedback loop). Geology (i.e. lithology, structure and discontinuities) directly controls the initial distribution of voids in limestone as well as the geometry of the aquifer volume (position of aquiclude layers). Flow thus depends strongly on geology! Beside aquifer geometry, geology determines mainly the position and characteristics of discontinuities (bedding planes, fractures). So-called inception horizons were identified as discontinuities, which are particularly favorable to dissolution. Their identification and mapping is therefore one key to predict the position of karst conduits. However, the relative position of the recharge areas with respect to the discharge region is even more important than geological parameters, because it determines the main flow direction (hydraulic gradient) within the limestone massive. Another condition is that conduits mainly develop close to the top of the phreatic zone (so-called "cave levels"). Predicting the position of conduits requires all these aspects to be taken into account. A series of examples will be presented, showing that an adequate inclusion of geological and geomorphological information, coupled with some hydraulics can lead to an explicit sketch of the main flow-paths within a limestone massif. Catchment areas and even a simplified network of karst conduits can be generated. They take into account processes taking place in the epikarst and vadose zone, as well as in the phreatic zone. The generated conduits can be used for flow simulation at catchment scale. These examples illustrate well the way geological conditions can be included in order to assess karst groundwater flow systems.

# Estimating the sources of recharge to karst spring flows in a snow and glacierized catchment, western Himalaya (India)

Jeelani, Gh and <sup>1</sup>Rouf Ahmad Shah

[geojeelani@gmail.com](mailto:geojeelani@gmail.com)

Department of Earth Sciences, University of Kashmir, Srinagar India 190006

In Kashmir the carbonate rocks provide important fresh, clean water to local population in the form of karst springs, which not only play an important role in drinking, irrigation but also provide an important scenic attraction (ecotourism). The objective of the present study was to understand the hydraulic behaviour of major karst springs located in Liddar, Kuthar and Bringi watersheds of Kashmir Valley.

The hydrograph analysis suggested the extensive development of subsurface karstification. During the monitoring period highest discharge of the spring is observed in August and September, whereas minimum discharge is recorded in January. The discharge is linked with ambient temperature, melting of snow and ice accumulated during winter and rainfall. The hydrogeochemical analysis suggested that calcium and magnesium together make up more than 82% on average of the cations in solution, with calcium generally being present in larger concentrations 53% than magnesium 29% and Sodium 14% particularly in cold springs down gradient from their respective source areas. Based on major ion chemistry the spring waters were classified as predominantly Ca-HCO<sub>3</sub> type resulted from the congruent dissolution of carbonate rocks.

$\delta^{18}\text{O}$  and  $\delta\text{D}$  of catchment waters (streams, springs, precipitation and snow) showed a marked spatial and temporal variation during the monitoring period. The precipitation were depleted at higher elevated stations and enriched in stations located at lower altitude. The isotopic composition of precipitation was more depleted in colder months i.e., in January ( $\delta^{18}\text{O}$ : -13‰) and enriched values during summer i.e., in July ( $\delta^{18}\text{O}$ : -1‰). The isotopic composition of streams is affected by the elevations of their catchments. Temporally, streams were enriched in June ( $\delta^{18}\text{O}$ : -4.2‰) and depleted in January ( $\delta^{18}\text{O}$ : -11.7‰). In springs the enriched values were observed in June and depleted in October. The study suggests that the seasonal changes in precipitation type and amount and differential melting of snow and glacier affect the isotopic variability of  $\delta^{18}\text{O}$  and  $\delta\text{D}$  of the spring. The quick response of springs to stream hydrological events coupled with positive correlation of chemical and isotopic species between karst springs and the streams revealed that these karst springs are recharged from respective streams in their catchment at an elevation range of 2000-3500m amsl with a less contribution of rain source.

It was observed that snowmelt (65-81%) and ice melt (16-37%) contributed a significant proportion to the karst spring flows. The average annual contribution of rain to spring flow is meager (up to 7%).

# Utilization of rainwater harvesting in bare karst areas for domestic use and ecological restoration

<sup>1</sup>Guanghai **Jiang**, <sup>2</sup>Kwong Fai, <sup>2</sup>Andrew Lo

<sup>1</sup> [bmnxz@126.com](mailto:bmnxz@126.com), Institute of Karst Geology, China

<sup>2</sup> College of Science, Chinese Culture University, Taiwan

Karst in the southwestern part of China is well known for its polygonal geomorphology and its support for an unique ecosystem. However, people living in this area usually suffer drought, flood and poverty. The geomorphology characteristic of South China forms well-developed underground river systems, intensive depressions and sinkholes. The surface is usually dry even though the annual precipitation is more than 1,000 mm. Groundwater extraction usually reaches 100 m depth and often fails if the subterranean stream location cannot be accurately determined. Epikarst zone is also well-developed. Epikarst water forms in the aeration zone of the aquifer and is collected by water tank which meets the basic water supply requirements in rural households. Because epikarst zone needs to satisfy both ecological water consumption and evaporation, the water tank has small limited storage volume ranging from 50 to 500 m<sup>3</sup> and rather low water security. Severe droughts often occur after extreme weather events. In 2010, a severe drought happened resulting in more than 20 million people drinking water being affected. Rainwater harvesting improvement technology may be able to remedy the water shortage problem and may also enhance local economic development and ecological restoration. Considering the characteristic of karst landform and gathered international experience, rainwater harvesting should not only restricted to roof collection and runoff from impervious surface, but should also include runoff from epikarst zone. Improved regulation of epikarst zone will increase water flow and water quality. To guarantee water storage enhancement, water cycle acceleration and water quality improvement, it is necessary to study in greater detail the process of rainwater collection in epikarst zone and the purification technology of water tanks. Most importantly the collected water should not only use for drinking, but also use for ecological restoration in degraded rock desertification environment. The goal of sustainable environment development may be achieved only through thorough understanding of the relationship of hydrology and ecosystem. This water use strategy escalates the value of karst landform and further enhances the tourism economy in rural areas.

# Neural networks modeling for long-term prediction of *Albarine* river discharge for various scenarii of global change (*Ain* basin – southern France)

<sup>1</sup>Kong-A-Siou, L., <sup>2</sup>Paran, F., <sup>1\*</sup>Johannet, A. & <sup>2</sup>Graillot, D.

\*lead presenter

anne.johannet@mines-ales.fr

<sup>1</sup>Ecole des Mines d'Alès, France

<sup>2</sup>Ecole des Mines de Saint-Etienne, France

During the last decades, droughts frequently occurred in France. One can remember droughts of 1976, 1988, 1997 and the most severe: 2003, which affected mainly the south-east of Europe. In France, regional climate models (ARPEGE) shows an increasing seasonal climatic variability with (a) hotter, drier summer and (b) an increase in the duration and severity of low-flow periods. Future climate changes join with modifications in anthropogenic activities would destabilize interactions between rivers and groundwater. Estimating these interactions is essential for achieving sustainable water use.

In this context, the assessment of groundwater flow between aquifers, rivers and their floodplains is investigated for the *Albarine*, a 59 km long karst tributary of the *Ain* river (Southern France). As a karst terrain, the *Albarine* river is difficult to model because of the lack of physics knowledge about hydraulics parameters of the aquifer. For this reason this study investigates a black box systemic approach based on data-driven modelling: neural network modelling to model rainfall-discharge model. This method was proved to be efficient to simulate drawdown on karst aquifers pumped for water drinking (Kong-A-Siou et al, 2015). This remarkable ability to satisfactorily simulate extreme events comes from a rigorous complexity selection process (Kong-A-Siou, 2011). Compared to classical reservoir models neural networks have the advantage to not be sensitive to parameters initialization, as soil moisture reservoir for example. This work thus proposes to apply neural networks to predict discharge of the *Albarine* river for the period (2010-2070) thanks to actual data (1990-2012) of rainfall and discharge. To this end four SRES B2 scenarii were used: Arpege\_2, Arpege\_1, Arpege\_A2 and Arpege\_B1 which have been widely adopted as standard *scenarii* in climate change impact studies. Rainfalls were taken at monthly time step.

Nevertheless as predicted rainfalls are not temporally synchronized with actual ones, the classical method devoted to complexity selection of the neural model can't be used to determine the optimal neural network for both actual and forecast rainfalls. This work thus will present a new complexity selection method devoted to optimization regarding statistical properties of both discharge and rainfalls. Comparisons performed on common period between rainfall scenario and measured rainfall data with rain gauge allow confirming the good quality of the model for low flow period as well as annual bias prediction.

Kong-A-Siou L, et al : Performance and complementarity of two systemic models (reservoir and neural networks) used to simulate spring discharge and piezometry for a karst aquifer, J. Hydrol., 519, Part D, 3178–3192, doi:10.1016/j.jhydrol.2014.10.041, 2014.

Kong-A-Siou, L., et al. S.: Optimization of the generalization capability for rainfall–runoff modeling by neural networks: the case of the Lez aquifer (southern France), Environ. Earth Sci., 65(8), 2365–2375, doi:10.1007/s12665-011-1450-9, 2012.

# Investigation of presence or lack of hydraulic connection between Emam-Gheise karst spring and water wells of Shahreza, Iran

---

<sup>1</sup>Karami, G.H., <sup>2</sup>Khosravi, R., <sup>3</sup>Fazeli, A.

<sup>1</sup>g.karami@shahroodut.ac.ir, Shahrood University, Iran

<sup>2</sup>Shiraz University, Iran

<sup>3</sup>Chahar Mahal and Bakhtiari Regional Water Company, Iran

In recent decades protection and proper management of water resources in karstic aquifers has been considered because of their important role in providing drinking water. Water resources in karstic aquifers as a supply for drinking water consumptions include more importance in arid and semi-arid regions due to shortage of water resources with good quality.

The purpose of this study is the investigation of the presence or lack of hydraulic connection between the Emam-Gheis karstic spring and drinking water wells of Shahreza. In this study, hydrogeology, hydrogeochemistry and isotopic investigations are done in the catchment area of Emam Gheis karstic spring and water wells.

To determine the catchment area of Emam-Gheis spring firstly, according to geology and geomorphology conditions the probable catchment area was drawn. Then, according to hydrogeologic conditions and karst development, the recharge percentage was estimated about 60% of annual rainfall. According to the volume of dynamic recharge of spring in this water year, which is estimated about 2.4 Mm<sup>3</sup>, primary calculated catchment area was corrected.

To investigate spring and wells hydrogeochemical properties, their physicochemical properties were measured. Also for hydrogeochemical analyses, sampling were carried out 14 times from spring and seven times from wells. The results show that the electrical conductivity in spring is significantly lower than wells. Also, the major ion concentrations and ion ratios in spring and water wells show significant differences.

Stable isotope analyses of spring and nearest wells water samples, sampled simultaneously, showed that the spring water sample is heavier than well water samples. Therefore, the ground water flow from spring toward wells seems unlikely.

# Functional organization and lithostratigraphic control of a large hypogene cave system in the Precambrian carbonates, NE Brazil

<sup>1</sup>Klimchouk, A., <sup>2</sup>Auler, A.S., <sup>3</sup>Bezerra, F.H.R., <sup>4</sup>Cazarin, C.L., <sup>5</sup>Balsamo, F.

<sup>1</sup>klim@speleogenesis.info, Institute of Geological Sciences, NAS, Ukraine

<sup>2</sup>Instituto do Carste, Brazil

<sup>3</sup>Department of Geology, Federal University of Rio Grande do Norte, Brazil

<sup>4</sup>Petrobras, Centro de Pesquisa e Desenvolvimento Leopoldo A. Miguez de Mello, Brazil

<sup>5</sup>NEXT - Natural and Experimental Tectonic Research Group, Italy

Multi-disciplinary studies involving lithostratigraphy, structural geology and morphogenetic analysis, were performed in Toca da Boa Vista and Toca da Barriguda, the largest caves in South America, located in the São Francisco Craton, Brazil. The studies were aimed to reveal the origin and the functional organization of the caves and major controls over its architecture. The system, hosted by the Neoproterozoic Salitre Formation, is an analogue of deep-seated carbonate reservoirs dominated by fracture and hypogene karstic porosity and permeability.

The rock sequence is gently folded, with a system of high frequency, low vertical magnitude (ca. 5-20 m) elongated anticlines and synclines, superimposed on larger dome-and-basin structures of ca. 30-40 m in magnitude. Five lithostratigraphic units within the part of the formation exposed in the cave system are, from bottom to top: (1) grainstone with cross-stratification, (2) fine grainstone with chert nodules, (3) microbial carbonate, (4) interbedded fine siliciclastics and marls, (5) crystalline grainstone interfingering with chert layers.

Tracing the position of cavities of different morphology across the cave system has allowed revealing its three-dimensional architecture. The accessible system exhibits three speleo-stratigraphic storeys, which are distinct relative to the lithostratigraphy although they are not hypsometrically steady because of bedding undulations. Cavities at the lower and upper storeys occur individually or in clusters, being laterally isolated at their respective levels, whereas the middle speleo-stratigraphic storey is laterally extensive and provides for integration of cavities into a single system.

The meso-morphology of the cave strongly suggests its development by ascending flow. Individual speleogens are clearly organized in the “morphological suits of rising flow” within every storey. The cave system was recharged from below via large sub-vertical fractures that occur in swarms mainly at the level of unit 1 but locally extend into the above-lying units. The pronounced lateral conduit development at the middle storey is conditioned by the presence of the densely stratified and pervasively fractured (and hence laterally-conductive) unit 4, the existence of a poorly permeable barrier for rising flow above it, at the bottom of the barely fractured unit 5, and the discordance in the permeability structure between the recharge level in unit 1 and the outflow level in unit 5. Vertical outflow conduits in unit 5, extending into still upper portion of the succession, are scarce compared to recharge conduits in unit 1.

The overall pattern of the caves is therefore clearly organized to conduct rising flow in deep-seated confined conditions, under given geological constraints. In the overall ascending flow system, the formation of the cave pattern was controlled by vertical and lateral heterogeneities in fracture distribution, which in turn depend on the lithostratigraphy and fold geometry. This study highlights the need for the speleo-stratigraphy and functional organization approaches in studying hypogene speleogenesis in layered sequences.

# Approaches for modeling of flow and transport in unsaturated fractured aquifers - From catchment to pore scale

<sup>1</sup>Kordilla, J., <sup>1</sup>Geyer, T., <sup>2</sup>Tartakovsky, A.M., <sup>2</sup>Pan, W. & <sup>1</sup>Sauter, M.

<sup>1</sup>jkordil@gwdg.de, University of Göttingen, Dept. Applied Geology, Germany

<sup>2</sup> Pacific Northwest National Laboratory, Computational Mathematics Group, USA

Karst aquifers are commonly characterized by strong contrasts in the hydraulic parameter field and require sophisticated modeling approaches to capture flow and transport dynamics. This concerns the saturated zone, often dominated by the influence of large conduits networks, but in particular the unsaturated zone with extents of up to several hundreds of meters. Fractures widened by dissolution, karstified horizons at former water table positions and highly conductive surface features such as sinkholes provide a vast number of preferential flow paths. Modeling recharge dynamics and transport through such a system still represents a significant challenge, not only for Karst aquifers but in general for fractured media. Modeling approaches on one hand have to deal with limited knowledge of the exact geometry and on the other hand provide a reliable approximation to the underlying physics of unsaturated flow in fracture networks, which is still not very well understood on pore scales.

Here we would like to present three modeling approaches covering catchment, fracture and pore scales. On catchment scale double-continuum models represent a robust modeling tool taking into account the strong hydraulic heterogeneity of karst aquifers without detailed information about the spatial distribution of discontinuities. Flow in the unsaturated and saturated zone is modeled using a Richards equation coupled with suitable Van Genuchten parameters. We demonstrate the applicability of the approach but also its weaknesses mainly arising from the insufficient description of rapid, gravity-driven flow processes in fractures that cannot be captured with classical soil-based water retention models.

In order to get a deeper understanding of such processes we developed two three-dimensional free-surface Smoothed Particle Dynamics (SPH) models that allow us to investigate the highly dynamic interfaces of such intermittent flow processes. We demonstrate that our models can be applied to simulate complex flow dynamics such as droplets, rivulets and films including the effect surface tension in smooth and rough fractures. Furthermore we present a pore-scale SPH model for stochastic Landau-Lifshitz-Navier-Stokes and advection-diffusion equation. The model allows us to investigate flow and transport processes on mesoscopic pore-scales, where classical Fickian diffusion begins to break down and converges towards a molecular particle description. The accuracy of both models is demonstrated by comparison with various (semi-) analytical solutions.

## What can we learn from hydrograph analysis? Theory and examples

<sup>1,3</sup>Kovács, A., <sup>2</sup>Perrochet, P., <sup>3,4</sup>Darabos, E., <sup>4</sup>Lénárt, L., <sup>3,4</sup>Szűcs, P

<sup>1</sup>Kovacs.Atila@mfgi.hu, Geological and Geophysical Institute of Hungary, 14 Stefania út, Budapest, H-1143, Hungary

<sup>2</sup>CHYN, University of Neuchâtel, Rue Emile-Argand 11, CH-2007, Neuchâtel, Switzerland.

<sup>3</sup>MTA-ME Research Group of Geoengineering, Miskolc-Egyetemváros, 3515, Hungary

<sup>4</sup>University of Miskolc, Department of Hydrogeology and Engineering Geology, Miskolc-Egyetemváros, 3515, Hungary

Spring and well hydrographs contain important information about the hydraulic parameters and geometric characteristics of karst aquifers. The hydraulic properties of matrix blocks and the spatial geometry of karst conduits determine the hydraulic behaviour of karst systems, and thus information about these properties is crucial for the adequate characterisation of karst aquifers.

This study provides an overview of quantitative tools for the estimation of hydraulic and geometric parameters of karst systems by means of spring and well hydrograph analyses. The analytical formulae provided in this study establish links between aquifer properties and hydrograph recession coefficients, and describe the spatial and temporal variations of the water table.

The proposed method is demonstrated through the application of field data. Hydrograph data from test sites were analysed to obtain information about conduit network geometry and hydraulic functioning. While spring hydrograph analytical techniques provide information on the overall characteristics of a karst catchment, well hydrograph analysis provides information on the hydraulic and geometric characteristics of individual matrix blocks. Under persistent draft conditions the scale of groundwater flow can change, which is reflected in hydrograph recession of both spring and well hydrographs. The combination of the spring and well hydrograph analytical techniques provides a powerful tool for the characterization of the structure and hydraulic behaviour of karst systems.

The proposed investigation method provides useful information for water resource assessment, flood prediction, vulnerability assessment, contamination risk assessment, geotechnical and speleological studies.

# The response of Heilongtan spring to the 2010-2012 consecutive droughts of Yunnan Province, China

<sup>1</sup>Liu Hong, <sup>2</sup>Liu Jian, <sup>2</sup>Yang Xiangpeng, <sup>2</sup>Zhang Yinhua

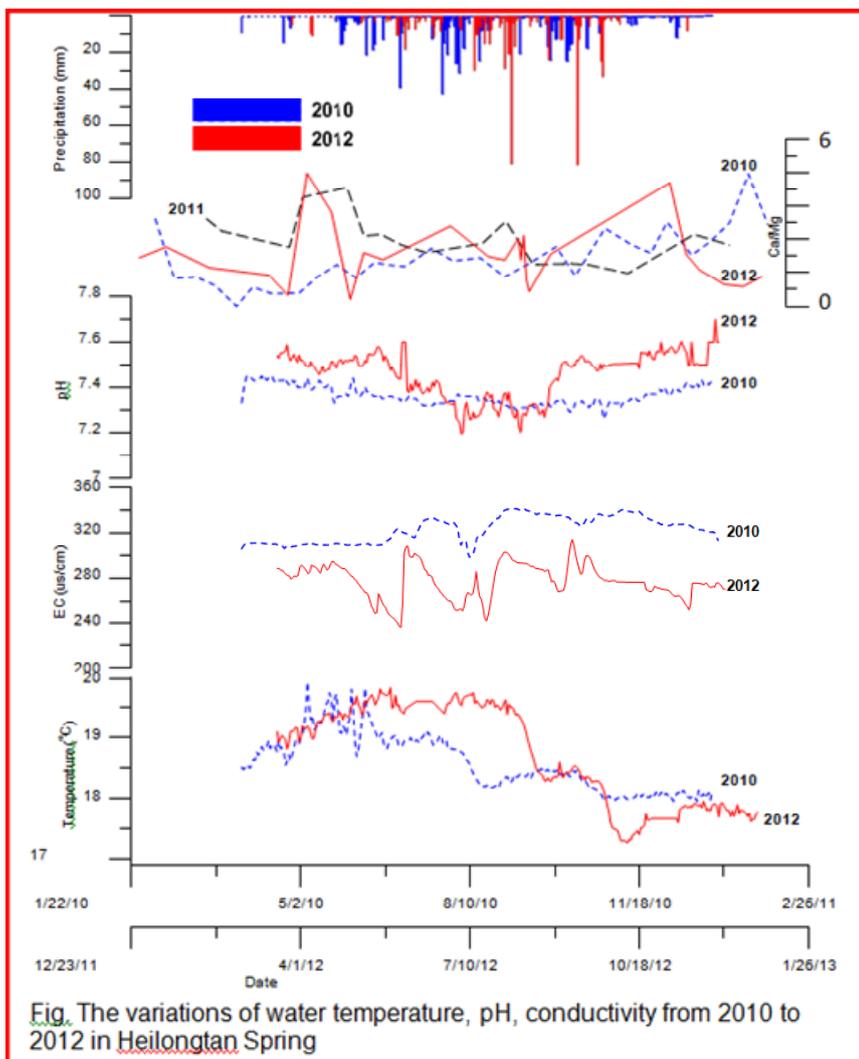
<sup>1</sup>hongliu@ynu.edu.cn, International Joint Research Center for Karstology, Yunnan University, China

<sup>2</sup>School of Resources & environment and earth sciences, Yunnan University, China

Heilongtan Spring is located at foothill of Wulao Mountains in the northern suburb of Kunming City, emerges along east branch of Heilongtan Fault after karst water meets quaternary sedimentary at edge of Kunming Basin. As a weak artesian spring, it is very sensitive to human activities and climate change. From 2010 to 2012, most of Yunnan Province, Southwestern of China has underwent a three years consecutive severe droughts. In those years just have half to two third of normal years' precipitation. A CTDP300 multi-parameter data-logger (measures water-level, Temperature, pH and conductivity with an interval of 15min) installed in March of 2010 has recorded the response of Heilongtan Spring to the drought (figure). Because of no data before drought, we take the data of 2010 to represent the normal situations of the spring due to buffer effects of aquifer system.

During the drought, besides the water table decreasing, the EC of spring was decreasing progressively from 320 $\mu$ S/cm yearly average, range from 295-337 $\mu$ S/cm in 2010 to 299 $\mu$ S/cm (range from 249-323  $\mu$ S/cm) in 2011 and 277 $\mu$ S/cm (range from 241-310 $\mu$ S/cm) in 2012. At the same time, the temperature and pH values of spring water were from relatively stable shift to dynamic change. In the first year of the drought, the ratio of Ca/Mg was constantly increasing from May, but in 2011 and 2012, Ca/Mg ratio was fluctuation

greatly, which highlights the rapid responses of spring to precipitation. All of the evidence shows that, with the drought went on, the water from karstic aquifer was drying and the proportion of water from deeper nonkarstic aquifer was increasing, which caused the EC of spring dropped. Meanwhile the water quality of spring was getting more sensitive to the rain events, with a small to medium quantities of rain, the concentrations of Cl<sup>-</sup> and NO<sub>3</sub><sup>-</sup> of spring water start to increase in a few hours after rain, which will take 7 to 14 days before drought.



# Hydrologically-driven variations in the karst-related carbon sink fluxes: insights from high-resolution monitoring of three karst catchments in Southwest China

Zaihua Liu, Cheng Zeng, Min Zhao & Rui Yang

liuzaihua@vip.gyig.ac.cn

State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang 550002, China

Rainfall (P), discharge (Q), water temperature, pH, and specific electrical conductivity of the three karst catchments, Banzhai, Huanghou and Houzhai, with different land uses and carbonate lithologies but similar subtropical monsoonal climate, in Guizhou Province, Southwest China, were monitored with CTDP 300 high-resolution multi-parameter data loggers during the period of May 2007-October 2013. In addition,  $\text{HCO}_3^-$  and calcium concentrations were titrated in the field and the other major ions determined in the laboratory monthly. Simple models were used to link the continuous physical and chemical data to monthly measured data to estimate the concentration of  $\text{HCO}_3^-$ , the  $\text{CO}_2$  partial pressures and the calcite saturation indices on the high-resolution logger data. Continuous karst-related carbon sink fluxes (CSFs) were also estimated with the continuous Q and  $\text{HCO}_3^-$  concentrations in each catchment area.

The primary goal of this study is to understand how discharge and  $\text{HCO}_3^-$  concentration determine the CSFs at the storm scale, seasonal scale and annual scale, and to estimate the CSFs for the three studied catchments. Results show that the variation in runoff (river discharge) played a more important role in controlling the CSFs than the variation in  $\text{HCO}_3^-$  for all the karst catchments, because of the chemostatic behavior of  $\text{HCO}_3^-$  in the catchments. Soil coverage, vegetation and bedrock lithology determined the CSFs by controlling the proportion of precipitation that recharges groundwater (and thus Q), and controlling the soil  $\text{CO}_2$  productivity (and thus  $\text{HCO}_3^-$ ). The average CSFs in the Banzhai, Huanghou and Houzhai karst catchments were 29, 33 and 39  $\text{t-CO}_2 \text{ km}^{-2} \text{ a}^{-1}$ , respectively, which are 15 times higher than those CSFs by silicate weathering in the silicate-rock catchments with similar hydrology, showing the dominant role of carbonate weathering in the rock-weathering-related carbon sink. The interannual change in CSFs was large (1.7 to 2.5-fold for this study), depending mainly on the variations of catchment river discharge (e.g. high flow year vs low flow year). This suggests that the conventional view that pre- and post-anthropogenic riverine carbon fluxes are equal is problematic, in that large changes in river hydrology caused by global climate and land use and land cover changes have already been documented.

# Multi-causality and spatial non-stationarity in the determinants of groundwater biodiversity patterns in Europe

<sup>1</sup>Malard, F., <sup>1</sup>Eme, D., <sup>2</sup>Zagmajster M., <sup>2</sup>Fiser, C., <sup>3</sup>Galassi, D. & <sup>3</sup>Stoch, F.

<sup>1</sup>malard@univ-lyon1.fr, LEHNA, University Lyon 1, ENTPE, CNRS, France.

<sup>2</sup> SubBioLab, University of Ljubljana, Slovenia

<sup>3</sup> Dept of Life, Health and Environmental Sciences, University of L'Aquila, Italy.

Energy, history and habitat heterogeneity are potentially important factors that drive patterns of groundwater biodiversity in Europe. Yet, their importance has so far been tested separately. The recognition of multi-causality and spatial non-stationarity in the determinants of groundwater biodiversity requires that we consider simultaneously the role of energy, history and habitat heterogeneity, and how these factors vary in strength relative to each other across regions. Here, we selected predictors representing each of these three factors and analyzed jointly their relative importance in shaping the richness and range size of groundwater crustaceans across Europe.

To map European patterns of species richness and range size, we used the European groundwater crustacean data set which contains 21,700 records collectively representing 1,570 species of crustaceans. Species occurrences were projected onto a grid of 10,000 km<sup>2</sup>-cells. Richness was expressed as the number of species occurring in a cell and median range size as the median value of range sizes of all species present in a cell. A species' range size was calculated as the maximum linear distance between the two most distant localities of a species.

We performed simultaneous autoregressive models and geographically weighted regressions to model patterns of species richness and range size. A total of eight environmental predictors representing spatial heterogeneity, energy and history were used in the models. Spatial heterogeneity was represented by aquifer area, elevation range, groundwater habitat diversity and climatic rarity, energy by annual actual evapotranspiration and precipitation seasonality and history by temperature and precipitation anomalies (i.e. the differences in mean annual temperature and annual precipitation between present time and the Last Glacial Maximum).

Overall, we found that species richness was maximum in mid-latitude regions where, in the absence of dry or cold events, productivity remained high over recent geological time. Lower species richness in northern and southern Europe would respectively be due to the long lasting effect of cold Pleistocene climates and increasing aridity, particularly in the Iberian Peninsula.

Median range size increased non-linearly with latitude. This pattern was primarily driven by long-term climate changes, rather than by area/habitat heterogeneity and/or climate seasonality. In the Palaeartic region, the pattern of increasing species range size at higher latitudes in the groundwater crustacean fauna may be the result of three main processes: a disproportionate extinction of small-range taxa in regions severely affected by the cold Pleistocene climate, a stronger selection for generalism and vagility imposed by the increasing amplitude of long-term climatic oscillations and the differential ability of some taxa to colonize vacant habitats following climatic recovery from the Last Glacial Maximum.

## **Recession curve analysis and water temperature vs. discharge relationship of karstic springs on the northern rim of the Silická Planina Plateau (Slovakia)**

<sup>1</sup>Malík, P., <sup>2</sup>Gregor, M., <sup>3</sup>Černák, R.

<sup>1</sup>peter.malik@geology.sk, State Geological Institute of Dionýz Štúr, Slovakia

<sup>2</sup> State Geological Institute of Dionýz Štúr, Slovakia

Three karstic springs are located within 800 metres in a narrow carbonate belt SE of Krásnohorská Dlhá Lúka municipality. The largest Buzgó spring is connected to underground stream of the Krásnohorská jaskyňa Cave. These springs were previously gauged by the Slovak Hydrometeorological Institute and given catalogue Nos. 1862 (Buzgó), 1861 (Pod kameňolom) and 1863 (Pod kapličkou). Middle Triassic carbonates of the Silická planina Plateau in the Slovenský kras Mountains' silicicum unit (sensu geologica) form the infiltration area of these three springs. Limestone block declination on this northern rim of the Plateau down to the Čremošná Brook level creates ideal conditions for groundwater exfiltration here. Neighbouring plateau slopes are formed by impermeable Lower Triassic shales, and the 800m lower edge of the declined block remains the only contact point between the limestone rock mass and the erosional base. According to Slovak Hydrometeorological Institute quantitative monitoring the average Buzgó spring discharge is  $55.96 \text{ L}\cdot\text{s}^{-1}$  and although it attains  $1,355.79 \text{ L}\cdot\text{s}^{-1}$  maximum discharge this decreases to  $5.30 \text{ L}\cdot\text{s}^{-1}$  minimum in drought periods.

Discharges of springs 1862 Buzgó and 1861 Pod kameňolom and their water temperatures that were recorded in the 1958–2012 hydrological period, show good correlation and rapid response to recharge events. However, at 1861 Pod kameňolomom, gauged between 1967 and 1992, recorded discharges were almost one order of magnitude lower than those in 1862 Buzgó. 1862 Buzgó water temperature ranged between 7.6 and 12.2 °C, with 9.3 °C mean, while 1861 Pod kameňolomom temperatures were slightly colder, ranging from 7.0 to 9.7 °C with a mean of 8.8 °C. Distance of orifices of these springs is not more than 200m. Water temperature differences for individual months gauged between 1968 and 1992 are different from those recorded in the 1991–1992 period. In 1991–1992 Buzgó summer, autumn and winter temperatures were 0.2 to 0.6 °C warmer. However, reversed temperature recordings following snowmelt recharge were found in the April – June period, where warmer water flowed out from the Pod kameňolom spring. Unfortunately, Pod kameňolom spring gauging terminated in 1992 and the Pri kapličke spring was gauged only from 1957 to 1965.

Recession curve analysis of the Buzgó stream discharge-time-series was performed by several authors. The first reported recession curve analysis was published in 1979, but mathematical description of recession shown was based solely on exponential equations. Later recession curve analyses of the Buzgó and Pod kameňolomom springs revealed flow components (sub-regimes) mathematically described by linear equations showing the dominant role of open conduits in groundwater flow. Here, laminar flow, mathematically described by exponential equations and linked to groundwater circulation in phreatic fissures is less significant. Open tectonic faults and large karst channels are responsible for high groundwater sensitivity to potential contamination of the limestone aquifer on the Silická planina Plateau's northern rim.

## The invertebrate ecology of Chalk groundwaters

Maurice, L<sup>1</sup>, A.R. Robertson<sup>2</sup>, D. White<sup>1</sup>, L. Knight<sup>3</sup>, T. Johns<sup>4</sup>, F. Edwards<sup>5</sup>, M. Arietti<sup>6</sup>, J.P.R. Sorensen<sup>1</sup>, D. Weitowitz<sup>2</sup>, B.P. Marchant<sup>1</sup>, and J.P. Bloomfield<sup>1</sup>

<sup>1</sup>[loma@bgs.ac.uk](mailto:loma@bgs.ac.uk), British Geological Survey, UK

<sup>2</sup> Roehampton University, UK

<sup>3</sup> Hypogean Crustacea Recording Scheme, UK

<sup>4</sup> Environment Agency, UK

<sup>5</sup> Centre for Ecology and Hydrology, UK

<sup>6</sup> Veolia Water, UK

The Chalk is a vital water supply aquifer and yet ecosystems within it have not been well characterised and are not fully recognised. Recent work has revealed that stygobitic invertebrates are extremely common in the English Chalk. A study of 198 boreholes in 7 areas identified stygobites in 69% of boreholes in the unconcealed Chalk. In Chalk boreholes *Niphargus kochianus* was very common in southern England, whilst *Niphargus aquilex* was more common in northern England and rare in southern England. Sampling a single habitat over a wide area enables improved understanding of species distributions, although some species are sufficiently rare that it is difficult to determine their distributions. Net sampling above the bottom of boreholes and CCTV imaging revealed how stygobites used borehole microhabitats relating to fissure distributions and changes in water column chemistry. A study using packers to isolate fissures identified from imaging and borehole dilution testing revealed that stygobitic invertebrates are present in fissures up to 98 m below the surface, and also enabled new understanding of borehole ecology sampling techniques. Genetic studies have revealed that the *Niphargus* species present in the Chalk aquifer separated from their nearest relatives in continental Europe between 0.6 and 5.6 million years ago and are therefore ancient species that have survived extreme climate and geological changes, representing an important contribution to biodiversity. Overall, the English Chalk harbours an important subsurface ecosystem, where groundwater adapted invertebrates exploit microbial resources at a variety of depths and water chemistries, across a wide geographic region, and where both historical (glacial) and geological (concealed versus unconcealed) constraints influence diversity and distributions. Some of these organisms turn out to be sufficiently widespread that they could potentially be valuable indicators of water quality, or provide other ecosystem services, and as specialist organisms, with their own habitat requirements, they represent a unique and little understood component of biodiversity.

# Quantification of submarine/intertidal groundwater discharge from a lowland karst catchment

<sup>1</sup>McCormack, T., <sup>2</sup>Gill, L.W., <sup>2</sup>Naughton, O., & <sup>2</sup>Johnston, P.M.

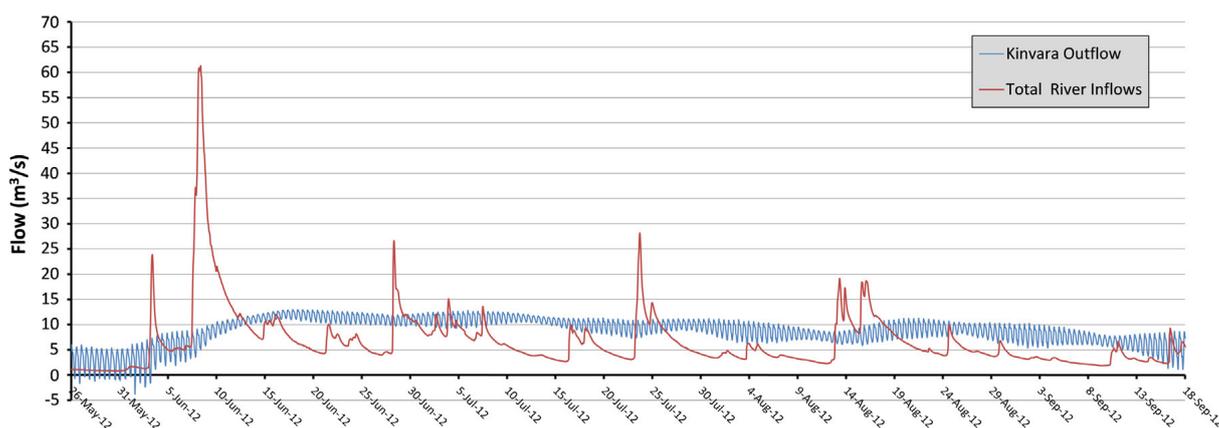
<sup>1</sup>mccormte@tcd.ie, Trinity College Dublin, Ireland

<sup>2</sup> Trinity College Dublin, Ireland

Submarine groundwater discharge (SGD) is now recognised to be a process of significant importance to coastal systems and is of increasing interest within oceanographic and hydrologic research communities. However, due to the inherent difficulty of measuring SGD accurately, its quantification at any particular location is a relatively slow process often involving multiple labour intensive methods.

In this study, the SGD occurring at Kinvara Bay, the outlet of a lowland karst catchment in Western Ireland, is estimated using a hydrological pipe-network model. The model has been calibrated based on observed water levels in a series of ephemeral lakes and was then further verified by means of a relatively simple salinity survey in the bay. Discharge at Kinvara predominantly occurs via two springs, Kinvara West (KW) which serves as the outlet of a major, primarily allogenicly fed, karst conduit network and Kinvara East (KE) which discharges water from more diffuse/autogenic sources. Discharge from these springs occurs intertidally and as such, their flow rates cannot be measured using traditional methods.

Using the hydrological model, flow rates from KW were seen to vary between 5 – 16 m<sup>3</sup>/s with a mean value of 8.7 m<sup>3</sup>/s. Through hydrochemical analysis, this estimated discharge was found to be supplemented by an additional 14-18% via sources not accounted for by the model. Mean discharge at KE was also estimated as approximately 2 m<sup>3</sup>/s, thus the total mean discharge from both Kinvara Springs was determined to be 11.9 – 12.3 m<sup>3</sup>/s (See Figure 1). Overall, the range of discharge was found to be lower than previously thought as earlier studies had no means of quantifying attenuation within the conduit network.



**Figure 1.** Allogenic river inflow vs modelled spring outflow (May 2012 – September 2012)

This research illustrates the benefits of a numerical modelling approach to the quantification of SGD when used in the appropriate hydrological scenario.

# Groundwater Vulnerability Assessment of an Agricultural Karst Landscape

<sup>1</sup>Mellander, P.-E., <sup>2</sup>Jordan, P., <sup>3</sup>Melland, A.R., <sup>4</sup>Murphy, P.N.C., <sup>5</sup>Wall, D.P., <sup>6</sup>Meehan, R., <sup>7</sup>Meehan, R., <sup>8</sup>Kelly, C., <sup>1</sup>Shine, O. & <sup>1</sup>Shortle, G.

<sup>1</sup> Per-Erik.Mellander@teagasc.ie, Agricultural Catchments Programme, Teagasc, Ireland.

<sup>2</sup> School of Environmental Sciences, University of Ulster, N. Ireland.

<sup>3</sup> National Centre for Engineering in Agriculture, Univ. of Southern Queensland, Australia.

<sup>4</sup> School of Agriculture and Food Science, University College Dublin, Ireland.

<sup>5</sup> Crops, Environment and Land Use Programme, Teagasc, Ireland.

<sup>6</sup> Environmental Protection Agency, Ireland

<sup>7</sup> Talamh Consulting, Ireland.

<sup>8</sup> TOBIN & CO. Ltd., Ireland.

It is perceived that nutrients, and in particular Phosphorus (P), in groundwater from karst aquifers contribute to poor ecology of the surrounding surface waters. For this reason concepts of specific groundwater vulnerability have been developed in the European Union.

This study applied concepts of specific P vulnerability to develop intrinsic groundwater vulnerability risk assessments in a 32 km<sup>2</sup> karst spring zone of contribution in a relatively intensively managed agricultural landscape in western Ireland. Concepts of P attenuation potential were investigated along the nutrient transfer continuum based on soil P buffering, depth to bedrock and retention within the aquifer in order to explain why emergent spring water was below an ecological impairment threshold.

Despite the area having thin soils; much of the P was buffered by the soil. Phosphorus was to some degree buffered even in the dolines, bedrock fissures and larger conduits. Dolines were found to be the most common surface karst feature in the area of which 1327 were mapped and classified based on the potential to buffer P by the soil at the base. More than 90% were classified as being of low risk for P transfer to groundwater. New techniques using high frequency monitoring of P concentrations and water discharge in the emergent spring made it possible to estimate P transfer pathways and retention within the aquifer. Small-medium fissure flows were estimated to be the dominant pathway, delivering 52-90 % of P loads during storm events. Annual total P delivery to the main emerging spring was 92.7 and 138.4 kg total P (and 52.4 kg and 91.3 kg as total reactive P) for two monitored years, respectively.

A proposed 'specific vulnerability map' classified 14% of the site as highly vulnerable for P loss to groundwater and matched the observed water quality in the emerging spring better than the previous 'intrinsic vulnerability map'. When overlaying areas of high source pressure on high vulnerability areas to generate a 'Critical Source Area map' only 2% of the area was identified as at high risk. Encouraging farmers to reduce soil P to the optimum for farming offers a simple way to reduce that risk with no impact on production. The assessment can be used to modify expectations of risk and focus management efforts in karst landscapes sensitive to nutrient loss and eutrophication.

# Chemical and isotope characteristics of the surface water in karst-dominated area of Kinta Valley, Malaysia

Ros Fatimah **Muhammad** & Norhidayah Masuari

University of Malaya, Kuala Lumpur

Concentration of major ions and environmental isotope of oxygen ( $\delta^{18}\text{O}$ ) and hydrogen ( $\delta\text{D}$ ) of river and pond waters have been studied in the karst dominated area of Kinta Valley. The sampling point distribution widely covers different lithologies and various human activities. River and pond waters throughout Kinta Valley demonstrate the variability of chemical composition. The river water chemistry is dominated by  $\text{Ca}^{2+} > \text{Na}^{+} > \text{K}^{+} > \text{Mg}^{2+}$  and  $\text{HCO}_3^{-} > \text{CO}_3^{-} > \text{NO}_2^{-} > \text{SO}_4^{2-}$  while pond water chemistry is dominated by  $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^{+} > \text{K}^{+}$  and  $\text{HCO}_3^{-} > \text{SO}_4^{2-} > \text{CO}_3^{-} > \text{Cl}^{-}$ . The water facies in the river change from type Na- $\text{HCO}_3$  to Ca- $\text{HCO}_3$  from upstream to downstream and the pond water type belongs to Ca- $\text{HCO}_3$ . Differences in the chemical facies show the relationship of the water-rock interaction in different lithologies. The major mechanism that is controlling the surface water chemistry of the study area is known as chemical weathering of rocks, with a minor contribution from the atmospheric input. The silicate weathering is predominant in the (Na+K) rich water and carbonate weathering is significant in the (Ca+Mg) rich-water. The regression line of surface water in the area is nearly correlated with Local Meteoric Water Line (LMWL) in tropical and subtropical island ( $\delta\text{D} = 4.6 (\pm 0.4) \delta^{18}\text{O} + 0.1 (\pm 1.6)$ ). The regression line of the river is described by the equation:  $\delta\text{D} = 5.6 \delta^{18}\text{O} - 4.24$ . The regression line of the pond is illustrated by the equation:  $\delta\text{D} = 6.5 \delta^{18}\text{O} - 1.1$ . The high range of d-excess (0.8-23.7) recorded that the surface water of Kinta Valley is highly affected by the evaporation and would suggest contribution of fractionation (evaporation) of the moisture flux along the incoming vapour.

## **Fresh-water lens dissolution: The lack of strong lithologic and structural control in a laminar and transitional flow system**

<sup>1</sup>**Mylroie, J E** and <sup>1</sup>Joan R. Mylroie

<sup>1</sup>jem2@msstate.edu

Mississippi State University, USA

Dissolution as a result of mixing in the discharging margin of the fresh-water lens creates a well-known cave type called the *flank margin cave*. The caves are not conduits, but receive diffuse flow from the lens interior and pass that flow seaward as diffuse flow with release to the ocean. Flow is not turbulent and has little focus other than an outward radial character; flank margin caves are mixing chambers embedded in a diffuse flow system. The host carbonate rock can be in a wide variety of configurations: from 30% primary-porosity eogenetic aeolian calcarenites and reefs, to rounded rubble deposits, to angular breccias, to paleotalus, to highly fractured teleogenetic rock. Unlike turbulent flow conduit (epigenic) caves, dissolution occurs not along favored planar features, but across a three-dimensional volume, which works best with a well-distributed porosity that is highly permeable, which is true of the facies listed above.

The dissolutional mechanism is powerful, as it cuts directly across variations in the host rock: vadose speleothems and wall rock, corals and matrix; dipping cross beds; and terra rossa paleosols. The significant available dissolutional power allows cave development in very short time periods (geologically), including glacioeustatic sea-level highstands of less than 10 ka duration. Such rapid dissolution makes flank margin caves excellent sea-level indicators, and unlike other indicators such as wave-cut notches, are not immediately vulnerable to removal by surface denudation after sea-level fall. The constancy of form and morphology in a variety of carbonate rock types makes these caves readily identifiable across the globe, and in the rock record. Their presence on the margin of carbonate platforms places these caves in an environment predisposed to preservation as carbonate sedimentation continues and isostatic subsidence occurs; most paleokarst voids are likely either hypogenic or flank margin in origin. As a result, the majority of paleokarst reservoirs may be the direct result of earlier coastal karst processes

# Reducing the ambiguity of karst aquifer models by pattern matching of flow and transport on catchment scale

<sup>1</sup>Oehlmann, S., <sup>1</sup>Geyer, T., <sup>1</sup>Licha, T. and <sup>1</sup>Sauter, M.

<sup>1</sup>sandra.oehlmann@geo.uni-goettingen.de, University of Göttingen, Göttingen, Germany

Distributed numerical modeling is an effective and process-based tool for the prediction of groundwater quantity and quality. However, the development of distributed models is highly challenging for heterogeneous karst aquifers. This is mainly due to the generally unknown positions and hydraulic properties of highly conductive karst conduits. Therefore, distributed numerical models are often only used for the simulation of theoretical scenarios. If applied to a real karst catchment area, they are usually strongly simplified and only able to simulate a single objective, e.g. the hydraulic head distribution, spring discharge or tracer breakthrough curves. However, experiences with the more frequently applied lumped-parameter models show that the calibration for several independent field objectives can be used to greatly reduce model ambiguity. Especially the combination of groundwater flow and transport could significantly improve the abilities of the model to not only serve for aquifer characterization but also for predictive assessment of contamination scenarios.

In this work, a hybrid model for groundwater flow and transport was developed for a well-investigated karst catchment area in south-western Germany. For this, an interface for one-dimensional flow and solute transport coupled to a three-dimensional fissured matrix was implemented in the software COMSOL Multiphysics<sup>®</sup>. The model was calibrated for the steady-state hydraulic head distribution derived from 20 observation wells, the spring discharge of six karst springs and the transport velocities of two tracer tests. Furthermore, a number of measured parameters like the hydraulic conductivity of the fissured matrix and the maximum karst conduit volume were available for model parameterization. Parametric studies were conducted including different conduit geometries for assessing the influences in a large-scale, heterogeneous karst catchment area.

Results show that it is possible not only to derive a consistent flow and transport model for a 150 km<sup>2</sup> karst area but also to use the combination of flow and transport for reducing model ambiguity. Under the given boundary conditions, the model is able to reproduce all objectives. Additionally, it gives reasonable approximations for the catchment areas of the two major karst springs in the model area and can therefore be used for spring catchment delineation. The karst conduit network in the area is not available for direct field measurements. However, the model gives information about the geometry and hydraulic properties. It is shown that the conduit radius and the conduit roughness change throughout the model area and cannot be represented by constant parameters. Furthermore, the conduit network volume for the main karst spring could be narrowed down to approximately 100 000 m<sup>3</sup>, which is only 50% of the maximum volume derived by other estimation methods, which were neglecting the influence of the fissured matrix.

# The characterization of karst hydrological functioning based on spring responses analysis

<sup>1</sup>Paiva, I., <sup>1</sup>Cunha, L. & <sup>2</sup>Ramos, C.

<sup>1</sup>[isabelrp@ci.uc.pt](mailto:isabelrp@ci.uc.pt), University of Coimbra, Portugal

<sup>2</sup> University of Lisbon, Portugal

The presentation overviews the results of different methods used on the study of karst hydrodynamic functioning based on spring responses analysis. These methods were developed and applied separately in order to better understand a complex karst system functioning. From a global to a detailed perspective, we applied three different methods, widely used in karst hydrology: (i) study of recession curve; (ii) study of the relationship between rainfall and spring response using time series analysis (correlation and spectral analysis) and the interpretation of water temperature and electrical conductivity variations at spring outflow. The time series considered in the analysis are daily and hourly data of rainfall (recharge area), flow, temperature and electrical conductivity of the main spring collected every twenty minutes during four hydrological years (since 2009-2010 to 2012-2013).

This analytical perspective provides valuable results because spring response reflects a composite of everything that happens upstream. As a result, water discharging from a karst spring carries an imprint of the global functioning of the aquifer. Due to the complexity of karst aquifers and of the processes involved, the hydrodynamic behaviour of the karst aquifer is studied here from an input-output systems analysis viewpoint, establishing the relationship between hydrological inputs and the spring discharge as outputs. Thus, karst aquifer is considered as a black-box system, i.e. a filter that transforms, retains, or eliminates the input signal in the creation of an output signal.

The study system is a non-well-known karst aquifer that covers an area around 120 Km<sup>2</sup> in middle Jurassic rocks (Bajocian and Bathonian limestone) at the central-western part of Portugal. This rock massif is highly karstified and extremely faulted at western and south shore. The recharge area locates about 300 to 350 meters a.s.l. and is quite flat but heterogeneous in terms of soil/epikarst thickness spatial distribution and karst surface forms as well. The discharge points are intermittent and perennial springs at 40-70 meters a.s.l. along western boundary of the aquifer. The main outlet of the system is Olhos d'Água do Anços spring, where the data are collected. Daily discharge rates present a significant annual variation: from 0.2 m<sup>3</sup>/s (low waters period) to 5.5 m<sup>3</sup>/s (winter period).

The main results reflected simultaneously high and low transformation of the input signal, which provided valuable information on the nature of global flow dynamics in the karst aquifer. Furthermore, these results revealed some general characteristics of the structure of the karst aquifer, mainly in terms of functionality of network drainage system, storage capacity and internal degree of karstification.

The improvements on the knowledge of the hydrodynamics of the studied karst aquifer prove that the compilation of several methods and techniques is an excellent methodology to karst hydrological functioning study.

## **Duration and Significance of Vadose Perching in Karst: Mammoth Cave Region, USA**

**Palmer, A.N.**

arthur.palmer@oneonta.edu, State University of New York, Oneonta, NY, USA

Perching of vadose water in karst is a significant topic in speleogenesis, and of even greater concern in contaminant dispersion. This presentation is based on structural mapping of many karst areas of the USA, with specific emphasis on the Mammoth Cave region of Kentucky.

Much of the vadose water in stratified aquifers follows the local dip of bedding planes, with interruptions where fractures deflect flow along steeper paths. In low-dip strata the lateral component of vadose flow can extend for great distances. In the Mammoth Cave region, where the mean dip is only  $0.3^\circ$ , the down-dip flow component can exceed 5 km. Perched water can pass not only beneath topographic divides, but also above groundwater divides. Groundwater gradients indicated by well data generally differ in direction from vadose paths determined by dye tracing. In many places they trend in nearly opposite directions. Perched vadose flow directions can rarely be detected by well borings or geophysical methods.

Structural mapping of ~80 km of passages in various caves, including >50 km in the Mammoth Cave region, shows that vadose water follows local dips influenced by depositional irregularities in perching strata and by small tectonic warps. In low-dip settings, the flow directions of perched water can deviate greatly from the dip directions implied by the structural contour lines shown on published geologic maps. Cave passages that cross over or under each other generally occupy different strata that have incongruent structural attitudes. Active vadose stream passages remain perched as much as 300 m above the local water table. Dating of cave sediments with cosmogenic radionuclides shows that some perched vadose streams have persisted at elevations up to 50 m above the local water table for more than 1.3 My. Data from cave passages can be extrapolated back in time to when they were inaccessibly small bedding-plane partings containing laminar flow.

Perching is most common atop shale and chert beds (even where thin), limestone/dolomite interfaces, partings between massive beds, and disconformities. These can all be considered inception horizons, whether or not they involve a favorable chemical process such as pyrite oxidation. The cave data base shows that >90% of vadose flow paths in well-bedded, low-dip strata are perched and oriented down the dip, with  $<10^\circ$  deviation from the dip direction, and with an overall discordance of  $<10^\circ$  between dip angle and passage gradient.

In well-bedded but folded and fractured strata, the down-dip proportion is ~50%, and in massive fractured rocks it is only ~25%. Vadose perching is prominent in these two types, but the flow direction and discordance show more scatter than in the sample described in the previous paragraph.

This perching phenomenon has great application to the problem of contaminant dispersion and the monitoring of waste facilities. A sobering thought is that this is likely to be an unrecognized problem in all prominently bedded rocks – not only in soluble strata.

# **Influence of layering on the formation and growth of dissolution pipes in karst systems**

**Petrus, K and Piotr Szymczak**

Karine.Petrus@fuw.edu.pl

Faculty of Physics, University of Warsaw, Pasteura 5, 02-093 Warsaw, Poland.

In karst systems, hydraulic conduits called dissolution pipes (a.k.a. wormholes) are formed as a result of the dissolution of limestone rocks by the water surcharged with CO<sub>2</sub>. The dissolution pipes are the end result of a positive feedback between spatial variations in porosity in the initial matrix and the local dissolution rate. A small enhancement in porosity at some point in the reaction front increases the fluid flow in that region, which convects reactant further downstream. By this means any local variation in porosity is amplified as the reaction front passes through and propagates downstream with the front, eventually developing into dissolution pipes. As dissolution proceeds the growing pipes interact, competing for the available flow, and eventually the growth of the shorter ones ceases.

Here, we investigate numerically the effect of rock stratification on the dissolution pipe growth, using a simple model system with a number of horizontal bedding planes, which are less porous than the rest of the matrix. Stratification is shown to affect the resulting piping patterns in a variety of ways. First of all, it enhances the competition between the pipes, impeding the growth of the shorter ones and enhancing the flow in the longer ones, which therefore grow longer.

Next, it affects the shapes of individual dissolution pipes, with characteristic widening of the profiles in between the layers and narrowing within the layers.

These results are in qualitative agreement with the piping morphologies observed in nature. Importantly, measuring the ratio between the pipe diameters in different layers can provide one with information on the conditions prevailing during the formation of the pattern as well as on the physical characteristics of the layers in a given natural system.

Finally, we relate our results to the Laplacian path models, in which the growth takes place only at the tips of the long-and-thin fingers. This description, although simplified, turns out to capture many features of the dynamics of the dissolution pipe system and allows for the effective prediction of the resulting patterns.

# Complex hydrogeological dynamic of the Lomme Karst System (Belgium) characterized by high resolution monitoring and tracer tests

<sup>1,2</sup>**Poulain, A.**, <sup>2</sup>Rochez, G., <sup>2</sup>Hallet, V.

<sup>1</sup>amael.poulain@unamur.be

<sup>2</sup>Department of Geology – University of Namur, Belgium

Paleozoic carbonate aquifers represent major groundwater resources in Belgium. Karstification processes affect most of them and Belgium counts many hydrologically active karst networks. Given the intrinsic vulnerability of such geological objects, comprehensive studies are required in order to improve their protection and management.

The **KARAG** project (**K**arst **A**quifer **R**ese**A**rch by **G**eophysic, 2013-2017) aims to identify the specific dynamic of karst aquifers by using geophysical and hydrogeological tools. This study is funded by the Belgium National Fund for Scientific Research (FNRS) and conducted by the University of Namur, University of Mons and the Royal Observatory of Belgium.

The **LKS** – **L**omme **K**arst **S**ystem (Rochefort, southern Belgium) was chosen for this purpose. It is a major Belgian karst system (10 km long) in the Givetian carbonated aquifer (Middle Devonian). The system is formed by two parallel components; the surface system (the Lomme River) and a complex underground system (multiple sinkholes with one main exsurgence). Based on this layout, it is possible to study the aquifer dynamic and its relationship with the surface river.

A high resolution monitoring has been set up since July 2013 (temperature, EC, water level, 15 stations with 15 minutes time step) in order to follow the system dynamic during several hydrogeological cycles. Detailed analysis of the probe record provides insights about flow path organization and the karst aquifer dynamic.

Multi-tracing experiments with several injection and monitoring points (Fluorometer GGUN FL30, Schnegg, 2002) allow to highlight the complexity of underground flows dynamic. The connectivity between the monitoring points has been detailed and shows the variability of karst network connection under variable hydrologic conditions. The results also show the partitioning of the carbonated aquifer in different sub-catchments within the same hydrographical catchment. The breakthrough curve analysis allows to characterize the hydrodynamic behavior of the underground flows within the sub-catchments.

Further advanced modeling steps will be necessary to bring together hydrochemical and tracer tests data in order to build a hydrogeological conceptual model for this karst system. This model will also be used to interpret geophysical data (ERT, gravimetry) collected in order to study unsaturated zone and epikarst.

*Schnegg, P.-A., (2002) An inexpensive field fluorometer for hydrogeological tracer tests with three tracers and turbidity measurement. Groundwater and Human development, Balkema, Mar del Plata, Argentina, pp. 1484-1488.*

# Parameters controlling the general groundwater flow of the carbonate karst aquifers in the Zagros Simply Folded Belt

Raeisi, E.

[e\\_raeisi@yahoo.com](mailto:e_raeisi@yahoo.com), Shiraz University, Iran

The Zagros orogenic belt is divided into the Simply Folded Belt (ZSFB), the Fold-and Thrust-Belt, the Zagros Thrust System and the Sanandaj-Sirjan Metamorphic Belt. The ZSFB is characterized by the repetition of long and regular anticlinal and synclinal folds. The anticlines are normally mountain ridges, mostly consist of limestone, and the synclines are valleys and plains. The karstic rocks are composed of limestone, dolomite, anhydrite and halite. The main carbonate aquifers are in the Asmari-Jahrum, Tarbur, Sarvak, Daryian, Fahliyan, Surmeh, Dalan and Kangan Formations in south-central part of Iran, forming broad highlands. The karstic carbonate aquifers overlay and underlay the impermeable formations. Only the top of the anticlines are bare, therefore exposing the carbonate formations. The types of karstic aquifers are shallow depth unconfined and confined, and oil or gas-capped deep confined. The characteristics of these aquifers are not unique. The exposed anticlines consist of only one main aquifer, two aquifers on each limb, or several sub-aquifers (Ashjari and Raeisi, 2006; Raeisi, 2008). The general flow directions are parallel to the strikes toward one or both plunges of anticlines, from one limb to the other, or toward adjacent aquifers. The general flow route may be less than one to tens of kilometers. The variability in geometry, number of aquifers, discharging points and general flow direction depend on the characteristics of the ZSFB, such as its lithological settings, folding, faulting, topography, rate of uplift, fault brecciated rocks, outcrop of the impermeable formations in the core of the anticline, superimposed river and local base of erosion.

High-pressure oil or gas-capped deep confined aquifers are trapped at the crest of some of the ZSFB anticlines. These types of aquifers were developed under special structural settings and have special characteristics in comparison to the shallow confined aquifers (Nadri, et al., 2013). The source of the brine is evaporated sea-water (Bagheri, et al., 2014). The stratigraphy and structural settings are the main parameters, controlling characteristics of the ZSFB aquifers. Detailed knowledge of the ZSFB geological settings is the main key element to optimum usage and protection of the karstic water resources.

## References

1. Ashjari, J. and Raeisi, E. 2006. Influences of Anticlinal structures on regional flow, Zagros, Iran. *Journal of Caves and Karst Studies*. 68: 118-127.
2. Bagheri, R., Nadri, A., Raeisi, E., Eggenken, H.G.M., Kazemi, G. A., Montaseri, A. 2014. Hydrochemical and isotopic ( $\delta^{18}\text{O}$ ,  $\delta^2\text{H}$ ,  $87\text{Sr}/86\text{Sr}$ ,  $\delta^{37}\text{Cl}$  and  $\delta^{81}\text{Br}$ ) evidence for the origin of saline formation water in a gas reservoir. *Chemical Geology*. 384:62–75.
3. Nadri A, Bagheri R., Raeisi, E. Ayatollahi S. S. and Bolandparvaz-Jahromi, K. 2013. Hydrodynamic Behavior of Kangan Gas-Capped Deep Confined Aquifer in Iran. *Environmental Earth sciences*. 71: 1925-1936.
4. Raeisi, E. 2008. Groundwater Storage Calculation in Karst Aquifers with Alluvium or no-flow boundaries, *Journal of Cave and Karst Studies*, 70: 62-70.

# Determination of controlling parameters for hydrodynamic and physicochemical signatures of karst aquifers by distributed parameter hybrid models

<sup>1</sup> Kavousi, A., <sup>2\*</sup>Reimann, T., <sup>3</sup>Giese, M., <sup>3</sup> Raeisi, E., & <sup>2</sup> Liedl, R.

\*presenting author

<sup>1</sup> kavousi@shirazu.ac.ir, Department of Earth Sciences, Shiraz University, Iran

<sup>2</sup> thomas.reimann@tu-dresden.de, Institut für Grundwasserwirtschaft, TU Dresden, Germany

<sup>3</sup> Geoscientific Centre, University Göttingen, Germany

Karst aquifers are recognized as highly anisotropic, heterogeneous media where recharge, storage, flow, and discharge processes may take place throughout a wide range of opening sizes. Due to this peculiar hydrogeological setting, characterization of karst aquifers is a very challenging and costly task. Although some karst aquifers are well studied, based on recorded long-term data of hydrodynamic and physicochemical signatures of spring, accessible cave streams, and boreholes, controlling aquifer parameters on these signatures are less quantitatively inspected. Different numerical modeling approaches, with certain advantages but also limitations, have been applied for karst aquifers. Among all, only distributed hybrid models, coupling discrete conduits with a matrix continuum, directly incorporate the observed aquifer geometry and measured hydraulic parameters; and therefore, facilitate evaluation of different aquifer realizations. Inverse applications of such models enable us to characterize parameter sensitivities and uncertainties for complex real-world karst systems.

An enhanced version of the recent hybrid model MODFLOW-2005 Conduit Flow Process is complemented by additional hydraulic features like conduit associated drainable storage (CADS) together with transport modules for advective-dispersive heat- and solute transport under consideration of matrix diffusion. The numerical hybrid flow- and transport model is used to investigate three idealized model settings with different conduit geometries (i.e. single, branched and networked), but with similar distributed and direct recharge components. The model sizes are based on the Sheshpeer karst catchment, located in south central Iran. Model input parameters are selected according to the catchment properties or feasible ranges from literature, and generated by Sobol's quasi-random sequence. Aquifer signature time series (i.e. spring hydro-chemo-thermographs beside potentiometric heads of matrix and conduit) were simulated for different parameter combinations; and their descriptive statistical indicators, such as arithmetic mean, standard deviation, lag time, and global maximas/minimas, were considered as the outputs for variance based sensitivity analysis (VBSA). The indexes of VBSA and Spearman coefficients were used to reveal the aquifer controlling parameters.

Results of the parameter study / sensitivity analysis show that the conduit diameter is by far the main controlling parameter on spring hydro-chemo-thermo-graphs, for all considered model settings. CADS width, conduit tortuosity, conduit roughness, and saturated water content of epikarst/vadose zone are the next key parameters on spring signatures; while the matrix parameters are insensitive (i.e. unidentifiable). Finally, these model results are used to set up a realistic and detailed model of the Sheshpeer catchment that can be inversely solved, based on measured long-term hydrographs together with chemo- and thermographs, with acceptable computational effort.

## **Strategies for the Response to Hazardous Materials Releases in Karst**

**Schindel, Geary M.**

Edwards Aquifer Authority/Karst Works, Inc., San Antonio, Texas USA

[gschindel@edwardsaquifer.org](mailto:gschindel@edwardsaquifer.org)

Karst aquifers are one of the most vulnerable aquifer types to contamination. In regards to other aquifer types, karst aquifers are noted for rapid recharge, high groundwater velocities, and little attenuation of contaminants. The release of hazardous materials into a karst terrain can result in a direct and rapid impact to public health and aquifer and surface water ecological systems. The response to hazardous materials releases is well developed in most industrialized and urbanized communities. However, many communities may not understand some of the unique aspects of karst terrains resulting in unforeseen and potential catastrophic consequences to groundwater resources.

This paper identifies some of the sources of hazardous materials releases and recommendations regarding a response strategy including research on aquifer properties, preplanning with agents responsible for hazardous materials incident responses, techniques to investigate potential receptors, and on-site remediation and monitoring recommendations that include special considerations in karst.

# Evaluation of rapid recharge processes and spring source vulnerability of karst aquifers in semi-arid environments based on high-resolution monitoring

---

<sup>1</sup>Schmidt, S., <sup>2</sup>Ries, F., <sup>3</sup>Doummar, J., <sup>1</sup>Licha, T. & <sup>1</sup>Sauter, M.

<sup>1</sup> Sebastian.Schmidt@geo.uni-goettingen.de, University of Göttingen, Geoscience Centre, Applied Geology, Germany

<sup>2</sup> University of Freiburg, Chair of Hydrology, Germany

<sup>3</sup> American University of Beirut, Department of Geology, Lebanon

Recharge processes in karst aquifers are often difficult to determine and despite their importance for water resources assessment and management, they are not very well understood, especially in (semi-)arid environments. Furthermore, recharge processes determine aquifer vulnerability. This study aims at the evaluation of recharge processes and source vulnerability parameters predominantly from high-resolution spring monitoring. A continuous monitoring scheme (e.g. discharge, electrical conductivity, chloride concentration, turbidity) was implemented at four major karst springs located in the Lower Jordan Valley near Jericho together with meteorological stations and surface runoff gauging stations in the recharge area. The continuous monitoring covers ca. five years, characterised by different hydrometeorological conditions. The data enable:

(1) Insights into the hydrogeological characteristics of the flow system, e.g. karst network geometry and conduit system volumes. For example, the relationship (common conduit system and groundwater catchment) between the two large artesian oasis-springs of Jericho, located ca. 3500 m apart, was identified.

(2) The quantification of the fast flow component and associated source vulnerability parameters at the springs: a short transport time lag (range: 1–6 d for the investigated springs) is regarded as problematic, whereas a short breakthrough duration (range: ca. 3–40 d) is regarded as favourable because of rapid flushing of the pollution.

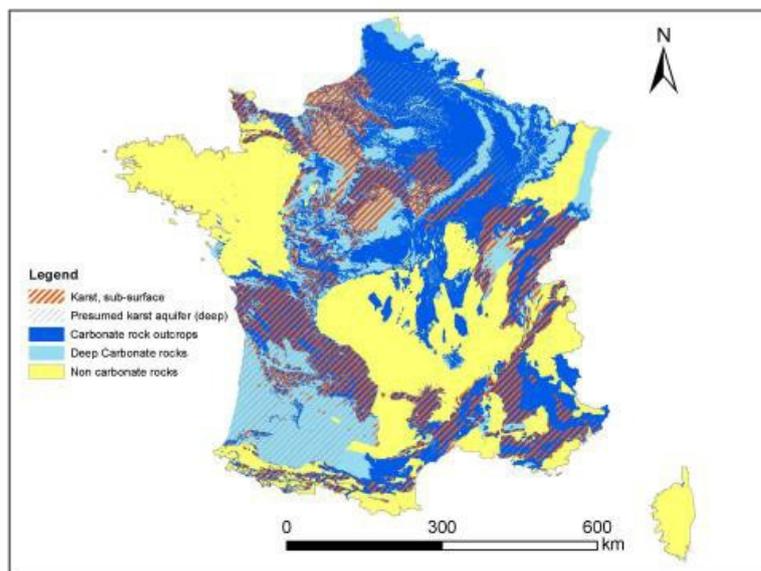
(3) The qualitative evaluation of rapid recharge processes, i.e. (i) areal infiltration of precipitation, subsequent flow concentration in the soil/epikarst and rapid vadose zone percolation along preferential pathways are regarded as important recharge processes in this karst region, whereas (ii) the infiltration of episodic surface runoff into ponors in the ephemeral valleys is relatively insignificant.

Furthermore, the seasonal variable wastewater impact at the springs could be evaluated. In this karst environment, electrical conductivity is an excellent and easy to monitor proxy for the environmental tracer chloride, enabling quantitative results at comparatively low costs.

# Representation of karst units in the Aquifer Reference System of France - BDLISA: challenges of small-scale mapping

<sup>1</sup>Schomburgk, S, <sup>2</sup>D. Allier and <sup>2</sup>J.J. Seguin

<sup>1</sup>[S.Schomburgk@brgm.fr](mailto:S.Schomburgk@brgm.fr), BRGM, France, <sup>2</sup> BRGM, France



The Aquifer Reference System of France (BDLISA<sup>1</sup>) proposes a delineation of its hydrogeological units, including aquifer reservoirs and impervious units, according to local, regional and national scale. Each unit is characterized by a class of permeability, porosity and type of geological formation. The ranking number increases with increasing depth and this enables identification of the vertical position at each point with respect to the other units. Thus, an aquifer in a sedimentary basin can be covered by several dozen other units. The classes enable identification of all carbonate rocks in France and their vertical position: from surface outcrops down to deep carbonates (Figure 1). Carbonate rocks cover more than 60% (350,000 km<sup>2</sup>) of Metropolitan France, of which 55% (193,000 km<sup>2</sup>)

in outcrop.

Each carbonate rock is a potential karst aquifer (World Karst Aquifer Mapping Project). Nevertheless, the absence or differing degrees of karstification demand a classification of these aquifers according to karst indicators. Specialists strive to find approaches that are both adapted and homogeneous on a national scale.

Initially, BDLISA was built on a regional scale, with each region employing its own approach depending on data availability: mapping of all surface disorders related to karst (swallets, sinkholes, dolines etc.), tracer tests in karst aquifers and identification of groundwater catchment areas, borehole analyses (flow out by fractures and karst)<sup>2</sup>, karst springs, wells with very high specific discharge, stream sink, etc. In a later stage, and in order to harmonize the national scale of BDLISA, two approaches were proposed depending on the surface karstification rate:

- 1) The whole unit is classed as a karst aquifer: four classes distinguish whether the geological formation can be characterized by a network of underground karst systems or, moreover, a second or third network, all being part of the hydrodynamic system.
- 2) Karst only constitutes part(s) of the unit: a supplementary layer enables the delineation of areas inside the aquifer unit where the presence of karst is well known.

The national cavity database ([www.bdcavite.net](http://www.bdcavite.net)) provides a non-exhaustive listing of natural karst cavity as well as karst springs and wells with very high specific discharge (BSS). These GIS layers were overlain on the extension of carbonate rocks. This information enabled a better understanding of many karst areas. For approach 1, the complete unit classed as karst aquifer, the mapping reveals 2/3 of the karst at outcrop and 1/3 in the subsurface (25%, corresponding to 545 units at local scale). For approach 2, 108 karst areas have been delineated and linked to their 60 aquifer units.

A new 1:1M scale hydrogeological map of France will be published in 2015, based on the information of the BDLISA units. It is designed for hydrogeologists and is a communication and educational tool: the representation of karst aquifers had to be modified in order to allow visibility at this scale by a differentiation of karst aquifer outcrops and deeper karst units, the display of karst springs (World Karst Aquifer Mapping Project) and karst aquifer labels.

<sup>1</sup> Base de Données des Limites des Systèmes Aquifères

<sup>2</sup> Base de données du Sous-Sol français (BSS)

# **A water resource management tool for the Cotswolds Oolitic Limestone aquifers: Using the EA's MODFLOW/4R approach to regional groundwater modelling in a complex karstic system**

<sup>1</sup>Streetly, H.R., <sup>1</sup>Girardin, I.J., <sup>1</sup>Streetly, M.J. & <sup>2</sup>Kelly, T.J.

heatherstreetly@esinternational.com

<sup>1</sup>ESI Ltd, UK

<sup>2</sup>Environment Agency, UK

The Jurassic limestones of the Cotswolds (the Great and Inferior Oolite) form an important aquifer that supports the headwaters of the River Thames, a number of important public water sources, and several SSSI and SAC wetland sites. The hydrogeology of the area is complex, due to the layered and karstic nature of the limestone aquifer(s) and the important role that faults play in offsetting/connecting the various strata. Examples of karstic behavior in the Oolitic Limestone aquifers are the presence of small caves, numerous springs and sink holes and discontinuous streams during low flows. Although the karstic features are not as conspicuous as in other UK limestone terrains (e.g. Carboniferous Limestone), there is clear evidence for enhanced flow along broad zones which presents a challenge for the groundwater modeller.

In order to quantify and manage the local groundwater resources more accurately, the Environment Agency wanted to develop a spatially variable regional groundwater model of the Cotswolds Jurassic aquifer system. A key objective was to understand the likely position of the groundwater divide between the Thames and Severn catchments and the distribution of groundwater abstraction effects between the two catchments. A regional groundwater model of the system was developed by ESI during 2012-13.

The Cotswolds model simulates groundwater flow in the Great and Inferior Oolite aquifers using the Environment Agency's integrated groundwater surface water modelling approach (MODFLOW/4R). The 4R code calculates the recharge and surface water inputs to the MODFLOW Stream Cells. Zones of very high permeability associated with faults and springs have been incorporated within the representative elementary volume of the MODFLOW grid cell (using a 250 m horizontal grid spacing).

Most other Environment Agency regional groundwater models are of either Chalk or Permo- Triassic Sandstone aquifers. The Cotswolds model required very large localised variations in transmissivity (an order of magnitude difference in adjacent cells) and vertical hydraulic conductivity to calibrate the model to the observed data (from 22 permanent gauges and 122 observation boreholes). The flow data show that there is a significant difference between the topographic and groundwater catchments so the calibration process involved introducing high permeability zones to induce substantial groundwater flow across topographic divides. Justification of this zonation needed to be supported by other lines of evidence. The calibrated groundwater model forms an effective and credible investigative tool. The model can be used to simulate naturalised flows and hence calculate effects of abstractions on flows and the spatial/temporal distribution of abstraction effects on groundwater levels. The model can also be used to provide quantified water balances for input to on-going abstraction management assessments within the study area.

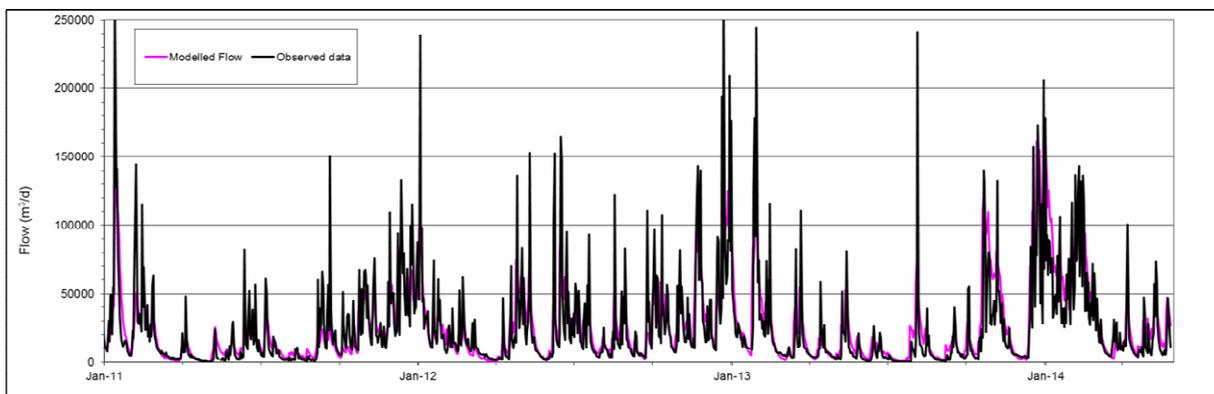
# Use of transient soil moisture balances and simple 1-D stores for investigating and protecting groundwater resources

Streetly, M.J., Harding, B.J. & Kelly, H.

mikestreetly@esinternational.com  
ESI Ltd, UK

Due to thin soil zones, karstic groundwater systems are usually very responsive to antecedent rainfall and this, combined with the very low storage coefficients in these aquifers, means that groundwater levels and spring flows can vary rapidly and substantially over short time periods. These large and sudden changes in groundwater conditions mean that small and steady effects on the aquifer, such as those that may be associated with abstraction or dewatering activities, may be hard to detect. This in turn poses a challenge for those looking to regulate activities affecting these aquifers, particularly in cases where there are potentially vulnerable, high status eco systems that are partially or wholly dependent on groundwater.

This paper presents a range of tools that have been developed and applied over the last 10 years at a number of sites located on the Carboniferous Limestone outcrops of South Wales. The technical core of the tools is a spreadsheet based transient soil moisture balance and associated epikarst/groundwater linear store calculation (as described in Streetly, 2008). This approach has now been successfully applied to simulate a large number of different groundwater level and surface water flow hydrographs across South Wales. In addition, it has been used to develop a linked water balance across an entire groundwater system to create a distributed assessment of groundwater flows.



Successfully simulating the baseline time series is however, only the start of the management process. Once an initial calibration is achieved, the calculation can be regularly updated as part of the ongoing QA procedures for checking incoming data. Accurate statistical tests can also be used to check for deviations between observed and simulated time series. The presentation will illustrate a number of ways in which various changes in the catchment might affect the observed time series and hence how these effects might be detected.

# Towards a new typology of subterranean habitats: Defining geo-habitats for groundwater ecosystem investigations

---

<sup>1</sup>Weitowitz, D.C., <sup>2</sup>Maurice, L., <sup>2</sup>Lewis, M. & <sup>1</sup>Robertson, A.

weitowid@roehampton.ac.uk,

<sup>1</sup>University of Roehampton, UK

<sup>2</sup> British Geological Survey, UK

Previous studies assessing groundwater ecosystems have often grouped geologies into very broad categories, such as karstic, porous and fractured habitats. Most of these studies agree that geology represents an important control on the distribution of subterranean life. However, the coarse grouping of geological units ignores the immense variability of hydrogeological and –chemical conditions observed in the field. It has furthermore resulted in the false interpretation that some rocks (e.g. granite in south-west England) are less suitable groundwater habitats than other geologies. Consequently, many researchers have called for a more inclusive typology of available habitats.

This study conceptually defines geological habitats (geo-habitats) by consulting diverse information such as geological age, lithology and water flow type in UK rocks. We have adopted a high-resolution approach by categorizing 50k mapping data into 11 different habitats. The newly developed habitat framework was then validated by examining key hydrogeological (transmissivity, porosity) and hydrochemical (e.g. oxygen, organic carbon, nitrate) parameters, known to be important for groundwater ecosystems. Most variables, including oxygen, organic carbon, nitrate and carbon were found to be significantly different between habitats (Kruskal-Wallis: all  $p < 0.001$ ). Karstic and unconsolidated habitats generally showed higher concentrations of oxygen, solutes and nutrients. The Chalk in particular appears to be a favourable habitat for groundwater ecosystems. One exception was the Highly Karstic Limestone that, despite our prediction had significantly lower levels of carbon, nitrate and potassium than other karstic geo-habitats. One of the hypotheses tested was whether transmissivity, a measure of permeability, could act as a useful proxy for hydrochemical conditions in groundwater habitats. While highly transmissive habitats typically also had good chemical status, there were some exceptions to this rule. For example, despite having very low permeability, Igneous Rock has the highest mean oxygen concentration. This could help explaining why it functions as an important UK habitat, harbouring the only endemic UK groundwater species. Overall, transmissivity is a good indicator for habitat quality, yet should be used with caution.

By providing a more integrative typology of groundwater habitats we intend to develop a better understanding of which rock types are better habitats than other geologies and why. Using a similar approach, based on hydrogeological concepts, high resolution and water chemistry assessment, could also improve groundwater ecosystem assessments in other areas of the world. Moving towards a better knowledge of habitat types and quality will be an integral part of making informed conservation decisions in the future.

# Stable Isotope comparison of two major karst valley systems in the Canadian Rockies

Yonge, C.J.

chas-karst@telus.net

Yonge Cave & Karst Consulting, Canada

The two major karst valley systems under consideration here are associated with a very well-developed conduit karst (the Crowsnest Pass) and a less developed (in terms of major caves) karst in the Bow Valley Corridor. The former has one of the most extensive cave areas of any in the country with many caves aggregating to over 20km explored. The latter contains the iconic Cave and Basin Hot Springs, many cold springs important to the local towns' water supplies and a 4km-long cave system. The hydrogeology of both areas including the use of stable isotopes has been studied by Grasby (at the GSC) and Yonge in a government report (Toop and Cruz, 2002) and Worthington in a PhD on the Crowsnest karst. Additionally Grasby studied hot springs in the Bow Valley Corridor and Yonge, as consultant to Stantec Canada, used stable isotopes of O and H as tracers for urban water development.

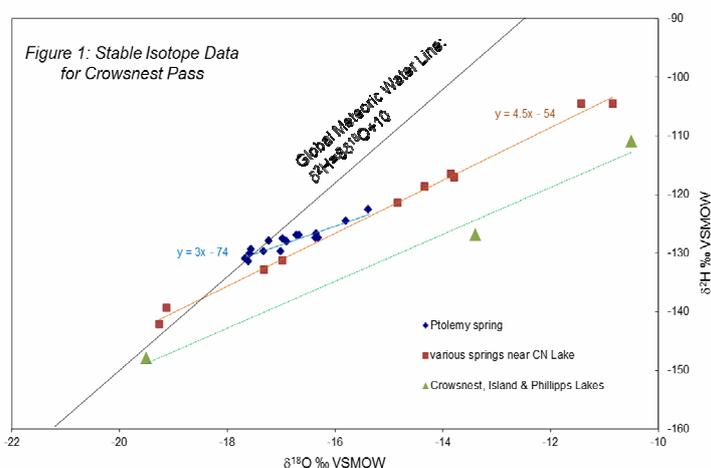
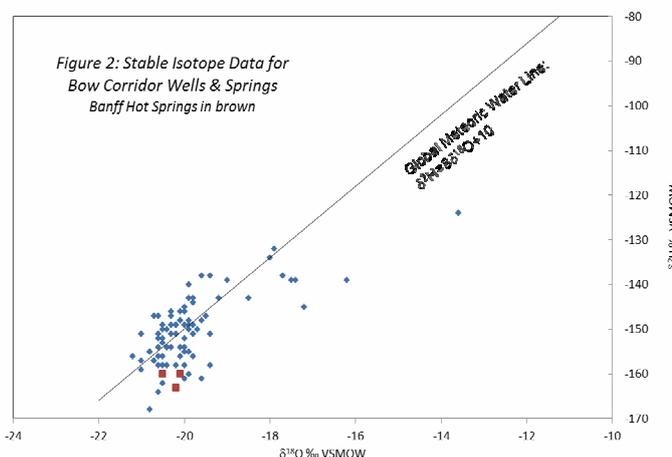


Figure 1 shows a distinctive isotopic pattern for both springs and lakes at Crowsnest. Groundwater initially on the GMWL evolves along slopes of 3 (time-based) and 4.5 (spatially-based), suggestive of a strong evaporative component, due perhaps to the very strong westerly winds over surface waters at this locality.

Figure 2 shows data for the Bow Corridor (figure 2) scattering around the GMWL - a few points fall below it at more easterly locations. The data do nonetheless exhibit both altitude (-400‰/km) and west-east (0.38‰/km) trends in  $\delta^2\text{H}$  due to temperature and

Rayleigh Distillation respectively. Additionally, latitude (temperature) effect of around 30‰ occurs between the Bow Corridor and Crowsnest. The altitude effect is highly anomalous (model slope are around -25‰/km) to the low springs surrounded by high mountains (2km elevation range).

The striking differences in the stable isotopes the two study areas may partly be accounted for the karst types, with Crowsnest dominated by conduit flow and the Bow Corridor by more diffuse flow – i.e. resurgences versus exsurgences. Thus evaporative groundwater signatures at Crowsnest suggest faster flow through times than in the Bow Corridor.



a  
due  
for  
by

## **Thermodynamic and kinetic modelling groundwater - carbonate rocks interactions for karst terrain Izhora plateau, Russian Federation.**

<sup>1</sup>Zhdanov, S.V. and <sup>2</sup>Kurilenko V.V.

de-mo@yandex.ru

<sup>1</sup>U.S. Civilian Research and Development Foundation

<sup>2</sup> Saint-Petersburg State University, Russian Federation

Destruction of buildings, road infrastructure in some cases connected with karst. Karst processes were investigated for the territory Izhora Plateau, which situated in the north-west of Russian Federation. The upper part of the Izhora Plateau consists of Ordovician carbonate rocks. Carbonate rocks have large areas, which contained karst forms of relief: dolines and sinkholes. Porous and fractures media of the Carbonate rocks form the Ordovician unconfined aquifer. Atmospheric precipitation supplies groundwater of the Ordovician aquifer (Zhdanov, 2013). During the studies was defined that karst sinkholes formation related with carbonate rocks fracturing.

Thermodynamic and kinetic modelling based on a data, which were got from groundwater hydrochemical sampling of the macrocomponents and microcomponents composition. Rocks dissolution is the main process is responsible for the development of karst processes. Calculated equilibrium concentration of calcium ion in groundwater and recharge water is based on equilibrium thermodynamics. Groundwater in the transit and discharged areas saturated to calcium carbonate, but infiltration water is not saturated. The chemical denudation rate of the whole Izhora Plateau was calculated from concentration of dissolved calcium and hydrocarbonate ions in groundwater flow per year. The chemical denudation rate is  $2,6 \times 10^8 \text{ kg} \times \text{year}^{-1}$  (Brantley, 2008).

Infiltration water dissolve carbonate rocks, increase saturation index and decrease dissolution rate with depth. The dissolution rate was calculated by John W. Morse equation (Morse, 2008). Modeling based on the calculations of changes saturation index and dissolution rate with depth step by step. Simulation of dissolution process produced for more and less fractured carbonate rocks, where width of the fractures opening 0,002 m, which cause emptiness 2% and width of the fractures opening 0,002 m, which cause emptiness 0,2%.

Comparison of the simulation results and observed data revealed that precipitation is not saturated to carbonate rocks, during the infiltration through vadose zone average thickness of 20 m infiltration water dissolved rocks and gradually saturated. In more fractured rocks infiltration dissolves rocks to a depth of 50 m. In less fractured rocks infiltration dissolves rocks to a depth of 5 m. Only 53% or  $1,42 \times 10^8 \text{ kg} \times \text{year}^{-1}$  carbonate rocks dissolved in the vadose zone. In the aquifer upper part formed unsaturated layer, which dissolves carbonate rocks. This layer dissolves 47% or  $1,24 \times 10^8 \text{ kg} \times \text{year}^{-1}$  dissolved rocks.

## **Optimization of Groundwater for Urban Water Supply and Energy Use in Karst Areas**

**Zhu, Yan**

yanzhu42@gmail.com, ZHU-Wasser & Energie UG, Germany

In order to improve the urban environment and resident's life quality, the urban environments settings and the urban water technics and resource & energy efficiency problems, during its usage cycle of urban water from groundwater resource as water source for urban water supply, until the used wastewater from industry and domestic purpose, have been systematically analyzed and studied, through the case studies and comparative study in and between German and Chinese cities, especially in Karst areas and for the the developing megacities.

The results can be used to for better understanding the scientific conception of green cities and technology application and promotion and optimization of sustainable management of urban groundwater and new energy source.

**Abstracts of Poster Presentations**

**listed alphabetically by presenting author**

**(first author is presenting author unless shown otherwise)**

## Soil Carbon Export characterized using Novel Tracers (SCENT)

**Bourdin C<sup>1</sup>**, Fairchild I<sup>1</sup>, Baldini J<sup>2</sup>, Bartlett R<sup>1</sup>, Boomer P<sup>1</sup>, Hartland A<sup>3</sup>, Howden N<sup>4</sup>, Hu C<sup>5</sup>, Müller W<sup>6</sup>, Worrall F<sup>2</sup> & Wynn P<sup>7</sup>

<sup>1</sup>School of Geography, Earth and Environmental Sciences, University of Birmingham, Birmingham B15 2TT, UK. C.Bourdin@bham.ac.uk

<sup>2</sup> Department of Earth Sciences, Durham University, Science Labs, South Road, Durham DH1 3LE UK

<sup>3</sup>Environmental Research Institute, School of Science, Faculty of Science and Engineering, University of Waikato, Hamilton, New Zealand

<sup>4</sup>Department of Civil Engineering, University of Bristol, Queen's Building, University Walk, Clifton, Bristol BS8 1TR, UK

<sup>5</sup>State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences, Wuhan, 430074, China

<sup>6</sup>Wolfgang Müller, Department of Earth Sciences, Royal Holloway, University of London, Egham Hill, Egham, Surrey, TW20 0EX, UK

<sup>7</sup>Lancaster Environment Centre, University of Lancaster, Lancaster, LA1 4YQ, UK

DOC (Dissolved Organic Carbon) monitoring in rivers in the northern hemisphere shows an increase of the carbon export over the past decades. It is still unclear whether temperature or atmospheric CO<sub>2</sub> changes, soil pH recovery from acidification or other factors triggered this evolution. Especially, determining the possible importance of T and pH in controlling the DOC increase would tell if the current trend is likely to stop or remain steady by the end of the century. Besides, recent studies showed the role of organic matter to transport trace metals in cave systems, and the analysis of palaeoenvironmental archives such as stalagmites might lead to the reconstruction of past DOC fluxes, especially on periods anterior to the available DOC river time series.

In this 3-year NERC-funded project, we combine the analysis of speleothems from four distant sites having experienced different acidification and climate histories with soil column leaching experiments on soils from the same sites. Among the two UK locations, Brown's folly Mine (Somerset) has been historically strongly acidified and is recovering from it, while at Tartair Cave (Scotland) the acid atmospheric deposition has been very mild. The last two sites are Heshang Cave (China) which is still strongly undergoing acidification, and the Yok Balum Cave (Belize) which has not been acidified and where the average temperature has not changed much compared to the higher latitudes.

The soil column mesocosm experiment has been running for over six months during which the cores, made of soil material freely lying over bedrock, maintained in plastic tubes, underwent watering with control synthetic rainwater at pH >5 first then a sudden change to more acidic conditions (pH ~ 4). Furthermore, the UK cores are split in two pools staying in incubators set at 7 and 15°C. Water leaching at the bottom of the cores and in soil solution has been sampled weekly for organic (total organic content, fluorescence) and inorganic parameters (conductivity, pH, anion content, trace elements), in order to test the temperature and the pH control on the DOC flux, and check how the trace element content can be a proxy for organic matter fluxes. We present here the first results of DOC evolution over the control and the acidification periods. The experimental results will be used for interpreting the DOC river data and laser-ablation ICPMS trace element data from stalagmites that grew at least since the preindustrial period. The evolution of these organic matter proxies in the different environmental contexts described earlier will be tested against the DOC sensitivity to temperature and pH changes determined experimentally.

## **Vulnerability of urbanization in karst areas (Northeast of Algeria)**

Benhammadi, H. and \***Chemseddine, Fehdi**

\* presenter

Laboratory "Water and Environment" (LWE), Department of Geology, University of Tebessa, Constantine road, 12002 Tebessa.

E-mail: [benkam61@yahoo.fr](mailto:benkam61@yahoo.fr) and fehdi@yahoo.fr

Urban development is often dependent on adequate land for expansion, except that sometimes these areas have vulnerability. This is the case of karst regions characterized by carbonate geological formations marked by the presence of cavities and cracks.

The impact of climate variability in Cheria area marked by a growing shortage of rainfall, the impact resulted in the development of the vulnerability of these structures. This vulnerability has led to the appearance of collapse phenomena as well in both agricultural and urban areas.

Two phenomena have emerged to explain the collapses, the first is assigned a filling process in the cavities, and the second is due to a weakening of the resistance that collapses limestone slab shear phenomenon.

In urban areas, the weight of the buildings has increased the load on the limestone slab and accelerated the collapse

The analysis of the environmental process is in the context of our modest work, after which we indicate the appropriate methods for management policy of urban expansion. This management more preventive (upstream), much less expensive than remedial solutions (downstream) needed after the event and sometimes ineffective.

# Characterisation of the main karst aquifers of the Tezben Plateau, Tebessa region, NE Algeria, based on hydrogeochemical and isotopic data

<sup>1</sup>Chemseddine F, <sup>2</sup>Belfar D and <sup>3</sup>Audra P

<sup>1</sup>[fehdi@yahoo.fr](mailto:fehdi@yahoo.fr), Laboratoire Eau et Environnement, Department of Geology, Tébessa University, 12002 Tébessa Algeria

<sup>2</sup> Laboratoire Eau et Environnement, Department of Geology, Tébessa University, 12002 Tébessa Algeria

<sup>2</sup> Polytech Nice Sophia , University of Nice , France

The Hammem Plain, situated in the northwest of the Tezben mountain range, northeast of Algeria, drains carbonate aquifers through some important karst springs. The physical and chemical characteristics of spring and well water samples were studied for two years in order to assess the origin of groundwater and determine the factors driving the geochemical composition. The ionic speciation and mineral dissolution/precipitation was calculated.

Water wells, characterizing groundwater circulation at shallow depths, are moderate to high mineralized waters of Na-HCO<sub>3</sub> type. In contrast to the shallow environment, the CO<sub>2</sub>-rich, deeper waters are of the Ca-HCO<sub>3</sub> type, and undergo significant changes in the baseline chemistry along flow lines with increasing residence time.

The main factors controlling the groundwater composition and its seasonal variations are the geology, because of the presence of carbonate formations, the elevation and the rate of karst development. In both groups, the carbonate chemistry is diagnostic of the effect of karst development.

The supersaturation with respect to calcite indicates CO<sub>2</sub> degassing, occurring either inside the aquifer in open conduits, or at the outlet in reservoirs. The undersaturation with respect to calcite shows the existence of fast flow and short residence-time conditions inside the aquifer. Interaction between groundwater and surrounding host rocks are believed to be the main process responsible for the observed chemical characteristics of groundwater in the study area.

The  $\delta^{18}\text{O}$ ,  $\delta^2\text{H}$  of the groundwater show that the groundwater recharge is of meteoric origin and suggest the absence of the evaporation effect on the isotopic composition.

# Mapping Groundwater Flooding in the Republic of Ireland

Poster presented by Alexander **Crow**

<sup>1</sup>Hardisty, R.A.L., <sup>2</sup>Beeson, S., & <sup>3</sup>Poole, G.

<sup>1</sup>Mott MacDonald, UK

<sup>2</sup>Formerly Mott MacDonald, UK

<sup>3</sup>Office of Public Works, Ireland

The European Floods Directive (2007/60/EC) aims to assess and manage the consequence of flooding from all sources on human health, the environment, cultural heritage, economic activity and infrastructure. Under this directive the competent authority of each member state was required to undertake Preliminary Flood Risk Assessments (PFRAs) by December 2011. The competent authority in the Republic of Ireland is the Office of Public Works (OPW).

Prior to 2010 the assessment of flood risk for PFRAs in the Republic of Ireland was largely with respect to fluvial, pluvial and coastal flooding. OPW recognised that the issue of groundwater flooding needed to be addressed, particularly as this form of flooding is common in the west and northwest. This led to the development of a methodology to assess groundwater flooding in the Republic of Ireland and the creation of a nationwide preliminary map of the hazard.

The hazard of groundwater flooding in the Republic of Ireland has been assessed and a preliminary nationwide groundwater flood hazard map has been produced. The map shows the outlines of floods defined by applying a new methodology, which was developed for the OPW to take account of the unique karstic nature of the hydrogeological environment in the Republic of Ireland. The key findings of this project are described in this poster.

The methodology used is based on a consideration of physical variables and hydrogeological environments in the Republic of Ireland as these control the amount, location and extent of groundwater floods. Information used in the mapping includes: evidence provided by groundwater experts; reports held on a database of flood events; digital images from aerial photography; satellite images of historic floods; and topographical elevations derived from a digital terrain model. The methodology comprises three interlinked stages, which differ from each other in terms of the amounts and quality of available information.

The evidence indicates that the vast majority of extensive, recurring groundwater floods originate at turloughs; groundwater-fed, seasonal lakes. Turloughs are associated with two definable main regions: the lowland karst of the western lowlands in and around Counties Clare, Galway and southern Mayo; and the upland karst in the west, north-west and locally in the midlands.

# A protocol for a development, reproduction and population growth test with freshwater copepods

<sup>1</sup>Cifoni, M., <sup>2</sup>\*Di Lorenzo, T., <sup>2</sup>Faraloni, C. & <sup>3</sup>Galassi, D.M.P.

\* presenter [tiziana.dilorenzo@ise.cnr.it](mailto:tiziana.dilorenzo@ise.cnr.it)

<sup>1</sup>Department of Life, Health and Environmental Sciences, University of L'Aquila, Via Vetoio 1, Coppito 67100, L'Aquila, Italy

<sup>2</sup> Institute of Ecosystem Study - CNR - National Research Council of Italy, Via Madonna del Piano 10, 50019 Sesto Fiorentino, Florence, Italy

OECD test guidelines in aquatic ecotoxicity have assigned high priority to the development of acute and chronic tests with species of Crustacea. Copepods occur widely in marine, brackish and freshwater ecosystems and are dominant in groundwater habitats. However, there is currently limited experience for the accomplishment of development, reproduction and population growth tests with freshwater copepods. Problems arise for features that require experience and technical proficiency, such as handling small-sized freshwater copepods, defining maturation, gender identification, acclimating and rearing.

Our aim is to present a guidance to perform a development, reproduction and population growth test lasting no more than 40 days with *Eucyclops serrulatus*, a widely distributed freshwater copepod species, primarily hyperbenthic but also commonly found in the epikarst, saturated karst, alluvial aquifers and hyporheic zone.

Development endpoints can be assessed observing the growth of newly hatched nauplii (F0 generation), aged less than 24 hours at the start of the test, individually exposed to selected pollutants (at least in five test concentrations) and freshwater (i.e., control), in microwell (300- $\mu$ L total volume) test chambers at 18°C. Microwell water renewal and copepod feeding with *Chlorella* cells should be done at every 6<sup>th</sup> day up to 20 days which is the time needed for the control nauplii to reach adulthood at 18°C (F1 generation). Reproduction endpoints can be then assessed: at the day 20<sup>th</sup> individual adult males and females are paired and allowed to mate for 20 days in new isolated microwell test chambers. The mating pairs, fed on *Chlorella* cells each 6 days, are followed until the females have been fertilized and have released two clutches of offspring (F2 and F3 generation). Finally, estimations of population growth rates ( $\lambda$ ) are modeled by a Lefkovich matrix. The life-stage transition rates that must be entered into the matrix can be produced by collection of individual survival, development and reproduction data from the microplates.

The whole test duration is up to 40 days at 18°C, which is the time needed for the control animals to reach adulthood, be paired, mate and produce at least two clutches of offspring. Other chemical-related effects on reproduction, such as reproductive success, failed fertilization, depressed clutch sizes, infertile or unhatched eggs, altered time intervals between successive clutches and possibly depressed intrinsic or instantaneous rates of population increase, may also be recorded or calculated from the microplates according to research purposes.

# The Great Spring, South Wales UK: updating a Source Protection Zone in a complex karst aquifer

<sup>1</sup>Farr, G, <sup>1</sup> Whitbread, K, <sup>2</sup> Jones, D. A. & <sup>2</sup> Roberts, K.

[garethf@bgs.ac.uk](mailto:garethf@bgs.ac.uk)

<sup>1</sup> British Geological Survey, Columbus House, Cardiff, CF15 7NE

<sup>2</sup> Natural Resources Wales, Ty Cambria, Newport Road, Cardiff, CF24 0TP

Source Protection Zones (SPZs) have been delineated around public water abstractions in England and Wales since the late 1980s. SPZs are used to regulate potentially polluting activities such as discharges to ground that could degrade groundwater quality. SPZ are also identify groundwater abstractions that could have a quantitative impact on the yield of the protected abstraction.

The Great Spring, South Wales, UK is a large abstraction associated with dewatering operations at the Severn Tunnel railway<sup>1</sup>. Dewatering has been continuous since the completion of the tunnel in the late 1800s. Between 60-120MI/day of groundwater is abstracted from the lowland coastal Carboniferous Limestone catchment as part of this operation. A proportion of the water abstracted from the Great Spring is used for public drinking water supply.

The first SPZ for the Great Spring was delineated in the late 1980s however it had become evident that an updated SPZ was required to underpin an increasingly risk based approach to regulatory decision making.

A methodology<sup>2</sup> based on vulnerability mapping was applied to the catchment, which included the updating of superficial and bedrock geological maps, collation of tracer test and borehole data and identification of karstic features. Recharge from losing streams was estimated using stream geometry, ‘bypass features’ such as sinkhole and losing rivers were mapped as were areas considered to be ‘protective cover’ above the principal karstic aquifer.

Through integration of these data with vulnerability mapping we were able to significantly improve the SPZ by both improving the boundaries of the SPZ and delineating high and low vulnerability zones within the total catchment.

<sup>1</sup>WALKER, T A. 1888. The Severn Tunnel: Its Construction and Difficulties (1872–1887). Reprinted edition 2004, ISBN 1-84588-000-5.

<sup>2</sup>ENVIRONMENT AGENCY. 2004. Vulnerability Mapping for the Protection of Karst Aquifers. R&D technical report W6-032/TR. David Drew and Suzanne Dunne.

## The EC-AQUALIFE Project in Italy: state of the art and future prospects

<sup>1</sup>Fiasca, B., <sup>1</sup>Di Cioccio, A., <sup>1</sup>Stoch, F., <sup>2</sup>Di Lorenzo, T., <sup>3</sup>Di Francesco, M., <sup>1</sup>Porfirio, S., <sup>1</sup>Cifoni, M., <sup>1</sup>Galassi, D.M.P.

[barbara.fiasca@univaq.it](mailto:barbara.fiasca@univaq.it)

<sup>1</sup>University of L'Aquila, Department of Life, Health & Environmental Sciences, 67100 L'Aquila, Italy

<sup>2</sup> Institute of Ecosystem Study - CNR - National Research Council of Italy, Via Madonna del Piano 10, 50019 Sesto Fiorentino, Florence, Italy

<sup>3</sup> Gran Sasso-Laga National Park, via del Convento 1, 67010 Assergi, Italy

The AQUALIFE project (LIFE12BIO/IT/231), which commenced in late 2013, is focused on the development of an indicator system for evaluating the conservation status and threats of invertebrate species entirely or partially relying on groundwater for completing their life-cycle. The first phase of the project consisted in a monitoring survey, at the regional scale, of four main kinds of groundwater dependent ecosystems (GDEs) occurring in the pilot area (Abruzzo region; central Italy): (1) saturated alluvial aquifers and (2) saturated karstic aquifers sampled in boreholes/wells; (3) springs, (4) cave waters; and (4) hyporheic zones of streams and rivers. Each GDE was analysed by selecting monitoring sites along an impact gradient, previously assessed on the basis of the location of the main pressures known at the regional scale, according to the classification given in the Water Information System for Europe (WISE).

In total, 270 sites, located in the epibenthic layers of cave waters, springs, and rivers, in the hyporheic zone, in the subsurface of karstic springs and aquitards, and in the boreholes/wells in alluvial and karstic aquifers, were monitored. For each site, biological and physico-chemical parameters were sampled with different sampling devices according to the GDE typology and following the PASCALIS project sampling manual.

The preliminary results of the project, showed that: boreholes/wells in alluvial and karstic aquifers harboured the highest stygobiotic species richness, being the copepod crustaceans the most abundant group, followed by amphipods of the genus *Niphargus* and, to a less extent, by the Syncarida. Wells polluted by chlorinated organic solvents were devoid of fauna, suggesting their heavy detrimental effect on biodiversity. Boreholes with marine intrusion harboured euryhaline stygobionts. Conversely, organic pollution impacted less the biodiversity. Sites downstream large hydropower plants harboured invertebrates in both the epibenthic habitats and the hyporheic zone, but only rarely stygobionts were found. In the hyporheic zone of streams polluted by nitrates and ammonium the distributions of stygobites was patchy at the point-site scale: sites with ammonium concentration higher than  $0.08 \text{ mgL}^{-1}$  (the minimum TV value assessed by most EU-countries) showed a statistically significant lowering of stygofauna. In the hyporheic zone of the Tirino River, fed for more than 60% by groundwater, a strong increase in concentration of toxic substances was found in a contaminated site of national interest (SIN). This point industrial waste pollution was reflected in a dramatic lowering of biodiversity along with the total disappearance of stygobionts. The final aim of the project is to set up the user-friendly AQUALIFE working Package for monitoring GDEs, management planning and development of field interventions.

## **A database to assess impacts of land use and climate change on Europe's karst regions**

**Hartmann, A. and Marx, V.**

[andreas.hartmann@hydro.uni-freiburg.de](mailto:andreas.hartmann@hydro.uni-freiburg.de)

Universities of Freiburg, Germany and Bristol, UK

To assess the impact of climate and land use change on present and future karst water resources multi-site studies are necessary. Comparison of different karst systems and karst regions at different scale will enable us to provide large-scale quantification of karst water resources and their water quality. Furthermore, it will set the base for future projections of water availability and quality to facilitate sustainable management of karst water resources. We aim at establishing a Europe wide database of system characteristics of karst regions and their local water supply. The desired data will include field observations as well as data on water use and water supply.

In the phase of data acquisition catchment and aquifer characteristics as well as time series (of i.e. groundwater and discharge observations) will be collected from published papers, public national databases and hydrology studies over Europe. In order to obtain regional information about karst water resources and water supply over entire Europe the water authorities in all regions that have considerable fractions of carbonate rock within their surface area will be officially contacted. All data will be fed into a database using the "Aquarius Time Series" software which allows storage and processing of time series data for defined locations and attributing metadata with catchment properties as well as individual files such as shapefiles to these locations. The progress of data collection as well as a catalogue of metadata will be published with a suitable web-based GIS tool. In its finalized stage, the metadata catalogue can function as a switchboard between researchers and data holders facilitating research on Europe's karst water resources. This will be done in close collaboration with the World Karst Map (WoKaM) of the IAH Karst Commission.

With this presentation we kindly want to ask for your support. If you would like to contribute to the database please contact: [andreas.hartmann@hydro.uni-freiburg.de](mailto:andreas.hartmann@hydro.uni-freiburg.de) or [vera.marx@hydro.uni-freiburg.de](mailto:vera.marx@hydro.uni-freiburg.de)

# Isotopic and hydrogeochemical characterization of karst aquifer in the Port del Comte (Lerida, Spain)

<sup>1</sup>Herms, I., <sup>2</sup>Soler, A., <sup>3</sup>Jorge, J. & <sup>4</sup>Vadillo, I.

[ignasi.herms@icgc.cat](mailto:ignasi.herms@icgc.cat),

<sup>1</sup>Institut Cartogràfic i Geològic de Catalunya (ICGC), Spain

<sup>2</sup> Dpt. Cristal·lografia, Mineralogia i Dipòsits Minerals, Grup Mineralogia Aplicada i Geoquímica de Fluids, Fac. Geologia, Universitat de Barcelona (UB), Spain

<sup>3</sup> Departament de Física Aplicada Universitat Politècnica de Catalunya (UPC), Spain

<sup>4</sup> Center of Hydrogeology, University of Malaga (UMA), Spain

The Port del Comte karstic aquifer is located in the southernmost part of the Catalan Pyrenees, northeast Spain. First studies were made in early the 90's, in the context of some water supply projects (Gencat 1990, 1991), and the second and last one was undertaken at 2003, which and focused on the SW part of the massif (Gil and Núñez 2003, Núñez et al. 2004). The Port del Comte thrust sheet contains one of the main mountain karst aquifers of the Catalan Pyrenees. The geologic structure and stratigraphy of the thrust strongly influences the location of karst spring and groundwater geochemistry especially on snowmelt periods. No previous studies regarding its geochemical and isotopic groundwater characterization are available in this area. This work presents the results of field and sampling campaigns of all groundwater springs carried out during periodic monitoring campaigns. The monitoring plan of the study started in October 2013 and is still going on. It takes into account a discharge measurements plan based on volumetric method and by means of slug salt dilution injection tests; spring water sampling, and rain sampling at seasonal scale at eight rain stations. The hydrogeochemical characteristics distribution on a regional scale is studied on forty karst springs, where groundwater discharge is sampled before snowfall and after snowmelt. The hydrogeochemical evolution is studied on six karst springs. All of them are regularly sampled every three to four weeks, and discharge monitoring each two weeks or continuously by means of transducer sensors. In all cases, the "in-situ" physico-chemical parameters are controlled (pH, EC, T, redox, alkalinity, TDS). Geochemical analysis considers major elements and isotopic composition ( $\delta^2\text{H}_{\text{H}_2\text{O}}$ ,  $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ ,  $\delta^{34}\text{S}_{\text{SO}_4}$ ,  $\delta^{18}\text{O}_{\text{SO}_4}$ ,  $\delta^{15}\text{N}_{\text{NO}_3}$ ,  $\delta^{18}\text{O}_{\text{NO}_3}$ ) of spring and precipitation waters ( $^2\text{H}_{\text{H}_2\text{O}}$ ,  $^{18}\text{O}_{\text{H}_2\text{O}}$ ). Results are discussed through spatial and temporal variations in hydrological and physicochemical variables during two complete snowmelt periods.

## References

- Gencat (1990, 91, 1993). *Proyecto de prospección e investigación hidrogeológica (Solsonès– Lleida)*. 117, 20 y 58 páginas. Internal unpublished report.
- Gil, R. & Núñez, I. (2003). *Estudio hidrogeológico de la sierra de Odén – Port del Comte (Solsonès– Lleida)*. CIHS, 85pp. Internal unpublished report. □
- Herms, I & Jorge, J. (2012). *Variación anual e interanual del manto nivoso en el macizo del Port del Comte (Solsonès– Lleida) a partir de imágenes MODIS*. Book of Abstracts XV Spanish National Congress on Geographic Information Technologies pp. 97-105. □
- Núñez, I., Gil, R., García M.A, & Vázquez, E. (2004). *Estudio hidrogeológico de la cabecera de la Ribera Salada, (Lleida)*. Book of Abstracts VIII Hydrogeology symposium, (AIH - IGME), p. 107-120.
- Vergés, J. (1999). *Estudi geològic del vessant sud del Pirineu oriental i central. Evolució cinemàtica en 3D*. PhD Thesis. University of Barcelona (UB), Faculty of Geology, 180 pp.

## Assessment of annual resources in Swiss karst aquifers

<sup>1</sup>Malard, A., <sup>1\*</sup>Jeannin, P.-Y., & <sup>2</sup>Sinreich, M.

\*lead presenter

<sup>1</sup>info@isska.ch, SSKA - Swiss Institute for Speleology and Karst Studies, Switzerland

<sup>2</sup> michael.sinreich@bafu.admin.ch, FOEN – Federal Office for the Environment, Hydrogeological Basics Section, Switzerland

Karst aquifers in Switzerland outcrop at least over 20% of the territory and may store 80% of the groundwater reserves. In the frame of the Swisskarst project, it has been possible to assess the recharge of karst aquifers (i.e. annual resources) which is here defined as the renewable amount of water transiting through the aquifers for a hydrological year. Assessing this value at the scale of a country – even a small one like Switzerland – reveals almost difficult as information about aquifers and their regimes are scarce and often heterogeneous. Then a pragmatic method has been elaborated to extrapolate the hydrological regimes of measured and documented systems in Switzerland (and also in neighboring countries) at the scale of the whole territory. The methodology applies and extends the notion of specific discharge rate in karst by using the average of meteorological data from 2000-2011. The specific discharge of monitored karst systems in Switzerland - and abroad but still close to the border and with comparable climatic conditions - has been correlated with the extension and the elevation of the catchment and corrected with a regional factor corresponding to the average-rainfall deviation

Results show that the annual resources transiting through this type of aquifer range between 6.6 and 9.1 km<sup>3</sup>, i.e. respectively 27.8 to 38.3 L/s/km<sup>2</sup> of specific discharge. Compared to the whole groundwater resources in Switzerland, karst aquifers represent 30% to 40% of them. Highlights of the spatial extrapolation are:

- Low-elevated karst systems (<700 m) as in tabular Jura or northern Switzerland represent 15% of the karst outcrops and less than 13% of the resource;
- Middle-elevated karst systems as in folded Jura and Prealps areas (between 800 and 1500 m of mean elevation) represent 50% of the karst outcrops and solely 32 to 38% of the karst groundwater resources;
- Alpine-karst systems which the mean elevation exceeds 1500 m represent 40% of the karst surfaces in Switzerland but more than 45% of the karst groundwater resources. Alpine karst systems whose catchments are partly fed by glacier-melt do not strictly reflect the distribution of the rainfall. Their specific discharge will be inflated for a couple of decades.

These values could be precised, especially for karst systems ranging between 800/1000 m and 1500/2000 m of elevation which correspond to systems suffering for a lack of monitoring. The deviation between minimal and maximal evaluation reaches 2.5 km<sup>3</sup> (i.e. an annual discharge rate of 79 m<sup>3</sup>/s). This deviation could be seen as the uncertainties on the method and the data but it may also express the inter-annual disparities in the recharge processes (for certain years, annual precipitations in certain regions fluctuate from -70 to +150% compared to the mean value).

These results are a step further in the field of the water resource characterization and management in Switzerland in the perspective of the global changes which are expected to modify the distribution of the rainfall over the hydrological years, impacting by the way the groundwater recharge processes. Additional studies in the field of groundwater resources evaluation and storage are in progress.

# Hydrochemistry and effect of karst of the spring water in the Soreq catchment/ Ramallah /West Bank, Palestine

Jebreen, Hassan<sup>1</sup> and Marwan Ghanem<sup>2</sup>

---

<sup>1</sup>Institute of Environmental and Water Studies, Birzeit University, P.O. Box 526, Ramallah, West Bank, Palestine. E-mail: [h.jabareen@student.birzeit.edu](mailto:h.jabareen@student.birzeit.edu)

<sup>2</sup>Geography Department, Birzeit University, P.O. Box 14, West Bank, Palestine. E-mail: [mghanem@birzeit.edu](mailto:mghanem@birzeit.edu)

The hydrochemical characteristics of the spring's water in Soreq – Catchment were determined to identify the different pollutants to the spring water. The pH of all spring water ranged between 7-8 with mean temperature of 20.2 °C, which is neutral to slightly basic. Electrical conductivity and total dissolved solids for spring water ranged from 421-1385  $\mu\text{s}/\text{cm}$ , 185-763 mg/L, respectively. The concentration of anion and cation of the spring water within the allowable WHO limits except in Ein Beit Soreq and Ein Albalad. The water of most of the springs is contaminated to fecal Coliform and total Coliform. The concentration of nitrate show moderate values below the WHO limits. The Hardness of water samples ranges from hard to very hard types. The order of cation abundance (mg/L) was ( $\text{Ca}^{+2} > \text{Mg}^{+2} > \text{Na}^+ > \text{K}^+$ ), but that of anions ( $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{-2} > \text{NO}_3^-$ ). The water of springs in the study area is polluted with some heavy metals like ( $\text{Zn}^{+2}$ ,  $\text{Cd}^{+2}$ ,  $\text{Mn}^{+2}$ ,  $\text{As}^{+2}$ , Co, Cu, Ni, Pb, Al,  $\text{Fe}^{+2}$ , and V) because their concentrations are higher than the permissible limits of WHO (2007) and PWA (2001) standards. Most springs in the study area have water type of (Ca-Mg-  $\text{HCO}_3^-$ ) and the other springs range between (Ca- $\text{HCO}_3^-$ ) and (Ca-Cl- $\text{HCO}_3^-$ ). Piper's classification of the spring water ranges in the areas of earth alkaline water with increased portion of alkali with prevailing bicarbonate and alkaline water with prevailing bicarbonate in both seasons. Comparing the quality of spring water with standards for different uses proved that some springs shows of unsuitable for human drinking purposes like Ein Beit Soreq and Ein Albalad, but it's suitable for agricultural and irrigation, except some samples which are poor due to high salinity.

# Characterization of karst/river exchanges thanks to rainfall runoff modelling and sorted water level: case study of Cèze river with the karst plateau of *Méjannes-le-Clap*, FRANCE

<sup>1</sup>Coutouis, A., <sup>2</sup>Chapuis, H., \*<sup>1</sup>Johannet, A., <sup>1</sup>Salze, D., <sup>1</sup>Vayssade, B., <sup>1</sup>Vinches, M., <sup>2</sup>Ré-Bahaud, J., <sup>2</sup>Paran, F., <sup>2</sup>Graillot, D., <sup>3</sup>Jolivet, J., & <sup>4</sup>Cadilhac, L.

\*lead presenter

anne.johannet@mines-ales.fr,

<sup>1</sup>École des Mines d'Alès (LGEI), France

<sup>2</sup> École des Mines de Saint-Etienne (centre SPIN), UMR 5600 EVS, France

<sup>3</sup> UMR Espace, France

<sup>4</sup> Agence de l'Eau Rhône Méditerranée Corse, France

In karst context, sustainable management of water resource needs knowledge about karst aquifers and rivers exchanges. Regarding specifically Mediterranean karst aquifers, it appears that they are the unique water resource of the territory and that they are often underexploited.

The site of the *Cèze* river (*Rhône* river tributary) and its karst aquifer of *Méjannes-le-Clap* is interesting because it is subjected to important anthropogenic impacts linked to drinking water, irrigation water, and seasonal increasing population due to tourism (pleasant weather, beautiful landscape and swimming area). The complexity of the aquifer can be related to the existence of a probable deep reservoir due to the Messinian episode. Moreover the Mediterranean climate led to rainfalls heterogeneous in time and in space making the behavior difficult to characterize.

Due to the important cited societal stakes, the public Water Agency (*Agence de l'Eau Rhône, Méditerranée, Corse*) initiated a multi-disciplinary research project in order to better apprehend water circulations and consumptions. This project investigates the karst river exchanges thanks to several approaches: (i) thermic infrared imagery, (ii) analysis of interstitial invertebrates, (iii) sampling and analysis of major ions, and (iv) hydrological modelling. This poster aims to present this last point using 2 well known tools in hydrology: neural network modelling and sorted water level.

Thanks to a database composed of 20 years of daily measurements of water levels, the proposed methodology consisted in establishing a daily rainfall / water level model taking into account the effect of the upstream river, and local karst aquifer. To this end a specific architecture was designed taking into account upstream rainfall information (rain gauges) in one set of hidden neurons, near local information (rain gauge) and estimated water level in another set of hidden neurons and potential evapotranspiration in a third set of hidden neurons. All these 3 sets are inputted in a second layer of hidden neurons implementing a kind of multilayer perceptron with three layers of neurons. This modelling at the station of Tharoux showed good modelling of low water level and of recession curves leading to Nash criteria up to 0.8. The second step consisted in computing sorted water levels at the same station in order to identify exchanges between river and karst. In a third step, sorted water levels were calculated using estimated water levels in order to estimate the quality of the model and to estimate prediction of exchanges using scenarios of rainfalls.

## Monitoring water quality using a through-flow fluorescence sensor

<sup>1,2</sup> Khamis, K., <sup>1</sup> Bradley, D. C., <sup>1</sup> Hannah, D.M. & <sup>2</sup>Stevens, R.

<sup>1</sup> School of Geography, Earth and Environmental Science, University of Birmingham, Birmingham, B15 2TT.  
Email: k.khamis@bham.ac.uk

<sup>2</sup> RS Hydro Ltd, Leask House, Hanbury Road, Stoke Prior, Worcestershire, B60 4JZ,

Given recent developments in field-deployable optical sensor technology, continuous quantification and characterisation of dissolved organic matter (DOM) is now possible. Fluorescence spectroscopy is a sensitive and selective optical technique ideal for monitoring low DOM concentration groundwater. In particular, tryptophan-like fluorescence (TLF) is indicative of human influence on water quality and is associated with labile organic carbon (e.g. sewage or farm waste) and products of its microbial breakdown. Coloured Dissolved Organic Matter (CDOM) fluorescence is associated with humic/fulvic acids and when combined with TLF measurements can provide information on DOM source and quality. Hence, real-time recording of TLF and CDOM fluorescence and could potentially be invaluable in identifying groundwater aquifer microbial contamination events at a higher temporal resolution than has been previously possible. However, an understanding of sensor measurement repeatability/transferability and interaction with environmental parameters (e.g. temperature / water matrix properties) is required.

Here, we present results from rigorous laboratory and field trials of a custom through-flow, fluorometer (multi-wavelength - including TLF). Findings highlight that with careful consideration and correction of potential interferences this *in-situ* fluorometer is ideal for rapid assessment of groundwater contamination.

## **Auto-ecological Studies on *Niphargus glenniei* (Spooner, 1952) and *Niphargus aquilex* (Schiödte, 1855) (Crustacea: Amphipoda: Niphargidae).**

**Knight, L.R.F.D.**

[lee.knight01@btinternet.com](mailto:lee.knight01@btinternet.com) Hypogean Crustacea Recording Scheme, England.

Whilst there have been several studies into various aspects of the auto-ecology of *Niphargus* species on the continent, such studies are sadly lacking in Britain. To address this, an experimental aquarium was set up in Join-Minor Cave within the Higher Kiln Quarry SSSI in Devon. This site contains several caves, two of which contain stable populations of the stygobitic shrimps *Niphargus aquilex* and *N. glenniei*.

*Niphargus glenniei* is a British endemic limited to the south-western counties of Devon and Cornwall, which according to recent genetic studies has survived in Britain for at least 19.5 million years. During 2007 *Niphargus glenniei* was placed on the Biodiversity Action Plan (BAP) list of priority species, primarily due to its endemic distribution. One of the actions identified in the *Niphargus glenniei* Species Action Plan was the need for further research into its ecology.

*Niphargus aquilex* is widespread across Europe, although recent molecular studies have identified a number of cryptic taxa within the nominal species complex. It occurs across southern England and Wales, with several outlying records north of the Devensian glacial limit and is the most common and widely distributed of the British niphargids.

The aims of the project were to investigate the two species' response to temperature, both higher and lower limits, their phototactic responses and also to make general observations on their locomotion, substrate preferences and inter-species interactions.

The phototactic response experiments were inconclusive but suggested that there was little phototactic response, either positive or negative in *N. glenniei* and a weak negative phototaxis in *N. aquilex*, although this was more pronounced when this species was exposed to ultra-violet light. As predicted by similar experiments on *Niphargus* in Europe, both species were tolerant of a wide range of temperature, from 1 to 26°C and were clearly eurythermic, disproving an early mis-conception that cave animals are stenothermic. Although they could survive temperatures down to 1°C, *N. glenniei* entered a state of torpor at 4°C and *N. aquilex* at 2°C. *Niphargus aquilex* was shown to be predacious on *N. glenniei* when the two were placed in a confined space and to even indulge in cannibalism on smaller specimens of the same species.

## The Aquatic Invertebrate Fauna of the Ogof Draenen Cave System in South Wales

<sup>1</sup>**Knight**, L.R.F.D and <sup>2</sup>Maurice, L.

<sup>1</sup>[lee.knight01@btinternet.com](mailto:lee.knight01@btinternet.com), Hypogean Crustacea Recording Scheme, England

<sup>2</sup> British Geological Survey, England

Whilst biological recording has been carried out in many British caves in the past, there have been few systematic studies of their aquatic fauna, with those of the Peak-Speedwell system of Derbyshire and Swildon's Hole in the Mendips Hills being the exceptions.

Ogof Draenen is a vast, complex cave system that lies beneath the southern edge of the Brecon Beacons National Park in South Wales. The system includes some 80km of discovered passage and a number of subterranean, autogenic catchments fed by water percolating down through the epikarst or by seepages feeding into dolines on the moorland above. The drainage of the karst is extensive and complicated with a number of resurgences in the surrounding valleys identified by dye tracing studies.

From 2012-2015 an extensive investigation has been undertaken of the various aquatic habitats present in the cave, ranging from small pools to the extensive number of active stream-ways present. The main method employed was a timed period of net sampling in order to provide comparison between the lotic sites. Sampling was also carried out in the small surface seepages feeding into the dolines and the resurgences.

The majority of the samples were dominated by populations of stygobitic Crustacea including the amphipods *Niphargus fontanus* (Bate, 1859) and *Microniphargus leruthi* (Schellenberg, 1934), the isopod *Proasellus cavaticus* (Leydig, 1871) and the syncarid *Antrobathynella stammeri* (Jakobi, 1954). *Niphargus fontanus* and *P. cavaticus* were already known from the cave but the records of *M. leruthi* are the first from a Welsh cave system and the records of *A. stammeri* are the first for this species from Wales.

Epigeal benthic fauna were present in the cave close to surface inlets, the seepages and resurgences although the later were also characterised by stygobitic Crustacea, including a second *Niphargus* species, *N. aquilex* (Schiodte, 1855). The presence of five stygobitic Crustacea from the system makes this the most diverse stygobitic fauna recorded so far from a British cave.

## Cave air dynamics and drip water geochemistry in Pisani rov-Postojna cave (Slovenia)

<sup>1</sup>Krajnc, B., <sup>2</sup>Ferlan, M., <sup>3</sup>Lojen, S., <sup>4</sup>Gabrovšek, F., <sup>3</sup>Vaupotič, J. & <sup>3,1</sup>Ogrinc, N.

<sup>1</sup>bor.krajnc@ijs.si, Jožef Stefan International Postgraduate School, Ljubljana, Slovenia

<sup>2</sup> Department of Forest Ecology, Slovenian Forestry Institute, Ljubljana, Slovenia

<sup>3</sup>Department of Environmental Sciences, Jožef Stefan Institute, Ljubljana, Slovenia

<sup>4</sup>Karst Research Institute SASA, Postojna, Slovenia

Studying drip water and cave atmosphere carbon chemistry along with cave air dynamics is important for better understanding of ecosystem carbon dynamics e.g. factors affecting eddy flux tower measurements of ecosystem CO<sub>2</sub> dynamics. The aim of this work was to determine the sources of cave CO<sub>2</sub> and factors affecting it.

Research was performed in a dead-end passage of Postojna cave (Pisani rov) in south-western Slovenia. We measured CO<sub>2</sub> concentrations, its carbon (<sup>13</sup>C) stable isotope composition, <sup>222</sup>Rn activity concentrations, temperatures and air pressure. Along with air samples we also measured drip water parameters from three different drip sites including: conductivity, pH, alkalinity, δ<sup>18</sup>O in water and δ<sup>13</sup>C in dissolved inorganic carbon (δ<sup>13</sup>C<sub>DIC</sub>), concentrations of cations (Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup>, K<sup>+</sup>, Sr<sup>2+</sup>, Si<sup>+</sup>, Fe<sup>3+</sup> and Al<sup>3+</sup>) and anions (Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, NO<sub>3</sub><sup>-</sup>, F<sup>-</sup> and Br<sup>-</sup>).

Cave CO<sub>2</sub> concentrations range from around 800 ppm up to around 10000 ppm with the highest concentrations in summer and the lowest concentrations in winter. Cave air temperature was constant 8.4 ± 0.01 °C. It was found that cave air CO<sub>2</sub> concentrations correlate with outside temperatures (R<sup>2</sup>=0.46, p=0.05), and outside soil temperatures at 0.5 m (R<sup>2</sup>=0.65, p=0.01) suggesting that Pisani rov acts as a so called thermal cave. Carbon isotopic signatures of cave air CO<sub>2</sub> follows “two endmembers mixing lines” of organic matter and atmosphere suggesting that cave CO<sub>2</sub> originates from soil CO<sub>2</sub> transported directly into the cave. Further our data will be compared with carbonate equilibrium model (such as MIX4) assuming that cave CO<sub>2</sub> originates from soil CO<sub>2</sub> transported into the cave via drip water with δ<sup>13</sup>C<sub>DIC</sub> values ranging from -15 ‰ up to -10 ‰ with the highest values observed in winter and the lowest values obtained in summer and autumn.

# **Groundwater flooding: Responses of groundwater ecosystems to an extreme recharge event.**

**Robertson A.L.**<sup>1</sup> Fussmann K.<sup>2</sup>, Krause S.<sup>3</sup> & Reiss J.<sup>2</sup>

<sup>1</sup> [a.robertson@roehampton.ac.uk](mailto:a.robertson@roehampton.ac.uk), Roehampton University, U.K.

<sup>2</sup> Roehampton University, U.K.

<sup>3</sup> Birmingham University U.K.

Last winter was the wettest in the UK since records began resulting in extremely high groundwater levels and very extensive groundwater recharge, particularly in chalk aquifers. Understanding of the impact of such conditions on the unique ecosystems that exist in groundwaters is very limited yet such extreme events are predicted to become more frequent under climate change.

We hypothesised (1) that the composition of the groundwater community will change following flooding cessation and the onset of community recovery. (2) Dissolved Organic Carbon (DOC) will be highest immediately after flooding, the microbial compartment will respond rapidly to high DOC levels and groundwater macrofauna will recover more slowly.

We collected environmental data (e.g. DOC, nutrients, oxygen profiles) and measured microbial functional diversity, fungal activity, and the abundance and biomass of bacteria, protozoa, meiofauna and macrofauna. We did this at multiple boreholes in each of two chalk aquifers across a 7 month period following the recharge event.

We found that DOC and bacterial abundance were higher shortly after the recharge event and then declined whereas protist biomass and macrofaunal abundance increased with increasing distance from the recharge event. However, even in the early months of the study macrofaunal abundance was higher than that found in a study a few years earlier. Although macrofaunal abundance increased over time, biomass was lower because juvenile stygobites were more numerous, possibly as a result of reproduction.

Our study presents the first data on the responses of groundwater communities to flooding and provides a baseline against which future extreme events in groundwaters can be measured. It will enable us to compare the responses of groundwater ecosystems to stressors with those of other aquatic ecosystems.

## Density and richness estimates of invertebrates at the surface water – groundwater interface reflect the pump sampling method used

<sup>1</sup>Hogan, J.-P., <sup>1</sup>Stephens, B., <sup>1</sup>\*Stubbington, R. & <sup>2</sup>Wood, P. J.

\*lead presenter

<sup>1</sup>[rachel.stubbington@ntu.ac.uk](mailto:rachel.stubbington@ntu.ac.uk), Nottingham Trent University, UK

<sup>2</sup>Loughborough University, UK

The contribution of the hyporheic zone and its resident invertebrate fauna to ecosystem functioning has been recognized for several decades. However, sampling invertebrates from subsurface sediments for research or biomonitoring purposes remains inherently challenging due to their inaccessibility. Sampling techniques include freeze-coring, colonization devices and pump sampling, with the latter category including methods suitable for repeated sampling and roaming surveys.

We conducted field surveys to compare taxa richness, invertebrate abundance and community composition, in samples collected by the two most commonly used pump sampling methods, Bou-Rouch and vacuum pump sampling. Samples were collected from three streams with contrasting geologies and sedimentary characteristics: the River Lathkill is underlain by karst limestone, River Ashop, by Millstone Grit, and Black Brook by Mercia Mudstone. We also conducted laboratory experiments using the freshwater shrimp *Gammarus pulex* (Crustacea: Amphipoda), to determine both the proportion of a known population sampled by each method in multiple sediment treatments. We compared the body size of: (a) experimental organisms captured by Bou-Rouch and vacuum pump sampling; (b) organisms captured and not captured by each method.

In field samples, richness and abundance were both significantly higher in Bou-Rouch samples than in vacuum pump samples, in all rivers. Community composition differed between methods due to the higher abundance of several common taxa in Bou-Rouch samples. In laboratory experiments, abundance was significantly higher in Bou-Rouch samples, across multiple sediment treatments. Organisms sampled by the vacuum pump were significantly smaller than those in Bou-Rouch samples, and organisms captured in vacuum pump samples were smaller than individuals not captured by this method; this size-bias was not observed in Bou-Rouch samples.

Our results demonstrate the advantages of Bou-Rouch over vacuum pump sampling in the characterization of hyporheic invertebrate communities and we therefore recommend this method for roaming and one-off surveys. However, despite the reduced assemblage sampled by the vacuum pump, this method can also characterize variability between sites, and has several benefits, including: the ease of repeated sampling during a temporal sequence; the collection of a sample from a precise point; low initial financial outlay; reduced bed disturbance; and, reduced damage to sampled organisms.

# **An applicable model for karst in Gambier limestone in order to improve the water management in Mount Gambier region, southeast South Australia, Australia**

<sup>1,2</sup>Salomão, G.N., <sup>2</sup>Abreu, F.A.M., <sup>2, 3\*</sup>Venturieri E.M

\*lead presenter

<sup>1</sup>gabriel.negreiossalomao@student.adelaide.edu.au, University of Adelaide, Australia

<sup>2</sup>Federal University of Pará

<sup>3</sup>e.m.venturieri@durham.ac.uk, Durham University, England

Southeast South Australia has large potable groundwater reserves, usually located close to the surface. Historically, the settlement contributed to the impact on groundwater quality due to the existence of an extensive karst in the unconfined aquifer. For instance, industries were sited close to caves and sinkholes as a convenient means of waste disposal. Consequently, today is possible to identify the traces of pollution left behind. During the 20<sup>th</sup> century, the irregular activity in Mount Gambier region was emerging. Currently, the philosophy of waste disposal is becoming more responsible due to the dependence on groundwater as the major part of the water supply in the region. Moreover, groundwater inflow from a highly karstic limestone aquifer provides 90% of the recharge to the Blue Lake, which is the source of water supply (Emmett and Teller 1994). This lake is considered a high-value resource, but it is located in a high-risk environment. A better understanding of the Gambier karst model may assist the water quality management in southeast South Australia in order to minimize the risks.

Mount Gambier is part of the Otway Basin, a large sedimentary basin of marine origin. Herczeg et al. (1997) described the surface of the landscape as Quaternary Bridgewater Formation dunes, which parallel the current coastline with several hundred sinkholes and swamps, consisting of depressions in the landscape with small cavities. Underlying the dunes is the extensive Oligocene-Miocene Gambier Limestone. Moreover, the unconfined aquifer in the Gambier Limestone is the most accessible water resource in the region and it is used extensively for domestic, agricultural, and industrial use. The karst features stated previously, swamps and open drainage boreholes throughout the study area are potential recharge sites to the upper part of the Gambier limestone aquifer, which underlie depression-dominated karst landscape (Emmett and Teller 1994; Herczeg et al. 1997). However, the importance of these point-source recharges to the water balance of karstic aquifers in the area is relatively poorly understood.

In order to minimize the risks in Mount Gambier region, the model from New Zealand karst proposed by Gunn (1983) may improve the understanding of the area. The model of depression hydrology incorporates three concentrating mechanisms and three input mechanisms. As a result, by examining previous literatures about the area, the model seems to be perfectly useful in explaining the recharge mechanism of the Gambier aquifer and it can assist the understanding about the area in order to prevent future irregular activities. Moreover, further research should be considered due to the lack of information and the fact that many sources are not updated.

## References

- Emmett, A.J. and Teller, A.L., 1994. Influence of karst hydrology on water quality management in southeast South Australia. *Env. Geol.*, 23: 149-155.
- Gunn, J., 1983. Point-recharge of limestone aquifers – A model from New Zealand Karst. *J. of Hydrol.*, 61: 19-29.
- Herczeg, A.L., Leaney, F.W.J., Stadter, M.F., Allan, J.L. and Fifield, G.K., 1997, 'Chemical and isotopic indicators of point-source recharge to a karst aquifer, South Australia', *J. of Hydrol.*, 192: 271-299.

## **Groundwater and macroinvertebrate recovery on the River Lathkill (Derbyshire) following supra-seasonal drought**

<sup>1</sup>Little, S., <sup>2</sup>Gunn, J. <sup>1</sup>Mathers, K.L., <sup>3</sup>Parry, S. & <sup>4</sup>Worrall, T.P., & <sup>1\*</sup>Wood, P.J.

\*lead presenter

<sup>1</sup>p.j.wood@lboro.ac.uk, Centre for Hydrological and Ecosystem Science, Department of Geography, Loughborough University, UK.

<sup>2</sup> Limestone Research Group, GEES, University of Birmingham.

<sup>3</sup> Centre for Ecology and Hydrology, Wallingford, UK.

<sup>4</sup> APEM, UK

Knowledge regarding the recovery of in-stream communities following drought and drying events are relatively limited for temperate riverine systems. Many iconic groundwater dominated streams in the UK (karstic limestone and chalk) are typically buffered from hydrological extremes, although headwater systems may be subject to wetting and drying regimes reflecting local groundwater levels. This paper reports the recovery and recolonization of the headwaters of the River Lathkill (Derbyshire, UK) following a high magnitude supra-seasonal drought (2010-2011). In November 2011, flow was recorded for the first time following an extended period of flow cessation over the majority of the summer and autumn. Due to loss of water along most of the headwaters of the R. Lathkill, only 12 aquatic macroinvertebrate taxa were recorded at sites where groundwater was emerging seven days after flow resumed at three upwelling spring sites. Although only a small number of taxa were recorded, this demonstrated that a number of refuges for these taxa persisted throughout the period when surface water was absent. Recovery was monitored from a total of 15 sites over the subsequent year to gauge how rapidly faunal populations recovered and if the drought had any long-term effects on community composition. The recovery of faunal abundance and diversity occurred relatively rapidly and was facilitated by a period of above average precipitation from April until late autumn 2012. Despite the rapid recovery of faunal abundance and diversity, community composition was markedly different compared to that recorded before the drought. These differences were associated with the replacement of key taxa such as the freshwater shrimp (*Gammarus pulex*) and several aquatic snail taxa with aquatic-insect taxa which recolonized via aerial dispersal as adults. The results illustrate the importance of groundwater in supporting aquatic biodiversity and the influence that high magnitude droughts have in shaping the ecology of these systems.