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**43<sup>rd</sup> IAH Congress**

**Groundwater and society:  
60 years of IAH**

**September 25-29<sup>th</sup> 2016**

**Montpellier, France**

**Organized by**

**The French and German National Chapters of the  
International Association of Hydrogeologists**



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## 43rd IAH International Congress: “Groundwater and society: 60 years of IAH”

On behalf of the French and German hydrogeologist communities, the French and the German National Chapters of the IAH are proud to host the 43<sup>rd</sup> IAH International Congress, and at the same time celebrate the existence of 60 years of IAH, in Montpellier, France, from 25<sup>th</sup> to 29<sup>th</sup> September 2016.

Already at the occasion of its 40<sup>th</sup> anniversary, John Day, the former vice-president of IAH, stated: *“From small beginnings, and by its members’ persistent exertions, the Association has achieved a truly international stature and a professional reputation second to none, motivated only by its members’ desires to get to know each other and to share professional expertise despite the various political and economic barriers of the times.”*

This statement is still true and our 60<sup>th</sup> anniversary again offers ample opportunities to reflect, take stock and to assess the current state of hydrogeology within societies worldwide. Increasing challenges and contributions of hydrogeologists to society will be a central topic at the conference in Montpellier. We welcome active participations of hydrogeologists and experts of related fields from all over the world.



**Michel Bakalowicz**

President of the French IAH Chapter



**Johannes A.C. Barth**

President of the German IAH Chapter



## IAH at sixty

2016 is a very special year for the International Association of Hydrogeologists as we reach the major milestone of the 60th anniversary of our founding in 1956. From small beginnings, IAH has grown into a truly worldwide scientific and professional association with just over 4100 members in 125 countries and 40 national chapters, fourteen scientific commissions and networks, a high quality journal, well-established book series and a programme of international scientific congresses, of which this one in Montpellier is the 43rd.

IAH grew rapidly during the 1980s and early 1990s as the importance of mapping and investigating groundwater resources became more widely recognised and the number of groundwater professionals increased. More recently, the increasing importance of managing groundwater resources and protecting aquifers from pollution have produced evolving scientific directions within hydrogeology. All of these changes are naturally reflected in the titles of IAH's commissions, books and congresses. The changing emphasis has also become embedded in the IAH mission to further the understanding, wise use and protection of groundwater resources throughout the world. This manifests itself in the growing need for a responsible professional association to advocate for greater awareness of groundwater amongst policy makers, the general public and professionals in other disciplines. In developing the topics for this congress, the organisers wished to fully reflect the evolution of our science and profession, and to look ahead to future scientific and educational needs.

Throughout 2016 we will be recognising our 60th anniversary in a number of ways. The main international focus of our celebrations will be the congress here in Montpellier. Many of the IAH national chapters will be holding technical meetings, field visits or social events to acknowledge the anniversary at national level. Delving back into our history, membership in the early years of the Association was dominantly in Europe. French and German hydrogeologists in particular played defining roles during that time. It is entirely fitting, therefore, that having been hosted for our 50th anniversary in Dijon, the Association should celebrate its 60th by returning to France for the 43rd Congress, co-convened by IAH's French and German Chapters.

It is hoped that as many as possible of IAH's members and friends reading this will join in the anniversary celebrations, either in Montpellier or nationally closer to home. A major anniversary such as this provides an opportunity to meet and reflect on past experiences but also to look forward. This congress provides an excellent opportunity to do that, and we look forward to seeing you in Montpellier.

**Ken Howard, IAH President**



## The sessions of the Congress

The eight topics of the Congress were animated by specialists of each scientific field who proposed several "Provisional Sessions" during the abstract submission process. The definitive list of the Congress' "sessions" was progressively completed till the end of the abstract submission and selection process.

During the Congress, each "session" comprises:

- oral presentations during parallel session(s);
- oral flash presentation of several posters of the "session" during plenary sessions;
- at least one e-poster session for each session.

### TOPIC 1 - WHAT ROLE DO OR SHOULD HYDROGEOLOGISTS PLAY IN OUR SOCIETIES?

**Session 1.03:** Sharing groundwater knowledge

### TOPIC 2 - HYDROGEOLOGY(ISTS) AND ECONOMIC DEVELOPMENT

**Session 2.01:** Groundwater in semiarid regions – a long-term view on changes in aquifer balances. Hydrogeology in developing countries.

**Session 2.02:** Groundwater for sustainable water supplies in developing countries

### TOPIC 3 - HYDROGEOLOGISTS FOR THE FUTURE: INFORMATION, EXCHANGE, EDUCATION AND TRAINING

**Session 3.01:** Groundwater data in the New Digital Age

### TOPIC 4 - ECONOMICS IN GROUNDWATER AND GROUNDWATER MANAGEMENT

**Session 4.01:** Innovative economic instruments and institutions for achieving sustained groundwater use. Integrated socio-economic and biophysical modeling for groundwater and conjunctive use management

### TOPIC 5 - GROUNDWATER, AND GLOBAL & CLIMATE CHANGE

**Session 5.01:** Groundwater resources in a world facing climate change

**Session 5.02:** Groundwater and global change

**Session 5.03:** CO<sub>2</sub> storage in deep saline aquifers and potential impacts on shallow aquifers

**Session 5.04:** Emerging contaminants in the water cycle and risk to Groundwater

**Session 5.05:** Groundwater and Ecosystems – Hydrological role of forests and wetlands

### TOPIC 6 - ACTIVE MANAGEMENT OF GROUNDWATER IN THE WATER CYCLE

**Session 6.01:** Managed Aquifer Recharge

**Session 6.02:** Treated WasteWater REUSE for groundwater recharge: addressing the challenge

**Session 6.03:** Innovative tools to improve understanding of groundwater recharge processes

### TOPIC 7 - GROUNDWATER USES AND MANAGING GROUNDWATER USE CONFLICTS

**Session 7.01:** Groundwater and Energy Resources

**Session 7.02:** Urban Hydrogeology

**Session 7.03:** Agricultural and sanitation contaminants and implications for water services and health

**Session 7.04:** Groundwater and man-made underground works

**Session 7.05:** The Challenges for Transboundary aquifer management

**Session 7.06:** Groundwater protection and governance: examples of groundwater protection models, and the role of the private sector

**Session 7.07:** Transdisciplinary and participatory approaches in groundwater research and management

### TOPIC 8 - PROGRESS IN CONCEPTUAL MODELS, TOOLS AND METHODS

**Session 8.01:** Fiber-Optic Distributed Temperature Sensing as an innovative method in hydrogeology and geothermal energy

**Session 8.02:** Groundwater Development and Protection in Coastal and Volcanic Environments with Complex Geological Structures



**Session 8.03:** Geometrical structure and hydrogeological properties of Hard-Rock aquifers.

**Session 8.04:** Isotopic and residence time tracers

**Session 8.05:** Karst aquifers

**Session 8.06:** Verification of conceptual patterns and expected natural effects of regional groundwater flow by interpretation of relevant field observations

**Session 8.07:** Hydrogeophysics: innovative non-invasive technologies for groundwater resources exploitation and management

**Session 8.08:** Mineral and Thermal water: an indicator of deep processes and source of economically valuable minerals

**Session 8.09:** Hydrogeology: a focus on groundwater ecology

**Session 8.10:** Recent developments in groundwater modeling and mathematical tools in Hydrogeology

**Session 8.11:** Hydrogeodesy: new surface tools to characterize and monitor active and managed groundwater systems

## SESSION KINDRA

### TOPIC 1 - WHAT ROLE DO OR SHOULD HYDROGEOLOGISTS PLAY IN OUR SOCIETIES?

#### Session 1.03: Sharing groundwater knowledge

The diffusion of hydrogeological knowledge and its uncertainty is more than ever a critical issue at a time when global changes critically affect the environment and natural resources. Hydrogeologists have the responsibility of being stewards of groundwater and watersheds, communicators, and educators. They, in fact, play an important role in society in characterizing and protecting water, hopefully providing information and opinions to users, regulators and decision makers. How is the message shared, understood, and used? This, in a context where there are many challenges: technical, societal, political. This session will provide examples of situations in the Himalayas, India, New-Zealand, Canada, and France.

**Conveners:** Massuel Sylvain (IRD, France, [sylvain.massuel@ird.fr](mailto:sylvain.massuel@ird.fr)), Gilles Wendling (GW Solutions, Canada, [gw@gwsolutions.ca](mailto:gw@gwsolutions.ca))

### TOPIC 2 - HYDROGEOLOGY(ISTS) AND ECONOMIC DEVELOPMENT

#### Session 2.01: Hydrogeology in developing countries. Groundwater in semiarid regions – a long-term view on changes in aquifer balances

Aquifers represent a key resource for the economic development of semiarid regions due to (i) relatively higher volume and larger extent of groundwater compared to surface water, and ii) lower sensitivity of groundwater resources to short time scale climate variability.

Over the past decades groundwater recharge and discharge rates have dramatically changed in these regions as a consequence of the numerous forms of global change like modifications of land use and land cover, increased pumping (irrigation, domestic water), hydraulic works, and wet and dry climate cycles.

This session will focus on multidecadal evolution of aquifer balances, with a focus on:

- direct (water table surveys) and indirect (vadose zone, environmental tracers) evidence of these changes,
- quantitative and qualitative consequences in terms of biophysical processes and exploitation by populations,
- impacts on accuracy and reliability of groundwater models at various scales, especially with respect to potential future changes.

**Conveners:** Favreau G. (IRD, France, [guillaume.favreau@ird.fr](mailto:guillaume.favreau@ird.fr)), Leduc Chr. (IRD, France, [christian.leduc@ird.fr](mailto:christian.leduc@ird.fr)), Scanlon B. (University of Texas at Austin, USA, [bridget.scanlon@beg.utexas.edu](mailto:bridget.scanlon@beg.utexas.edu))

#### Session 2.02: Groundwater for sustainable water supplies in developing countries

Increasing water demand for sustaining human activities is raising severe concerns worldwide, and particularly in developing countries where the access to water is already poor. To support developing countries moving out of poverty, adequate and safe water supply is a priority, and developing groundwater is often the best solution due to its dispersed occurrence and its ability to buffer climate variability. However, sustainably developing and managing groundwater supplies requires knowledge about aquifer systems and groundwater chemistry and how they respond to stresses from climate, abstraction, land use change and contamination.

This session focuses on groundwater supplies in developing countries and aims to discuss: (1) the contribution of groundwater to domestic and agricultural needs; (2) new approaches for improving knowledge on groundwater availability and renewability; (3) current and future challenges of increasing groundwater supply in developing countries; and (4) the opportunities of developing participative approaches for long-term sustainable management.



**Conveners:** Jean-Michel Vouillamoz (IRD-LTHE, France - Direction Générale de l'Eau, Benin, [Jean-Michel.Vouillamoz@ird.fr](mailto:Jean-Michel.Vouillamoz@ird.fr)), Viviana Re (Ca' Foscari University of Venice, Italy – National Engineering School of Sfax, Tunisia, [re@unive.it](mailto:re@unive.it)), Alan MacDonald (British Geological Survey, United Kingdom, [amm@bgs.ac.uk](mailto:amm@bgs.ac.uk))

### TOPIC 3 - HYDROGEOLOGISTS FOR THE FUTURE: INFORMATION, EXCHANGE, EDUCATION AND TRAINING

#### Session 3.01: Groundwater data in the New Digital Age

Emerging from the digital revolution, we have entered an era of unprecedented change and opportunity in which it is estimated that the global volume of digital data doubles every two years. This data deluge can now provide hydrogeologists and citizens with place-based information on demand, and hence encourage a deeper understanding, consideration and appreciation of our global groundwater systems. Ubiquitous internet technologies provide access to all this data, particularly when that information is delivered on demand via high speed broadband to mobile tablet devices. These technologies have created a society that is spatially enabled and aware. Big business and citizens increasingly expect to be able to access past and current information about any location of interest, to find answers to their spatial queries. Deeper appreciation and understanding comes from the sheer volume of information that can be amassed about any particular place in the landscape, and how that information can be dynamically synthesised to provide the most definitive answer to the user's question. Hence the use of spatial digital technologies for a more holistic understanding of groundwater systems and environmental sustainability are rapidly emerging.

This session invites contributions that showcase examples of groundwater data management, mobile applications (Apps) for hydrogeologists and e-research developments that will transform the way we utilise groundwater data. Examples may demonstrate interoperable technologies that can dynamically federate data from disparate databases, or internet portals developed for citizen contributed observations and monitoring data. New technological developments are supporting novel and more efficient methods for data collection and processing, visualization and communication, with crowdsourcing. These opportunities make reflecting upon the challenges and opportunities of citizen science, especially in a context of a better knowledge for example in monitoring of groundwater resources. Case histories could include sensor technologies, time-series legacy data, and visualisations of groundwater data together with other socio-economic and environmental data. We particularly welcome examples where the access to big data has led to new discoveries in the data spawning novel applied research projects as well as industry investment and community engagement.

**Conveners:** Peter Dahlhaus (Federation University Australia, [p.dahlhaus@federation.edu.au](mailto:p.dahlhaus@federation.edu.au)), Laurence Chery and Sylvain Grellet (BRGM, France, [l.chery@brgm.fr](mailto:l.chery@brgm.fr), [s.grellet@brgm.fr](mailto:s.grellet@brgm.fr))

### TOPIC 4 - ECONOMICS IN GROUNDWATER AND GROUNDWATER MANAGEMENT

#### Session 4.01: Innovative economic instruments and institutions for achieving sustained groundwater use. Integrated socio-economic and biophysical modeling for groundwater and conjunctive use management

Groundwater resources are increasingly being used intensively worldwide. While this allowed significant short term economic development, it also generated longer term negative environmental, social and economic impacts. Policy makers are increasingly aware of the need to implement policies that can ensure sustained groundwater through better control of groundwater abstraction. The approach generally consists of capping total water abstraction (based on hydrogeological studies) before allocating water entitlements to users or groups of users. This shift from an open access regime to one of regulated abstraction raises important economic questions which this session intends to investigate. On which basis should individual water entitlements be allocated to individual or groups of users, considering economic efficiency and social justice criteria? What mechanisms should be implemented to facilitate temporary or permanent reallocation of water among users? What different models are there for these reallocation schemes? What should be the relative role of the State and water users associations in monitoring and enforcing water allocation rules? What is the social acceptability of alternative policy options and how do stakeholders influence the policy reform process? What is the fundamental role of property rights and tenure arrangements to water and land in relation to groundwater?

This session is seeking contributions dealing with:

- Case studies describing recent policy development; we particularly welcome papers dealing with groundwater markets; the establishment of groundwater users associations; monitoring and enforcement problems; the political economy of groundwater policy reform; stakeholders' engagement in such groundwater policy reform.
- The design of innovative economic instruments and associated institutions; the evaluation of their impact using economic models, experimental economics or participatory approaches.



**Conveners:** Jean-Daniel Rinaudo (BRGM, France, [jd.rinaudo@brgm.fr](mailto:jd.rinaudo@brgm.fr)), Guillermo Donoso (Pontificia Universidad Catolica de Chile, [gdonosoh@uc.d](mailto:gdonosoh@uc.d)), Antony Jakeman (The Australian National University, Canberra, Australia, [Tony.Jakeman@anu.edu.au](mailto:Tony.Jakeman@anu.edu.au))

## TOPIC 5 - GROUNDWATER, AND GLOBAL & CLIMATE CHANGE

### Session 5.01: Groundwater resources in a world facing climate change

Groundwater is the world's most voluminous and best protected source of freshwater resource. It is used intensively supplying approximately half of the world's drinking water supply and increasing proportion of that used for irrigation. The sustainability of groundwater use is therefore of rapidly growing importance to enhancing global food security. Groundwater also plays a vital role in sustaining surface flows and ecological function of groundwater-dependent ecosystems. Groundwater therefore needs to be managed wisely as outlined in major regulatory initiatives such as the European Water Framework Directive. This is, in itself, a challenge under changing environments, climates, land uses, and populations. This task is especially challenging in light of limited availability of data in many environments, both arid and humid.

In this topic we invite contributions, which particularly report on research on the consequences of climate change for future management, protection, and sustainable use of groundwater, as well as studies on detection and/or attribution of changes in groundwater in response to climate change. Methodologies, strategies, case studies as well as quantitative techniques for dealing with uncertainty and limited data availability are of interest for this session. Studies focusing on the impact of the adaptation strategies are also sought. Furthermore, contributions describing case studies and new techniques are welcome. The session is open to contributions focusing on methodology or results, including societal and economic impacts, from local to regional to global scales.

**Conveners:** Roland Barthel (University of Gothenburg, Sweden, [roland.barthel@gvc.gu.se](mailto:roland.barthel@gvc.gu.se)), Florence Habets (CNRS, Paris, France, [florence.habets@upmc.fr](mailto:florence.habets@upmc.fr)), Richard Taylor (UCL, London, UK, [richard.taylor@ucl.ac.uk](mailto:richard.taylor@ucl.ac.uk))

### Session 5.02: Groundwater and global change

The current pace of global environmental change across the world is unprecedented. These anthropogenic pressures (climate change, pumping, land use change, water diversion, urbanization, agricultural intensification, deforestation, mining, etc) can strongly impact on aquifers' systems by: 1) altering water fluxes (e.g. recharge and discharge), 2) modifying surface and groundwater interactions, 3) leading to new hydrological processes, and 4) compromising the quality of groundwater resources. This session addresses the key scientific challenges associated with linking global change to the evolution of groundwater quantity and quality over the past 60 years. Of particular interest are studies looking at separating the impact of climate change (that is mostly addressed in session 5.01) from the effects of other anthropogenic activities. We welcome contributions from a variety of approaches including analysis of long-term time series (groundwater levels and water quality records), and modelling studies of past and future changes.

**Conveners:** Conveners: Marc Leblanc (Avignon University, France, [marc.leblanc@univ-avignon.fr](mailto:marc.leblanc@univ-avignon.fr)), Tales Carvalho Resende (UNESCO IHP, [t.carvalho-resende@unesco.org](mailto:t.carvalho-resende@unesco.org)), Maciek Lubczynski (University of Twente, ITC, Netherlands, [m.w.lubczynski@utwente.nl](mailto:m.w.lubczynski@utwente.nl))

### Session 5.03: CO<sub>2</sub> storage in deep saline aquifers and potential impacts on shallow aquifers

CO<sub>2</sub> Capture and Storage (CCS) is a key climate change mitigation technology. Geological storage of the CO<sub>2</sub> captured at industrial facilities such as power plants, gas production, cement and steel plants is a promising approach for reducing CO<sub>2</sub> atmospheric emissions and can even generate negative emissions when it is combined with CO<sub>2</sub> capture at biomass plants (BECCS - BioEnergy with CCS), or directly from the atmosphere. Globally, there are 15 large-scale CCS projects in operation, with a further seven under construction. Deep saline aquifers constitute suitable widespread targets with a large overall storage capacity, thus enabling worldwide deployment of CCS. Depleted oil and gas fields are also suitable for storing CO<sub>2</sub> and can offer an economic added value through the CO<sub>2</sub>-enhanced recovery of hydrocarbons.

In the present session, we seek contributions on both the use of deep saline aquifers for CO<sub>2</sub> storage and potential impacts of CO<sub>2</sub> storage on potable groundwater resources in the overlying shallow aquifers. Impacts could result from pressure perturbations or from leakage through faults or wellbores of the injected CO<sub>2</sub>, CO<sub>2</sub> plus in situ compounds like H<sub>2</sub>S or hydrocarbons, or associated reservoir brines. We are particularly interested in studies highlighting preventive measures to limit potential impacts (such as characterization and monitoring) as well as research into assessing potential impacts via



laboratory and controlled release field experiments. The session will also accept abstracts dealing with other issues relating to CO<sub>2</sub> storage in the subsurface.

**Conveners:** Isabelle Czernichowski-Lauriol (BRGM/CO<sub>2</sub>GeoNet, France, [i.czernichowski@brgm.fr](mailto:i.czernichowski@brgm.fr)) and Stan Beaubien (Sapienza University of Rome/CO<sub>2</sub>GeoNet, Italy, [stanley.beaubien@uniroma1.it](mailto:stanley.beaubien@uniroma1.it))

#### **Session 5.04: Emerging contaminants in the water cycle and risk to Groundwater**

Since the beginning of the 20th century, an increasing amount of compounds originating from human activities have been introduced in the water cycle, via diffuse or point-source pollution. Notably, massive amounts of man-made organic compounds have been released in the atmosphere, surface water or directly in the soil, during the last 50 years, including some very stable molecules. These compounds or their metabolites are now detected in all the water compartments, from rain to groundwater, thanks to the recent development of very sensitive analytical instruments and methodologies, and the better targeting of contaminants of interest.

This session is aiming at understanding which are the relevant compounds to be investigated in groundwater and the relevant associated parts of the water cycle, using reliable methodologies from sampling to analysis, in order to: (1) Assess the vulnerability of the aquifer; (2) Identify the sources of diffuse or point-source pollutions that may affect the current or future quality of groundwater; (3) Understand the contamination timeframe. We encourage contribution covering all the aspects from the choice of molecules, particularly as regard their tracers' properties, origin (including rainwater), to methodologies, occurrence data and predictive approaches.

**Conveners:** L. Di Gioia (Danone Nutricia Research, France, [Lodovico.di-gioia@danone.com](mailto:Lodovico.di-gioia@danone.com)), B. Lopez (BRGM, France, [b.lopez@brgm.fr](mailto:b.lopez@brgm.fr)), D. Lapworth (BGS, UK, [dila@bgs.ac.uk](mailto:dila@bgs.ac.uk))

#### **Session 5.05: Groundwater and Ecosystems - Hydrological role of forests and wetlands**

Groundwater is particularly linked with some ecosystems such as wetlands. On the other hand, the forest ecosystems occupy large areas in the world.

Are forests beneficial or prejudicial to the functions and uses of water? Is it possible to concomitantly sustain forestry activities and to protect downstream water uses, particularly drinking water supply? For most scientists and practitioners, but also for a wider audience, woodland areas benefit from a very positive image. In fact, they often maintain or improve the quality of water resources, in addition to benefits for biodiversity, landscapes, and recreational activities, among others. Regarding the quantitative aspect of water resources, the issue is more often discussed with positive arguments for less runoff, and less floods and erosion, but also a decrease of water resource availability due to the higher evapotranspiration of forests in comparison with other landcovers.

Wetlands, and, more largely, surface-groundwater relationships also play a major role in the hydrological cycle. The quantitative and quality benefits, and impacts if any, of wetlands will be highlighted in this session as well as rules and case studies dealing with their maintenance and management.

This session seeks to answer these issues with hydrological, hydrogeological, and socio-economic contributions from the ecosystems, forestry, wetlands and water resource communities.

**Conveners:** Julien Fiquet (CNPFR, France, [julien.fiquet@cnpr.fr](mailto:julien.fiquet@cnpr.fr)), Michel Lafforgue (Suez Consulting, France, [michel.lafforgue@suez.com](mailto:michel.lafforgue@suez.com)), Patrick Lachassagne (Water Institute by Evian, Danone Waters, [patrick.lachassagne@danone.com](mailto:patrick.lachassagne@danone.com))

### **TOPIC 6 - ACTIVE MANAGEMENT OF GROUNDWATER IN THE WATER CYCLE**

#### **Session 6.01: Managed Aquifer Recharge**

With a trend of increasing water demand and a decreasing availability of water resources, an increasing number of aquifers are overexploited. This can have critical consequences, more especially in coastal areas. This issue will become more important considering the potential impacts of global warming. One of the key options consists of intentionally recharging aquifers to stop/limit the deepening of the piezometric level and protecting environmental ecosystems of connected surface waters. It may be used to enhance recharge of rainwater or urban stormwater or as a complementary treatment prior to wastewater reuse. Managed Aquifer Recharge (MAR) needs to be operated effectively to produce these benefits and avoid problems. Technical issues, such as avoiding clogging, water quality deterioration, or unwanted discharge of stored water need to be addressed along with regulatory, cultural, and economic issues. With appropriate site selection and sound knowledge Managed Aquifer Recharge has become a highly effective water resources management tool.



In this session, contributions include hydrogeologic, hydraulic, and water quality aspects, both geochemical and microbiological, for a range of water types, (particularly urban sources). Both scientific advances and practical case studies are presented.

**Conveners:** Michel Lafforgue (Suez Consulting, France, [michel.lafforgue@suez.com](mailto:michel.lafforgue@suez.com)), Co-Chairs of IAH Commission on MAR: Peter Dillon, Australia, [pdillon500@gmail.com](mailto:pdillon500@gmail.com), Enrique Fernández Escalante, Spain, [efernan6@tragsa.es](mailto:efernan6@tragsa.es), and Weiping Wang, China, [wangweipingwwp@126.com](mailto:wangweipingwwp@126.com)

### **Session 6.02: Treated Wastewater REUSE for groundwater recharge: addressing the challenge**

Water scarcity and the overexploitation of conventional water resources are two of the main drivers to Treated Wastewater (TWW) Reuse. TWW groundwater recharge projects are blooming in the world especially in coastal areas and in the Mediterranean area where increasing pressures on the resource cause deep depletion and high salinization impacts. TWW can either be directly reinjected or indirectly through dedicated infiltration basins as evidenced by several pilot facilities. This practice enables to restore groundwater in terms of quantity and quality, but also to limit salt intrusion and mitigate climate change impacts. TWW could then be pumped from the aquifers for indirect surface reuse like agricultural irrigation. Ground properties are used and considered as a way to improve TWW quality, while much attention is often paid to TWW quality (pathogens, salinity, etc.) prior to recharge to avoid groundwater contamination.

In this session, we are seeking contributions about feedback from pilot- to full-scale experiences on the risks and benefits of such practices regarding regulatory, environmental, social and sanitary conditions both on the qualitative and quantitative sides. This session will also focus on methodologies (cost-benefits Analysis, Life Cycle Analysis, environmental impact assessment...) and development of decision support tools to assess and design the TWW groundwater recharge as a success factor for the water circular economy.

Wastewater reuse is a topical but complex subject and we firmly believe we still need to learn from everyone's experience to help build a framework that is suitable for the wide range of water reuse situation.

**Conveners:** Nicolas CONDOM (PhD, Ecofilae, [www.ecofilae.fr](http://www.ecofilae.fr), France, [nicolas.condom@ecofilae.fr](mailto:nicolas.condom@ecofilae.fr)), Manuel SAPIANO (Water Policy Unit, SEWCU, Malta, [manuel.sapiano@gov.mt](mailto:manuel.sapiano@gov.mt)), Rudy ROSSETTO (PhD, Institute of Life Sciences, Scuola Superiore Sant'Anna, Italy, [r.rossetto@sssup.it](mailto:r.rossetto@sssup.it))

### **Session 6.03: Innovative tools to improve understanding of groundwater recharge processes**

Improving the understanding of groundwater recharge and the ability to predict its sensibility to global change is crucial for a sustainable resource management. Several methods have been developed to investigate groundwater recharge, but it is highly variable in space and time, and large uncertainties remain on its quantification. This session aims at bringing together recent developments of the methods to quantify groundwater recharge at various spatial and temporal scales, as well as in various hydrogeological settings. We seek to gather contributions based on a variety of approaches, from geochemical or geophysical field investigations to integrated hydrogeological modeling.

**Conveners:** Sophie Guillon (Mines ParisTech, France, [sophie.guillon@mines-paristech.fr](mailto:sophie.guillon@mines-paristech.fr)), Florent Barbecot (Université du Québec à Montréal, Canada, [barbecot.florent@ugam.ca](mailto:barbecot.florent@ugam.ca)), Hervé Jourde (Hydrosciences Montpellier, France, [hjourde@univ-montp2.fr](mailto:hjourde@univ-montp2.fr))

## **TOPIC 7 - GROUNDWATER USES AND MANAGING GROUNDWATER USE CONFLICTS**

### **Session 7.01: Groundwater and Energy Resources**

Groundwater and energy resource development are connected in a variety of ways. Contamination of shallow groundwater resources by oil and gas development has been an ongoing issue, with public concern increasing in recent years with the advent of hydraulic fracturing. Similar concerns about contamination have also been associated with nuclear energy. Potential impacts to groundwater quality from long-term waste disposal by the energy sector have also created significant concerns. The availability of groundwater is also affected by energy resource developments, which are often significant users of water. This has created competition between the energy sector and other water users. Use of brackish and saline groundwater by the energy sector has been increasing to alleviate this competition. Finally, the energy content of groundwater itself is of interest. Geothermal energy development is increasing in many parts of the world and these developments can have important interactions with other subsurface developments and groundwater systems. In this session, the interplay of the energy resource development and groundwater will be examined from a variety of



perspectives including conventional and unconventional oil and gas development, biofuels, geothermal energy and nuclear energy.

**Conveners:** Grant Ferguson (University of Saskatchewan, [grant.ferguson@usask.ca](mailto:grant.ferguson@usask.ca)), Bridget Scanlon (Bureau of Economic Geology, The University of Texas at Austin, [bridget.scanlon@beg.utexas.edu](mailto:bridget.scanlon@beg.utexas.edu)) and Philipp Blum (Karlsruhe Institute of Technology, [philipp.blum@kit.edu](mailto:philipp.blum@kit.edu))

### Session 7.02: Urban Hydrogeology

Urban groundwater is a resource under pressure, often subject to quantitative and qualitative deterioration. Urban land-use changes the water balance drastically and urban groundwater is threatened by overexploitation and contamination from a multitude of sources. More recently, urban groundwater has also become subject to geothermal use. This session encourages all contributions on urban groundwater use and management as well as on urban impacts on quantity and quality of groundwater and its receiving waters.

**Conveners:** Gudrun Massmann and Victoria Burke (Carl von Ossietzky Universität Oldenburg, Germany, [gudrun.massmann@uni-oldenburg.de](mailto:gudrun.massmann@uni-oldenburg.de), [victoria.burke@uni-oldenburg.de](mailto:victoria.burke@uni-oldenburg.de)), Gesche Grützmaier (Berliner Wasserbetriebe, [gesche.gruetzmaier@bwb.de](mailto:gesche.gruetzmaier@bwb.de)), Ken W.F. Howard (University of Toronto, [gwater@uts.c.utoronto.ca](mailto:gwater@uts.c.utoronto.ca)), Helen Bonsor (British Geological Survey, UK, [helns0@bgs.ac.uk](mailto:helns0@bgs.ac.uk))

### Session 7.03: Agricultural and sanitation contaminants and implications for water services and health

Between a third and half of the world's population depend on groundwater as their main drinking water supply. There is growing recognition that groundwater of high quality is not ubiquitous. Diffuse pollution by nitrates and pesticides is the main cause of groundwater quality degradation in many countries, and regions are affected by pathogens, which can cause health problems of differing severity. Such pollution is due to agricultural and livestock practices, as well as on-site sanitation and urban wastewater.

From the point of view of government and other agencies responsible for drinking water supply, methodologies to evaluate a degraded resource and how to regain quality are important. In rural and peri-urban settings, there is need to promote changes in agricultural practices to protect aquifers. This may require farmers to adopt new methods and accept different policies. Their willingness may depend on their awareness of the impact of their practices on water quality. Farmer unions often blame poor on-site sanitation or inadequate wastewater treatment for pollution. Clearly, there is need to discriminate between contamination sources.

Rural and peri-urban settings are not only managed by public agencies and are increasingly marked by investments in decentralized water services by water users themselves, particularly in boreholes for drinking water as well as on-site sanitation systems and reuse of wastewater. Consequently, the effects of bacteria and viruses are of increasing concern. In this context, there is need for drilling professionalism particularly regarding borehole siting, sanitary seals and groundwater quality surveillance. Promising technical solutions must be identified, based on the management by the user of water and soil. It is also necessary to understand user's perception of decentralized services and ultimately improve water management policies. Diffuse pollution includes hydrocarbon, metal contaminants, organic micro-pollutants from chemicals used in a variety of products, most of which are from industrial origin. There are knock on effects of such contamination on health (e.g. endocrine disruption, thyroid or liver diseases, cancer) and associated costs for individuals and society.

Pathogens and pollutants tend to be systematically associated with sanitary deficiencies but may also vanish with natural attenuation, in the subsurface and through interaction with surface waters and river sediments.

This session explores complementary approaches to this increasingly important problem: sampling, biomonitoring, geochemistry, hydrodynamic integrated modeling, field surveys on the user's practices and perception and experiments in management. Pollution sources, the fate of the contaminants and the effects of groundwater contamination on society are examined. The session will question the extent to which stakeholders face localized or diffuse pollution and the scale at which these challenges need to be solved.

It is becoming clear that groundwater quality is an interdisciplinary issue that spans the technical, social and political sciences. The authors of selected submissions will be invited to publish in a special issue of an international journal involved in interdisciplinary approaches of environmental issues.

**Conveners:** Olivier Fouché (Cnam - Ecole des Ponts, France, [olivier.fouche@enpc.fr](mailto:olivier.fouche@enpc.fr)); Manuela Lasagna (Earth Sciences Department, Torino University, Italy, [manuela.lasagna@unito.it](mailto:manuela.lasagna@unito.it)); Kerstin Danert (Rural Water Supply Network, Skat Foundation, Switzerland, [kerstin.danert@skat.ch](mailto:kerstin.danert@skat.ch)); Chandrakant Jangam (CSIR - NEERI, Nagpur, India,



[chandu.jangam164@gmail.com](mailto:chandu.jangam164@gmail.com)); Behzad Nasri (Water Engineering Department, Urmia University, Iran, [beza d61@yahoo.com](mailto:beza d61@yahoo.com)), P. Hynds (DIT/ESHI, Ireland, [hyndsp@tcd.ie](mailto:hyndsp@tcd.ie)).

#### **Session 7.04: Groundwater and man-made underground works**

This session focusses on underground facilities such as tunnels, underground storages, underground research laboratories or any other type of underground facilities. The main topics are more especially the impact on groundwater and changes of hydrogeological conditions around and towards the facility, mitigation in case of excess impact and possible cases of using groundwater as an ally for the facility operation.

**Conveners:** François Cabon (GEOSTOCK, Rueil-Malmaison, France, [francois.cabon@geostock.fr](mailto:francois.cabon@geostock.fr)), Alain Rouleau (Pr, Université du Québec à Chicoutimi, Québec, Canada, [arouleau@uqac.ca](mailto:arouleau@uqac.ca))

#### **Session 7.05: The Challenges for Transboundary aquifer management**

In 2016, the UN General Assembly is due to decide the fate of the UN International Law Commissions' Draft Articles on the Law of Transboundary Aquifers following the repeated postponing the decision. The Draft Articles, in whose development the IAH took the scientific lead, represent arguably the most authoritative international legal instrument that specifically addresses the governance of aquifers. At the start of the SDG's, it is becoming imperative to ensure that there is adequate regulation over transboundary aquifers, as their integrity and surrounding ecosystems are threatened by over exploitation, land-use changes and pollution. The science behind these drivers needs to be made more explicit and prominent.

This session of the IAH Congress, in its 60th Anniversary year, calls for papers from the science, the law and social science fields, to come together and provide the background and the justification that could be submitted to the UN General Assembly in Nov 2016 on how the Draft Articles can be turned into an international instrument.

**Conveners:** Shammypuri (Chair IAH Commission on Transboundary Aquifer, [shampypuri@aol.com](mailto:shampypuri@aol.com)), Alice Aureli (Chief Groundwater Section, UNESCO-ISARM, [a.aureli@unesco.org](mailto:a.aureli@unesco.org)), Neno Kukuric (Director IGRAC, [neno.kukuric@un-igrac.org](mailto:neno.kukuric@un-igrac.org)), Karen Villholth (Principal Researcher and Coordinator of GRIPP, IWMI - International Water Management Institute, South Africa, [k.villholth@cgiar.org](mailto:k.villholth@cgiar.org)), [gabriele.ckstein@law.tamu.edu](mailto:gabriele.ckstein@law.tamu.edu)), Ralf Klingbeil (Federal Institute for Geosciences and Natural Resources (BGR), Germany, [r.klingbeil@gmx.de](mailto:r.klingbeil@gmx.de))

#### **Session 7.06: Groundwater protection and governance: examples of groundwater protection models , and the role of the private sector**

Groundwater plays a strategic role in our societies as it is often a prime source of water for communities, agriculture and industries. In a global context of growing water needs, resource use and rising pollution threats, groundwater governance and groundwater protection have to be strengthened. Depending on the regulatory framework, socio-economic, hydrogeological contexts, etc., stakeholders engagement models of groundwater protection can really, and must surely differ.

This session is open to contributions presenting diverse models and cases studies on groundwater protection implementation, from developed and developing countries.

In some areas, the private sector can have a key role to play to protect, quantitatively and qualitatively, groundwater resources, not only to secure their operations but also because tapping water from a non-protected aquifer can seriously impact their reputation. Several tools or methods have emerged during the last decade to help the private sector to drive and implement their water stewardship into their corporate organisation.

The session is thus also open to contribution presenting the different tools and methods, comparing the different approach as well as case studies where private sector engagement has been predominant in groundwater protection initiatives. It also aims at comparing these tools/methods with those developed by other stakeholders (such as public water supply, agriculture, etc.), and favoring their improvement.

**Conveners:** Heru Hendrayana (Gadjah Mada University, Indonesia, [heruha@yahoo.com](mailto:heruha@yahoo.com)), Olivier Beon (Danone Waters, France, [olivier.beon@danone.com](mailto:olivier.beon@danone.com))

#### **Session 7.07: Transdisciplinary and participatory approaches in groundwater research and management**

There is a growing consensus among scientists, policy makers and society in general that the huge challenges of a changing world – not only climate change, but also land and water-use changes arising from social, political and demographic pressures -- can only be solved by through collaboration between scientists from different disciplines. Moreover, there is growing agreement that science needs to take stakeholder knowledge and public opinion into account if the results of



research are to be translated into meaningful and implementable policy. These concepts are known as “participatory research” or “transdisciplinarity” (or simply “science with society”). Participation is a key concept of regulatory initiatives such as the European Water Framework Directive, and forms an essential concept within Integrated Water Resources Management. In particular in the field of groundwater, the world’s largest, best protected and most exploited freshwater resource, the inter-dependence of nature and mankind is of fundamental importance. In this session, contributions that describe experience of participatory, transdisciplinary collaboration between groundwater science and society will be presented.

**Conveners:** Roland Barthel (University of Gothenburg, Sweden, [roland.barthel@gvc.gu.se](mailto:roland.barthel@gvc.gu.se)), Stephen Foster (IAH Past President & GWP Senior Adviser, [iahfoster@aol.com](mailto:iahfoster@aol.com)), Karen G. Villholth, (IWMI, International Water Management Institute, Pretoria, South Africa, [k.villholth@cgiar.org](mailto:k.villholth@cgiar.org)), Frank van Steenberg (MetaMeta Research, [fvansteebergen@metameta.nl](mailto:fvansteebergen@metameta.nl))

## TOPIC 8 - PROGRESS IN CONCEPTUAL MODELS, TOOLS AND METHODS

### Session 8.01: Fiber-Optic Distributed Temperature Sensing as an innovative method in hydrogeology and geothermal energy

For several years, Fiber-Optic Distributed Temperature Sensing has been widely used in hydrogeology to characterize infiltration within the vadose zone, hyporheic flows, and groundwater discharge in lakes or towards the sea. In addition, this emerging tool has also been used to monitor temperature changes during hydraulic tests, geothermal tracer tests, and for monitoring oil recovery. In the present session, we are seeking contributions about the theory, application, and data analysis of Distributed Temperature Sensing applications in hydrogeology and geothermal energy. Such applications may be about the improvement of reservoir monitoring or the characterization of thermal and hydrological processes in the subsurface.

**Conveners:** Olivier Bour (University of Rennes 1, [Olivier.Bour@univ-rennes1.fr](mailto:Olivier.Bour@univ-rennes1.fr)), Victor Bense (Wageningen University, [victor.bense@wur.nl](mailto:victor.bense@wur.nl)) and John Selker (Oregon State University, [John.Selker@OregonState.edu](mailto:John.Selker@OregonState.edu))

### Session 8.02: Groundwater Development and Protection in Coastal and Volcanic Environments with Complex Geological Structures

Session Description: Groundwater resources in coastal and insular contexts are often of high strategic importance but are threatened by natural processes (seawater intrusion, floods, tsunamis, subsidence, sea-level variations, climate changes, and land erosion), and anthropogenic activities (overpumping, drainage, land reclamation, urbanization, and contamination). This session aims at reviewing the latest advances in groundwater investigations, and management criteria in coastal and insular environments characterized by complex geological contexts such as volcanic, sedimentary, karstic, and hard rocks.

Topics of interest include: a. The use of advanced monitoring networks, b. The definition of hydro-geophysical, conceptual, and numerical modeling and model validation focused on Fresh-Salt-water interface, c. Management modeling of integrated water resources in the particular context of coastal areas, considering (1) local hydrogeological catchment characteristics, and (2) quantity and quality demands for different purposes, so as to grant a real sustainable economic development for present inhabitants and future generations.

**Conveners:** Alexandre Pryet (ENSEGID, Bordeaux, France [alexandre.pryet@ensegid.fr](mailto:alexandre.pryet@ensegid.fr)), Giovanni Barrocu (University of Cagliari [barrocu@gmail.com](mailto:barrocu@gmail.com) // [barrocu@unica.it](mailto:barrocu@unica.it))

### Session 8.03: Geometrical structure and hydrogeological properties of Hard-Rock aquifers.

Hard-rock aquifers (i.e. fractured granitic and metamorphic rocks) cover about 35% of the continental surface and constitute a valuable water resource, particularly for many developing and emerging countries. However, determining their geometrical structures as well as their hydrogeological properties (permeability, porosity, recharge...) still remains a challenge which makes difficult the evaluation of these resources and their sustainable management.

The topic of the present session seeks contributions about new methodologies, technologies, conceptual models or modelling techniques developed to improve the knowledge of these fractured aquifers. Expected applications both at borehole or watershed scales concern techniques for evaluating their properties, their geometries, tools supporting the groundwater management, etc.

**Conveners:** Benoît Dewandel (BRGM, France, [b.dewandel@brgm.fr](mailto:b.dewandel@brgm.fr)), Üwe Troeger (University of Berlin, Germany, [uwe.troeger@tu-berlin.de](mailto:uwe.troeger@tu-berlin.de)) & John Sharp (USA, University of Texas, [jmsharp@jsg.utexas.edu](mailto:jmsharp@jsg.utexas.edu))



#### Session 8.04: Isotopic and residence time tracers

While isotopic and chemical tracers are known to be powerful tools to refine groundwater conceptual models and their management strategies, including protection actions, most of abstraction plan rely on the general knowledge of water masses flow. However, recent progress in analytical techniques and in use of isotopic and chemical tracers may provide a substantial support for identifying and modelling flow paths and transit time distributions in aquifers.

This session will focus on both recent development and particular case studies using isotopic and residence time tracers to investigate water flow and contaminant transport in aquifers. This comprise among other things the use of new tracer measurement technologies (e.g. relevance of continuous field monitoring using laser spectrometers), the application of innovative tracers and the development of new modeling strategies to derive the distributions of residence times.

**Conveners:** Florent Barbecot (Université du Québec à Montréal, Canada, [barbecot.florent@uqam.ca](mailto:barbecot.florent@uqam.ca)), Przemysław Wachniew (AGH University of Science and Technology, Krakow, Poland, [wachniew@agh.edu.pl](mailto:wachniew@agh.edu.pl)), Luc Aquilina (Rennes I University, France, [luc.aquilina@univ-rennes1.fr](mailto:luc.aquilina@univ-rennes1.fr)), Vincent Marc (UMR EMMAH, Avignon University, France, [vincent.marc@univ-avignon.fr](mailto:vincent.marc@univ-avignon.fr))

#### Session 8.05: Karst aquifers

Increasing stress on water resources has emphasized the need for alternative groundwater resources, among which karst aquifers. The latest are increasingly studied and this session will be the opportunity to provide a state of the art on karst hydrogeology focused on techniques and methodologies able to deliver to the Society the expected responses.

Abstracts on the following topics are welcome: innovative metrology (flow and quality monitoring, tracing experiments, temperature measurements, geophysics.), groundwater and surface water flows (interaction), solute transport (fate and transport of contaminants, contaminants as tracers, sediment transport, etc), modelling techniques, water management including active management. Submissions on case studies especially on Mediterranean karst systems are welcome.

**Conveners:** J.C. Maréchal (BRGM, France, [jc.marechal@brgm.fr](mailto:jc.marechal@brgm.fr)), B. Mahler (University of Texas Jackson School of Geosciences and USGS, USA, [bimahler@usgs.gov](mailto:bimahler@usgs.gov)), M. Sauter (Göttingen University, Germany, [Martin.Sauter@Geo.Uni-Goettingen.de](mailto:Martin.Sauter@Geo.Uni-Goettingen.de))

#### Session 8.06: Verification of conceptual patterns and expected natural effects of regional groundwater flow by interpretation of relevant field observations + RGFC Competition

The session's objective is to encourage comparisons between theoretical predictions of flow patterns and their natural effects in a given study area, on one hand, and measurable parameters of their real-life flow-fields and empirically observed manifestations of interaction between moving groundwater and its environment in the same area, on the other. Such comparisons, if used iteratively, may be developed into a novel method of groundwater flow-system evaluation. Papers are welcome from any specialty dealing with regional groundwater flow and groundwater dependent processes and phenomena, such as: geothermics, soil salinization, wetland hydrology, surface and subsurface ecology, hydrochemistry, slope stability, petroleum and metallic mineral accumulation, and so on.

**Conveners:** Judit Mádl-Szőnyi (Eötvös Loránd University, Hungary, [szjudit@ludens.elte.hu](mailto:szjudit@ludens.elte.hu)), René Lefebvre (Centre Eau Terre Environnement, INRS, Canada, [rene.lefebvre@ete.inrs.ca](mailto:rene.lefebvre@ete.inrs.ca)), Carlos Molano (Universidad de los Andes, Colombia, [cmolano@uniandes.edu.co](mailto:cmolano@uniandes.edu.co)) John Molson (Université Laval, Canada, [john.molson@ggl.ulaval.ca](mailto:john.molson@ggl.ulaval.ca)), Jose Joel Carrillo-Rivera (UNAM, Mexico, [joeljcr@igg.unam.mx](mailto:joeljcr@igg.unam.mx)) and Adam Toth (Eötvös Loránd University, Budapest, Hungary, [adam.geophysics@gmail.com](mailto:adam.geophysics@gmail.com))

#### Session 8.07: Hydrogeophysics: innovative non-invasive technologies for groundwater resources exploitation and management

Geophysical data from ground-based, borehole logging and remote sensing measurements are being increasingly used to provide qualitative and quantitative information about hydrogeological parameters and processes. Groundwater resources structure, hydrodynamic functioning, contaminant transport, recharge monitoring, surface and groundwater interactions, ecological and climate investigations are some of the hydrological topics where hydrogeophysics actively contributes and that will be discussed during this session.

The "hydrogeophysics" session will focus on both recent methodological developments and case studies. Abstracts on the following topics are welcome: integrative methodologies; relevant hydrogeophysical case studies; recent progress in



equipment (ground based, logging, airborne, satellite) and in methods, measuring techniques and inversion schemes; hydrogeophysical monitoring; biogeophysics.

**Conveners:** Konstantinos Chalikakis (UMR EMMAH, Avignon University, France, [konstantinos.chalikakis@univ-aix-marseille.fr](mailto:konstantinos.chalikakis@univ-aix-marseille.fr)), Roger Guerin (UMR METIS, UPMC Paris-6 University, France, [roger.guerin@upmc.fr](mailto:roger.guerin@upmc.fr)), Lee Slater (Rutgers University Newark, USA, [lslater@rutgers.edu](mailto:lslater@rutgers.edu))

#### **Session 8.08: Mineral and Thermal water: an indicator of deep processes and source of economically valuable minerals**

Mineral and thermal waters are groundwater which are mainly characterised by i) a special chemical composition, ii) a unique origin, iii) high temperature in the case of thermal water, and iv) high total mineralization in the case of saline waters and brines. Geochemical and isotopic studies of these waters shows that they can be an important indicators of deep processes taking place in the Earth's crust nowadays or in geological past.

Active tectonic processes as earthquakes, stress accumulation in the deep underground upwelling of magma chambers are influencing deep fluids which induce changes in groundwater composition. The continuous monitoring of the chemical and physical composition as well as periodic measurements on samples of mineral and thermal water provides information of the occurrence of such processes. The application of these information for the discovery of ongoing processes as leading to earthquakes, volcanic eruptions, gas emissions, etc. as also the interpretation of the processes and effect itself is the one of the main of this session.

On the other hand, deep geological processes ongoing nowadays or taken place in geological past usually induce extensive water rock-interaction which considerably influence on the groundwater chemical and isotopic composition, their origin and mineralization. Mining activities, oil and gas exploration and exploitation, the use of geothermal energy, are examples for human activities of growing up economic relevance that come into touch with highly mineralized waters and brines. In many cases the specific chemical composition of such waters allows to recover many valuable minerals or elements, including critical ones. In this session presentations and posters are also welcome which shows the examples of mineral water utilization as a resource for valuable minerals, technology which are used to this purposes and future prospects in this field.

**Conveners:** Werner Balderer (retired, ETH Zurich, Department of Earth Science, Swiss Geotechnical Commission, Switzerland, [balderer@ethz.ch](mailto:balderer@ethz.ch), [bawemer@retired.ethz.ch](mailto:bawemer@retired.ethz.ch)), Şebnem Arslan (Ankara University, Turkey, [sarslan@eng.ankara.edu.tr](mailto:sarslan@eng.ankara.edu.tr)), Jim LaMoreaux (PELA, Geoenvironment, USA, [jlamoreaux@pela.com](mailto:jlamoreaux@pela.com))

#### **Session 8.09: Hydrogeoecology: a focus on groundwater ecology**

Saturated underground layers, including all types of groundwater bodies from shallow to deep subsurface environments (shallow groundwater interacting with surface soil or water, sedimentary and karstic systems, deep water systems), host a significant part of the prokaryotic biodiversity and biomass on earth, complemented by numerous eukaryotic organisms. These play a key role in the cycling of major elements, particularly at the interface between water and solid matter. They modify the kinetics of chemical reactions, directly or indirectly, inducing dissolution or precipitation of minerals and steering natural attenuation of organic pollutants. Driving the cycling of organic matter and nutrients, groundwater organisms contribute to carbon sequestration or conversely to the release of greenhouse gases. They form a non-negligible part of the set of mechanisms governing hydrogeological evolution of groundwater. Therefore, these organisms reflect, contribute and respond to the status of the underground environments and the two-way interactions of organic pollutants/metals with groundwater microbial communities are potentially important drivers of Global Change. Improvement in knowledge about groundwater organism biodiversity, activity, distribution and evolution are keys to preserve the quality of pristine groundwater bodies, to remediate polluted or disturbed zones, and to rationally manage groundwater resources.

The topic of the present session seeks contributions about ecology of groundwater bodies. Targeted topics include: i) assessment of biodiversity (taxonomic and functional), activity and ecosystem functioning ii), contribution of the groundwater organisms to biogeochemical cycles, iii) identification and assessment of biological processes affecting geochemical quality e.g. bio-transformation of pollutants, iv) development and application of bio-indicator tools to assess groundwater ecosystem status and services and to be implemented in future groundwater regulations and policies.

**Conveners:** Aourel Mauffret (BRGM, France, [a.mauffret@brgm.fr](mailto:a.mauffret@brgm.fr)), Christophe Douady (University of Lyon, France, [christophe.douady@univ-lyon1.fr](mailto:christophe.douady@univ-lyon1.fr)), Christian Griebler (Helmholtz Zentrum Muenchen, Germany, [griebler@helmholtz-muenchen.de](mailto:griebler@helmholtz-muenchen.de))



### Session 8.10: Recent developments in groundwater modeling and mathematical tools in Hydrogeology

Groundwater modelling remains the standard approach to integrate the numerous types of data used for characterizing aquifers. It is also emerging as the approach to synthesize institutional memory on the recent history of the aquifer and to derive management policies. In addition, modelling is a standard tool for addressing emerging challenges, such as CO<sub>2</sub> storage, fracking, enhanced geothermics. Proper groundwater modelling often requires reasonable assumptions on the governing parameters and their spatial distribution and variability. Presentations are welcome on model concepts, numerical methods, geostatistical approaches and actual applications.

**Conveners:** Jesus Carrera Ramirez (Instituto de Diagnóstico Ambiental y Estudios del Agua, Consejo Superior de Investigaciones Científicas, Spain, [jesus.carrera.ramirez@gmail.com](mailto:jesus.carrera.ramirez@gmail.com)), Maria-Th. Schafmeister (Applied Geology, University Greifswald, Germany, [schaf.hydrogeology@uni-greifswald.de](mailto:schaf.hydrogeology@uni-greifswald.de))

### Session 8.11: Hydrogeodesy: new surface tools to characterize and monitor active and managed groundwater systems

Recent development of ground-based and satellite gravimetry (GRACE and ground gravimeter) and deformation (InSAR, tiltmeter and strainmeters) have profoundly changed our vision of dynamic processes in groundwater systems on a wide range of spatial scales. Gravity provide access to a unique observation to constrain aquifer mass balance while deformation offers an image of pressure changes – powering fluid flow – applied on a reservoir. Both non-invasive tools are growing in popularity considering their high potential to remotely image aquifer structure and hydro-dynamical parameters, assess the impact of heterogeneity, improve model predictability skills and evaluate water management policies and their impact on groundwater sustainability.

The hydrogeodesy session will focus on instrumental and methodological developments, as well as case studies on the different applications highlighted.

**Conveners:** Laurent Longuevergne (Géosciences Rennes, Rennes 1 University, France, [laurent.longuevergne@univ-rennes1.fr](mailto:laurent.longuevergne@univ-rennes1.fr)), Di Long (Tsinghua University, Beijing, China, [dlong@tsinghua.edu.cn](mailto:dlong@tsinghua.edu.cn)), Cédric Champollion (Géosciences Montpellier, Montpellier 2 University, France, [cedric.champollion@univ-montp2.fr](mailto:cedric.champollion@univ-montp2.fr))

### Special session KINDRA:

An accurate assessment of the state of the art in hydrogeology research and knowledge is the main aim of the KINDRA project (Knowledge Inventory for hydrogeology research, Grant Agreement 642047, [www.kindraproject.eu](http://www.kindraproject.eu)), funded by the European Commission's HORIZON2020 Framework Programme. Last year, a terminology and classification methodology on groundwater research and knowledge based on a keyword list has been realized. The Hydrogeological Research Classification System (HRC-SYS) has been developed by categorizing groundwater research in three main categories: 1) Societal Challenges, 2) Operational Actions and 3) Research Topics. Each of these three main categories include 5 overarching sub-categories for an easy overview of the main research areas. The complete merged list of keywords, selected from the Water Framework and Groundwater directives and from high impact scientific journals has been organized in a tree hierarchy. This year, the European Inventory of Groundwater Research (EIGR) is populating by groundwater national experts selected by the European Federation of Geologists, by inserting results of research activities, projects and programs realized at national and international scale among Europe.

**Conveners:** Marco Petitta (Sapienza University of Rome, Italy, [marco.petitta@uniroma1.it](mailto:marco.petitta@uniroma1.it)), Isabel Fernandez (EFG: European Federation of Geologists, Brussels, Belgium, [ifernandez.efg@outlook.com](mailto:ifernandez.efg@outlook.com))



	Room BC1	Pasteur Auditorium	Louisville
09:00		<b>Opening ceremony 60 IAH</b>	
10:00		<b>Coffee break &amp; E-Posters Session 1</b>	
10:20		<b>60<sup>th</sup> IAH Anniversary</b>	
11:50 - 12:30		<b>Keynote speaker</b> People and Groundwater: Anatomy of a Long-Term Relationship <b>Craig T. Simmons</b>	
12:30 - 12:45		<b>Plenary Flash Oral Presentations</b> <b>Session 4.01 - Economics</b> 2554 - 1635 - 1789 <b>Session 7.07 - Transdisciplinary</b> 2014 - 1644 - 2013 <b>Session 2.01 - Semi-arid</b> 1869 - 2325 - 2395 <b>Session 7.01 - GW - Energy Resources</b> 2286	
12:45		<b>Lunch/ E-Posters 2</b> 4.01-7.07-2.01-7.01-8.05-2.02-8.04-8.09	
2:00 - 2:30 pm		<b>Keynote speaker</b> Thinking and modeling beyond the aquifer: integrating policy, socioeconomics, ecology and interest groups into groundwater science and management through model-based processes <b>Antony Jakeman</b>	
2:30 - 3:00 pm		<b>Plenary Flash Oral Presentations</b> <b>Session 8.05 - KARST</b> 1749 - 1750 - 1535 - 1434 - 2485 - 1705 - 2295 <b>Session 2.02 - GWDC</b> 2208 - 2145 - 2671 - 1728 <b>Session 8.04 - Isotopes</b> 2372 - 2683 - 2147 - 1421 - 2241 <b>Session 8.09 - Hydrogeoeology</b> 2169 - 1984 - 1721	

	Room BC1	Pasteur Auditorium	Louisville
		<b>Session 7.07 - Transdisciplinary and participatory approaches in groundwater research and management</b>	<b>Session 2.01 - Groundwater in semiarid regions – a long-term view on changes in aquifer balances. Hydrogeology in developing countries</b>
		<b>2089</b> Groundwater Futures in Sub-Saharan Africa-an integrated approach to assessing sustainable groundwater use for poverty alleviation <b>Taylor Richard</b>	<b>1390</b> Estimation of recharge and evaporation losses in the arid zones by using stable isotopes and chloride profiles in soil water <b>Guendouz Abdelhamid</b>
		<b>2332</b> Developing a programme of measures to reduce groundwater pollution a collaborative approach <b>Burke Sean</b>	<b>1405</b> Groundwater Resources in the Aquifer Systems of the Iullemeden and Taoudéni Tanezrouft Basins, Sahelo-Saharan Region <b>Barrat Jean-Marie</b>
3:10 - 4:25 pm	<b>A day in the life of Hydrogeologist (ECHN V.)</b>	<b>1865</b> Unlocking the Potential of Interdisciplinary Research on Groundwater <b>John Thompson</b>	<b>1581</b> Mapping irrigation potential from renewable groundwater in Africa D a development perspective <b>Altchenko Yvan</b>
		<b>1833</b> A path towards aquifer management through the empowerment of water stakeholders <b>Lefebvre Rene</b>	<b>1848</b> A pan-African inter-comparison of the relationship between precipitation and groundwater recharge from in-situ observations and large-scale models <b>Shamsudduha Mohammad</b>
		<b>1519</b> The Role of Hydrogeologists as social-scientists in Nigeria- from theory to practice <b>Bakari Ali</b>	<b>1896</b> Groundwater recharge in Africa- identifying critical thresholds <b>Macdonald Alan</b>
4:25		<b>Coffee break / E-Posters session 3 • 5.05-7.03</b>	

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	Room BC1	Pasteur Auditorium	Louisville
4:45 - 6:45 pm	Workshop "Conjunctive Management of Surface Water and Groundwater" UNESCO-IMP	Session 4B1 - Innovative economic instruments and institutions for achieving sustained groundwater use: Integrated socio-economic and biophysical modeling for groundwater and conjunctive use management	<p><b>Specific session</b></p> <p><b>IGFC Student Competition (1/2)</b> Chairs: Viviana Rio, Adam Tolt</p> <p><b>IGFC Student Competition</b> Slot/Order</p> <ul style="list-style-type: none"> <li>• Gonzalo Ojumbay Ospina, Andrea Erickson-Palacios Colorado 1/1</li> <li>• Zsófia Kinczy, Carmen Febate 1/2</li> <li>• Marc Laurencelle, Delores Jones 1/3</li> <li>• Raphael Brunel, Vincent Villet 1/4</li> <li>• Jana Salway, Jana Ringler 1/5</li> <li>• Anwar Zulkhoor, Wijayanti Adnan 1/6</li> <li>• Jacki Den-Telencz, Daniel Skowro 1/7</li> </ul>
		Economics - Rivarolo J.D.	
		2228 The New Sustainable Groundwater Management Act in California Parker Timothy K.	
		2138 Groundwater management under the Murray D Darling Basin Plan Hyde Peter	
		3967 Policies and tools to promote economic use of groundwater in South Australia Barnett Steve	
		2142 Institutional Approaches to Groundwater Management in Coastal Aquifers- An Empirical Analysis Zakri Slim	
		2838 Multicriteria Decision Analysis of Freshwater Resource Management in Southwestern Bangladesh Peters Chelsea	
2427 When companies support protection of water resources- the co-creation of territorial value in Natural Mineral Water watersheds Bacchi Thomas			

	Room BC1	Pasteur Auditorium	Louisville
4:45 - 6:45 pm	Workshop "Conjunctive Management of Surface Water and Groundwater" UNESCO-IMP	2673 Assessing the economic benefits of preserving strategic groundwater reserves for present and future generations using the ecosystem services approach Gonzalez Marlene	
		2962 Which funding for Research and Innovation for Water in Europe and Beyond Europe? Dammekroll Beate/Jan	
6:45 pm		Session Water JPI -What funding is there for European research in Water? French National Research Agency	
		IAH General Assembly	

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	Room BC1	Pasteur Auditorium	Barthez 1	Barthez 2	Rondelet 1	Rondelet 2	Louisville	Barcelone		
09:00 - 09:30 am		<p><b>Keynote speaker</b> Karst aquifer resources of the Mediterranean Basin: a model of world's karst groundwater? <b>Michel Bakalowicz</b></p>							09:00 - 09:30 am	
09:30 - 10:00 am		<p><b>Plenary Flash Oral Presentations</b> <i>Session 5.05 - Forest - Wetland</i> 2687 - 1567</p> <p><i>Session 7.03 - Agriculture &amp; sanitation practices</i> 1774 - 2056 - 1860 - 1944 - 1894 - 1923 - 1370</p> <p><i>Session 5.04 - Emerging contaminants</i> 1773 - 1913 - 2229</p> <p><i>Session 1.03 - Sharing Groundwater knowledge</i> 2598 - 2366 - 2199 - 2668 - 2125 - 2135 - 2385</p>								09:30 - 10:00 am
10:10 - 11:10 am	<p>10:10-12:15 am <b>Workshop UNESCO-IHP Groundwater and Climate Change programme (GRAPHIC) and IAH Commission on Groundwater and Climate Change</b></p>	<p><i>Session 8.05 - Karst aquifers</i></p> <p><b>KARST - Maréchal J.C., Sauter M.</b></p> <p>2578 Quantifying the natural protection of karst aquifers <b>Sineich Michael</b></p>	<p><i>Session 2.02 - Groundwater for sustainable water supplies in developing countries</i></p> <p><b>GWOC</b> <b>JM Vouillamoz &amp; Alan MacDonald</b></p> <p>1889 An Atlas of Groundwater in Africa <b>O Dochartaigh Brighid</b></p>	<p><i>Session 7.01 - Groundwater and Energy Resources</i></p> <p><b>GW - Energy Resources</b> <b>Ferguson G., Scanlon B.</b></p> <p>2409 The importance of an effective and adequate baseline for shale gas- the UK experience <b>Ward Robert</b></p>	<p><i>Session 7.07 - Transdisciplinary and participatory approaches in groundwater research and management</i></p> <p><b>Transdisciplinary</b> <b>Barthel R., Foster S., van Steenberg F., Villholth K.</b></p> <p>1716 Socio-hydrogeology- enhancing the role of hydrogeologists as advocates for public engagement in water management and governance <b>Re Viviana</b></p>	<p><i>Session 8.04 - Isotopic and residence time tracers</i></p> <p><b>Isotopes</b> <b>Barbecot F., Wachniew P., Marc V., Aquilina L.</b></p> <p>2480 Are the Springs of the Grand Canyon At Risk? - Groundwater Exploitation and the Hydrogeology of the Grand Canyon, USA <b>Kreamer David</b></p>	<p><i>Session 8.01 - Fiber-Optic Distributed Temperature Sensing as an innovative method in hydrogeology and geothermal energy</i></p> <p><b>Fiber optic temperature</b> <b>Bour O., Selker J.</b></p> <p>2122 Comparing Fiber-Optic Distributed Temperature Sensing to Hydrochemistry for understanding groundwater inflows to streams <b>Daughney Christopher J.</b></p>	<p><b>IAH network on "Coastal aquifer dynamics and coastal zone management"</b> <b>G. Barrocu</b></p>	10:10 - 11:10 am	

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	Room BC1	Pasteur Auditorium	Barthez 1	Barthez 2	Rondelet 1	Rondelet 2	Louisville	Barcelone					
10:10 - 11:10 am	10:10-12:15 am <b>Workshop UNESCO-IHP Groundwater and Climate Change programme (GRAPHIC) and IAH Commission on Groundwater and Climate Change</b>	<b>2524</b> Monitoring and Assessment of Anthropogenic Contaminant Distributions in Karst System <b>Padiña Ingrid Y.</b>	<b>2168</b> Stakeholder engagement in groundwater management- sharing decisions, sharing opportunities <b>Tringali Chiara</b>	<b>2154</b> An old slate mine as lower reservoir for UPSH (Underground Pumping Storage Hydroelectricity)- groundwater interactions and limitations <b>Pujades Estanislao</b>	<b>1588</b> Stakeholder Engagement and Groundwater D A practical approach <b>Peter Penning</b>	<b>2133</b> The use of particle tracking-based groundwater age distributions in assessments of contamination risk from coal seam gas development <b>Sreekanth J</b>	<b>2062</b> Comparison of temperature from DTS and ERT with direct measurements during heat tracer experiments in heterogeneous aquifers <b>Nguyen Frédéric</b>	<b>IAH network on "Coastal aquifer dynamics and coastal zone management"</b> <b>G. Barrocu</b>	10:10 - 11:10 am				
11:10 - 11:30 am		<b>2640</b> Multiscale karst sediment dynamic study- from the flood scale to the pluriannual scale Example with Bruisresse spring, Normandy, France <b>Chedeville Stéphane</b>	<b>2237</b> Facing climate change- Development of a participatory water management in urban slums in Jaipur, India <b>Frommen Theresa</b>	<b>1381</b> Groundwater-energy-food nexus- Conflicts between groundwater use for energy and fishery production <b>Taniguchi Makoto</b>		<b>1919</b> Inferring groundwater ages in complex aquifers using gas tracers and tritium. <b>Henriot Abel</b>	<b>2036</b> Multi-corehole thermal tracer tests using DTS to identify flow pathways in a fractured dolostone aquifer <b>Munn Jonathan</b>		11:10 - 11:30 am				
11:30 - 12:45 am		<b>2069</b> Regional assessment of contamination dynamics of a Eastern Mediterranean karst aquifer system <b>Schmidt Sebastian</b>	<b>2019</b> Evaluation of groundwater resources in the Tana and Beles sub-basins (Ethiopia) within a framework of River Basin Authorities development and Water Resources Master Plan build-up <b>Garoute Aude</b>	<b>2210</b> Geological potentials of aquifer thermal energy storage in North Algeria <b>Abdelkader Ait Ouali</b>		<b>2032</b> 81Kr Dating of Groundwater in the Baltic Artesian Basin on the One-Million-Year Timescale <b>Gerber Christoph</b>	<b>2035</b> Heat dissipation test to estimate groundwater fluxes- test case at an unconsolidated coastal aquifer <b>Del Val Alonso Laura</b>		11:30 - 12:45 am				
<b>Coffee break / E-Posters session 4 • 5.04 - 5.01 - 7.03 - 7.04</b>					<b>Coffee break / E-Posters session 4 • 5.04 - 5.01 - 7.03 - 7.04</b>								
<b>Session 8.05 - Karst aquifers</b>		<b>Session 2.02 - Groundwater for sustainable water supplies in developing countries</b>		<b>Session 5.05 - Groundwater and Ecosystems - Hydrological role of forests and wetlands</b>		<b>Session 7.03 - Agricultural and sanitation contaminants and implications for water services and health</b>			<b>Session 8.09 - Hydrogeocology: a focus on groundwater ecology</b>		<b>Session KINDRA Fernandez I., Petitta M.</b>		<b>Session 1.03 Session 1.03 - Sharing groundwater knowledge</b>
<b>KARST</b> <b>Maréchal J.C., Sauter M.</b>		<b>GWDC</b> <b>JM Vouillamoz &amp; Viviana Re</b>		<b>Forest - Wetlands</b> <b>Fiquepron J., Lachassagne P., Laforgue M.</b>		<b>Agriculture &amp; sanitation practices - Nitrates</b> <b>Fouché O., Hynds P.</b>		<b>Hydrogeocology</b> <b>Mauffret A., Douady C., Griebler C.</b>		<b>Sharing Groundwater knowledge</b> <b>S. Massuel and G. Wendling</b>			
<b>2312</b> A hydrodynamical approach to understand sediment fluxes in a karstic aquifer <b>Vuilleumier Cécile</b>		<b>1901</b> Examining functionality and sustainability of groundwater supplies equipped with hand pumps <b>Macdonald Alan</b>		<b>1829</b> Quantitative interactions between forest and the water resources <b>Lachassagne Patrick</b>		<b>1868</b> 40 years of rising nitrates and future concentrations in UK groundwater <b>Dottridge Jane</b>		<b>2041</b> Diversity and functionality of groundwater viral communities <b>Griebler Christian</b>		<b>2436</b> KINDRA Project- Hydrogeological Research Classification System (HRC-SYS) <b>Marco Petitta</b>		<b>2191</b> How to make groundwater visible? A review of communication tools <b>Richard-ferroujji Audrey</b>	

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11:30 - 12:45 am		<p><b>2322</b> Karst flow system information from shape analysis and numerical modeling of tracer concentration curves <b>Bartolomé Andreo</b></p> <p><b>2338</b> Prediction of turbidity using neural networks- application on chalk aquifer of Normandy (France) <b>Savary Michal</b></p> <p><b>2347</b> Design of a recurrent rainfall-water level model for water management. Application to the karst Plateau of Méjannes-le-Clap (South-eastern France) <b>Coutouis Adrien</b></p>	<p><b>1846</b> Influence of Bedrocks on Hydraulic Characteristics of Weathered Basement Aquifers- A Case Study from South-Western Nigeria <b>Tijani Moshood Niyi</b></p> <p><b>1853</b> Improvement perspectives for borehole implementation in tropical basement rock aquifers using electrical resistivity- the example of Benin, West Africa <b>Allé Iboukoun Christian</b></p> <p><b>1850</b> Groundwater reserve and aquifer buffer capacity in weathered hard rocks of Africa- comparison of results obtained in Benin, Burkina Faso and Uganda <b>Lawson Fabrice Messan Amen</b></p>	<p><b>1772</b> The effects of land use change on the surface water groundwater interactions in the coastal lakes and wetlands of eastern South Africa <b>Tanner Jane</b></p> <p><b>1538</b> Multi-model approach to evaluate the impact of a future well field on forest production (South-West of France) <b>Saltel Marc</b></p> <p><b>2281</b> Qualitative interactions between forest and the water resources <b>Laffogues Michel</b></p>	<p><b>2700</b> Nitrate trends in groundwater of the Campania region (southern Italy) <b>Ducci Daniela</b></p> <p><b>2171</b> Groundwater nitrate pollution and water scarcity- anticipating pressures as a means to define adaptive strategies <b>Josep Mas-pla</b></p> <p><b>1887</b> A robust hydrochemical and isotopic method for urban and agricultural origins of nitrate in groundwater <b>Aunay Bertrand</b></p>	<p><b>1651</b> European maps of habitats, bioregions, and species in groundwater <b>Malard Florian</b></p> <p><b>1980</b> Towards an EQS assessment in groundwater bodies- ammonium contamination and response of groundwater copepods <b>Galassi Diana M.p.</b></p> <p><b>2094</b> GroundCare - Concept for the integrative ecological assessment of groundwater ecosystems status and services <b>Hug Katrin</b></p>	<p><b>2441</b> KINDRA Project- European Inventory of Groundwater Research (EIGR) <b>Marco Petitta</b></p> <p><b>2388</b> KINDRA Project- End user requirements <b>Fernandez Isabel</b></p> <p><b>2448</b> KINDRA Project- relevance for implementation of EU Water Directives <b>Marco Petitta</b></p>	<p><b>2127</b> Demystifying hydrogeology training barefoot hydrogeologists in the Himalayas <b>Mukherji Aditi</b></p> <p><b>1954</b> Site C Dam - Inadequate Hydrogeological Assessment and Lack of Assessment of Cumulative Effects <b>Wendling Gilles</b></p> <p><b>2215</b> Presenting the rejected hypothesis D it's contribution to science success <b>Cameron Stewart</b></p>	11:30 - 12:45 am
12:30 am-1:30 pm	<b>DHI Workshop</b>								12:45 am
1:45 pm	<i>Lunch &amp; E-Posters - Session 5 • 8.10 - 1.03 - 8.03 - 7.04 - 8.01 - 6.02 - 7.03</i>				<i>Lunch &amp; E-Posters - Session 5 • 8.10 - 1.03 - 8.03 - 7.04 - 8.01 - 6.02 - 7.03</i>				1:45 pm
1:45 - 2:15 pm		<p><b>Keynote speaker</b> Emerging contaminants in groundwater <b>Dan Lapworth</b></p>						<p><b>2141</b> Groundwater allocation, community concerns and uncertainty <b>Kalbus Edda</b></p>	1:45 - 2:15 pm

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2:15 - 3:00 pm		<p><b>Plenary Flash Oral Presentations</b>  <b>Session 8.10 - Modeling</b>            1572 - 2181 - 2251 - 1712 - 1965 - 2288</p> <p><b>Session 6.01 - MAR</b>            1634 - 1842 - 2413 - 2248</p> <p><b>Session 8.01 - Fiber optic temperature</b>            2035 - 2010</p> <p><b>Session 8.03 - Hard Rock Aquifers</b>            1875 - 2278 - 2266 - 1878 - 2631</p> <p><b>Session 7.04 - Underground work</b>            2137 - 2224</p> <p><b>Session 8.11 - Hydrogeodesy</b>            1687 - 2173</p>								2:15 - 3:00 pm
		<p><b>Session 8.10 - Recent developments in groundwater modeling and mathematical tools in Hydrogeology</b></p>	<p><b>Session 2.02 - Groundwater for sustainable water supplies in developing countries</b></p>	<p><b>Session 5.01 - Groundwater resources in a world facing climate change</b></p>	<p><b>Session 7.03 - Agricultural and sanitation contaminants and implications for water services and health</b></p>	<p><b>Session 6.01 - Managed Aquifer Recharge</b></p>	<p><b>Session 5.04 - Emerging contaminants in the water cycle and risk to Groundwater</b></p>	<p><b>Session 8.03 - Geometrical structure and hydrogeological properties of Hard-Rock aquifers</b></p>		
		<p><b>Modeling (Regional - Statistics - contamination source detection)</b>            M.T. Schafmeister, J. Carrera</p>	<p><b>GWDC</b>            Re V., Mac Donald A.</p>	<p><b>Climate change</b>            Barthelemy R., Habets F., Taylor R.</p>	<p><b>Agriculture &amp; sanitation practices</b>            Fouché O., Hynds P.</p>	<p><b>MAR</b>            Lafforgue M., Dillon P., Fernandez Escalante A.E.</p>	<p><b>Emerging contaminants</b>            Di Gioia L., Lapworth D., Lopez B.</p>	<p><b>Hard Rock Aquifers</b>            Dewandel B., Sharp J., Tröger U.</p>		
3:00 - 4:30 pm		<p><b>2126</b>            Characterising status and changes of regional scale groundwater systems using similarity            Barthel Roland</p>	<p><b>1800</b>            Identification of groundwater natural recharge areas in the productive thiaroye urban aquifer (dakar, senegal)            Faye Seynabou Cissé</p>	<p><b>1371</b>            Analysis of groundwater level historical data to detect climate change impact in France            Vernoux Jean Francois</p>	<p><b>1425</b>            Is the provision of on-site sanitation a threat to rural domestic water supplies in India?            James Sorensen</p>	<p><b>2271</b>            Sixty years of progress in research and practice of Managed Aquifer Recharge            Dillon Peter</p>	<p><b>1771</b>            Micro-organic groundwater contamination in the Indo-Gangetic aquifer system            Lapworth Dan</p>	<p><b>1554</b>            Crystalline rock aquifers- The Llano Uplift, Central Texas, USA            Setlur Neeraja</p>	3:00 - 4:30 pm	
		<p><b>2114</b>            Interpreting hydraulic and hydrochemical data in an Australian alluvial aquifer-aquiclude system using multivariate statistics            Cook Scott</p>	<p><b>2178</b>            Numerical modeling for groundwater management and protection D The case of the Nyanzare well field in Gitega, Burundi            Vassolo Sara</p>	<p><b>1463</b>            Impact of climate change on irrigation needs and groundwater resources in the metropolitan area of Hamburg (Germany)            Hermann Frank</p>	<p><b>1399</b>            Contamination fingerprinting techniques for private water supply wells- Identifying the impact from domestic water treatment systems            Fennell Chris</p>	<p><b>2632</b>            Managed Aquifer Recharge (MAR) as to supply Libreville water-stressed city (Gabon)            Collignon Bernard</p>	<p><b>1444</b>            New insights in transport processes by applying emerging contaminants as tracers            Scheytt Traugott</p>	<p><b>2452</b>            Groundwater Divides in a Fractured Crystalline Rock Setting            Normani Stefano</p>		

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3:00 - 4:30 pm		<p><b>2470</b> CSI- Forensic hydrogeology <b>J. Jaime Gomez-Hernandez</b></p> <p><b>2110</b> Loosely coupled modeling of a regional groundwater-surface water system, Southland, New Zealand <b>Daughney Christopher J.</b></p> <p><b>1828</b> Reverse modeling - a simple and robust method for modeling and forecasting the piezometric level discharge of a pumping well. A case study in a Hard Rock Aquifer <b>Lachassagne Patrick</b></p> <p><b>1781</b> Flow-adapted parametrization of subsurface heterogeneity - Estimating aquifer statistics from transient pumping tests <b>Zech Alfraune</b></p>	<p><b>1484</b> Mapping groundwater availability and renewability in rural areas in Cambodia- a multi-disciplinary approach including geophysics, hydrogeology and geochemistry <b>Valois Remi</b></p> <p><b>1993</b> A case of natural contaminants in groundwater- High uranium concentrations in water supply wells in Burundi <b>Vassolo Sara</b></p> <p><b>1841</b> Hydrogeochemical-multivariate analysis of underground water in the middle magdalena valley region - colombia- study at a regional scale <b>Juan Pablo Malagin</b></p> <p><b>2472</b> Hydrologic Interconnection between the Volcanic Aquifer and Springs, Lake Tana Basin on the Upper Blue Nile <b>Abera Fenta Nigate</b></p>	<p><b>1792</b> Groundwater flow and saltwater intrusion modelling in the Continental Terminal (CT) aquifer near the Saloum inverse estuary in Senegal <b>Faye Serigne</b></p> <p><b>1936</b> Global methodology for climate change impacts on groundwater resources assessing- Morocco's case study <b>El Assaoui Naima</b></p> <p><b>1979</b> Groundwater resource management facing global changes- from the European Directive to the local action plan for the Crau aquifer (SE France) <b>Baillieux Antoine</b></p> <p><b>2096</b> Impact of climate change and human activities on groundwater resources in Kenya- current knowledge and initial findings in Nairobi aquifer system, a strategic aquifer under high pressure <b>Oiro Samson</b></p>	<p><b>1859</b> Dependence of low-cost urban water and sanitation in Sub-Saharan Africa on conjunctive use of groundwater and shallow subsurface- a town city mega-city inter-comparison <b>Taylor Richard</b></p> <p><b>2446</b> Shallow groundwater and Self-supply- Potential and the risks as water supply for rural Ethiopians <b>Mekonta Lemessa</b></p> <p><b>1633</b> Nitrate contamination of groundwater and health effects due to unhygienic sanitation practices in rural India <b>Taneja Pinky</b></p> <p><b>2091</b> Groundwater Quality Monitoring and Testing- A Key Necessity for Identifying Groundwater pathogens and preventing Endemic and Epidemic Infection due to Borehole Proliferation in Nigeria <b>Akpan Anthony</b></p>	<p><b>2097</b> Saturated-Unsaturated Groundwater Flow model to assess the design of Sustainable Urban Drainage Systems <b>Borda Sergio</b></p> <p><b>1823</b> Numerical simulation of managed aquifer recharge into a karst groundwater system at the Wala reservoir, Jordan <b>Xanke Julian</b></p> <p><b>2680</b> Integrating Managed Aquifer Recharge into regional water management in Jordan <b>Klinger Jochen</b></p> <p><b>2121</b> A new technique for perforating steel casing to seal and protect aquifers <b>Ben Hall</b></p>	<p><b>2482</b> Groundwater contamination by pesticides and metabolites in an alluvial aquifer- timeframe and trend <b>Baran Nicole</b></p> <p><b>2192</b> Spatial and temporal evolution of antibiotics in the 'Baix Fluvi' alluvial aquifer and its impact on groundwater resources quality <b>Merce Boy-roura</b></p> <p><b>1803</b> Monitoring of micro-organic pollutants in groundwater by means of passive sampling- case study Dravsko polje, Slovenia <b>Anja Koro_a</b></p> <p><b>2189</b> Perchlorates in French groundwater- Former uses and emerging concerns <b>Lopez Benjamin</b></p>	<p><b>1960</b> Evaluation of the groundwater potentialities of the Yeounde (Cameroon) fissured hard rock aquifers <b>Bon André Firmin</b></p> <p><b>2194</b> Conceptual model of fractured hard rock aquifer functioning through monitoring contamination downstream a landfill (Case of Médiouna landfill, Casablanca, Morocco) <b>Fekri Ahmed</b></p> <p><b>2166</b> Evolution of fluvial, weathered and fractured basement aquifers in Uganda <b>Tindimugaya Callist</b></p> <p><b>1948</b> Measurement and characterization of hydraulic conductivity of peridotites in New Caledonia <b>Jeanpert Julie</b></p>
4:30 - 5:00 pm	<i>Coffee break / E-Posters session 6 • 8.03 - 7.06 - 6.01</i>				<i>Coffee break / E-Posters session 6 • 8.03 - 7.06 - 6.01</i>			
5:00 - 6:30 pm	<p><b>IAH Burdon Groundwater Network for International Development (IAH-BGID) annual general meeting</b> Chairpersons Alan MacDonald (network director), Viviana Re and Tamiru Abiye (network co-directors)</p> <p><i>Modeling (Uncertainty - Geostats-subsurface characterization)</i> <i>M.T. Schafmeister, J. Carrera</i></p>	<p><i>Session 7.04 - Groundwater and man-made underground works</i></p> <p><i>Underground work</i> <i>Cabon F., Rouleau A.</i></p>	<p><i>Session 5.01 - Groundwater resources in a world facing climate change</i></p> <p><i>Climate change</i> <i>Barthel R., Habets Fl., Taylor R.</i></p>	<p><i>Session 7.03 - Agricultural and sanitation contaminants and implications for water services and health</i></p> <p><i>Agriculture &amp; sanitation practices - Sanitation and drinking water</i> <i>Danert K., Fouché O., Hynds P.</i></p>	<p><i>Session 6.02 - Treated WasteWater REUSE for groundwater recharge: addressing the challenge</i></p> <p><i>REUSE</i> <i>Condom N., Rossetto R., Sapiano M.</i></p>	<p><i>Session 7.06 - Groundwater protection and governance: examples of groundwater protection models, and the role of the private sector</i></p> <p><i>GW protection</i> <i>Béon O., Heru H.</i></p>	<p><i>Session 8.03 - Geometrical structure and hydrogeological properties of Hard-Rock aquifers</i></p> <p><i>Hard Rock Aquifers</i> <i>Dewandel B., Sharp J., Tröger U.</i></p>	



	<i>Room BC1</i>	<i>Pasteur Auditorium</i>	<i>Barthez 1</i>	<i>Barthez 2</i>	<i>Rondelet 1</i>	<i>Rondelet 2</i>	<i>Louisville</i>	<i>Barcelone</i>	
5:00 ~ 6:30 pm	<b>IAH Burdon Groundwater Network for International Development (IAH-BGID) annual general meeting</b> Chairpersons <b>Alan MacDonald</b> (network director), <b>Viviana Re</b> and <b>Tamiru Abiye</b> (network co-directors)	<b>1953</b> Modelling spatio-temporal variability of water table depths monitoring data <b>Lilla Manzione Rodrigo</b>	<b>2396</b> Analysis by cross plot method for anticipating seepage during operation of unlined underground storage caverns <b>Van Hasselt Blanca</b>	<b>2098</b> Short and long term coastal aquifer comprehensive vulnerability mapping. The ACVM method a valuable tool for groundwater managing plan. <b>Carrubba Salvatore</b>	<b>2910</b> Critical Role of High Permeability Zones on Field-Scale Pathogen Transport and Retention, Infection Risk, and Setback Distance <b>Bradford Scott A.</b>	<b>1999</b> The Llobregat aquifer in the water cycle management of Barcelona (Spain) <b>Enric Queralt</b>	<b>1570</b> Protecting Critical Groundwater Resources above Coal Seam Gas Operations- The Roles of Chemistry and Isotopes <b>Cresswell Richard</b>	<b>1769</b> Fluid Flow in the Faulted Crystalline Basement of the Ore Mountains (Germany) <b>Achtziger-zupan?i? Peter</b>	5:00 ~ 6:30 pm
		<b>2331</b> Should we collect more K data or more aquifer samples for effective subsurface characterization? A comparative study based on reproducibility of flow and transport modelling results. <b>Jacopo Terrenghi</b>	<b>1874</b> Bedrock aquifer characterization based on underground mine site investigation- Results and opportunities <b>Rouleau Alain</b>	<b>2230</b> Comparing the effects of climate change and mitigation measures on urban groundwater resources <b>Kidmose Jacob</b>	<b>1499</b> Comparison of tools and protocols for groundwater sampling <b>Quiot Fabrice</b>	<b>2264</b> Infiltration in five artificial and natural wetlands downstream of wastewater treatment plants (France) <b>Lafforgue Michel</b>	<b>2589</b> Towards common groundwater management - the case of Copiapo in Northern Chile <b>Donoso-harris Guillermo</b>	<b>2153</b> In-situ measurements of permeability and development of a hydrogeological model that considers the permeability distribution around a fault in the Toki granite, Japan <b>Kashiwaya Koki</b>	
		<b>1464</b> Geostatistics and numerical modelling in the characterization of contaminated sites <b>Lotti Francesca</b>	<b>1494</b> Dewatering Impact Assessment of Longwall Coal Mining on Groundwater Resources in Central Turkey <b>Hasan Yazicigil Hasan</b>	<b>2277</b> Climate-induced warming imposes a threat to North European spring ecosystems <b>Klšve Björn</b>	<b>1922</b> COMETE project Valensole- lavender and water quality - spatiotemporal characterization of impacts to waters of agricultural pollution <b>Rivet Florence</b>	<b>2582</b> Evolution of the soil buffer capacity during the provision of two water related ecosystem services <b>Marchina Chiara</b>	<b>1758</b> The Development of AMATA PERSA-DAA, Assessment Tools for Groundwater Protection Practices <b>Hendrayana Heru</b>	<b>2383</b> A workflow for inferring vertical profiles of hydraulic conductivity in regional rock aquifers from specific capacity data affected by drilling and testing biases <b>Laurencelle Marc</b>	
		<b>2284</b> Longterm Saltwater injection into a confined aquifer- A density-coupled mass-transport model taken to the max? <b>Aus Der Beek Martina</b>	<b>2106</b> Use of the Conduit Flow Process for the simulation of passive mitigation measures against the piezometric damming effect at the new underground High Speed railway station of Florence <b>Filippini Maria</b>	<b>2303</b> Disaggregating the effects of climatic and anthropogenic drivers on groundwater availability in the Arkavathy watershed, India <b>Veena Srinivasan</b>	<b>2085</b> Understanding of a coupled groundwater - surface water system as a framework for mitigation of nitrate pollution in an agricultural catchment <b>Wachniew Przemyslaw</b>	<b>1931</b> Methodology to design a permeable reactive barrier for soil aquifer treatment <b>Garoute Aude</b>	<b>2611</b> Comparative study of the evaluation methods of the vulnerability of aquifers to pollution in a porous environment with the use of SIG tools. With application to the aquifer of Souss-Chtouka, Morocco <b>Mohamed Sinan</b>	<b>1987</b> Fracture Transmissivity Development as a Response to Hydraulic Fracturing and Hydraulic Jacking at Grimsel Test Site <b>Loew Simon</b>	
		<b>2659</b> First results of the AquFR project- assessment of the french national multimodel hydrogeologic system on past years. <b>Roux Nicolas</b>	<b>2058</b> Consequences of mine depressurization on a regional carbonate aquifer, Tata, Hungary <b>Kovacs Attila</b>	<b>2447</b> Occurrence of greenhouse gases (CO <sub>2</sub> , N <sub>2</sub> O and CH <sub>4</sub> ) in groundwater of the Walloon Region (Belgium) <b>Anna Jurado</b>	<b>1879</b> NH <sub>4</sub> <sup>+</sup> occurrence in subsurface aquifer- an assessment to binding mechanism of ammonium with OM in aquifers of Jianhan Plain, China <b>Huang Shuangbing</b>	<b>2049</b> Managed Aquifer Recharge in Barcelona with reclaimed and pre-potable water- towards a practical application in urban water supply <b>Marta Hernandez Garcèa</b>	<b>2368</b> The pretext of foresight to debate on irrigation groundwater management- lessons from six cases Ostudies in France <b>Rinaldo Jean-daniel</b>	<b>1510</b> Effects of test scale on hydraulic measurements in a crystalline rock setting <b>Novakowski Kent</b>	

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	Room BC1	Pasteur Auditorium	Barthez 1	Barthez 2	Rondelet 1	Rondelet 2	Louisville	Barcelone	
5:00 - 6:30 pm	IAH Burdon Groundwater Network for International Development (IAH-BGID) annual general meeting Chairpersons Alan MacDonald (network director), Viviana Re and Tamiru Abiye (network co-directors)	ECHN Coolest Paper Award Prize Coolest Paper Award (Opdal et al.)	2646 Hydrogeological impact of the access ramps and shafts of the French Cigeo deep radioactive waste disposal on the above aquifers Benabderrahmane Abdelhakim	2501 Long-Term Precipitation Patterns Prediction- A Data Mining and Remote Sensing Based Water Management Approach Racha El Kadiri	2349 Enhancing water resource management in rural areas by means of simulation tools De Filippis Giovanna	1571 Managed Aquifer Recharge with Highly Polished Treated Effluent in the Malta-South Regional Aquifer Manuel Sapiano	1573 The governance of groundwater and the state-community comanagement continuum Molle François	1915 Characterizing complex aquifers using flow dimension diagnostic sequences Rafini Silvain	5:00 - 6:30 pm
6:30 - 7:30 pm			IAH Commission on groundwater and Climate Change Richard Taylor, Bridget Scanlon	Meeting of the IAH French National Chapter - Castany Award Prize	IAH Transboundary Aquifers Commission Shammy Puri, Ralph Klingbeil, KKaren Grothe Villholth	2360 Climate change impacts on flash flood in Mediterranean mesoscale catchments- the Lez basin Colmet Daage Antoine	2287 The Role of Hydrogeologists in Drinking Water Source Protection Ford Donald	1468 Diversification of water source to enhance mar. The sat-mar case of alcazarfn+ valladolid, spain Enrique Fernandez Escalante	
7:45	Bus departure				Bus departure				7:45
8:00 - 11:00 pm	GALA DINNER				GALA DINNER				8:00 - 11:00 pm

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	Room BC1	Pasteur Auditorium	Barthez 1	Barthez 2	Rondelet 1	Rondelet 2	Louisville	Barcelone	
09:00 - 09:30 am		<b>Keynote speaker</b> Hydrogeophysics: Advances in geophysical characterization and monitoring in support of water resources sustainability for society <b>Lee Slater</b>							09:00 - 09:30 am
09:30 - 10:00 am		<b>Plenary Flash Oral Presentations</b> <b>Session 6.02 - REUSE</b> 2333 - 2518 - 1740 <b>Session 7.06- GW protection</b> 2612 - 2389 - 1883 <b>Session 6.03 - Recharge</b> 2330 - 1854 - 1985 <b>Session 8.06 - Regional hydrogeology</b> 1745 - 2364 - 1587 <b>Session 8.08 - Thermal and Mineral Water</b> 1575 <b>Session 5.03 - CO2</b> 1646 - 1622 - 1598 <b>Session 7.02 - Urban hydrogeology</b> 2285 - 1862 - 2119							09:30 - 10:00 am
10:10 - 11:10 am	10:10-12:45 am GRIPP – IAH/MAR	<b>Session 8.03 - Geometrical structure and hydrogeological properties of Hard-Rock aquifers</b>  <b>Hard Rock Aquifers</b> Dewandel B., Sharp J., Tröger U.  <b>2308</b> Combining geological mapping, aerial photos and geophysical methods to enhance groundwater abstraction <b>Gaut Sylvi</b>	<b>Session 8.10 - Recent developments in groundwater modeling and mathematical tools in Hydrogeology</b>  <b>Modeling IPT and fracture flow- Karst and mesh free simulation – hard math/ Others) - M.T.Schafmeister, J. Carrera</b>	<b>Session 8.05 - Karst aquifers</b>  <b>KARST</b> Maréchal J.C., Sauter M.	<b>Session 6.03 - Innovative tools to improve understanding of groundwater recharge processes</b>  <b>Recharge</b> Barbérot F., Guillon S., Jourde H.	<b>Session 8.06 - Verification of conceptual patterns and expected natural effects of regional groundwater flow by interpretation of relevant field observations</b>  <b>Regional hydrogeology</b> Judit Madl-Szonyi, Adam Toth	<b>Session 8.08 - Mineral and Thermal water; an indicator of deep processes and source of economically valuable minerals</b>  <b>Thermal and Mineral Water</b> Somay M. A., Balderer W.	<b>Session 8.11 - Hydrogeodesy: new surface tools to characterize and monitor active and managed groundwater systems</b>  <b>Hydrogeodesy</b> Longuevergne L., Long L., Champollion C.	10:10 - 11:10 am
		<b>2120</b> Numerical investigations of the spherical flow regimes induced by constant-rate pumping tests <b>Ferroud Anouck</b>	<b>1440</b> Quantifying the influence of surface water groundwater interaction on nutrient flux in a lowland karst catchment <b>Mccormack Ted</b>	<b>2484</b> Crash test for groundwater recharge models- The effects of model complexity and calibration period on groundwater recharge predictions <b>Moeck Christian</b>	<b>1790</b> Hydrochemistry study to determine an active hydrodynamic in hydrocarbon trap system <b>Atin Musti</b>	<b>2566</b> Origin of Methane in Edge Oil-field Mineral Waters of the Iwonicz Zdr.—Spa, Central Carpathian Synclinorium, SE Poland. <b>Porowski Adam</b>	<b>1702</b> Groundwater storage variations in the North China Plain from GRACE and ground observations <b>Feng Wei</b>		



	Room BC1	Pasteur Auditorium	Barthez 1	Barthez 2	Rondelet 1	Rondelet 2	Louisville	Barcelone	
10:10 - 11:10 am		2060 Granitic hard rock aquifers deep geometry from a 3D geological model based on an exceptionally high density geophysical survey <b>Belle Pierre</b>	2405 Insights into karstic systems through inverse application of discrete conduit-continuum models <b>Liedl Rudolf</b>	1473 Understanding groundwater surface water dynamics within the catchment of Bell Harbour Bay, Ireland, using Infoworks/ICM <b>Schuler Philip</b>	1997 A study on the seasonal recharge patterns in the shallow groundwater area of semi-arid regions <b>Ke-yu Zhao</b>	2213 Assessment of Fault Zone Properties for Groundwater Models <b>Underschultz Jim</b>	1917 The contribution of a multidisciplinary approach to conceptualize the structure and functioning of a complex Natural Mineral Water Glacial aquifer <b>Henriot Abel</b>	1912 Poroeastic response to terrestrial water loading of the Bengal Aquifer System provides high-resolution, in-situ measurements for comparison with GRACE <b>Burgess William</b>	10:10 - 11:10 am
		2240 Elaboration d'un modèle caractéristique des zones favorables à l'implantation des ouvrages de captage dans les aquifères du socle fissuré - Cas du bassin versant d'Ehania (Sud-est de la Côte d'Ivoire) - <b>Brou Dibi</b>	2239 Karst conduit geometry- reduction of ambiguity by using a multiple signal approach for numerical hybrid models <b>Giese Markus</b>	1610 Origin and dynamics of spring flows during flood events inferred from innovative tracers <b>De Montety Véronique</b>	1739 Tracer test to determine natural groundwater recharge at Pirna, Germany and comparison with simulation tools <b>Ringleb Jana</b>	2563 Regional scale hydrogeological investigation of the Bakken Formation in the Williston Basin <b>Daniel Skoreyko</b>	1895 Hydrogeological conceptual model of a crystalline thermo-mineral carbo-gaseous aquifer driven by a weathering profile and tectonic fractures <b>Alazard Marina</b>	2313 InSAR to understand groundwater flow systems and support groundwater management <b>Castellazzi Pascal</b>	
11:10 - 11:30 am	10:10-12:45 am <b>GRIPP – IAH/MAR</b>	1760 Groundwater in hard rock aquifer and resources evaluation base on field observation in Sudetes (SW Poland) <b>Stasko Stanislaw</b>		1709 Examining the Hydrogeochemical parameters of a multilayer karst system using high-resolution auto-monitoring. The case of Toulon springs (Dordogne, France) <b>Lorette Guillaume</b>	1523 Infiltration and recharge in a fractured, sedimentary rock aquifer in a semi-arid region <b>Manna Ferdinando</b>	2476 Quantification of the effects of topography-driven groundwater flow by coupling field observations and numerical models in Wood Buffalo National Park, Canada <b>Judit Déri-takács</b>	1417 Noble gas isotopes and gas compositions of on-land and subaqueous thermal springs in the Koycegiz Lake and Dalaman plain area, Turkey <b>Sebnem Arslan</b>	2555 Application of a New GRACE Product for Assessing Long-term Trends in Water Storage in Aquifers Globally <b>Scanlon Bridget R.</b>	11:10 - 11:30 am
		<i>Coffee break &amp; E-Posters Session 7 • 8.05 - 8.06 - 7.03</i>			<i>Coffee break &amp; E-Posters Session 7 • 8.05 - 8.06 - 7.03</i>				
		<i>Session 2.01 - Groundwater in semi-arid regions – a long-term view on changes in aquifer balances. Hydrogeology in developing countries</i>	<i>Session 8.10 - Recent developments in groundwater modeling and mathematical tools in Hydrogeology</i>	<i>Session 8.07 - Hydrogeophysics: innovative non-invasive technologies for groundwater resources exploitation and management</i>	<i>Session 6.03 - Innovative tools to improve understanding of groundwater recharge processes</i>	<i>Session 8.06 - Verification of conceptual patterns and expected natural effects of regional groundwater flow by interpretation of relevant field observations</i>	<i>Session 8.08 - Mineral and Thermal water: an indicator of deep processes and source of economically valuable minerals</i>	<i>Session 7.02 - Urban Hydrogeology</i>	
11:30 - 12:45 am		<i>DC</i> <b>Scanlon B., Leduc C.</b>	<i>Modeling (PT and fracture flow - Karst and mesh free simulation – hard math/ Others) - M.T. Schafmeister, J. Carrera</i>	<i>Hydrogeophysics</i> <b>Chalikakis K., Guerin R., Slater L.</b>	<i>Recharge</i> <b>Barbecot F., Guillon S., Jourde H.</b>	<i>Regional hydrogeology</i> <b>Lefebvre R., Molson J.</b>	<i>Thermal and Mineral Water</i> <b>Arslan S., Balderer W.</b>	<i>Urban hydrogeology</i> <b>Bonsor H., Massmann G., Burke V.</b>	11:30 - 12:45 am
		1643 The importance of heavy rainfall to groundwater recharge in the southwestern Chad basin- evidence from isotopic observations <b>Goni Ibrahim Baba</b>	1534 Kansa's Multiquadric Based Meshfree Solution for Confined Aquifer <b>Patel Sharad</b>	1479 Application of time-lapse electrical resistivity tomography and groundwater simulation models to monitor the transport of organic contaminants under unsaturated and saturated conditions <b>Payal Rani</b>	1733 Simulation of groundwater indirect recharge in a volcanic aquifer system using a probabilistic method - Tadjourah region, Republic of Djibouti, <b>Mohamed Ahmed Ibrahim</b>	1811 Recharge areas of deep aquifers- a simplified approach for the assessment in Piedmont Region (NW Italy) <b>Lasagna</b>	1992 Hydrochemistry, isotopic ratios and origin of thermal fluids in eastern Anatolia, Turkey <b>Aydin Harun</b>	2300 Investigating the Impact of Sustainable Drainage Systems on Groundwater <b>Butcher Andrew S</b>	



	<i>Room BC1</i>	<i>Pasteur Auditorium</i>	<i>Barthez 1</i>	<i>Barthez 2</i>	<i>Rondelet 1</i>	<i>Rondelet 2</i>	<i>Louisville</i>	<i>Barcelone</i>	
11:30 - 12:45 am	10:10-12:45 am <b>GRIPP – IAH/MAR</b>	<b>1787</b> Assessing groundwater flow pattern in the Bara volcanic aquifer system, Republic of Djibouti <b>Baudron Paul</b>	<b>1840</b> Estimation of Underground Water Flows in the Shallow aquifers Using Artificial Neural Networks (ANN) in North of Algeria <b>Guezgouz Noureddine</b>	<b>1664</b> Integrated use of geoelectrical imaging and hydrochemical methods in assessment of the impact of solid waste on the groundwater at abule-egba dumpsite, Lagos, nigeria <b>Fatoba Julius</b>	<b>1983</b> Semi-distributed lumped model to assess recharge of karst unsaturated zone <b>Ollivier Chloé</b>	<b>2336</b> Comparison of 2D simulated flow pattern and measured hydraulic data for a confined aquifer to reveal the influence of gravity and heat on flow pattern <b>Madl-szonyi Judit</b>	<b>1995</b> Origin and maturation of organic matter in thermal waters <b>Jozsef Fekete Jozsef</b>	<b>1530</b> Current research in urban hydrogeology- urban underground development confronted by the challenges of groundwater flow, quality and temperature <b>Attard Guillaume</b>	11:30 - 12:45 am
		<b>2008</b> Hydrogeological and geochemical dynamics of the Western Haouz Aquifers, Tensift Basin (Western Morocco) <b>El Mandour Abdennabi</b>	<b>2024</b> A multi-layer transient groundwater flow and transport model of the Crau aquifer using stable isotope tracers <b>Seraphin Pierre</b>	<b>2063</b> Interest and limits of electrical tomography for groundwater survey in metamorphic hard rock aquifer context <b>Belle Pierre</b>	<b>1926</b> Groundwater recharge assessment of Takelsa multilayer aquifer (Northeastern Tunisia) <b>Nesrine Ghouli</b>	<b>1910</b> Groundwater-related environmental phenomena in complex geologic setting of Tihany Peninsula, Hungary <b>cdm T—th</b>	<b>2719</b> Multi-tracer groundwater dating (CFCs SF6, Tritium and 14C activities) for the characterization of a thermal flow system D case of the Av ne-thermal spring <b>Bailly-comte Vincent</b>	<b>2351</b> Accounting for Groundwater in Future City Visions <b>Bricker Stephanie</b>	
		<b>2040</b> Groundwater recharge and vulnerability of shallow aquifers under a Sahelian metropole- N'Djamena (Chad Republic) <b>Kadjangaba Edith</b>	<b>2235</b> Modeling of the geological evolution of the Red River delta, Vietnam in the context of arsenic contamination of aquifers <b>Kazmierczak Jolanta</b>	<b>1856</b> Specific yield estimation using resistivity and chargeability in tropical basement rock aquifers- experimental relations in Benin, West Africa. <b>Alle Iboukoun Christian</b>	<b>1427</b> Insights into the spatial and temporal variability of water isotopic signatures in a small agricultural watershed in Atlantic Canada <b>Danielescu Serban</b>	<b>2226</b> Groundwater flow system models and interpretation of variable interactions at guasca municipality in colombia <b>Palencia-aguilera Carla</b>	<b>2298</b> Hydrothermal circulations in Eastern Pyrénées - brittle and ductile faults both act as drains for upward circulations. <b>Taillefer Audrey</b>	<b>2487</b> Urban groundwater budget under evaporation-optimized pervious concrete pavements <b>Patricia Gsbel</b>	
		<b>2044</b> Assessments of groundwater recharge in the hyperarid Tarapaca alluvial fan (Northern Chile) at various scales of time and space. <b>Viguié Benoit</b>	<b>1994</b> 3D hydrogeological modeling of the Turaida castle mound under changing precipitation <b>Kukemilks Karlis</b>	<b>1891</b> A 4D ERT tool to characterize heat transfer and storage in aquifers <b>Lesparre Nolwenn</b>	<b>2209</b> Nation-wide gridded baseflow from recharge and groundwater models	<b>1654</b> 3D Conceptualization and Numerical Model Analysis, and its Impact on Drawdown, in the Bulgarene Borefield, Port Hedland WA <b>McGovern Mal</b>	<b>1713</b> Spatial and temporal reconstruction of the temperature distribution to assess the water circulation in the Euganean Geothermal Field (NE Italy) <b>Pola Marco</b>	<b>1578</b> Proving 'Urban Karst' as a Mechanism for Basement Infiltration in a Till Aquitard <b>Shepley Martin</b>	
12:45 - 2:00 pm	12:45 am-2:00 pm <b>Meeting of IAH National Chapters Representatives</b>	<b>Lunch &amp; Posters-poster Session 8 • 8.11 - 8.10 - 7.05 - 7.02 - 5.02 - 3.01 - 8.02 - 8.07</b>			<b>Lunch &amp; Posters-poster Session 8 • 8.11 - 8.10 - 7.05 - 7.02 - 5.02 - 3.01 - 8.02 - 8.07</b>		12:45 am-2:00 pm <b>Commission on Thermal and Mineral Water - (J. Lamoreau)</b>	<b>Lunch &amp; Posters-poster Session 8</b>	12:45 - 2:00 pm
2:00 - 2:30 pm		<b>Keynote speaker</b> Groundwater dating <b>Florent Barbecot</b>							2:00 - 2:30 pm

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	Room BC1	Pasteur Auditorium	Barthez 1	Barthez 2	Rondelet 1	Rondelet 2	Louisville	Barcelone
2:30 - 3:00 pm		<p><b>Plenary Flash Oral Presentations</b>  <b>Session 8.02 - Coastal &amp; Volcanic aquifers</b>            2216 - 1493</p> <p><b>Session 8.07 - Hydrogeophysics</b>            1485 - 1867 - 1696 - 1673</p> <p><b>Session 5.02 - GW and global change</b>            1826 - 2343 - 1701 - 2236</p> <p><b>Session 3.01 - GW data digital age</b>            1568 - 2086 - 2696</p> <p><b>Session 7.05 - Transboundary aquifers</b>            1627 - 2323 - 2392</p>						
3:10 - 4:40 pm	3:10-4:25 pm <b>Meetings of IAH commissions and working groups</b>	<b>Session 8.02 - Groundwater Development and Protection in Coastal and Volcanic Environments with Complex Geological Structures</b>	<b>Session 8.05 - Karst aquifers</b>	<b>Session 8.07 - Hydrogeophysics: innovative non-invasive technologies for groundwater resources exploitation and management</b>	<b>Session 8.04 - Isotopic and residence time tracers</b>	<b>Session 5.03 - CO2 storage in deep saline aquifers and potential impacts on shallow aquifers</b>	<b>Session 5.02 - Groundwater and global change</b>	<b>Session 7.02 - Urban Hydrogeology</b>
		<b>Coastal &amp; Volcanic aquifers</b> Barrocu G., Pryet A.	<b>KARST</b> Maréchal J.C., Sauter M.	<b>Hydrogeophysics</b> Chalikakis K., Guerin R., Slater L.	<b>Isotopes</b> Barbecot F., Wachniew P., Marc V., Aquilina L.	<b>CO2</b> Isabelle Czernichowski-Lauriol (BRGM/CO2GeoNet, France), Stan Beaubien (Sapienza University of Rome/CO2GeoNet, Italy)	<b>GW and global change</b> Carvalho Resende T., Leblanc M., Lubczynski M.	<b>Urban hydrogeology</b> Grützmacher G., Howard K.
		<b>1579</b> Contrast of groundwater ages around saltwater-freshwater mixing zone Isao Machida Isao	<b>1513</b> Groundwater flooding in a lowland karst network in response to extreme rainfall and tidal event synchronicity Gill Laurence	<b>2280</b> Remote sensing and hydrogeophysics for hydrogeological conceptual models of hard rocks Lubczynski Maciek	<b>2037</b> Origin of groundwater and CO2 in the crystalline environment of Saint Galmier, France Alazard Marina	<b>1921</b> Storing CO2 in deep saline aquifers as part of integrated territorial energy and climate plans Czernichowski-lauriol Isabelle	<b>1474</b> Investigation and Evaluation of groundwater pollution in North China Plain and Research on Key Technology Yasong Li	<b>2315</b> Column experiments on the attenuation of organic micropollutants during bank filtration- The relevance of the hyporheic zone Burke Victoria
		<b>1933</b> Salinization of coastal groundwaters in multi-layered sedimentary aquifers- multi-isotope constraints illustrated by examples in North East of Brazil and South of France Petelet-giraud Emmanuelle	<b>1632</b> Water chemistry and carbon flux in a storm event in a karst river Shi Yu	<b>1858</b> Efficiency of Magnetic Resonance Sounding to characterize hydrogeological properties of weathered hard rock aquifers Lawson Fabrice Messan Amen	<b>2489</b> Estimating amount and spatial distribution of artificial groundwater infiltration in a highly complex environment based on different tracers Moeck Christian	<b>2149</b> Multilevel U-tube monitoring of shallow aquifers for CO2 geological storage at the Shenhua CCS demonstration site in China Li Qi	<b>1618</b> Offshore aquifers- an answer to water scarcity? Martin-nagle Renee	<b>1526</b> Urban groundwater model of Bucharest city, Romania Gogu Constantin Radu



	Room BC1	Pasteur Auditorium	Barthez 1	Barthez 2	Rondelet 1	Rondelet 2	Louisville	Barcelone	
3:10 - 4:40 pm	Meetings of IAH commissions and working groups 3:10-4:25 pm	2661 Private, public and common pool management of natural resources in France - a comparative analysis of groundwater with marine resources <b>Mongruel Remi</b>	1998 Hydrological and data assimilation models for pseudo-forecast flash karst floods forecast- application to flood forecasting in the Lez catchment in Southern France <b>Borrell Estupina Valerie</b>	2200 Predictive uncertainty and data worth analysis to determine cost effectiveness of airborne EM data for defining hydraulic properties in a groundwater flow model used for predicting long term groundwater level drawdowns. <b>Moreau Magali</b>	2314 What is the impact of land use change on the behaviour of shallow aquifers ? A comparison of particle-tracking and lumped-parameter models for evaluating the groundwater age distributions <b>Vincent Aude</b>	2006 Small scale gas injection experiments at the Maguelone shallow experimental site (Languedoc, France) <b>Pezard Philippe A.</b>	1738 Estimation des potentialités de renouvellement et de recharge naturelle d'un aquifère alluvial en zone semi-aride, approche multidisciplinaire - cas de l'aquifère de la plaine du Haouz (Marrakech- Maroc) <b>El Mandour Abdennabi</b>	1816 Implications of storm water recharge on groundwater quality <b>Daus Anthony</b>	3:10 - 4:40 pm
		2292 The iah-cad.czm.net website- a tool to share and make information on coastal aquifers available <b>Giuseppe Sappa</b>	2404 Karst flash floods characterization and tools for warning system management (KRHU projet) <b>Fleury Perrine</b>	1569 Seismic amplitude anomalies revealed by the monitoring of underground CO2 injection <b>Perroud Hervé</b>	2087 Combined use of physico-chemical parameters and isotopic composition to characterize groundwater flow systems and their response to intensive extraction <b>Ouyse Samira</b>	2346 New insights on the changes induced by a potential CO2 leakage on the fate of trace metals in fresh groundwater- The case of the Albian aquifer <b>Devau Nicolas</b>	2689 Groundwater for Sustainable Development in the MENA Region <b>Klingbeil Ralf</b>	2103 Seepage water. A new resource? <b>Seidl Martin</b>	
		1492 Digital filters for application to tidal groundwater time series <b>Shirahata Katsushi</b>	2609 An innovative method for modeling the karstogenesis in carbonate reservoirs <b>Massonnat Gérard</b>	1449 Dependence of shear wave seismoelectrics on soil textures- a numerical study in the vadose zone. <b>Jouniaux L.</b>	2502 Lakes as groundwater window inferred from isotope signal, insight for sustainable management <b>Arnoux Marie</b>	1623 Coupled thermo-hydro-mechanical modeling of geological CO2 storage at In Salah, Algeria <b>Vilarrasa Victor</b>	1560 Impacts of irrigation on groundwater recharge, mixing and quality: sandy aquifer of the Limagne Bourbonnaise (central France) <b>Tweed Sarah</b>	2158 Development of urban shallow groundwater geothermal systems- How to promote a sustainable approach while preventing potential conflicts over underground and groundwater use? The case of Grenoble <b>Gaultier Ga'lle</b>	
4:40 - 5:00 pm		2159 The mechanism of groundwater fluctuations induced by sea tides in unconfined aquifers <b>Levanon Elad</b>	1604 Karst genesis modelling of a regional Mediterranean aquifer (Lez, France) <b>Leonardi Veronique</b>	1594 Modular TDR for real-time automated soil water content profile analysis <b>Kofakis Petros</b>	1606 Evaluation of groundwater ages in a layered aquifer system using analytical and numerical models <b>Koh Eun-hee</b>	1886 Assessment of brine migration along vertical pathways due to CO2 injection <b>Kissinger Alexander</b>	1775 Hydrogeological responses to intense groundwater pumping in the Indo-Gangetic Basin- Evidence from environmental tracers <b>Lapworth Dan</b>	2249 A multidisciplinary approach based on PSI- derived ground motion, hydrogeological and lithological data to estimate the Chalk aquifer properties in the London Basin <b>Bricker Stephanie</b>	
	Coffee break & E-Posters Session 9 • 5.02 - 8.08 - 6.03 - 5.03				Coffee break & E-Posters Session 9 • 5.02 - 8.08 - 6.03 - 5.03				4:40 - 5:00 pm

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		<i>Coastal &amp; Volcanic aquifers Barrocu G., Pryet A.</i>	<i>KARST Marechal J.C., Sauter M.</i>	<i>Transboundary aquifers Aureli A., Eckstein G., Kukuric N., Puri S., Villhuth K.</i>	<i>Isotopes Barbecot F., Wachniew P., Marc V., Aquilina L.</i>	<i>MAR Lafforgue M., Dillon P., Fernandez Escalante A.E.</i>	<i>GW and global change Carvalho Resende T., Leblanc M., Lubczynski M.</i>	<i>GW data digital age P. Dalhaus, S. Grellert, L. Chery</i>
		<b>2283</b> The interaction between surface reservoirs, multi-layered coastal aquifer and the sea <b>Tal Adi</b>	<b>1639</b> Volcanogenic Karst Systems <b>Sharp John M.</b>	<b>1814</b> Methodologies and best IWRM practices for joint management of groundwater and surface water at basin level <b>Donzier Jean-fran ois</b>	<b>1747</b> Behavior of Radium isotopes in a karstic spring (Lez) and a Mediterranean stream (Vidourle) in the South of France <b>Molina Porras Arnold</b>	<b>1467</b> ECONOMIC ASSESSMENT OF EL CARRACILLO MAR SYSTEM. LOS ARENALES AQUIFER, CASTILLA Y LEON, SPAIN <b>Enrique Fernández Escalante</b>	<b>1378</b> Rapid evolution of water resources in the Senegal River delta and impact on the development of Delta land. <b>Ngom Fatou Diop</b>	<b>1630</b> Hydrogeology education- University courses, core skills and the role of IAH <b>Misstear Bruce</b>
		<b>2656</b> Leros island (Greece)- how to exploit the hidden water <b>Tulipano Luigi</b>	<b>1974</b> Impacts of intensive exploitation of the Jurassic-Cretaceous aquifer system on the organisation of the subsurface water flows (Syria) <b>Zwahlen Fran ois</b>	<b>1586</b> The Contribution of the ISARM initiative to international cooperation and its role regarding SDG Goal 6.5.2 on water cooperation <b>Sindico Francesco Scotland</b>	<b>1884</b> Dating of saline groundwater from several Israeli aquifers, indication for paleo seawater intrusion <b>Yechieli Yoseph</b>	<b>2428</b> AQUARENOVA project - Active management of the Bas Gapeau aquifer to prevent saline water intrusion <b>Duzan Alexandre</b>	<b>1483</b> 35 years of data collection and regional modelling of the confined aquifer systems in N-Belgium <b>Vandersteen Katrijn</b>	<b>2692</b> Opening the sharing and reuse of groundwater datasets to new communities and citizens <b>Lagarde Pierre</b>
		<b>2410</b> The case of Biscayne Bay and Aquifer near Miami, Florida- Density driven flow of sea water or gravitationally driven discharge of saline groundwater? <b>Weyer K. Udo</b>	<b>2050</b> Recharge conditions of Mediterranean mountain karst aquifers. Consequences for resource protection and proactive management <b>Daher Walid</b>	<b>2675</b> The transboundary water resources of Lesotho, Swaziland and South Africa- complementarity, consistency, or neither? <b>Puri Shaminder</b>	<b>1487</b> Groundwater residence times of the Salar de Coposa basin, North Chile - Preliminary results <b>Konstantin Scheihing</b>	<b>1837</b> Hydrological and Geochemical Processes during Managed Aquifer Recharge with Desalinated Seawater <b>Ganot Yonatan</b>	<b>1834</b> Global Food Production - Share from Sustainable and Unsustainable Groundwater Use <b>Vilhuth Karen Grothe</b>	<b>1645</b> Making Australian groundwater data accessible <b>Sharples John</b>
		<b>1685</b> Improved groundwater management from in-situ geophysical monitoring of the Chateaulillon coastal aquifer <b>Baesset Matthieu</b>	<b>2028</b> Comprehensive Exploitation Strategy and management for Nandong Underground River System in Yunnan Province, Southwest China <b>Funing Lan Funing</b>	<b>1798</b> Genevese transboundary aquifer management as a model for the establishment of a water community in the Geneva region (Switzerland and France). Highlights on the technical aspects to be implemented <b>De Los Cobos Gabriel</b>	<b>2561</b> Regional Flow and Groundwater Residence Time Simulations in Chaudière-Appalaches, Québec, Canada- Implications for interpreting Regional Geochemistry <b>Janos Debora</b>	<b>1942</b> Investigating groundwater flow pattern at a bank filtration site in Québec province (Canada). <b>Baudron Paul</b>	<b>2161</b> Global Groundwater Monitoring Network- the role of information technology for international cooperation and global studies <b>Antoniu Andreas</b>	<b>2223</b> The Groundwater Interoperability Experiment 2- developing an international groundwater data exchange standard <b>Dahlhaus Peter</b>

5:00  
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pm4:25-6:30 pm  
« By invitation only.  
Water Research EuroGeosurveys:  
GeoERA meeting for further  
development of groundwater  
inputs to GeoERA call on Applied  
Geosciences  
Klaus Hinsby GEUS »5:00  
-  
6:30  
pm

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5:00 - 6:30 pm	<p>4:25-6:30 pm</p> <p>« By invitation only. Water Research EuroGeosurveys: GeoERA meeting for further development of groundwater inputs to GeoERA call on Applied Geosciences Klaus Hinsby GEUS»</p>	<p>2275 Geological controls on groundwater flow into the Salalah plain, Sultanate of Oman <b>Mueller Thomas</b></p>	<p>2185 Characterization of a High Altitude Karst Aquifer in Eastern Turkey <b>Aydin Harun</b></p>	<p>2649 Transboundary groundwater in Wes- tern Asia- A depleting resource that needs immediate attention <b>Al-mooji Yusuf</b></p>	<p>2297 Importance of immobile water for transport in porous aquifers <b>Stumpp Christine</b></p>	<p>2684 Monitoring Water quality in Induced RiverBank Filtration- The case study of the SantOAlessio plant (Italy) <b>Marchina Chiara</b></p>	<p>1566 The Impact of the Last Glaciation on Groundwater Flow in Estonia- A Nu- merical Study. <b>Sterckx Arnaud</b></p>	<p>2697 SWeing the groundwater data work- flow- from data collection to reuse, opportunities of interoperable sen- sor/Web approaches <b>Loigerot Stéphane</b></p>	5:00 - 6:30 pm
6:45 - 7:30 pm			<p>2669 A pilot study to use the 36Cl bomb peak as a tracer for groundwater flow velocities in the Western Dead Sea catchment <b>Wilske Cornelia</b></p>	<p>2445 Hydrogeology of Limestone Forma- tion of Sepingtiang, Lahat-Indonesia <b>Haryono Eko</b></p>	<p>1583 The Agreement of the Guarani Aq- ifer. A regional adaptation to the Law of Transboundary Aquifers <b>De Rosa Diego</b></p>	<p>1599 Use of 222Rn and 180-2H isotopes in detecting origin of water and in quan- tifying groundwater inflow rates in an alarmingly growing Lake <b>Kebede Seifu</b></p>	<p>1761 Web-based decision support system for planning and management of MAR sites <b>Sallwey Jana</b></p>	<p>2689 Groundwater for Sustainable Deve- lopment in the MENA Region <b>Klingbeil Ralf</b></p>	<p>1877 Tracing Recent Water Level Changes in a Saudi Arabian Cave by Mining YouTube Videos <b>Michelsen Nils</b></p>
	<b>CLOSING CEREMONY</b>				<b>CLOSING CEREMONY</b>				

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## International Association of Hydrogeologists and CHINA

### Abstract n° 1367

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KEYWORDS: IAH, CHINA, National Chapter

Before 1985, there were a few Chinese participators for International Association of Hydrogeologists which founding in 1956. A Chinese team who are senior hydrogeologist attended the 18th IAH congress in Cambridge, UK in 1985. More and more Chinese delegates presented the conferences since then. And a lot of young career hydrogeologists are interesting for IAH action. The IAH National Chapter of China was first established in 1987 and continuously since that time. The IAH members in P.R. China were increased in these years. The IAH members in Hong Kong and Taiwan, who have close contacted with China Chapter. IAH congress meeting have hold in China in twice. The 21th congress holds in Guilin city, 10-15 October, 1988 which theme is Karst Hydrogeology and Karst environmental Protection. The 34th congress holds in Beijing, 9-14 October, 2006 which theme is Groundwater – Present status and future task. IAH China Chapter is one of the organizers for both of the congress. The IAH China chapter serves for all IAH members and other scientists promoting groundwater sciences in China. Commission on Managing Aquifer Recharge and Commission on Regional Groundwater Flow have the meetings in China. There were a lot of national conferences on Hydrogeology and Groundwater sciences almost every year since 1987. Those national conferences associate with Commission on Hydrogeology, Geology Society of China in operation. There were more than one hundred attendees in each of the conferences. Many Chinese IAH members were the editors of Hydrogeology Journal. IAH China Chapter is responsible for the Chinese translation for the abstract. The Journal of Groundwater Science and Engineering is an international journal for the natural sciences. The sponsors are IAH China chapter, Institute of Hydrogeology and Environmental Geology, CAGS and Commission on Hydrogeology, Geological Society of China. It is published quarterly in English since 2013.



## Optimization of Groundwater Allocation in Beijing Plain

Abstract n° 1369

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Juyan Zhu Juyan, China Institute of Geo-Environment Monitoring, Beijing, China

KEYWORDS: Beijing plain, Groundwater allocation, Groundwater model

Large-scale groundwater development in Beijing plain has supported rapid growth of economic and urban population in last 30 years, while water shortage has become a critical factor restricting social-economic developments in this area. In order to make limited groundwater resources play the greatest role in the social and economic development, groundwater allocation scenarios need be optimized so that scientific and reasonable utilization of groundwater resources could be realized. A transient 3D groundwater model was constructed with MODFLOW to analyse groundwater flow systems and groundwater balance. Totally ten groundwater allocation scenarios were designed based on the water demand and the capacity of water supply in Beijing plain, and the effects of these scenarios on groundwater storage and levels were analyzed with the constructed groundwater flow model. An evaluation criterion set was constructed with considering some factors such as groundwater abstraction, evaporation of unconfined water, river outflow, regional average groundwater depth, drawdowns in depression cones and the ratio of storage to the total recharge. Based on this criterion set, the proposed groundwater allocation scenarios were assessed by a multi-criteria fuzzy pattern recognition model (MFPR), which is proven to be very useful for scientific analysis of reasonable development and utilization of groundwater resources. The evaluation results show that reasonable utilization of groundwater resources may be achieved when various measures such as control of groundwater abstraction and increase of recharge combine favourably. Among the ten proposed allocation scenarios, scenarios 9 and 10 are identified as best scenarios by the MFPR method outlined in this paper. However, scenario 10 is less feasible due to the difficulty in ensuring an alternative water source of 520x106m<sup>3</sup> a for artificial recharge.



## Iron Overload in Drinking Water (Surface and Ground) and Liver Diseases

Abstract n° 1370

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KEYWORDS: Keywords+ Water, Iron, Liver biopsy

Background- Several diseases have been caused by contamination of surface and groundwater. Metals are introduced into water systems as a result of the weathering of soils and rocks from volcanic eruptions and variety of human activities. Aim- The aim of the present work is to investigate the impact of iron overload in drinking water on liver pathology. Materials and Methods- Samples of drinking water, blood and true cut liver biopsies were taken from selected inhabitants, who attended in some Dakahlia governorate hospitals. Those inhabitants (16 patients) from Mit-ghamr and Aga districts were suffering from liver disorders (had hepatitis C) and 4 patients had chronic cholecystitis from Mansoura district as control cases. Measurement of iron level in water samples was carried out by the use of an atomic absorption spectrophotometer, analyzed for serum iron level with a micro lab 200 spectrophotometer. Results- The mean value of iron in surface water is lower than the permissible limit of Egyptian ministry of health (EMH) and World health organization (WHO). However, the mean value of iron in groundwater samples is higher than that permissible limit and than those of surface drinking water. Comparison between iron level in drinking water and human blood samples shows positive relationship. The control group depended on drinking surface water and had normal liver function tests, whereas the patient group that depended on drinking groundwater had abnormal values in liver function tests. These data suggest that the polluted iron drinking water is the reason for the liver disorder of the patients. Siderosis was apparent among those patients drinking polluted iron water in comparison to control cases. The siderosis appears to be responsible for resistance to treatment of HCV and progression of fibrosis. Conclusions+ The accumulation of iron in liver leads to fibrosis. Iron depletion therapy could interfere with fibrosis development and possibly reduce the risk of hepatocellular carcinoma (HCC). high level of iron in drinking water must be monitored regularly and groundwater samples should have special attention for treatment.



# Analysis of groundwater level historical data to detect climate change impact in France

Abstract n° 1371

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**KEYWORDS:** Climate change, groundwater monitoring network, Mann-Kendall test, trend detection

The level of groundwater bodies depends for many of them on the infiltration of meteoric water and will therefore be necessarily impacted by climate change if it causes a change in the infiltration system (intensity, period). To assess and monitor the impact of this change, a dedicated groundwater monitoring network is necessary. As this impact is currently unclear, the implementation of such a network involves an analysis of existing groundwater level data series. The study was based on Mann-Kendall trend detection tests from groundwater level data and a comparison of trends between groundwater level data and climate data (precipitation, temperature, potential evapotranspiration). Trend detection tests were carried out on 377 piezometers of the french national groundwater quantitative monitoring network for which we had a data series of at least 25 years. In the end, 70 have a significant trend, 44 down and 26 up. Piezometers showing significant trend mostly concern aquifers with predominant annual hydrologic cycle. But most of aquifers in France have longer hydrologic cycles and statistical tests are not relevant because the data are autocorrelated and we do not have at our disposal long time series which are required for such tests. The conclusion of this study is that we cannot demonstrate a significant impact of climate change on groundwater levels because of too short time series but it reinforces the need to set up a monitoring network dedicated to the impact of climate change on groundwater. In order to set up that network, about 40 aquifers were selected with following criteria - unconfined aquifer, recharge likely to be impacted by climate change, aquifer weakly impacted by withdrawals, Finally piezometers for each aquifer, the main criteria was a low anthropogenic impact. For each selected aquifer, a monitoring well or a spring was selected, based on a number of criteria and in particular the fact that the well is inside an unconfined aquifer which is not influenced by pumping.



# **Pollution of groundwater generated by the Municipal Landfill Linares Mexico**

**Abstract n° 1373**

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**KEYWORDS:** Leachate, Landfill, Groundwater.

This research deals with the quality of natural waters affected by pollution from leachate generated in the Municipal Landfill of Linares, Nuevo Leon, Mexico. The Municipal Landfill of Linares has more than 17 years of service and receives more than 50 ton day of municipal solid waste. Geological (geological structural profiles), hydrogeological (piezometric cards) and hydrogeochemical (water quality classification and determination of pollutants) methods was applied to identify external agents to the environment. A negative impact on the quality of surface water (dam El Cinco) and groundwater (wells) in accordance with national and international environmental standards were identified (NOM, WHO, EPA). The results reveal deficiencies in the management and final disposal of municipal solid waste (torn geomembrane) and null leachate management (oversaturation of the landfill). In particular, high concentrations of nitrate, lead, manganese and iron in groundwater and surface runoff were identifying, that generate a significant contamination of soil and water+ aspect very important if people in the region consume contaminated water from groundwater wells, that can cause harmful health effects.



# **Rapid evolution of water resources in the Senegal River delta and impact on the development of Delta land.**

**Abstract n° 1378**

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**KEYWORDS:** shallow saline groundwater, irrigation, soil salinity

The geological history of the Senegal River delta is linked to climate change, which, during the Quaternary, have led several phases of marine transgressions and regressions. These marine invasions led to the establishment of a body of salt water throughout the delta. The waters of this sheet are essentially sodium-chloride-type, and indicating their marine origin. Agricultural area par excellence, impoundment plots seems to be the cause of the accumulation of surface salts after a few years of operation. This accumulation of salts, induces secondary processes alkalizing and sodification land leading to their abandonment. This is probably related to the strong rise of the saline groundwater recharge period. It is in this context that this study was conducted to understand the factors behind the rise of the web. It was conducted by analyzing the relationship between water intake from the river, irrigation, rain on one hand and fluctuations in the other table. The results showed a relationship between water intake and changes in the water table. This influence is particularly felt in the agricultural water due to irrigation water intakes. This rise of the salt layer (the salt concentrations exceeding those of sea water) and participates in the degradation of cropland. This occurs due to evaporation which causes a deposit of salts overground due to the proximity of the web. This back up of the web is, however, linked to insufficient drainage of irrigated plots, including deep drainage which should lessen the groundwater recharge and unclog plots. Thus, it was proposed, in terms of alternatives, deepening drainage channels to fold the table. This, by lowering down the line of zero flux (pass line of water from the liquid phase to the gas phase), would, no doubt, to the cessation of accumulations of surface salts.



# Groundwater-energy-food nexus- Conflicts between groundwater use for energy and fishery production

Abstract n° 1381

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KEYWORDS: water-energy-food nexus, conflict, trade-off

Water, energy, and food are the most fundamental resources for human well-being and a sustainable society. Demands for these resources are estimated to drastically increase in the near future because of increases in population and changes in lifestyle. These three resources have also been inter-related, and make a nexus which causes trade-off between resources and conflict between stakeholders. In this study, the groundwater-energy-fishery nexus is analyzed and evaluated in the snowy area of Obama City, Fukui Prefecture, Japan. The objective of this study is to evaluate the effects of groundwater used as heat energy sources for the melting of snow accumulated on roads, on fishery productions in the coastal area. The submarine groundwater discharge which carries nutrients into the ocean is reduced by excess groundwater pumping for melting snow. Positive correlation has been found between primary production rates in Obama Bay and radon concentrations which show the magnitude of the submarine groundwater discharge. Therefore, the increase in groundwater pumping on land reduces fishery productions in the ocean. Results of 3D numerical simulations of the basin scale groundwater model show a reduction of SGD by 5 percent due to an increase in groundwater pumping by 1.5 times. This reduction of SGD caused a 3.7 ton decrease in fishery production under the aforementioned assumptions. The groundwater-energy-fishery nexus was found in Obama Bay, Japan and the tradeoff between water and food was evaluated.



# ESTIMATION OF RECHARGE AND EVAPORATION LOSSES IN THE ARID ZONES BY USING STABLE ISOTOPES AND CHLORIDE PROFILES IN SOIL WATER

Abstract n° 1390

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KEYWORDS: Recharge, Evaporation, stable isotopes, chloride profil, modelling, Sahara

Due to constant demographic growth and agricultural growing demand for irrigation water, the inescapable use of groundwater has continuously increased during the last forty years in North African arid and semi-arid regions. Some of these areas are known to comprise worldwide and in many locations huge underground water reserves. This is the case of The North-Western Sahara Basin (NWSAS). For the sake of integrated groundwater resource management, hydrogeologists and water managers have constantly been worried by the same question that is- what are the evaporative losses and the recharge rates of those huge aquifers? In addition to the technical and the logistic constraints related to the nature of these regions, they are also characterised by extreme climatic conditions. Whereas conventional techniques often failed, isotopic tools have proven their efficiency in tackling groundwater issues. The present paper examines the contribution of this methodology as applied to this basin. Water transfers through the unsaturated zone were investigated in order to compute steady-state groundwater recharge rates and evaporative losses. Many sites have been investigated during the last twenty years- Béni-Abbès, Chott Chergui (semi arid area), Ouargla, El-Oued and Hassi Messaoud (arid areas) in Algeria and Tozeur, Dissa in Tunisia within the framework of separate studies. These investigations aimed at estimating evaporation rates based on unsaturated zone stable isotopes and chloride profiles. This was implemented making use of the deterministic model developed by Barnes and Allison (1982). The recharge and evaporation rates obtained for a 10 m unsaturated soil profile varied between 1 and 30mm a. These results were found in the same range as those obtained elsewhere in other arid and semi-arid locations of the world. The extrapolation of these rates to the scale of the whole Basin is sought as possible and can help the water managers of the involved countries to develop or refine appropriate models.



# The Shared Resources in the North-Western Sahara Aquifer System- The use of Environmental Isotopes

Abstract n° 1391

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KEYWORDS: Isotope, Residence time , Shared, Water Resources, Paleowaters, Saharan Basin

The North-Western Sahara Basin (NWSAS) comprises two main aquifers- the deep “Continental Intercalaire” (CI), and the “Complexe Terminal” (CT). With a surface area of approximately 1 000 000 km<sup>2</sup>, the CI extends across three countries, Algeria, Tunisia and Libya, and constitutes one of the largest groundwater systems in the world. This resource is generally considered as being “fossil”, i.e. inherited from previous climatic conditions, more humid than at present, with a very limited modern recharge. This basin supplied an estimated volume of 2.2 billion m<sup>3</sup> fresh water for domestic water supply, agriculture and other industrial purposes. Groundwater withdrawals from the NWSAS increased from about 14 m<sup>3</sup> s in 1950 to 82m<sup>3</sup> s in 2000, resulting in decreases in the natural water flows. Over the last two decades, isotopic investigations have been carried out (<sup>18</sup>O, <sup>14</sup>C, <sup>36</sup>Cl) and rare gas (He, Ne, Ar, Kr, Xe) to assess the groundwater resource potential in the Sahara of Algeria, Tunisia and Libya. The compilation of isotopic data indicate that waters from CT and CI aquifers are characterized by depleted oxygen-18 and deuterium isotope contents as compared to that of the modern rainfall. This would suggest that the modern rainfall is not recharging these ground waters. Although some sources for active recharge cannot be neglected. Different studies have shown that the NWSAS is recharged by infiltration of surface runoff around the periphery of the domain, particularly around the Saharan Atlas, the Dahar, Tadmait and Tinrhert as well as in the Great Occidental basin during years of exceptional rainfall. The main objective of the present paper, is to gather all these data and to examine how they may be interpreted in terms of groundwater residence time, recharge rate, evaporation losses can help the water managers of the three involved countries to develop or refine appropriate models. This should facilitate the implementation of a trans-boundary integrated management of the shared resources.



# Spatial modeling of groundwater recharge by coupling SWAT and MODFLOW models

Abstract n° 1392

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KEYWORDS: SWAT, MODFLOW, Groundwater Recharge

Accurate estimation of groundwater recharge is extremely important for proper management of groundwater systems. Many different approaches exist for estimating recharge. This research proposes a combination of the most widely used hydrological models SWAT and MODFLOW, in order to calculate the groundwater recharge rates. SWAT is the acronym for soil and water assessment tool, a watershed scale model developed by USDA Agricultural Research Service (ARS). SWAT was developed to simulate the quality and quantity of surface water and groundwater, predict the impact of land management practices on water, sediment and agriculture chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. MODFLOW is a modular three-dimensional finite-difference groundwater flow model developed by USGS for numerical simulation of groundwater flow in porous media. The model is physically based, and capable of reflecting spatial characteristics and movement of groundwater. However, to form SWAT-MODFLOW model the recharge values of the hydrologic response units (HRUs) in the SWAT model are assigned with cells in the MODFLOW model. By using this HRU–cell conversion interface, the distributed groundwater recharge rate can be effectively simulated. This method is applied to the R'Mel coastal aquifer located in the north of Morocco. The application has been tested successfully, and which demonstrates that an integrated SWAT–MODFLOW is capable of simulating a spatio-temporal distribution of groundwater recharge rates. This model would be beneficial in the planning and the sustainable groundwater management.



# Impact Study of artificial recharge of Teboulba aquifer in the Oriental Sahel in Tunisia from Nebhana Dam in Central Tunisia.

Abstract n° 1393

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KEYWORDS: over-exploitation, aquifer, artificial recharge

The combination of the continuous increase in irrigation water demand and the high variability and unequal rain distribution in time and space scale, in the oriental regions, similar to Teboulba in Tunisia, caused brake down of the interface (saline good water) and led to the marine intrusion. In Fact, the major problem of this aquifer in agricultural is the over- exploitation. To minimize this problem, the government, from 1971, began to artificially recharge the groundwater table from Nebhana Dam. The question that can be asked now is- what is the impact of this recharge on the aquifer piezometers, can we improve it? To reach those goals, we used the database of piezo metric head and the rain (sum of rain from September of year  $i$  to April of year  $(i+1)$ ). We correlated piezo metric head of April of year  $(i+1)$  to this rainfall. We then plotted the piezo metric maps before and after artificial recharge and cuts of those maps. Analysis of annual piezo metric maps from 1940 to 2012, the monthly maps of the same parameter for the two years 2000 and 2001, the cuts of maps cited before and the correlations found between rain and piezo metric head showed that there is dependence between rain and piezo metric head but the recharge depends on other parameters like the artificial recharge and the wells pumping. All those respond differently to the recharge by their capacity of infiltration and their hydrodynamic characteristics. The interpretation of aquifer salinity maps showed that the quality of aquifer had improved where there is artificial recharge. The cuts done on salinity maps proved that the central part is improved by this recharge but the sea water intrusion from the sea and the sebkha disturbed this quality. The piezometric head of Teboulba aquifer is improved by this artificial recharge from Nebhana Dam in quantity and quality and this aquifer cannot leave without this recharge.



## **Structure et Hydrogéologie des monts d'Ougarta (La Saoura, sud Ouest algérien).**

**Abstract n° 1395**

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**KEYWORDS:** Mots clés - Aquifère- hydrogéologie - Ougarta- fissuré - Paléozoïque- Saoura.

Les Mont d'Ougarta présente le cœur de la géologie de la plate forme saharienne, située au sud ouest algérien. Au niveau des Monts d'Ougarta, les nappes sont mal définies, toutefois les différents captages réalisés au niveau des villages Zéghamra et Ougarta (sources, puits, forages) plaident en faveur de l'existence de plusieurs nappes du socle paléozoïques. Il s'agit vraisemblablement d'une superposition de nappes fossiles alimentées lors des périodes quaternaires humides. Les aquifères du socle Paléozoïques, il s'agit vraisemblablement d'un système multicouche, dont le détail est mal connu. L'extension importante des affleurements de roches volcanique et métamorphiques, Conjointe avec le climat aride ne permet pas de mettre ces aquifère en saturation. Il semble donc nécessaire d'identifier l'aquifère du Combro-Ordovicien et déterminer son mode de fonctionnement hydrogéologique et son mode de recharge. Les failles de direction N 140° E et N 50° et N 70° E, jouent un rôle de drain et d'alimentation, en fonction des formations qu'elles mettent en contact anormal. Au niveau de la palmeraie de Béni Abbès si, au niveau de la dalle du néogène, des foggaras et sources qui sortent par le biais de ces fissures et fractures, elles causent un changement local du sens d'écoulement. Selon leur épaisseur des formations, le Paléozoïque potentiellement important de point de vue hydrogéologique en revanche le Tertiaire et la Quaternaire présente de faible épaisseur et par conséquent, leurs potentialités hydriques demeurent limitées. Le présent poster a pour but d'un aperçu structural et hydrogéologique des terrains Paléozoïques des monts d'Ougarta.



## Communicating real-time water availability, allocation and use to the public through the web

Abstract n° 1397

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KEYWORDS: science communication, web

Communicating real-time water availability, allocation and use to the public through the web  
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A New Zealand and world first, Land, Air, Water Aotearoa ([www.lawa.org.nz](http://www.lawa.org.nz)) is a collaboration between regional and unitary councils, the Ministry for the Environment, and the Cawthron Institute. Regional Councils and Unitary Authorities collectively hold New Zealand's largest water monitoring database, with information on approximately 30,000 sites across the country. The goal of [lawa.org.nz](http://lawa.org.nz) is to make water monitoring data available to the public in one place and with a consistent and easy to understand presentation. It offers a place for the public, policy advisors and scientists to go to view the country's water data for environmental, economic and recreational purposes. LAWA was launched in 2014 with river quality data and has since grown to include bathing beaches, water quantity and most recently lake quality data. The water quantity module allows the public to use it as a tool by which they can assess the use of freshwater resources in each region of New Zealand. It brings together water permit information with actual metered use data, rainfall, groundwater levels and river flow information to paint a picture of water availability, allocation and use across time and space, in an easily digestible web format.



## Contamination fingerprinting techniques for private water supply wells- Identifying the impact from domestic water treatment systems

Abstract n° 1399

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KEYWORDS: Keywords- groundwater pollution, wastewater, contamination fingerprinting

This research compares a range of fingerprinting techniques for identifying sources of private water well contamination. In particular the focus is to quantify the extent of the pollution from domestic wastewater treatment systems (DWWTS) as distinct from agricultural sources. In predominantly rural areas of Ireland approximately 438,000 dwellings use septic tank or other onsite wastewater systems. Often such rural areas are not connected to a public drinking water supply, and so many households obtain their drinking water from a private water well. Hydrogeologists are rarely involved in the siting or construction of these small private schemes, and therefore the wells are often located within relative close proximity to a DWWTS, a known source of microbial pathogens, and are often poorly constructed, with no sanitary seal around the wellhead. A total of 212 households dependent on private wells and DWWTS have been evaluated by site assessments and sampling of chemical and microbial parameters. A total of 15% of the wells were at least intermittently contaminated with E.coli. Subsequent monthly monitoring of 24 wells found 45% to be contaminated with E. coli at least once. These wells have been used to assess a range fingerprinting techniques, including fluorescent whitening compounds (FWC), faecal sterols, anion ratios and Bacteroidales faecal source tracking (FST). FST tests of 42 wells targeting regions of Bacteroidales 16S rRNA genes found 62% were positive for human specific Bacteroidales. However, no wells to date have tested positive for FWCs using fluorometry and UV degradation methods. The research has also evaluated faecal sterols, artificial sweeteners, caffeine and pharmaceuticals as tracers. With DWWTS effluent recognised as a major factor in the incidences of waterborne disease worldwide, accurate identification of private wells impacted by human effluent is required to help guide corrective action and protect householder health.



# GROUNDWATER VULNERABILITY TO THE POLLUTION AND THE SAFE WATER SUPPLY CHALLENGE IN COTONOU TOWN, BENIN (WEST AFRICA)

Abstract n° 1401

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KEYWORDS: Cotonou, Benin, groundwater quality, ecosystems approach, sustainable potable water supply

Cotonou town (79 km<sup>2</sup>) is located in the lowest coastal sandy plain of Benin, between 6°20' and 6°23' N. It is established on a site that is between 4 and 6 km long, formed by a succession of offshore bars, lagoons and marsh, between the Atlantic Ocean and Lake Nokoue. Urbanization and rapid population growth with an annual rate of 2.07% have induced increasing water demand (about 66 m<sup>3</sup> day by 2012). But environmental change has impacted water systems. So, shallow groundwater is the most detrimentally impacted by uncontrolled land occupation due to the higher population density (10,431 people km<sup>2</sup>). Accordingly, it is important to improve the understanding of groundwater sensitivity to the pollution sources and alternative approaches to the provision of safe water for human consumption. This study was based on the existing literature, physicochemical and bacteriological analyses, assessment of drinking water quantity and the returns from participative investigations. Water quality standards in Benin reflect those set by the WHO. The results of the study suggest that the shallow aquifer means Quaternary (depth less than 2 m) is more polluted by wastes and often by septic tanks situated less than 5 m from water sources. Groundwater mineralization depends on human activities, induced recharge and saltwater intrusion. Bacteria counts frequently exceed drinking water guidelines and standards (0 coliform counting units (CFU) 100 ml). Given these pollution problems, the shallow Quaternary aquifer is excluded for drinking water supply which is restricted to the Continental Terminal aquifers on the Plateau of Allada. Sustainable safe water supply is dependent on groundwater quality protection using an ecosystems approach, deep aquifer water extraction and rational water use by multiple consumers.



# STUDY OF LAND SUBSIDENCE IN KEMAYORAN-KELAPA GADING, JAKARTA, INDONESIA CAUSED BY GROUNDWATER LEVEL LOWERING

Abstract n° 1402

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KEYWORDS: land subsidence, Jakarta, hydrogeology, groundwater

Geological conditions of Jakarta which has Quaternary and Tertiary relatively young rocks and heterogeneous systems may contribute to subsidence. We wanted to know the effect of the configuration of lithologies to subsidence in Kemayoran-Kelapa Gading by making four stratigraphic scenarios that may occur in Kemayoran-Kelapa Gading. Calculations with finite element method could be used, to to evaluate the contribution of groundwater withdrawal against subsidence throughout Kemayoran and Kelapa Gading. Rate of land subsidence are numerically simulated by finite element method using PLAXIS 8.2 (2D). This study uses data engineering geology data taken from bore log with 300 meters depth (full coring), subsidence data from GPS measurements and data on groundwater level from unconfined aquifer (0-34,8 m) and confined aquifer(100,4-213,8 m). This research establishes four different geometries of sediment that may occur in Jakarta which is are developed from drilling data correlation. The result of this study from four top layer sediment throughout the cross-of Kemayoran and Kelapa Gading shows that differences in the geometry of sediment role in the value of subsidence. Geometry 2 and 3 show the smaller value of subsidence rather than geometry 1 and 4. Average subsidence due to a decrease of groundwater level for 24 years (2001-2024), geometry 1 (0.53 meters), geometry 2 (0.33 meters), the geometry of 3 (0.33 meters), and geometry 4 (0.37 meters). The average contribution subsidence due to decrease of groundwater level for 24 years (2001-2024), geometry 1 (31.55%), geometry 2 (20.77%), geometry 3 (19.93%), and geometry 4 (22.29%). Interfingering on a layer of clay and sand at a depth of 100-125 meters affect of subsidence. The nonuniformity of land subsidence rate due to the heterogeneity of rock subsidence and aquifer geometry in Jakarta.



# Modelling groundwater nitrate concentrations at the African scale using Multiple Regression and Random Forest

Abstract n° 1403

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KEYWORDS: Groundwater contamination, Nitrate, Random Forest

Groundwater is considered as the most important natural resource in the African continent mainly in arid and semi-arid regions. However, contamination of groundwater by nitrate is a growing problem in many urban and agricultural areas at the African scale. Groundwater management decisions need robust methods, which allow an accurate predictive modelling of pollutant occurrences. Random Forest (RF) is a powerful machine learning data driven method that is rarely used in water resources studies, and thus has not been evaluated thoroughly in this field. When compared to more conventional pattern recognition techniques, key advantages of RF include- its non-parametric nature+ high predictive accuracy+ and capability to determine variable importance. This last characteristic can be used to better understand the individual role and the combined effect of explanatory variables in both protecting and exposing groundwater to pressures. In this study, the performance of random forest method has been explored. In the absence of a systematic monitoring program for groundwater at the pan African scale we identified 250 groundwater pollution studies in literature from books and the internet web of Sciences (mainly Scopus<sup>TM</sup>). These literature data were filtered using the following criteria- (i) the publication should explicitly report on nitrate concentrations in groundwater (ii) the publication should be published after 1999. As predictors, we collected a comprehensive GIS database of thirteen spatial attributes related to land use, soil type, hydrogeology, topography, climatology, regions types and nitrogen fertilizer application rate. The performance of the RF is also evaluated in comparison to the Multiple Linear regression (MLR). Results shows that random forest is a promising technique for the identification and characterization of nitrate contamination in groundwater with a higher predictive than a traditional linear regression model. The top variable selected common to both models is population density variable. Our model can provide relevant criteria for establishing groundwater management policies at regional scale, considering the increasing anthropogenic land-use trends at the African scale.



# **Arsenic contamination of tunnel seepage water along the Median Tectonic line, Japan**

**Abstract n° 1404**

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**KEYWORDS:** arsenic, tunnel seepage, tectonic line

Along the north of Median tectonic line, there were some metal mines with As minerals in Japan. Before the several tunnel constructions for the Keinawa high way road, arsenic contamination rocks composed of granite was found from borehole investigation at the north of the Median tectonic line in the Kii Peninsula. There were two types of arsenic contamination rocks. One was sheared black colored granite with minute As minerals. Another was hydrothermal quartz veins with chalcopyrite  $\text{CuFeS}_2$ , molybdenite  $\text{MoS}_2$  and arsenopyrite  $\text{FeAsS}$ . As concentration in rivers around the tunnel before tunnel construction were under  $0.01\text{mg l}$ , the Japanese Environmental Standard. No concern for As water contamination was carried before tunnel construction. Then, As concentration of tunnel spoil was measured by dissolution test and high As rocks were carried to the waste disposal site. However, As concentration of tunnel seepage water was over  $0.1\text{mg L}$ , the Japanese Effluent Standard. After in detail investigation for river water, As concentration for some rivers close to the tunnel were found to be over  $0.01\text{ mg L}$ . The relation between geology and As concentration of tunnel seepage was clarified. Along the valley close to the tunnels parallel to the Median tectonic line, high As seepage water was found in the sheared granite with chlorite and small amount of minutes arsenopyrite. Rarely quartz vein with small amount of chalcopyrite, molybdenite and arsenopyrite was found. Stable isotopic ratios of hydrogen for tunnel seepage water were always 4 to 5 per mil lower than those in the river waters around the tunnel. Tunnel was constructed at the small isolated plateau and maximum distance from the tunnel to surface is 150 m. Then, the big hydrogen isotope difference between tunnel seepage and river waters were thought not to depend on altitude effect but evaporation of river water.



# Groundwater Resources in the Aquifer Systems of the lullemeden and Taoudéni Tanezrouft Basins, Sahelo-Saharan Region

Abstract n° 1405

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KEYWORDS: Groundwater resources, recharge, arid & semi-arid climatic conditions

In the Sub-Sahara and Sahel Region, the aquifer systems of the lullemeden and Taoudeni Tanezrouft Basins cover 2.5 million km<sup>2</sup>, and are spread over seven countries (Algeria, Benin, Burkina Faso, Mali, Mauritania, Niger and Nigeria), with isohyets ranging from 50 to 1300 mm yr. The assessment of the potential groundwater resources of these aquifers and their relationship with the Niger River, together with climatic change impacts, were undertaken in 2012 & 2013. Such a study led to a significant improvement on the knowledge of the aquifer systems behaviour, through the development of innovative scientific technics for highlighting data recorded since decades in the numerous national databases. Results underlined the huge amount of available groundwater resources, of good quality, slightly sensitive to climatic changes and to pollutions, and under-exploited (0.5% to 3% of the renewable resource). A huge groundwater reservoir spreads over 2.5 M km<sup>2</sup>, in sandstone formations, up to 1000 m thickness (300 m average), with a quite good productivity almost everywhere and with some large areas of very high potential. Rainfall infiltration is the main source of aquifer recharge though recharge from the Niger River is not negligible but limited to the vicinities of the river. The recharge has been computed based on land and morphological parameters obtained from satellite imagery processing and on the spatio-temporal distribution of rainfall, at the mesh level of the groundwater flow model and for each time step. Exfiltration from the aquifer systems is by far the main output of the aquifer balance under the prevailing Sahelian climatic conditions. Five main widespread exfiltration areas were demonstrated in the studied area, with the particular case of the Gao Graben, which links - and proves - the continuity between the lullemeden and Taoudeni aquifer systems. This huge potential groundwater resource represents a great opportunity for the Region development. However, its management requires to be properly organized because this is a transboundary resource shared by seven countries in a very politically sensitive Region.



**Recharge computation at a mesh and measurement step scale in groundwater flow modelling- developed method using remote sensing and GIS applied to lullemeden & Taoudeni Tanezrouft aquifer systems (West Africa)**

**Abstract n° 1406**

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KEYWORDS: Recharge, remote sensing, West Africa

Recharge assessment and related spatial distribution remain a recurrent problem while addressing groundwater flow modelling development. Hence the study objective was to develop an automated method for computing the groundwater recharge at the mesh scale and for each time step of the aquifer model. The process was applied to the “lullemeden & Taoudeni Tanezrouft Aquifer Systems” case study spread over 2.5 M km<sup>2</sup>, in Sub-Saharan and Sahel Region where isohyets are ranging from 50 to 1 300 mm yr with large inter-annual variations. The developed process for computerizing the recharge is based on i) literature and existing local studies review, ii) senior experts experience, and iii) land (for dry and wet periods) and morphological parameters obtained by satellite imagery processing and on the rainfall spatio-temporal distribution. Monthly rainfall data are issues from the 1960-2010 recorded measurements in meteorological stations equally spread over the studied area. Land-use was assessed from MODIS satellite images at wet (September) and dry (April) seasons. The SRTM Digital Elevation Model (90 m) was used to define geomorphological classes (plateaux, slopes, valleys, drainage system). The developed recharge model is an automation of various developed applications and data processing using ArcGis™ Geographical Information System. Computerised recharge data at mesh level and for each time step are stored in a file at the format required by the groundwater flow model (Visual Modflow™). Recharge maps are also displayed at any time step. This fully automatized iterative process for computing the recharge greatly contributes to a far better assessment of the recharge and makes the recharge much more coherent and reliable than in classical cases of groundwater modelling where recharge is manually assessed by a trial and errors iterative process. Hence, groundwater flow model accuracy is greatly enhanced. This developed process is applicable under any geological and climatic conditions notwithstanding some adjustments to the parameters in accordance to the local climatic and geomorphological conditions.



# Groundwater vulnerability assessment in fractured rock hydromineral systems (Caldas da Cavaca, Central Portugal)

Abstract n° 1408

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**KEYWORDS:** Hardrock hydromineral systems, DISCO vulnerability assessment, GIS mapping

Assessing groundwater vulnerability is often done through GIS technologies. GIS has become a useful tool to generate vulnerability maps and for simple testing of methods of display. Groundwater protection for human activities with suitable quality makes necessary to determine source protection zones for watersheds in hardrock hydromineral systems to protect them from several risks of contamination. This study intends to develop a groundwater vulnerability approach in Caldas da Cavaca hydromineral system (Aguiar da Beira, Central Portugal), which has a thermal tradition for almost two centuries, and to contribute to improve the hydrogeological conceptual site model. In this work different layers were overlaid, generating several thematic maps to arrive at an integrated framework of several key sectors in Caldas da Cavaca site. Thus, to accomplish a comprehensive analysis and conceptualization of the site, a multi technical approach was used, such as, field and laboratory techniques, where several data was collected, like land use, geotectonics, hydrology and hydrogeomorphology, hydrogeology and hydrogeophysics. All these techniques were successfully performed and a groundwater vulnerability to contamination assessment based on DISCO index methodology was delineated. DISCO method indicated that the zones surrounding the hydromineral wells fit in a high vulnerability class, while the rest of the area fits in a low vulnerability category. DISCO index is in general accordance with other vulnerability indexes previously studied in this site (namely, DRASTIC Fm and SINTACS). Moreover, most of the high vulnerability groundwater protection zones, defined with DISCO method, include the immediate and intermediate wellhead protection areas previously established in 1996 by the Portuguese legislation for Caldas da Cavaca spa.



## Hydrodynamical, geochemical and isotopic preliminary results of Andean groundwater in an active volcanic zone, Mulalo (Ecuador)

Abstract n° 1411

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**KEYWORDS:** volcano-sedimentary aquifer, hydrogeochemistry, water stable isotope geothermism, Andean zone

Mulaló aquifer is located 80 km south of Quito, between the Royal and Western Cordilleras. The Upper Pleistocene Latacunga formation contains the aquifer (maximum depth 250 m). It is composed of fluviolacustrine deposits, pumice and volcanic ashes that give high water potential to this formation. The aquifer is partly phreatic but the presence of quaternary Holocene deposits (ash and lahar) in the central area, possibly makes the aquifer semi-confined. The study area covers about 200 km<sup>2</sup> and concerns the north part of aquifer. Annual precipitation is around 900 mm. There are about 50 water points between boreholes, wells and springs. The flow direction is from north to south. This groundwater is used for domestic water supply, irrigation of orchards and greenhouses where roses are cultivated, which is the main economic activity in this region. To improve the knowledge of this aquifer and guarantee a good management of groundwater use, a hydrodynamic and geochemical monitoring was made during the past few years that was completed by two campaigns of water stable isotopes sampling. Results indicate that the underground phreatic level lies between 2-3 m and 26 m, and fluctuates weakly year round, less than 0.5 m. Electrical conductivity was found between 100 and 4500 IS cm, with the more mineralized samples associated with geothermism or deeper aquifer levels. The chemical type is mainly HCO<sub>3</sub><sup>-</sup> - Mg<sup>2+</sup> (2 3 of samples) or HCO<sub>3</sub><sup>-</sup> - Na<sup>+</sup>, which is linked with ashes and volcanic material mineralogy from the Cotopaxi volcano that overhangs the study area, or other volcanoes around. Isotopic composition shows values from -10.5 to -12.8‰ (18O) and -84 to -91‰ (2H). The most depleted values reflect the isotope content of annual precipitation at this altitude according to the isotopic record of Quito. Plotted points are aligned with a very low slope of 3, which may reveal current or past geothermic processes or a mixing process between aquifers.



## **Social research as part of interdisciplinary groundwater research and management**

**Abstract n° 1413**

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KEYWORDS: Social research, multi-disciplinary teams,

This presentation draws upon ten years of experience as a social scientist working in multi-disciplinary teams and projects engaged in groundwater research and management in Australia. I begin by providing an overview of the range of contributions social researchers can make to those teams, including through the assessment of social impacts or the social acceptability of proposed policies, projects or management actions unravelling the complex set of factors influencing rural landholder management of groundwater, including those related to social norms, risk interpretation and trust in science or management agencies and providing advice about how to engage communities and stakeholders in participatory processes. That brief list illustrates one of the dilemmas for social researchers engaging in multi-disciplinary teams- that is, they will typically be seen as service providers who can assist with engagement and communication rather than having a legitimate research agenda. Other, related challenges include the tendency for social researchers to be included after key decisions have been made about research directions and to be allocated limited resources. I've also found that groundwater researchers are reluctant to focus their research around real-world problems that will facilitate interdisciplinary research. By comparison, social researchers are more likely to adopt a problem-based approach and indeed, find it helpful to focus on a specific context and apply theory and methods where those are relevant. Another challenge for social researchers is that our approaches are better at looking back than looking forward and that makes it more difficult to contribute to integration based on modelling. I will discuss some of the ways I've addressed that issue, including by drawing upon longitudinal census and survey data that are spatially-referenced+ and through the use of Bayesian Networks. Having said that, there are many benefits for social researchers who are part of larger teams, including access to key informants, learning from others with technical knowledge about groundwater systems, and the opportunity to be part of more effective responses to critical issues.



# Identification of groundwater flow systems in the hydrogeological system of the Aburra Valley

Abstract n° 1414

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**KEYWORDS:** local flows, intermediate flows, regional flows, hydrogeochemistry, hydrogeological system of Aburra Valley

Groundwater flow systems, into the saturated and unsaturated zones, come from different places depending on the geological, structural and geomorphological configuration of the area. Those which come from places near of recharge zone are known as local flows, and those which come from more distant places from this area are known as intermediate and regional flows. The former have short circulation times from months to years, the latest vary from hundreds to thousands of years. This paper had the aim to identify and to delimit the presence of these groundwater flow systems in the urban hydrogeological system of Aburra Valley –Colombia–, through the analysis of the current hydrogeological model, the variables that characterize groundwater flow systems and hydrochemical information. The results were validated through isotopic analysis. By use of hydrochemical techniques was possible to establish that the main processes that govern chemical composition of groundwater in the aquifer system are weathering of silicates, dissolution of ferromagnesian minerals, direct ionic exchange, chemical evolution of groundwater and some events of anthropic contamination. By analyzing the variation of chloride and sulphate was found that the main source of these ions is in depth, from intermediate and regional flows. Zones where local, intermediate and regional groundwater flow systems are present were delimited. Local flows are widely distributed by the study area, are recharged inside the Aburrá river basin, main source of discharge of the area, and are discharged both the slopes and valley. Intermediate and regional flows are recharged outside the Aburrá river basin and discharged exclusively in the valley, near the axis of the river, by vertical upward flows. It was determined that within the aquifer system processes of groundwater mixture from different chemical composition are presented.



# Quantification of Submarine Groundwater Discharge Using Radon ( $^{222}\text{Rn}$ ) Mass Balancing and Numerical Groundwater Modelling

Abstract n° 1415

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**KEYWORDS:** Submarine groundwater discharge, coastal hydrogeology, radon, mass balance

Subsurface discharge of groundwater plays a key role in coastal water and matter budgets. Two major forms of submarine groundwater discharge (SGD) can be distinguished- (i) pure freshwater discharge (FSGD) and (ii) recirculation of seawater through coastal sediments (RSGD), e.g. driven by tidal pumping. The localization of SGD zones and the quantification of SGD fluxes are of interest for coastal water management due to two potential threats related to SGD- (i) the discharge of nutrient- or contaminant-laden groundwater into the coastal sea and (ii) the loss of freshwater. In this work, we compare estimates of FSGD and RSGD derived from a mass balance of radon ( $^{222}\text{Rn}$ ) and estimates of FSGD derived from a numerical groundwater water model. The mass balance source and sink term calculations are based on salinity,  $^{18}\text{O}$ ,  $^{222}\text{Rn}$ ,  $^{223}\text{Ra}$ ,  $^{224}\text{Ra}$  and  $^{226}\text{Ra}$  in seawater and groundwater. Numerical model results rely on groundwater level measurements, river flow data, groundwater recharge estimates, tidal dynamics, and density effects along the freshwater seawater interface. The mass balance results derived from two field campaigns indicate FSGD of 1.1 A 1.0 mE d respectively 1.0 A 0.9 mE d per m of coastline and RSGD of 1.4 A 1.3 mE d respectively 1.4 A 1.3 mE d per m of coastline for a defined budget area. The steady-state solution of the numerical hydrogeological model indicates FSGD of 2.4 mE d per m of coastline in this area. Possible reasons for quantitative differences are seasonal variability and unknown groundwater abstraction. We compare both approaches for SGD localization and quantification+ discuss the results regarding their relevance for the regional water balance and reason implications of SGD flux for the water management of the coastal zone.



**Noble gas isotopes and gas compositions of on-land and subaqueous thermal springs  
in the Koycegiz Lake and Dalaman plain area, Turkey**

**Abstract n° 1417**

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**KEYWORDS:** Noble gas isotopes, subaqueous thermal springs, Koycegiz lake, Turkey

The purpose of this study is to demonstrate noble gas isotope and water and gas composition data from subaqueous thermal springs in Koycegiz Lake and from on-land hot springs located in the Koycegiz and Dalaman plains to contribute to hydrogeochemical conceptual modeling of the geothermal system in the area. To this end, seven locations were sampled for free gas and four were sampled for gas dissolved in water. Water samples are of the Na-Cl type. Koycegiz Lake on-land samples have relatively high discharge temperatures (between 37 and 40 °C) when compared to Dalaman plain samples (26-30 °C). Gases from the majority of the locations are composed mainly of nitrogen with variable amounts of CO<sub>2</sub>, Ar, O<sub>2</sub>, CH<sub>4</sub>, H<sub>2</sub> and He. In one gas sample from Koycegiz Lake there is a major contribution of CH<sub>4</sub>. Air corrected helium isotope ratios of all samples are above the crustal value (0.02-0.05 Ra, Ra is the atmospheric <sup>3</sup>He/<sup>4</sup>He ratio of 1.39x10<sup>-6</sup>), exhibiting a mantle component. The mantle helium percentages are calculated by using a two-component mixing model between mantle-He and crustal-He. Mantle-He percentages are between 2 and 6% for samples from subaqueous springs, 2% for samples from on-land springs located around Koycegiz, and 17-18% for on-land springs located in the Dalaman plain. High contributions of mantle helium in the Dalaman plain suggest that the faults of extensional tectonics in the area are enhancing the escape of gases originating from the upper mantle through the brittle parts of the crust and this affects the geothermal system. The differences in mantle helium contributions of subaqueous and on-land Koycegiz Lake samples on the one hand and Dalaman plain samples on the other hand indicate that these samples are products of two different geothermal systems. Acknowledgements- This study was supported by TUBITAK under Grant No. CAYDAG-112Y137



# Geogenic arsenic and other trace elements in the groundwater system of Develi Closed Basin, Kayseri, Turkey

Abstract n° 1418

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KEYWORDS: Arsenic contamination, groundwater, Develi Closed Basin- Turkey, volcanism, soil

In Turkey, General Directorate of State Hydraulic Works (SHW) is the governmental organization responsible for the discovery, exploitation and allocation of the groundwater resources besides monitoring the quality. During a regular hydrogeological investigation study carried out by SHW between 2008-2010 in Develi Closed Basin, located in Central Anatolia, high arsenic concentrations (up to 770 µg/l) were detected in the groundwater in north-northwestern parts of the basin. The aim of this study is to investigate the sources and processes involved in the release of As and other trace elements (B, Fe, Mn, Cu, Zn, Ni, V, Ba, Cr and Sr) to the groundwater in Develi Closed Basin. To this end, 10 samples from groundwater wells, 5 samples from the springs, 10 samples from geologic units and 13 samples from soils were collected between 2013-2014. The area is characterized by a semiarid climate and geologic formations of volcanic origin formed during the latest stages of Mount Erciyes volcanism between Miocene and Quaternary. The tectonic components like Salt Lake and Ecmis faults caused alteration zones in the geologic units. The pull-apart basin formed in the depositional area located between these faults caused enrichment in heavy metals. During wet periods, arsenic leaches from the rocks due to weathering in alteration zones and transported to soils and groundwaters. In-situ pH and Eh measurements in water samples are used to prepare Pourbaix diagrams and the dominant arsenic species are found out as As<sup>+5</sup>. The cluster analysis carried out in soil and rock samples indicate that there is correlation between As, V, Cr, Ni, B and Ba and between As, V and Co, Zn, Cr and Ni, respectively. The elements that As have significant correlation in groundwater samples are Cu, Zn, Pb, Mn according to Pearson correlation analysis.



# STAKEHOLDER PARTICIPATION IN GROUNDWATER MANAGEMENT – REFLECTIONS ON POSITIVE & NEGATIVE EXPERIENCES

Abstract n° 1419

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KEYWORDS: groundwater management, stakeholder participation

Given the disperse nature of groundwater resources some form of ‘stakeholder participation’ is an essential pre-requisite for successful management, but management by stakeholder initiative alone is only occasionally sustainable under a combination of exceptional conditions. This paper will reflect upon the experience – positive and negative – of stakeholder participation in groundwater management from 10 aquifer (and sub-aquifer) systems selected from South & East Asia, Middle East & North Africa and Latin America regions during 2002-11. From this extensive experience it is concluded that stakeholder leadership in groundwater management and conservation is only likely to succeed alone in small clearly-defined aquifer systems being exploited by a ‘socially-homogenous’ group of users, and even then it needs to be nurtured by technical and logistic support from a local groundwater agency. In more extensive aquifer systems with major storage reserves, experiencing competitive stress from large-scale withdrawals for urban utility and or industrial water-supply and for irrigated agriculture, a government agency will need to take the initiative on regulating groundwater use and potentially-contaminating discharges seeking support of the bulk of stakeholders for its implementation in the balance of their interests.



# Stable isotope-based investigation of infiltration effect of snow melting water on the groundwater in the large landslide block, Japan

Abstract n° 1421

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KEYWORDS: landslide, groundwater, d-excess

One of the strongest trigger factors of land sliding is a rise of groundwater level caused by heavy rainfall and snow melting etc. Many landslide areas are distributed in snowy region of the northern part of Japan, and therefore, the landslide management in consideration of infiltration of snow melting water is highly important in these areas. In this study, stable isotopic compositions of oxygen and deuterium in rainwater, snow, stream water and groundwater were observed to investigate the infiltration effect of snow melting water on the groundwater in the large landslide block in Yamagata prefecture, northern part of Japan. It can be found from the observations that the d-excess is different in rainwater and snow packs in this basin+ the mean values are 10.42 and 28.22 per mil, respectively. The high d-excess in snowfalls seems to arise from the increasing kinetic isotopic fractionation as relative humidity in the air above the ocean surface decreases in winter. This seasonal difference of d-excess in precipitation can be used to characterize the infiltration effect of snow melting water on the groundwater in the landslide block. The d-excess in the stream water was increased by spring runoff in snowmelt season, and it decreased thereafter. Although the fluctuation range of d-excess in groundwater is smaller than in stream water, the d-excess in the groundwater of the landslide block was slightly increased in snowmelt season as well as in the stream water. It is thus deduced that the snow melting water has a certain effect on the groundwater in this landslide block and d-excess can be used as an index to evaluate an infiltration of snow melting water in landslide areas of snowy region.



**Tryptophan-like fluorescence- an effective real-time indicator of faecal contamination  
in drinking water  
Abstract n°1424**

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KEYWORDS: Subsurface microbial source tracking

Enteric pathogens are typically inferred from the presence of cultured surrogate indicator organisms such as thermotolerant coliforms (TTCs). Their analysis requires suitable laboratories, specialist trained personnel, and is time-consuming, which can limit sampling resolution, particularly during critical pollution events. We will demonstrate the use of tryptophan-like fluorescence as a reagentless, real-time indicator of thermotolerant coliforms from a synthesis of work undertaken on African and Indian groundwater. We will show it is a significant indicator of both the presence-absence and number of these surrogate organisms, including where traditional real-time indicators of surface derived pollution like turbidity fail. The technique is now being trialled as a real-time pollution alert system at public abstraction boreholes in the UK and has potential widespread applications within the WASH and development sector globally.



# Is the provision of on-site sanitation a threat to rural domestic water supplies in India? Abstract n°1425

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KEYWORDS: On-site sanitation

India is the global epicentre for open defecation where it is practised by an estimated 600 million people. There has been a strong political drive to eliminate the practice for decades, with the current Prime Minister declaring this a national priority and pledging to provide a toilet in every home by 2019. However, there are concerns that developing on-site sanitation within rural communities could contaminate groundwater, which these populations are heavily dependent upon for the self-supply of domestic water. To investigate this link 150 domestic groundwater supplies in four villages in Bihar State currently undergoing sanitary interventions were tested for thermotolerant coliforms. These selected sites were at varying distances from recently installed on-site sanitation. Currently, local NGOs recommend a lateral separation of 10 m between a supply and on-site sanitation, but this was evidently not adhered to due to the high housing density and proliferation of self-supply. Overall, 91% of contaminated supplies were located less than 10 m from on-site sanitation, which was statistically identified as the only significant risk factor. This was despite the aquifer being confined beneath 25 m of clayey silt and, thus, suggesting that it was the vulnerability of the supply completions that was leading to contamination. The results from the study suggest that the ongoing sanitation development in India is likely to lead to the increasing faecal contamination of water supplies which are critical drinking water sources across rural India.



**Aquifer sampling using ball check-valves system- what about sample representativeness?**  
**Abstract n°1426**

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KEYWORDS: deep sampling, representativeness, water chemistry

Deep aquifer monitoring is a challenge in terms of representativeness of the sample. Such monitoring is often done when pumping is not adequate due to- 1) too deep water table level, 2) no willing to add disturbance to the aquifer (low recharge rate) or 3) too difficult management at surface of discharge waters. Deep sampling may rely on the use of sampling bottles but these have a fixed volume and need to lower and to remove the bottle each time a sample is needed. Ball check-valves and pressure gas drive samplers have been developed to overcome this bias such as the US U-tube system. Here we present investigations with a system developed by the BRGM (GazOGaz, patent FR1259214), relying on similar functioning but having more flexibility in the use. Such a system allows the collection of a virtually unlimited volume of water at any depth in the water column. Nevertheless, there is a frequent question about the use that may be done of waters collected using deep sampling. Site managers or public authorities wonder about the comparisons that can be made with samples obtained using classical pumping methodology. The present survey has been designed in that objective. By carefully describing physico-chemical parameters along the water column and by performing both in-situ deep sampling and pumping at fixed depth, characteristics of waters existing in 2 boreholes located near Castres (Tarn, France) are investigated in details with specific focus on the dissolved elements. Conclusions on how deep sampling may be used and useful for aquifer characterization are presented together with the limits of applicability of such a sampling procedure.



**Insights into the spatial and temporal variability of water isotopic signatures in a small agricultural watershed in Atlantic Canada**  
**Abstract n°1427**

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KEYWORDS: water isotopes, tracers, groundwater recharge

In this study, water isotopes, together with other tracers have been employed for understanding the interconnectivity between precipitation, surface runoff, groundwater recharge and discharge, and streamflow. The study has been carried out in Black Brook Watershed (14.5 km<sup>2</sup> watershed area+ moderately cool temperate climate) and involved watershed-scale seasonal sampling complemented by intensive event-based sampling. The water isotopic signatures of all the samples were narrowly distributed along the regional meteoric water line, however precipitation showed significantly larger range ( $-99\text{‰} < \delta^2\text{H} < -18\text{‰}$  +  $-14\text{‰} < \delta^{18}\text{O} < -4\text{‰}$ ) than groundwater ( $-97\text{‰} < \delta^2\text{H} < -60\text{‰}$  +  $-14\text{‰} < \delta^{18}\text{O} < -9\text{‰}$ ) and stream water ( $-80\text{‰} < \delta^2\text{H} < -58\text{‰}$  +  $-12\text{‰} < \delta^{18}\text{O} < -9\text{‰}$ ). Isotopic signature of precipitation during events showed significant temporal variability (e.g.  $-34\text{‰} < \delta^2\text{H} < -72\text{‰}$ ) and this was reflected in the isotopic signature of both surface runoff and streamflow. The event-based samples collected from the unconfined aquifer showed a more stable isotopic signature, despite the quick response in water table, thus indicating a possible mixing effect that is dampening the precipitation signature. Groundwater isotopic composition during the spring season showed lighter isotopic composition, an effect triggered by the significant recharge event produced by snowmelt and lighter isotopic composition of precipitation in the colder months. Deep groundwater samples (>40 mbg) showed slightly more negative isotopic signature when compared to shallower groundwater, potentially indicating mixing with ancient waters recharged under a different climate. Isotopic signature of precipitation showed no spatial variability at the watershed scale. Groundwater and stream had similar seasonal isotopic composition, showing that groundwater is the major contributor (~70%) to streamflow, which has been confirmed by hydrograph separation. Mixing models developed using additional tracers (e.g. NO<sub>3</sub>, Cl), yielded similar results with respect to water partitioning and groundwater recharge during the sampled events as well as throughout the year, showing that water isotopes are a powerful tool when used in combination with other methods.



## Hot spring along the Median tectonic line in the Kii peninsula, Japan Abstract n°1428

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KEYWORDS: hot spring, Li, median tectonic line

Along the median tectonic line, there are some hot springs in Japan. In particular, in the Kii Peninsula, extreme characteristic hot spring water was observed. High Li concentration, 100mg l, of hot spring water with high salt was pumped up over 1500 m in depth. High carbonate and Fe rich hot spring was also observed along the Median tectonic line. These hot spring waters were high salty however oxygen and hydrogen isotopic ratios were variable and were not always high. On the other hand, surface water such as river water and shallow well water is low soluble substances and low stable isotopic ratios of oxygen and hydrogen. Relation between Cl or Na ions and stable hydrogen isotopic ratios shows hot spring water is not mixture of seawater and surface water. Stable isotopic ratios of hot spring with high salt content were too low relative to those of seawater. Ratios of Na ion concentration per the other soluble cations such as Ca, Mg and K ions were low relative to seawater. Hot spring water sometimes has high concentration of carbonate. Along the Median tectonic line, widely granite was distributed and high Li concentration hot spring was observed. Generally granite contains high Li concentration. Therefore, hot spring water was thought to contact with rocks for long term and carbonate and cation ion were thought to be dissolved from rocks. There are over 10's hot springs along the Median tectonic line in the Kii Peninsula. In some cases, over 100 people a day visited one hot spring bath and then hot spring water is important for tourist industry and health. In future, high Li hot spring water will be used for Li resource and now the water just is used for bath. Therefore, tectonic line is important for making hot spring.



**The safe yield of aquifers- estimation methods and implications for sustainable  
aquifer management  
Abstract n°1429**

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**KEYWORDS:** aquifer, safe yield, groundwater, climate, management, drought, aquatic ecosystems, seawater intrusion, land subsidence.

The safe yield is the amount of groundwater that can be continuously extracted from an aquifer without adverse hydrogeologic, economic, and environmental effects. The safe yield is a useful metric of aquifer serviceability that is widely used to set baseline groundwater extraction strategies that ensure sustainable use of aquifers, that is, long-term extraction that preserves the groundwater resource. There are however, difficulties with the assessment of the safe yield. One of them is that its definition is meaningful over a representative climatic period for the area encompassing the aquifer. In areas with high climatic variability it is necessary to have long periods of precipitation to assess what the correct representative climatic period might be. Another issue concerns aquifers that have vulnerabilities during drought conditions. Examples are groundwater-fed springs with sensitive aquatic ecosystems whose viability depends on thresholds of groundwater discharge, or coastal aquifers that require a threshold of submarine discharge to prevent seawater intrusion, or aquifers with compressible strata that have thresholds of effective stress to avoid damaging land subsidence. The latter examples of adverse impacts imply that sustainable aquifer use requires adaptive strategies for groundwater extraction that are guided by a properly estimated safe yield but constrained by aquifer vulnerabilities. Examples of safe yield calculation constrained by aquifer vulnerabilities are presented in this paper. Implications for sustainable groundwater management are highlighted. The examples presented involve aquifers that supply urban, water for agriculture, and support sensitive aquatic ecosystems or are vulnerable to sea water intrusion or land subsidence.



## **A 18O isoscape for the shallow groundwater in the Baltic Artesian Basin Abstract n°1430**

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**KEYWORDS:** shallow groundwater, precipitation, isoscape

When studying water reservoirs, it is critical to describe the stable isotopic composition of modern precipitation because it serves as an input signal to the isotopic composition of surface water bodies and aquifers. The network that monitors the isotopic composition of precipitation over space and time (GNIP) does not cover the Earth evenly. The Baltic Artesian Basin (BAB) can be cited as an example of a region, where historically only one GNIP station (Riga) provides data for over ca. 175000 km<sup>2</sup>. BAB is an important paleogroundwater reservoir but little has been known about the spatial variability of D and 18O values in modern precipitation input across the region. To overcome this limitation, we hypothesized that the isotopic composition of shallow groundwater in the BAB could be used as a proxy for the weighted mean annual isotopic composition of local precipitation. However, our results reveal clear discrepancies between the isotopic composition of precipitation and shallow groundwater in the area. The isotopic composition of shallow groundwater is mostly biased towards isotopically depleted wintertime precipitation. We believe that the long daylight period in the BAB area during the summer growing season allows plants to transpire a substantial portion of the summer precipitation input, which causes the groundwater recharge to be strongly biased towards the spring snowmelt and autumn precipitation. The results suggest that when making palaeoclimatic interpretations in palaeoenvironmental research, we should not assume that 18O values of shallow groundwater are identical to those of precipitation. The derived isoscape of the BAB shallow groundwater 18O values is characterized by a high spatial resolution and its estimated error is comparable to the analytical precision of the 18O measurements. Therefore, it can serve as a fairly accurate reference basis for further hydrogeological modelling and also for ecological, or even forensic applications. The variogram analysis revealed that the spatial dependence structure of shallow groundwater 18O values in the BAB area is characterized by a mixed geometric and zonal anisotropy.



## **Groundwater resources and Transboundary Aquifers in Asia**

### **Abstract n°1431**

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**KEYWORDS:** Groundwater, Transboundary Aquifers, Governance, Asia

Asia is the largest continent in the world. It could be divided into East Asia, Southeast Asia, South Asia, West Asia and Central Asia and Caucasus. Groundwater characters in Asia are various. Some regions are underlined by aquifers extending over large areas, while the floodplain alluvial deposits usually accompany the largest rivers. There is small rainfall and strong evaporation in inland arid area of central Asia. However the thawing of glaciers and snow from high mountains is favorable to recharge groundwater. The carbonate rocks are widely distributed in Southeast Asia, in which karst is considerable developed. The groundwater could be differentiated into eleven groundwater systems and 36 sub-systems. Groundwater resources assessments have been taken in most countries of Asia. The hydrogeological survey on a medium scale has performed regional quantitative assessment of natural groundwater resources. As the groundwater abstractions increases, negative consequences may become manifest like falling groundwater tables, land subsidence and seawater intrusion. To sustain groundwater use in such stressed aquifers, interventions need to be developed that slow down or even reverse aquifer depletion, including the management of groundwater demand and the conjunctive use of surface water. To conserve the productive capacity of aquifers requires constant monitoring of groundwater quantity and quality and includes aquifer protection. There are several aquifers, involving two or more countries in Asia. Transboundary aquifers as part of groundwater resource systems are important for Asian countries. The updated regional inventory of Transboundary aquifers will form basis to governance TBAs among the political leaders, policy makers and planners. We have collected the essential and the missed Transboundary aquifers data. Most Transboundary Aquifers are inventory according the published achievements in the last several years. 67 Transboundary Aquifers are inventoried. Those aquifers in Asia are important for building a society where all civilizations coexist harmoniously and accommodate each other.



## **Geothermal potentialities of northern Algeria- mapping of geothermal gradient Abstract n°1432**

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**KEYWORDS:** thermal springs, deep reservoirs, BHT, DST, geothermal gradient

Given the potential energy highlighted by high temperature values determined during geothermometric and hydrogeochemical studies as well as surface manifestations of different hot springs that rise to very significant temperatures (up to 98 ° C), the drawing up of the geothermal gradient map, is a key to understanding the hydrogeothermal systems of deep reservoirs in northern Algeria. The map of geothermal gradient was drawn as part of a research work developed to characterize and evaluate the geothermal potential of northern Algeria. Established from the correction of 198 Bottom Hole Temperatures (BHT) measured during logging operations deep boreholes and temperatures obtained in drill steam tests (DST), this map shows essentially three areas with high geothermal gradients related to geological structures in depth- 1) The thermal anomaly of eastern Algeria, bounded by the gradient curve 4°C 100m, which is the largest anomaly 2) the center anomaly, at the bibanic area, where the gradient reached 4.27°C 100m 3) And the west thermal anomaly, with a gradient of 4.29 ° C 100m.



**Geothermal reservoirs in Hodna Mountains (Algeria)- Hydrogeochemical and lithostructural study**  
**Abstract n°1433**

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**KEYWORDS:** Hydrogeochemistry, geothermometry, deep reservoirs, geothermal gradient

The hydrochemical characteristics of deep reservoirs in Hodna Mountains are addressed through the hot springs that exist there. These springs are associated with very complex fault systems due to the recent compressive tectonic activity affecting northern Algeria. The use of chemical data revealed that all samples are of calcium sulfate facies with high concentrations of Na-Cl. The origin of the water chemistry is mainly due to the dissolution of evaporite rocks, especially sulfates contained in the Triassic and Eocene formations. The combined study of data on water chemistry, the geothermometry and geothermal gradient, faced with lithostructural context of reservoirs, allows a consistent approach to deep circulations, by identifying potential reservoirs and their depth.



**Protection and management of a sensitive natural environment- the grottes  
merveilleuses , jijel cornice - Algeria  
Abstract n°1434**

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**KEYWORDS:** Environmental Management, Karst Cave, Temperature, Humidity

Karst caves constitute a sensitive and specific environment which requires specific management constraints for its protection and development (tourism and culture). Various factors such as the combined influence of temperature and air humidity variations (of condensation and evaporation) and exposure to air flows can be the cause of degradation. Human factors for their part are not negligible. The approach developed in the case of "Grottes Merveilleuses" of Jijel Cornice in Algeria, is based on a functional analysis of the environment- after a description of the geological and hydrogeological aspects that govern the formation of this cave and after a topographic survey of 3th degree, the environment is instrumented to determine its sensitivity to direct or indirect influences on the factors involved in the conservation of this heritage. Thus, continuous monitoring of temperature, humidity, heat exchanges and aerodynamic conditions, shows that the introduction of excess energy (visitors, lighting, air mass) destabilizes the natural system, determining a risk of degradation in the cavity. These results are used to optimize visit protocols and define amenities and improvements (lighting power, entrance area, visitor's circuit) compatible with satisfactory storage conditions.



**Solar pumping and irrigation- sustainability and limitations of a silver-bullet technology**  
**Abstract n°1436**

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KEYWORDS: groundwater, solar pumping, sustainability

The increasing demand for solar-powered irrigation systems in developing countries in recent years has been heralded as a new technology 'silver bullet', spurring a race for projects as it potentially offers a cost-effective and sustainable solution to off-grid communities and farmers. As a result, international development projects in countries such as Morocco and Yemen and national plans with variable finance schemes and subsidies like in India have appeared, aiming to make this technology available to farmers. By focusing on the application of solar photovoltaic (PV) pumping systems in groundwater-fed agriculture, this paper highlights the need to further study the application of this potentially leap-frogging technology. Building on an existing pool of case studies around the world (from the Middle East to South Asia), this paper shows how most studies overlook the economic and financial sustainability of these projects and do not incorporate concerns regarding the availability of water resources and the potential negative impacts on the environment. Failing to address these issues could lead to technology adoption limitations and a potential depletion of groundwater, which could potentially threaten the attractiveness and implementation of this technology in the future.



**Quantifying the influence of surface water groundwater interaction on nutrient flux in a lowland karst catchment.**  
**Abstract n°1440**

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KEYWORDS: Karst, Groundwater Surface Water Interaction, Nutrients, Ireland

Nutrient contamination of surface and groundwaters is an issue of growing importance as the risks associated with agricultural runoff escalate due to increasing demands on global food production. In this study, the surface and groundwaters of a lowland karst catchment in western Ireland was investigated in order to determine whether temporary karst lakes (turloughs) are subject to the same nutrient gain loss process as permanent lakes. Water samples were tested from a variety of rivers, lakes (or turloughs), boreholes and springs at monthly intervals over three years. Alkalinity sampling was used to elucidate the contrasting hydrological functioning between different turloughs. Such disparate hydrological functioning was further investigated with the aid of a hydrological model which allowed for an estimate of allogenic and autogenic derived nutrient loading into the karst system. The model also allowed for an investigation of mixing within the turloughs, comparing observed behaviours with the hypothetical conservative behaviour allowed for by the model. Within the turloughs, nutrient concentrations were found to reduce over the flooded period, even though the turloughs hydrological functioning (and the hydrological model) suggested this should not occur. As such, it was determined that nutrient loss processes were occurring within the system. Denitrification during stable flooded periods (typically 3-4 months per year) was deemed to be the main process reducing nitrogen concentrations within the turloughs whereas phosphorus loss is thought to occur mostly via sedimentation and subsequent soil deposition. The results from this study suggest that, in stable conditions, ephemeral lakes can impart considerable nutrient losses on a karst groundwater system.



**Application of the KARSYS modelling technique to lowland karst catchments in  
Ireland  
Abstract n°1441**

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KEYWORDS: Karst, Hydrogeological Modelling, Ireland

Carboniferous limestone is the most common rock type in Ireland. It underlies almost half the land surface (making it the primary aquifer in the country) and is often heavily karstified. Over 90% of these limestones are in lowland regions (<150m a.s.l.) and coincide with areas of productive agricultural land or centres of population. As such, these aquifers require protection and the first step of such protective measures is to determine the zone of contribution's (ZOC's) of important water sources. In order to determine these ZOC's in karst, traditional karst techniques (tracers, hydrograph analysis etc.) have been used with varying degrees of success. In this study, two catchments in which traditional karst techniques have thus far proven inconclusive are being trailed with the 3D modelling technique, KARSYS, developed by the Swiss Institute for Speleology and Karst Studies (ISSKA SSKA). The KARSYS approach involves the development of a three dimensional model of the carbonate aquifer geometry coupled with a series of fundamental principles of karst hydraulics. The resulting 3D conceptual model is thus a hypothesis to test, and improve, by further investigation. Models have been developed for the Bell Harbour and North Cork catchments which have enabled enhanced delineation of ZOC's in these previously uncertain karstic catchments. Overall, the study has shown the rigor of the KARSYS modelling approach whereby the model is developed based on structural geology with the addition of hydrological concepts, rather than defining a karst system based on spring hydrographs alone. This study also marks the first time such a modelling technique has been used in Ireland and the first time the KARSYS model has been used in low-lying and coastal karst.



**Multiphase flow modelling of the pumping of a DNAPL- case study of  
hexachlorobutadiene in a shallow alluvial aquifer  
Abstract n°1442**

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KEYWORDS: hexachlorobutadiene, remediation, modelling

In France, organo-chlorinated compounds (VOHC) are responsible of about 15 percent of contamination of soils and groundwater. In this context, the SILPHES project combines innovative characterisation tools and emerging remediation technologies applied on VOHC-contaminated groundwater. For this project, four square impermeable concrete compartments of 9.5 m long and 10 m deep were dug at the location of a free-phase source zone of VOHC, mainly composed by hexachlorobutadiene (HCBD). The aquifer is made of superficial alluvial materials, from fine sand to gravel, reversely graded. A numerical modelling was elaborated, with the three-dimensional and multiphase flow simulator TMVOC, to model, at the field scale, the VOHC pumping, in one of the compartments. Two scenarios were experimented on site- an on off pumping during 50 days+ an up-welling technique. Interpolation of geological layers was done with LeapFrog, from drilling survey data. Chemical data of 8 VOHC was computed to fit TMVOC parametric requirements. Soil and hydrogeological parameters were obtained either from literature or experiments (i.e. water VOHC retention curves). Numerical model grid consisted of 9 layers for a total of 1188 3-D grid blocks, modelling the interior volume of one concrete compartments. Numerical modelling results show a good match between simulated and field data of VOHC and water masses pumped during the two scenarios. Partitioning tracer tests will be conducted in the compartments to assess the efficiency of the pumping scenarios and evaluate volumes of residual VOHC. This study is, at the best of the knowledge of the authors, the first multiphase flow modelling of a VOHC source composed mainly by HCBD, a chemical which has a poor occurrence data in the environmental literature. It offers a new perspective in remediation, by using multiphase flow numerical tools to predict immiscible pollutants behaviour in groundwater, in natural or forced flow.



# How global changes impact water resources in a southern coastal metropolis ? Case of Recife (Brazil)

## Abstract n°1443

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**KEYWORDS:** transdisciplinary approach, South America metropolis, groundwater salinization, isotopes, water governance, geochemistry, sociology, Brazil

The Recife Metropolitan Region is a hot spot illustrating the problems of southern countries on water issues where water resources are threatened both for quantity and quality in the context of global changes. Based on a transdisciplinary approach, the purpose of the study was to assess the impact of human activities on coastal aquifers, through the analysis of pressure on groundwater resources and their social and structural reasons+ the identification of sources and mechanisms of groundwater quality degradation+ and the evaluation of the impacts of the global change on water resources at the regional level. The methodology was based on a multi-isotopic fingerprinting of groundwater and surface water, on gas analyses, and on sociological and ethnographic investigations including ethnography to characterize the daily life of the Recife inhabitants facing the lack of water or its poor quality. The results revisit the aquifer system functioning. In the deep aquifers, the groundwater displays a residence time over 10 000 y with a residual salinity inherited from the Pleistocene marine transgressions. Their recharge is very limited resulting in large water level decrease. Inversed flow directions due to overexploitation favour leakage from the surficial contaminated aquifers. The access to water and its social perception vary according to the social environment and to the residence location of individuals. Access to water is more a political problem than a technical one. The public authorities tend to deny the difficulties of poor people, especially in times of drought. The discredit of the water and sanitation public actors, and political and institutional rivalries and fragmentation are obstacles to technical solutions implementation. Integrated water management is urgently needed knowing that local climatic scenarios predict a reduction of rainfall volume of 20% together with a sea level increase of 18-59 cm by 2100.



## **New insights in transport processes by applying emerging contaminants as tracers** **Abstract n°1444**

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**KEYWORDS:** Artificial sweeteners, Catchment, Karst

Pharmaceuticals, personal care products, life style products, and pesticides have been detected in groundwater at low concentrations worldwide. Organic trace compounds may pose a risk to safe drinking water as their effects as single compounds or as combination of a multitude of compounds is still unknown. However, concentration levels are generally very low, rarely exceeding the Ig L level and far below a toxicological effect concentration. Due to high analytical precision these concentrations can be analyzed quite easily, allowing to analyze a whole set of compounds with different physical and chemical properties. This properties can be used to characterize subsurface transport processes. Unlike a real tracer test, e.g. with dye tracers, the input function of these compounds is almost always unknown. Using emerging contaminants as tracers needs another approach. If concentrations in groundwater along a known groundwater flow path are analyzed these measurements can be used to deduce transport processes between the two measuring points. At the Gallusquelle karst spring on the Swabian Alb, southern Germany, the artificial sweeteners acesulfame and cyclamate have been used to identify a sewage input into this rural catchment. The catchment had been studied intensively in the past, including geology, hydrogeology, and groundwater flow. Acesulfame and cyclamate have been used to identify an input of sewage water into the system after intensive rainfall events. The spring water at Gallusquelle was analyzed for more the 50 emerging contaminants, among them pharmaceuticals and the herbicides isoproturon and atrazine. Based on the results, we were able to distinguish the arrival of relatively old from new water components in the spring. These old and new components match quite closely with the fast and slow flow fractions in the water indicating the effect of groundwater recharge on the local flow regime. These results coincided very well with data on turbidity and microbiology which was measured at the same time.



**Dependence of shear wave seismoelectrics on soil textures- a numerical study in the vadose zone.  
Abstract n°1449**

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KEYWORDS: vadose zone, seismoelectrics, shear waves

The seismo-electromagnetic method can be used for non-invasive subsurface exploration. This method is appropriate for detecting fluids such as water, oil, gas, CO<sub>2</sub>, or ice, and also helps to better characterise the subsurface in terms of porosity, permeability, and fractures. The seismo-electromagnetic method combines seismic and electric methods, with the resolution of the seismics and the sensitivity of the electromagnetic methods to the fluids. However, the challenge of this method is the low level of the induced signals. The purpose of this work is to study seismoelectric conversions generated in the vadose zone, when this region is traversed by a pure SH wave. We assume that the soil is a partially saturated one-dimensional porous media and we use the van Genuchten [1] constitutive model to describe the water saturation profile. Correspondingly, we extend Pride's formulation [2] as suggested by Warden et al. [3] to deal with partially saturated media, introducing two substantially different saturation dependent functions into the electrokinetic coupling coefficient linking the poroelastic and the electromagnetic wave equations. In order to study the influence of different soil textures we perform a numerical analysis considering, among other relevant properties, the electrokinetic coupling coefficient and coseismic responses (Cos) and interface responses (IR). We observe that the Cos are consistent with analytical results. Moreover, the IR are several order of magnitude stronger than the Cos, and markedly depend on the soil texture and the chosen coupling model. The results obtained suggest that seismoelectric prospection using shear waves could be developed as an useful tool for vadose zone characterization studies. References 1.aa L. Richards, Capillary conduction of liquids through porous mediums. *Physics* 1, 318—333, 1933. 2.aaS. Pride, Governing equations for the coupled electromagnetics and acoustics of porous media. *Phys. Rev. B-Condens. Matter* 50, 15678—15695, 1994. 3.aaS. Warden, S. Garambois, L. Jouniaux., D. Brito, P. Sailhac, C. Bordes, Seismoelectric wave propagation numerical modeling in partially saturated materials. *Geophys. J. Int.* 194, 1498—1513, 2013.



**A platform to harmonize the regional hydrodynamic models in the southwest of  
France  
Abstract n°1450**

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**KEYWORDS:** regional hydrodynamic models, harmonization, geological modeler, groundwater recharge

To support the authorities in water resource management, different hydrodynamic models have been developed in south-western France (the new Large Region- Aquitaine - Limousin - Poitou-Charentes) for nearly twenty years. These models also contribute to understand the functioning of multilayered aquifers on this territory. Four developed models coexist and cover a total area of 82,570 km<sup>2</sup> (Jurassic and Cretaceous models in Poitou-Charentes, the North Aquitaine Model and the South Aquitaine Model). They cover 87% of the sedimentary formations of the new Large Region. In addition of these regional models, others models with refined geometry or mesh have been developed on a part of the same territory in order to respond to local and specific problems. All these models, developed independently from each other, will be integrated in a common platform in order to harmonize their functioning with the experience gained during the development and the use of each of them. Thus, the use of a geological modeler upstream to create geometrical models allows some flexibility in order to regularly integrate the latest geological data (used for the North Aquitaine Model). Moreover, the use of climate spatialized data (SAFRAN data from Météo-France) coupled with the use of a specific recharge module allows to homogenize and calculate in the same way the groundwater recharge in the different models (used for the Jurassic model). Including the restitution of surface runoff and rivers flow in modeling allows as well to properly constrain the distribution of effective precipitation between infiltration and runoff. Finally, a database of water withdrawals is built to handle and treat in the same way data from different origins with variable time step and specific issues to be considered in each model (water withdrawals in groundwater and or surface for various uses as water supply, industry, irrigation, dam releases, sewage discharges, etc.). All of these works aim to consolidate regional hydrodynamic models and to allow the update and faster adaptation of these models.



**Hydrodynamic, geochemical and isotopic characterization of the volcanic-sedimentary aquifer of Tumbaco-Cumbayá-Illaló, Ecuador**  
**Abstract n°1452**

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**KEYWORDS:** volcano-sedimentary aquifer, geothermalism, geochemistry, water stable isotopes, dating, Ecuadorian Andes

Volcanic and volcano-sedimentary aquifers often result from a complex geological history that induced a heterogeneous distribution of primary and reworked volcanic materials. The different stages, deposition, erosion, and tectonics affect the groundwater through its complex circulation flow. The Tumbaco – Cumbayá – Illaló aquifer near Quito, Ecuador, exemplifies this context. It is an Andean confined volcano-sedimentary aquifer which has been used to supply water to the population in the valleys near Quito for three decades. In spite of abundant surface water resources, the increase of population and the industrial development leading to high contamination levels of rivers made it necessary to find new sources of potable water supply. This system is mainly composed of a sedimentary series including an aquitard (Cangahua), overhanging two volcanic sedimentary series (Chiche, Guayllabamba) presenting high hydraulic capacities, and a volcanic aquifer cone (Illaló) virtually dividing the study zone in two. The Chiche-Guayllabamba aquifer is limited by natural barriers (river ravines or volcanoes) in all directions. A large hydrodynamical, geochemical and isotope study was carried out during four years, 2010 to 2013, complementing some old and partial data survey. It allowed to propose a conceptual model improving the understanding of the recharge process and flow circulation, seeking to aid the resource management. Results showed weak piezometric variations year round (A40 cm). Geochemical data highlighted a hydraulic continuity between the volcanic and sedimentary aquifers. Stable isotope data indicated the recharge area to be located on the volcanic slopes at local and regional scale. Tritium and radiocarbon gave apparent ages between 400 and more than 15000 years for the North Chiche formation, and between 11000 and 45000 years for Illaló volcano. In the northern part, modern water was found in a spring which could be linked to a fractured zone allowing direct recharge from the surface by direct infiltration.



**Groundwater management of large aquifers in southwestern France by regional hydrodynamic models**  
**Abstract n°1453**

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**KEYWORDS:** groundwater management, hydrodynamic models, conflicts over water

In southwestern France, groundwater resources are withdrawn for various uses (drinkable water, irrigation, industry, geothermal energy, forestry, conservation of wetlands, shellfish breeding among others) which can sometimes cause conflicts between users. To help the management of these resources, regional hydrodynamic models have been developed. These models have been a support to the public policies for over 20 years. In the northern region, groundwater is in close relation with rivers, especially during periods of low-water levels. Indeed, groundwater used for irrigation impact not only the stream flows, but also the water supply for the second large wetland of France- the Marais Poitevin. The developed models have permitted to test the impact of several scenarios of water withdrawals. These tests help to determinate the amount of water that can be pumped to respect defined objectives as water levels in piezometer and river flows. These models were also used to test the impact of the eventual implementation of water tanks (400,000 to 800,000 m<sup>3</sup>). Further south, the major problem is the important reduction of the level of the Eocene aquifer in the department of Gironde. In this area, the regional hydrodynamic model has been developed since 1990. Its development allows the management of deep groundwater resources and contributes to validate strategies of exploitation based on different simulations. This model also allows to answer problems of overexploitation and to analyse areas where water savings could be done to avoid this overexploitation, and to estimate the impact of new resources. The extreme southern region has a significant particularity- on two different sites, groundwater is used for the storage of gas. The cyclic injection and withdrawal of gas impacts significantly the aquifer level. The proposed model is adapted for the groundwater resources knowledge and management of this case. Finally, these models were used to evaluate impacts of climate change on groundwater resources in order to allow authorities to evaluate strategies to adapt to this change (Project Explore 2070 for example).



**Potential impacts of hydrocarbon exploration and production on shallow aquifers in eastern Canada**  
**Abstract n°1461**

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**KEYWORDS:** shale gas impacts, aquifer vulnerability, groundwater, eastern Canada

In eastern Canada, two provinces currently have a moratorium on hydraulic fracturing due to the concerns voiced about its potential environmental impacts, especially on shallow groundwater resources. The Geological Survey of Canada is carrying out two projects to assess potential fluid migration pathways from deep (~2 km) shale or tight sand units to shallow aquifers in southern Quebec (St-Édouard area, St. Lawrence Lowlands) and in southern New Brunswick (Sussex area, McCully gas field). The geological and hydrogeological contexts of these study areas are very different. One of the main differences is the aquifer types, which are mainly composed of organic-rich black shales in St-Édouard and dominated by sandstone in the Sussex area. Also, while no shale gas well is in production in the St. Lawrence Lowlands, the McCully gas field has been in production since 2001. Because the intermediate zone, located between aquifers and reservoirs, is poorly known, these projects are using multi-source direct and indirect data. In the St-Édouard area, dissolved methane is ubiquitous in groundwater. 45 sampled wells contain biogenic methane and 15% show a thermogenic component. Core analyses suggest that both types of gas likely come from the shallow bedrock. There is no evidence that fluids are migrating from the deep gas shale reservoir to the surface, although brines were discovered in a few shallow wells along a normal fault, indicating a hydraulic link with deeper parts of the flow system. Core sample and pore water analyses are ongoing to better understand the system hydrodynamics. The project in New Brunswick just started last fall with the drilling of 6 wells. Preliminary results show that only one well contains dissolved methane in low concentration, but its isotopic signature is thermogenic. These studies will provide independent scientific assessments of aquifer vulnerability to hydrocarbon activities that will help provincial authorities to take informed decisions.



**KINDRA Project- classification and inventory of groundwater research and knowledge  
in Europe  
Abstract n°1462**

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**KEYWORDS:** classification, inventory, groundwater research

Hydrogeology-related research activities cover a wide spectrum of research areas at EU and national levels, but they are widespread into several projects, plans, actions, fragmented into wider programs generally related to water, environment or ecology. At the same time, the management of groundwater brings additional challenges to the implementation of the Water Framework Directive (WFD) and the Groundwater Directive (GWD). An accurate assessment of the state of the art in hydrogeology research and knowledge is the main aim of the KINDRA project (Knowledge Inventory for hydrogeology research, Grant Agreement 642047, [www.kindraproject.eu](http://www.kindraproject.eu)), funded by the European Commission's HORIZON2020 Framework Programme. In the first year, a terminology and classification methodology on groundwater research and knowledge based on a keyword list has been realized. The Hydrogeological Research Classification System (HRC-SYS) has been developed by categorizing groundwater research in three main categories- 1) Societal Challenges, 2) Operational



Actions and 3) Research Topics. Each of these three main categories include 5 overarching sub-categories for an easy overview of the main research areas. The complete merged list of keywords, selected from the Water Framework and Groundwater directives and from high impact scientific journals has been organized in a tree hierarchy. The classification system maps the relation between the three main categories through a 3D approach, where along each axis the 5 overarching groups are plotted. To facilitate analysis and report of relationships, this approach also allows for a 2D representation for each of the Societal Challenges, where in Operational Actions and Research Topics intersect in a 5x5 matrix. Successively, an European Inventory of Groundwater Research (EIGR), to be populated by metadata, has been created with the following aims i) for insertion of information pertaining to groundwater research and knowledge ii) for consultation during and after the project by people and organizations dealing with groundwater research, and iii) for analysing collected and stored information to identify trends, challenges and gaps in groundwater research in Europe.



**Impact of climate change on irrigation needs and groundwater resources in the metropolitan area of Hamburg (Germany)**  
**Abstract n°1463**

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KEYWORDS: Groundwater recharge, irrigation need, climate change

Irrigated agriculture is an important economic factor in the rural parts of the metropolitan area of Hamburg (Germany, approx. 22,400 km<sup>2</sup>). It is commonly expected that climate change will reduce the groundwater quantities available for field irrigation. Against this background the ratio of irrigation need and groundwater recharge (IGR-ratio) is suggested as an indicator to assess climate change impacts on the vulnerability of groundwater resources towards overexploitation by agricultural irrigation. The IGR-ratio has been assessed based on the distributed water balance model mGROWA (Herrmann et al, 2015), i.e. under consideration of the simulated groundwater recharge levels and the field crop specific irrigation need of the commonly cultivated field crops. The resulting IGR-ratio maps may serve as decision support in governmental institutions when allocating water rights for agricultural production. The spatial IGR-ratio distribution determined for the observed reference period 1971-2000 has shown that the delineated vulnerable areas coincide with the regions for which high irrigation quantities have been documented at present. The possible impact of future climate on IGR-ratios was determined by using a model chain of mGROWA and the regional climate models REMO and WETTREG2010. Depending on the magnitude of future precipitation and reference evapotranspiration increase during winter, groundwater recharge may possibly increase. In contrast, decreasing precipitation and increasing reference evapotranspiration during summer will cause rising irrigation need of field crops. As a consequence, the mGROWA-WETTREG2010 ensemble indicates a severe increase of IGR-ratios until 2100, whereas the mGROWA-REMO realisations suggest only a moderate increase. Reference- Herrmann F, Keller L, Kunkel R, Vereecken H, Wendland F. Determination of spatially differentiated water balance components including groundwater recharge on the Federal State level – A case study using the mGROWA model in North Rhine-Westphalia (Germany). *Journal of Hydrology- Regional Studies* 2015+ 4- 294-312.



## **Geostatistics and numerical modelling in the characterization of contaminated sites**

### **Abstract n°1464**

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**KEYWORDS:** geostatistics, numerical modelling, uncertainty analysis, contaminated sites

Groundwater characterisation in a contaminated site requires wells and piezometers to collect and analyse samples. By means of this information, the lateral and vertical extensions of the contaminant plume are depicted, constituting the starting point of any risk assessment or remediation procedures. This task requires all available knowledge on the site, in the effort to clarify the conceptual site model. Sometimes the pieces of the puzzle do not fit together, are contradictory or simply missing, especially when heterogeneous and or fractured aquifers are involved. Complexity of the data analysis is increased by the fact that contaminant plumes in groundwater are usually highly heterogeneous, anisotropic and non-stationary. Different geostatistical approaches have been proposed to define the optimal method for plume estimation. Nevertheless, even in the condition of the best plume estimate, the geostatistical analysis represent a "snapshot" of the plume not embedding any information about fate and transport of contaminant. This issue implies to extend the analysis through the inverse modelling approach- measured heads and concentrations in space and time are used as targets to estimate physical parameters, such as hydraulic conductivity, porosity and dispersivity. Most of the time the modelling phase come separately from any geostatistical approach, though any of the modelled parameters comes evidently with its spatial distribution. Incorporating different approaches (e.g. fate-and-transport models and geostatistical analyses) can greatly improve the ability to describe the shape, extent and temporal change of groundwater contaminant plumes. In addition, inverse modelling can handle multiple calibrated versions that satisfy geostatistical, historical data, and expert knowledge constraints. The whole process is necessarily completed by the quantification of geostatistical and model uncertainty to reasonably inform the decision makers. Explicative case studies are presented.



## **A meta-analytic model for groundwater pollution by nitrates for North Africa Abstract n°1465**

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**KEYWORDS:** Nitrate pollution of groundwater, meta-analytic model, North Africa.

Groundwater is an important freshwater resource that sustains agricultural and economic activities in North Africa. Yet, it is subjected to many pressures and degradation. The contamination of groundwater with nitrates has been reported in many cases, but there is no holistic view yet of this problem at the regional scale. Also there is little quantitative information about the factors that explain this pollution. We therefore developed in this work a model that explains the different factors affecting the distribution of nitrates in the North African groundwater bodies. We made a meta-analysis of studies of nitrate pollution of groundwater in North Africa, and enhanced the literature data by readily available generic environmental data. Subsequently we used a statistical stepwise multiple regression technique to link the dependent variable, i.e. the logtransformed average nitrate concentration (mg l) to possible explanatory variables. The variables that were selected for the development of explanatory model are the distance from the sea, the distance from the urban area, the type of irrigation, the population density, slope, lithology, depth of groundwater, soil texture, recharge, precipitation and soil type. Finally, we identified four variables (the type of irrigation, water table depth, slope and soil type) that explain the variability of the average nitrate concentration in the groundwater. The model was able to explain 57% of observed variation



**Depleting groundwater resources in the semi-arid region of the Kerdous Inlier,  
Morocco  
Abstract n°1466**

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**KEYWORDS:** Semi-arid, Climate change, Groundwater development, Morocco

Groundwater resources in drylands show significant reductions over the last decades. Nevertheless, groundwater in terms of quantity and quality is vital for the local population supplying drinking water and sustaining agriculture. To cope with the reduction groundwater management options have to be developed on the basis of a sound understanding of the hydrogeological system. The presented study aims in the identification of recharge areas, flow path conditions, and origin of springs in two areas, the Ameln valley and the Ait Mansour valley in the Precambrian Kerdous Inlier of the Western Anti-Atlas Mountains. Hydrogeological mapping together with a sampling campaign of all major springs and wells in both study sites including hydrochemical and isotopic analyzes of water as well as mineralogical and hydraulic characterization of rocks were performed. While Proterozoic quartzite and schist shape the geology of the Ameln valley, granites and micaschists build the bedrock geology of the upper Tasrirt Plateau and Infracambrian limestones, silt- and sandstones dominate in the lower Ait Mansour valley. Spring discharge within the Ameln valley is caused by the difference in hydraulic conductivity between highly fractured quartzite and less permeable schists. In the lower Ait Mansour valley springs occur due to the alternation of karstic limestone aquifers and inter-bedded impermeable silt- and sandstones. Spring discharge in both valleys was reduced by more than a half compared to former studies. The combination of hydrochemical composition, isotopic signatures, and hydraulic conductivities in the Ameln as well as in the lower Ait Mansour proved direct infiltration along with relatively rapid movement through the underground passage until spring discharge. Thus, groundwater quality is highly vulnerable to contaminants. This vulnerability together with the ongoing depletion of the reservoirs emphasizes the need for management options in respect to overexploitation, wastewater treatment and agricultural practices.



**ECONOMIC ASSESSMENT OF EL CARRACILLO MAR SYSTEM. LOS ARENALES  
AQUIFER, CASTILLA Y LEÓN, SPAIN  
Abstract n°1467**

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**KEYWORDS:** Managed Aquifer Recharge (MAR), benchmarking, economic assessment

Within the framework of MARSOL project [Managed Aquifer Recharge (MAR) as a solution to water scarcity and drought], experiences in 8 demo-sites have been developed and tracked. In this context, a single site has been selected to apply a new methodology to monitor the economic aspects and their evolution- Carracillo District, Castilla y León, Spain. This site has an important agro-industry related to MAR activity based on groundwater exploitation and the evolution has been tracked by means of specific indicators related to benchmarking. In Spain about 80% of water is used for irrigation though this sector represents around 3% of the Spanish Gross Domestic Product (GDP). These figures represent a serious constraint for agroindustry agents, and some of them, as the selected case, apply MAR since 2003 to make their activity sustainable, to the extent that MAR has become an assumed action for local farmers and authorities, who adopted, regulated and applied it. A broad scope of indicators using a benchmarking approach, a useful tool but scarcely used in previous water management studies, have been established, measured, tracked and charted to evaluate the difference between areas with and without MAR activities integrated in their water management habits. The attention paid to economic indicators has permitted to assess the economic trend along time demonstrating that MAR activity is contributing to achieve some assets such as- the permanence (even raise) of rural employment, rural flight decrease, greater crop productions, energy savings due to the raise of the water table, guaranteed water supply during short drought periods, etc. In short, this area with MAR technique already inserted in their idiosyncrasy is having, according to performance indicators results, a positive rural development in comparison to other close areas with bare groundwater exploitation and rain fed crops.



**DIVERSIFICATION OF WATER SOURCE TO ENHANCE MAR. THE SAT-MAR CASE OF  
ALCAZARÉN+ VALLADOLID, SPAIN  
Abstract n°1468**

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**KEYWORDS:** Managed Aquifer Recharge, SAT-MAR, Alcazarén

Los Arenales is an extended aquifer located in Castilla y León, Spain, where Managed Aquifer Recharge (MAR) activities started in 2002. The zone has an important agro-industry associated to this irrigated area. In 2002 and 2003 MAR started at Santiuste basin and Carracillo District, consisting in pioneer passive and intermittent systems which take most of the water from rivers and, consequently, are dependent on weather conditions. In 2012 a new area, Alcazarén-Pedrajas, adopted MAR as a solution to ensure irrigation supply, with some novelties with respect to previous experiences- the diversification of the source of water, depending not only from Pirón River, but also from the rainwater harvesting from roof tops collected in a MAR canal and reclaimed water from a Waste Water Treatment Plant. All of these sources guarantee that the system is not intermittent any longer, ensuring a certain continuity of MAR further the winter season when river surplus is available for recharging. Anyway, this site presents some problems and impacts to be solved regarding water quantity and quality, e.g. the risk in case of over-floods, the purification process issues, the restricted efficiency rate... The tests performed regarding modifications in the initial design, such as spillways drawing, use of different filters (gravel, grit, biofilters), DBPs... to improve the recharge water quality, reduce TOD, organic carbon concentration... have driven to a permanent enhancement process where technicians are learning from the experiences to apply new solutions. Other not technical problems have been faced too, especially regarding regulations and conflicts of interest. In short, the article exposes the diversification of the water source as a key for MAR and describes some of the technical, legal and management problems found, and how they are being solved by means of permanent research and deployments in a constant feedback process.



## Characterization and Origin of karstic thermal waters of the Northeast of Algeria. Abstract n°1472

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KEYWORDS: karst, hydrochemistry, thermal waters.

The northeastern part of Algeria has numerous thermal karstic springs which present an economical interest for the national office of the Algerian tourism. This organization considers the setting-up of infrastructures dedicated to the thermal tourism. The springs are located in a region of a 535 000 km<sup>2</sup> which extends from Bejaïa to El-Kala (Tunisian border). The geological context is marked by a geological structure inherited of the alpine tectonic episodes Priabonian to Tortonian at the origin of large faults and thrust systems. An analysis of the hydrochemical characteristics of these waters, has been realised, at the regional scale, mainly to determine the geotectonic factors being the cause of the chemical facies and rising, but also to identify one or several deep geothermal reservoirs. Two sampling campaigns were realized on 52 sites, one during low waters (September, 2014) and the other during high waters (May, 2015). The analysis concerned major and trace elements, and isotopes (<sup>18</sup>O, <sup>2</sup>H, <sup>3</sup>H, <sup>87</sup>Sr, <sup>86</sup>Sr). From binary diagrams and from ACP treatments, results allowed to discriminate 4 geochemical groups of waters. (1) a HCO<sub>3</sub>-Ca type, slightly mineralized and characterizing hypothermal waters with fast circulations, (2) a HCO<sub>3</sub>-Na type, more mineralized and characterizing mesothermal waters with deeper circulations, marked by phenomena of base exchange between water and clay levels, (3) a Cl-Na type, characterizing hyperthermal waters with deep circulations attested by chemical exchanges with sedimentary evaporite levels, finally (4) a SO<sub>4</sub>-Ca type having acquired its mineralization in triassic formations. Furthermore, a high percentage (75%) of hyper or mesothermal springs, with chloride or sulphate facies, are located along the large regional faults identified by geophysical investigation. These results will be clarified by the use of silicium and alkaline geothermometers and temperature estimation using saturation index.



**Understanding groundwater surface water dynamics within the catchment of Bell Harbour Bay, Ireland, using InfoworksI<sup>2</sup>CM  
Abstract n°1473**

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**KEYWORDS:** Ireland, karst, groundwater flooding, groundwater model, climate change

Within the recent hydrological years of 2010 and 2016 the south Galway and Bell Harbour regions of western Ireland have experienced excessive groundwater (GW) flooding beyond the seasonal long-term averages. In Ireland GW flooding occurs mainly within low lying (<100 masl) karstified Carboniferous limestone with a shallow drainage system- such aquifers underlie almost 40% of the country. Intense, protracted rainfall events quickly saturate the shallow karst aquifers resulting in extensive flooding which can inundate surrounding buildings, agricultural land and infrastructure. Climate change scenarios for Ireland predict that extreme weather events will intensify, and so, GW flooding is likely to become more significant too. In order to mitigate these extreme events, a better understanding of the dynamic of lowland karst aquifers and their responses is needed. Based on existing conduit-dominated karst models this research aims to better characterise the role of diffuse GW recharge and slow-flow components in order to incorporate both in more reliable hydrological models. Hence, the model shall serve as a Decision Support System to understand the complex interaction of SW and GW addressing flood mitigation and contaminant transport in Irish karst aquifers. The study area, Bell Harbour, is a 47 km<sup>2</sup> GW flow dominated catchment which discharges at a series of intertidal and submarine springs along the Atlantic coast. Mean freshwater discharge from the springs is estimated via water balance using continuous meteorological records. The discharge estimate is then validated by monitoring salinity fluctuations in the enclosed bay. Furthermore, a semi-distributed hydrological model has been developed using InfoWorksI<sup>2</sup>CM based on the results of geophysical studies in the catchment. Using this model, it is possible to couple turbulent fast-flow components within major conduits together with the slow flow component in the matrix and fissures, as well as with seasonal GW flooding on the surface concentrating in topographic depressions, groundwater dependent terrestrial ecosystems known locally as turloughs.



**Investigation and Evaluation of groundwater pollution in North China Plain and  
Research on Key Technology  
Abstract n°1474**

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KEYWORDS: North China Plain+ groundwater+ contamination+ assessment

The North China Plain is one of the important economic zones of China, with a population of 0.13 billion, and its main water source is groundwater. The groundwater has been polluted due to the sewage from industry and municipal life as well as the chemical fertilizer and pesticide from agriculture. Based on the research results and experiences at home and abroad, the sampling equipment of groundwater organic contamination suitable for China has been developed for the first time, along with the remote monitoring system for groundwater detection and groundwater contamination investigation and evaluation information systems. It constructs the technology system of groundwater pollution surveying, sampling, testing & data management and establishes the concept of groundwater quality, pollution detection, furnishing strong support for the investigation of groundwater contamination. It proposes new methods of groundwater quality and pollution evaluation, perfects the method of quantitative evaluation of groundwater contamination risks and zoning, and establishes its evaluation methodology. It provides technical support for the evaluation of groundwater contamination in China. Based on the extensive field survey data and sample test data, it systematically evaluates the groundwater quality and pollution situation in North China Plain. The authors analyzed several methods of groundwater contamination assessment and put forth a new method called Single Factor Standard Index Method which is obtained on the basis of Single Factor Index Method. Field investigation was conducted comprehensively. 6063 groups of groundwater samples were collected and 34 factors of each group were tested. According to the Single Factor Standard Index Method, 35.47% samples have been contaminated by human activities, being mainly slight contamination. Deep groundwater is better than shallow groundwater and uncontaminated deep groundwater accounts for 87.14%. Using the single Factor Standard Index Method, the indexes can be compared and the contamination degree can be showed directly. The results of using Single Factor Standard Index Method provide a basis for groundwater contamination prevention.



**Application of time-lapse electrical resistivity tomography and groundwater simulation models to monitor the transport of organic contaminants under unsaturated and saturated conditions**  
**Abstract n°1479**

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**KEYWORDS:** olive oil mills waste, time-lapse electrical resistivity, transport model

Production of olive oil is one of the most important activities in the Mediterranean area, particularly in Greece, which holds the third place worldwide after Spain and Italy. For every tone of produced olive oil, about 25% of liquid wastes (olive oil mill wastes- OOMWs) enriched with organic load and inorganic constituents are produced. The OOMWs are usually disposed in uncontrolled, unprotected and poorly constructed shallow evaporation ponds, causing several ecological problems such as odour, increased salinity, toxicity to soil and contamination to surface water bodies and groundwater. A pilot study area (an evaporation pond of OOMWs) has been constructed in Western Crete, at Alikianos village, very close (about 15 meters) from Keritis river. During the last decades, geophysical methods have gained popularity as efficient tools for monitoring the changes of subsurface physical properties over time and identifying the spatial distribution of pollutants. The OOMWs are mainly characterized by high electrical conductivity values and high concentration of phenolic compounds. Those characteristics of OOMWs can be used for detecting them and in particular using geoelectrical methods. In the present study, time-lapse electrical resistivity tomography (ERT) and self-potential techniques are used to map and monitor the subsurface contamination caused by OOMW. A three-dimensional finite-element model for groundwater flow and transport is developed to estimate the temporal and spatial distribution of the selected contaminant under unsaturated and saturated conditions. The resulted simulation models are verified by the obtained time-lapse two-dimensional ERT geophysical inversion images. Results of geochemical analysis of soil and liquid samples collected from two soil profiles excavated along the ERT profile have been used for calibration and validation of both simulation and geophysical results.



**Effects of aquatic phototrophs on geologic carbon sink in different geological background**  
**Abstract n°1481**

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KEYWORDS: hydrochemistry, rock weathering, aquatic phototrophs

Previous studies focused mainly on the combined action of carbonate dissolution, the global water cycle and photosynthetic uptake of DIC by aquatic organisms show that the carbonate weathering is also a kind of stable carbon sink. Because of the difference between the chemical weathering of silicate and carbonate, the observation and sampling were carried out in May 2013 to April 2014 in a hydrological year for two river basins with different geological background in upstream of Li river basin. Chemical composition of river water per month and carbon isotopes and C N of particular organic matter per quarter were analyzed. The results show that, the hydrochemistry types of both Darongjiang basin which has 9% of carbonates and Lingqu basin with nearly 50% carbonates in area are belonged to Ca-HCO<sub>3</sub> type. The main ion concentrations are higher in winter and lower in summer, affecting by the change of the flow. Ca<sup>2+</sup>, Mg<sup>2+</sup>, HCO<sub>3</sub><sup>-</sup> are mainly sourced from the weathering of carbonates by the carbonic acid. In addition, comparing to the Lingqu basin, the contribution of the weathering of carbonates is much more than the percent of carbonates area, because of the enhanced erosion of carbonate rocks by the allogenic water. What's more, geochemical characteristics of riverine organic carbon show that more than a half of riverine organic carbon is sourced from aquatic phototrophs. And the carbon sinks flux of silicate weathering, carbonate weathering and photosynthetic uptake of DIC by aquatic organisms are 6.25, 23.83 and 10.05 tCO<sub>2</sub>.a<sup>-1</sup>.km<sup>-2</sup> in Darongjiang basin, and 2.06, 29.26 and 7.49 tCO<sub>2</sub>.a<sup>-1</sup>.km<sup>-2</sup> in Lingqu basin, respectively. So that effects of aquatic phototrophs take an important role to the stability of geologic carbon sink in different geological background.



**35 years of data collection and regional modelling of the confined aquifer systems in N-Belgium**  
**Abstract n°1483**

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**KEYWORDS:** groundwater overexploitation, deep geological disposal, groundwater management

In the early 1980's, hydrological research at the Belgian Nuclear Research Centre was initiated. Although the research was initially conducted in the framework of the Belgian nuclear waste disposal programme, currently managed by ONDRAF NIRAS, the most recent groundwater model update (2016) frames within the responsibilities of the Flemish Environment Agency with respect to groundwater management. In the 35-year research period, most efforts have been put to characterizing the groundwater flow using piezometric measurements, collecting measurements of hydraulic properties, defining the hydrostratigraphy and integrating all information by means of groundwater flow modelling. By formulating a conceptual model, the latter method combines the measured data with general hydrogeological knowledge and hypotheses on the aquifer system. Therefore it can be used to discover knowledge gaps and gives way to new data acquisition followed by another modelling step. This iterative research cycle allowed increasing our level of knowledge while decreasing the level of uncertainty on the prediction of necessary indicators related to the aquifer systems. In this work, the evolution of the hydrogeological knowledge - both data and modelling efforts - in the confined aquifers in N-Belgium is presented, which are being heavily influenced by groundwater (over)exploitation. A thorough understanding of the phenomenology and the past evolution of this hydrogeological system in N-Belgium will facilitate simulating realistic future behaviour under different scenarios. In the case of deep geological disposal, this includes assessing the consequences that climate changes may have on the hydrogeological system (e.g. warming in combination with marine transgression, cold climate with permafrost). In the case of the groundwater policy, this includes assessing the consequences of historical long-term groundwater extraction on the confined aquifer systems and assessing the impact of alternative future exploitation scenarios on the quantitative status of these groundwater bodies.



**Mapping groundwater availability and renewability in rural areas in Cambodia- a multi-disciplinary approach including geophysics, hydrogeology and geochemistry  
Abstract n°1484**

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**KEYWORDS:** groundwater mapping, Cambodia, geophysics, water balance, water budget, recharge

The French Red-Cross in partnership with the Institut de Recherche pour le Développement have been running projects since nearly ten years in order to improve water access in Cambodian rural communities. Indeed, there is more pressure on water resources since the population had more than tripled during the last decade. 12 % of households were still drinking surface water collected from ponds and a large number of households have to walk several kilometers in order to get safe water. Geophysics surveys had first been carried out with Magnetic Resonance Sounding (MRS) and Time-Domain Electro-Magnetics (TDEM) to develop a strategy for siting boreholes, and the success rate increased from 60 to 95 %. Then, a four years study of water resources was implemented through the monitoring of all the components of the water balance. Geophysical surveys were still carried out in parallel in order to support the mapping of aquifers. The water budget method allowed the estimation of annual volumes of rainfall, actual evapotranspiration, surface runoff and groundwater recharge. Rainwater is mostly split into an evapotranspiration component (annual mean of 54 % of the rainfall) and a surface runoff component (mean of 49 % of the rainfall) as groundwater recharge is very low (mean of 1 % of the rainfall, i.e. from 10 to 700mm per year). Isotopes analysis suggested that recharge is direct and rapid, and simulations of pumping indicated that the aquifer can easily supply 100 L of drinking water per capita daily, even considering the estimated population in 2030. Empirical relationships have been drawn between the specific yield from 5 pumping tests, 60 MRS soundings and more than 500 TDEM surveys. The results allow the creation of a 3D model of resistivities which is used to produce a storage map. This map highlights higher storage aquifers especially in the North and the East of Oddar Meanchey province where sandstones lie.



**Structural characterization of sinkholes and epikarst by using time-lapse and 3D geophysics**  
**Abstract n°1485**

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**KEYWORDS:** time lapse, karst, geophysics, doline, sinkhole, epikarst, 3D,

Because of its heterogeneous structure, karst formations are one of the most challenging environments in terms of groundwater, engineering and environmental issues. Geophysical methods can provide useful subsurface information in such regions concerning groundwater vulnerability assessment, exploitation or hazard estimation. We present the results of 2D, 3D and time-lapse geophysical studies carried out on dolines and epikarst in South of France. It is believed that dolines are preferential infiltration pathways towards the phreatic zone. We study some of them for the protection of a karstic aquifer. We show that geophysics provides the lateral and bottom limits of the sinkholes and is able to detect a doline hidden by the soil cover. Information about dolines filling can also be derived from the electrical resistivity and seismic refraction. Time-lapse resistivity measurements show that the studied doline is more vulnerable to infiltration on its sides than at its centre. Epikarst could be defined as a highly fractured zone above the massive carbonate rocks, which could contain a perched aquifer. 3D seismic refraction was carried out on such epikarst located in dolostones. The results show an important velocity anisotropy linked to the fracturing direction and weathering of the dolostone. The 3D model presents also large heterogeneities- a corridor with highly weathered dolostone and an unweathered pinnacle. The corridor is probably situated on vertical joints, which have drained more aggressive water. The associated weathering with residual weathered-rock keeping its initial volume could create a ghost-rock corridor. Therefore, this epikarst seems to be composed by ghost-rock developed around a specific direction of fractures. Time-lapse electrical resistivity and seismic refraction velocity were also carried out on this epikarst in order to observe the influence of water saturation on the measurements. The results show important variations for both seismic and electrical methods, particularly in the weathered zone, in the first 6 m. Therefore, time-lapse measurements seem more efficient identifying the storage of the epikarst and its bottom than one-time measurements.



## Characterizing stream aquifer exchanges thanks to geophysics Abstract n°1486

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**KEYWORDS:** stream aquifer exchanges, geophysics, hydrogeophysics, seepage, infiltration

Characterizing stream aquifer exchanges is an important goal in hydrogeology as more and more models link these two units in one combined model. Indeed, assessing exchanged volumes is important in water balance and hydrogeological modeling, especially regarding water quality issues. The site studied here is producing clear water for Bordeaux metropole from wells in the porous-fractured and karstic unit of the Oligocene limestone. Hydrodynamics and geochemistry surveys highlights connections between those wells and a stream running close by. Due to the high vulnerability of the stream, the wells were impacted by a pollution and that's the reason why characterizing those connections with geophysics is important. Hydrodynamics suggests such connections, but a quantitative interpretation is rapidly limited by the difficulty of isolating the effect of the stream on groundwater levels from the effect of the recharge on both aquifer and stream levels. Geochemistry had clearly proven the existence of pathways from the stream to the wells, thanks to tracing tests and major ions analysis. Nevertheless, these surveys cannot help to locate such pathways in order to protect the wells from a polluted stream. Electrical resistivity tomography and electrical Self-Potential profiles have been carried out in and out the stream bed. Since these methods are sensitive to water content and flow, this study shows that they could give evidences of stream aquifer connections and help to determine if the stream is gaining or loosing. These methods could also help to reduces aquifer vulnerability by locating infiltration pathways in the riverbed.



**Groundwater residence times of the Salar de Coposa basin, North Chile - Preliminary results**  
**Abstract n°1487**

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KEYWORDS: Andean hydrology, Radiocarbon, Mining, Chile

Groundwater resources of the Salar de Coposa basin, which is situated in the Andean Altiplano of northern Chile, are being exploited since 1997 for mining purposes. In 2011 a detailed sampling campaign on groundwater isotope hydrology has been carried out by the local mining company, with the final aim to enhance groundwater management measures.  $\delta^{18}\text{O}$ -contents vary from -5‰ to -14‰,  $\delta\text{D}$  range between -63‰ to -111‰ (VSMOW). Data for pmC plot between 0.6 to 49 and Tritium between 0TU to 1.4TU, while in groundwater Tritium could not be detected. Hence uncorrected mean residence times of groundwater ranges between 5800 to 43000 years. Different applied correction models for mean groundwater residence times are being considered but still need to be discussed in conjunction with related hydrochemical models and the overall geological setting. Preliminary results of the analysis and interpretation of the full data set, containing altogether 37 samples, allow first conclusions about the dynamics and functioning of the hydrogeological system with broader implications for similar Altiplano basins exposed to semi-arid climate conditions.



# **Sulphur isotopes- a tool to understand the variations of chemical composition of deep waters**

## **Abstract n°1490**

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KEYWORDS: sulphur isotopes, water chemistry, flow paths

Chemical composition of waters from deep aquifers reflects the interactions between waters and reservoir rocks. The determination of an accurate chemical composition of waters is thus necessary to identify the origin of this mineralisation. The water chemistry of the Infra-Molassic Eocene aquifer (Aquitaine Basin - France) has been investigated through different studies highlighting various origins for water mineralization. Isotopic analyses helped, in agreement with hydrogeology, to identify geochemical basins whose properties modify the chemical water composition (André et al., 2002+ Douez, 2007). However, if the chemical composition of waters from this deep aquifer (about 500 to 1000 m depth) does usually not change with time, seasonal variations of sulphate concentrations occur in a specific area. About 200 analyses of sulphate collected during more than 10 years show variations between 10 and 110 mg SO<sub>4</sub> L. These variations of sulphate concentrations are correlated with the water conductivity but they are anti-correlated with piezometric variations (reaching about 80 m per year) which are due to the seasonal storage of natural gas in the aquifer and are recorded about 30 km around the storage area. Several hypotheses are considered in order to explain these sulphate variations- mixing of waters from different aquifers, vertical transfers by advection or dispersion from the molasse aquitard, local biological processes... This study uses both isotopic tracers (<sup>18</sup>O and <sup>34</sup>S of sulphates, <sup>13</sup>C and <sup>14</sup>C) and composition of trace elements (F, B, Ba, Sr...) in order to determine the origin of these variations. It will be based on existing chemical data but also on the acquisition of new ones. This chemical approach will be secondly coupled with a hydrological modelling of the specific area in order to understand the local behaviour of the aquifer (residence time, recharge processes, interaction with adjacent reservoirs aquitards).



## Digital filters for application to tidal groundwater time series Abstract n°1492

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**KEYWORDS:** nonrecursive filter, tidal filter, low-pass filter

Observation time-series data including significant tidal signals are commonly encountered in studies of groundwater in small islands or coastal areas. Groundwater data collected in such areas often include effects of other non-periodic agents, for example, the effect of a few day-long drops in atmospheric pressure when an intense low pressure system passes. When groundwater time-series data are subject to quantitative analysis of tidal or non-tidal component, separation of these components is an important preliminary step. In the field of oceanography, digital low-pass filters have long been used to smooth tidal time-series data. The filters suppress semidiurnal and diurnal tidal components in the observation data and disclose longer-period signals. However, uses of digital filters in groundwater hydrology are limited. A comparative study was made on digital filters presented in the literature, focusing on nonrecursive types that can be immediately used with a prevalent spreadsheet application with its built-in functions. In addition, new excellent tide-killer low-pass filters were produced as per a design method proposed in an oceanographic literature and compared. Following low-pass filters were evaluated- (1) running-mean filters, (2) selected-mean filters, (3) cosine-type filters using windows, and (4) optimized tide-killer filters newly produced. The desired low-pass filter in this study was what suppresses components of semidiurnal to diurnal tidal band, especially known eight major tidal components, with longer-period components (longer than two days) being completely preserved. The last two types of the studied filters above include desirable digital filters. The low-pass filters studied can easily be transformed into high-pass filters through an arithmetic procedure. High-pass filters transformed from the newly produced tide-killer low-pass filters are excellent in terms of preserving eight major tidal components. The new high-pass filters are optimal for use prior to quantitative analysis of specific major tidal components.



**A technique of pumping simultaneously from two depths to prevent saltwater  
upconing  
Abstract n°1493**

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**KEYWORDS:** saltwater upconing, scavenger well, single location doublet well

**Objectives-** Groundwater exists as a freshwater lens which is the mass of fresh groundwater floating on an underlying mass of denser seawater in many islands and atolls. The pumping of groundwater often causes saltwater upconing on such an island. The objective of this study is to develop the pumping technique that would produce freshwater overlying saltwater without upconing of the saltwater and pollution of the freshwater zone. **Design and methodology-** We made a device that installed a partition made of air packer in a borehole. The device also had two pumps. One pump was set above the air packer, and another pump was set under the air packer. By use of air packers, groundwater was pumped from one horizon and another horizon respectively. The device was set in the borehole of 100mm diameter with in the field of our laboratory, and groundwater was pumped. The length of packer was 1m, and packer was set at 2m below the groundwater table. The groundwater pumping ratio of two pumps was 1-2 liter minute respectively. EC, pH, DO, and ORP of groundwater that was pumped by the device were measured during the pumping. EC of groundwater drawn above packer did not fluctuate so much. The difference between EC of groundwater drawn above packer and EC of groundwater drawn from beneath a packer was kept. This result shows that the groundwater of two depth can be separately pumped with this device. **Conclusion-** Scavenger well system can be constructed with air packer and two pumps in a well. This system has the advantage that packer's position can be freely set, and it is possible to follow to the change in the saltwater-freshwater boundary.



# **Dewatering Impact Assessment of Longwall Coal Mining on Groundwater Resources in Central Turkey**

## **Abstract n°1494**

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**KEYWORDS:** underground panels, dewatering, FEFLOW

A thermal power plant is being planned to be constructed at a coal basin, located in Central Anatolia. The pre-feasibility studies indicate that about 100 million tons of coal can be extracted from the site, via open cut and underground longwall mining during the mine life of 26 years. Since dry working conditions are prerequisite for a safe and operational mining, prediction of the groundwater inflow rate to the open pit and underground panels play a critical role. This study intends to determine dewatering requirements of the underground panels and evaluate anticipated impacts of dewatering on the groundwater resources. To analyze these aspects, a 3D numerical groundwater flow model of the site was constructed by using FEFLOW software. The dewatering requirements were evaluated at the three critical panel locations. In the simulations, simultaneous operation of open pit and underground panels were considered. The preliminary results indicate that groundwater inflow rate to the panels range from 167 L s to 311 L s, based on the location of the panels. The long term impacts of dewatering on groundwater resources were assessed in terms of spring discharge and base flow rates in the Kirmir Stream. As a result of dewatering, majority of village water supply springs and fountains will dry up in the area. Also, the base flow rates to the Kirmir stream will be decreased by 20 – 35 % based on the panel locations.



# **Investigation of groundwater quality during managed aquifer recharge in the South of European Russia**

## **Abstract n°1495**

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KEYWORDS: groundwater quality, managed aquifer recharge

The report is devoted to the problem of groundwater quality during managed aquifer recharge (MAR) on certain water intakes in the South of European Russia. MAR is used worldwide as an important method of recharge enhancing and improving of groundwater quality. However, in Russia this method is not widely applied, though in former Soviet Union about 30% of groundwater intakes were equipped with artificial recharge systems. As is well-known, groundwater quality can be improved during MAR. We investigated the mixing of surface and groundwater in two groundwater deposits most favorable for MAR on the examined territory – Troitskoe and Bayartinskoye groundwater deposits in Kalmykiya and Troitskoe groundwater deposit in Krasnodarskiy Kray. Special equation for single and group water intakes in an isolated reservoir at a distance from the river was used for the calculation. In Russia this equation is given in regulatory documents for construction of groundwater intakes. The most appropriate proportion for Troitskoe groundwater deposit in Kalmykiya is 69% of treated surface water and 31% of groundwater. For Bayartinskoye groundwater deposit this proportion is 42% of treated surface water and 58% of groundwater. In this case sedimentation and using of coagulants and flocculants should be performed to the water after MAR. Thus, it will meet all sanitary requirements. The most appropriate proportion for Troitskoe groundwater deposit in Krasnodarskiy Kray is 45% of untreated surface water and 55% of groundwater. After the mixing, aeration and sedimentation should be performed to the received water. As the result of MAR in these cases the necessary demand for drinking water will be met without intensifying of groundwater extraction. Also the necessary reduction of groundwater pumping to recover groundwater levels will be performed. Quality issues during MAR are very important for groundwater management on the examined territory especially for developing of multipurpose water plans.



## Sharing water abstraction data in France - challenges and perspectives Abstract n°1497

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**KEYWORDS:** water abstraction, data collection, data sharing, database, interoperability

Information that must be collected for the implementation of the Water Framework Directive has the potential to be used for a number of different purposes. For example, data on water abstraction is essential for effective groundwater management and protection. In France, a national information system on water abstractions (called BNPE) has been set up to comply with the European and national laws and is now publicly accessible. The aims are to centralize data on water abstractions and to share them by the website [http- www.bnpe.eaufrance.fr](http://www.bnpe.eaufrance.fr), where data can both be consulted and exported. The BNPE project is managed by the national agency of water and aquatic environments (Onema). The database and the related tools are developed by the French geological survey (BRGM). The BNPE stores information about annual volumes of water abstraction, their localization, the purpose of the abstraction and the specific waterbody impacted (groundwater and surfacewater). BNPE data are expected to be the French reference for water abstraction information. The challenges are to collect data from different public institutions (mostly the basin water agencies and water police services) and to share them in a form that can be used for expertise, water management studies or scientific research. A dictionary, common repositories and a data exchange format were set up to allow the sharing. The main issue that still needs to be addressed is improvement of data quality. First, data on the waterbodies impacted should be compatible with the national groundwater and surfacewater repositories. Second, declared data by withdrawers should be confronted with actual abstraction data. Future prospects include addition of local data sources and the diffusion of pedagogic documentation to help water and groundwater managers use these data.



**Multi-time scale of soil water, salt and temperature distribution, and the physiological response of cotton serviced by mulched drip irrigation with brackish groundwater  
Abstract n°1498**

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**KEYWORDS:** Brackish groundwater, Salinization, Arid region

Shallow brackish groundwater which can be used for agricultural irrigation is distributed widely throughout north and northwest China, where is generally a shortage of freshwater. However, there is a serious risk of salinization for the field under mulched drip irrigation with brackish water, because of the strong evaporation and lack of leaching. This research aims to study the special soil water and salt distribution, which controls the soil environments under mulched drip irrigation. A set of experiments of mulched drip irrigation in a cotton field serviced by brackish water were carried out in Xinjiang, northwest China. The irrigation events, groundwater level and quality, soil water quality, moisture, evapotranspiration and photosynthesis were monitored. Based on these, soil water, salt and temperature dynamic and their relationships with physiology of cotton were analysed. The diurnal dynamic of soil water and salinity at the depths of 15, 25 and 40 cm in the first day of after a drip irrigation was flatten out with the increasing depth. Transpiration and photosynthesis were mainly occurred in day time, and the photosynthesis was more sensitive to the changes of environment than the transpiration. For a typical irrigation period of blooming stage, the soil water dynamic of narrow row zoon was stronger than the inter-mulch zone due to the root water uptake and evaporation. Besides the diurnal cyclical fluctuations, the amplitude of soil temperature series increased gradually over time in the period. The transpiration and photosynthesis rate have the characteristics of lower rate before and higher rate after irrigation. Soil salts at depths of 0~60cm accumulated during the growth season and reached the maximum at the later flowering stage due to the large amount of irrigation water. The results of the research could be suggested as theoretical and technological supports for sustainable using of brackish groundwater.



## Comparison of tools and protocols for groundwater sampling Abstract n°1499

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KEYWORDS: groundwater, sampling, pollution, water quality, tools and protocols

Prevention or management of pollution of groundwater is based on sampling. Sampling leads to determine the water quality and in case of deterioration, to understand its origin and evolution to better cope. Data must be reliable, the representativeness of a groundwater sample is essential. But obtain a sample which is “representative” of the water quality in the surrounding geological formation is partly related to the tools and protocols used. Remarkable progress have been done in site characterization, monitoring and field instrumentation over the past 25 years but some issues remain and profession lack of demonstration to clarify certain choices on tools (passive or active sampling techniques) and protocols (purging, sampling flow, filtration) best suited to the situation encountered and to the sampling purpose. A comparison of existing technology, whether or not conventionally employed by operators is currently underway by INERIS with academic and private partners - period 2014 to 2016. This work aims to produce a feedback and a cost benefit analysis on the various tools and protocols based on the results obtained at different scales- experimental tank (Figure 1) and real sites. This comparison process conducted on three sites (four campaigns by site) and on an experimental tank, will lead to the acquisition of a large amount of data. Interpretation of the results will allow to define some trends and to answer some questions mentioned above. At this stage, the acquired data concerning a surface sampling on two sites and tank show that for BTEX (benzene, toluene, ethylbenzene and xylenes), different sampling tools provide concentrations comparable (Figures 2 and 3, with Low-flow purging (LF), PDB, HydraSleeve™, multiple packers coupling with bladder pump, bailer, pumps, discrete interval sampler). Work continues to assess reproducibility of these preliminary results to improve the state of the art.



**Contamination by Selected Trace Elements in Groundwater of Azzaba district in  
Northeast of Algeria  
Abstract n°1506**

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KEYWORDS: Groundwater, pollution, norms

The region of Azzaba, located in northeast of Algeria, is geologically characterized by various mineral-bearing indices which are classified as polymetal (Pb, Zn and Cu) and mercurio-polymetallic (Hg, Pb, Zn, Cu) elements. Fifteen groundwater samples were analyzed to understand the chemical composition of the selected trace elements. The results have shown that Hg, Pb and Arsenic were identified as contaminants in almost all the groundwater samples. The bicarbonated calcic facies could be explained by the presence of cavernous limestone and calcareous sandstone of the Paleocene-Eocene age. The chlorided sodic and sulphated calcic facies were found in sandy and clayey reservoirs of Oligocene. Referring to the WHO standards, the mercury and lead norms are largely exceeded in groundwater. Geochemical modeling carried out to study the possibility of metal precipitation and the formation of the secondary ores, has shown an over saturation with regard to calcite, dolomite and aragonite+ and under saturation with respect to halite, gypsum and anhydrite. The minerals of Hg, As and Pb are under saturated in the groundwater of the study area.



## Effects of test scale on hydraulic measurements in a crystalline rock setting Abstract n°1510

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KEYWORDS: Hydraulic Testing, Scale Effects, Fractured Crystalline Rock

Concern about the scale of representation for the results of hydraulic tests conducted in crystalline rock aquifers has been a long-standing issue in the hydrogeological characterization of these settings. In this study we evaluate the effects of measurement scale on bulk values of transmissivity, storativity, vertical hydraulic conductivity, vertical specific storage and specific yield in a sparsely-fractured granite gneiss having a very thin overburden cover (ie. the water table resides in the bedrock). Scale effects are identified through the comparison of results from constant head tests conducted contiguously with depth, open-well slug tests, open-well pulse interference tests and long-term, open-well pumping tests. Scale artefacts relating to measurement or analysis methods are reduced by testing the same well array at each measurement scale. The wells were constructed using air-percussion methods to a depth of approximately 30 m and are arranged in a triangular format with separation of approximately 10 m between each pair. The slug and pulse interference test results were interpreted using new analytical models developed to accommodate horizontal fracturing in this type of setting. The long-term pumping tests were interpreted using an analytical model based on porous-media equivalency. All transient tests were interpreted using formal parameter estimation methods. The results show that the geometric mean values for the bulk horizontal properties (transmissivity, and storativity) vary over less than an order of magnitude from local-scale tests to long-term pumping tests. Although interpretation of the pumping tests for vertical properties and specific yield proved inconclusive, averaging the results of open-borehole pulse interference tests provided a good estimate of the value of specific yield that was obtained from the results of the constant head tests. Based on our observations, we conclude that scale effects are relatively minimal in this setting, and that pulse interference tests may be a less time-intensive and more reliable alternative to pumping tests in the determination of vertical hydraulic properties and specific yield.



**Groundwater contamination by mercury and other heavy metals in traditional mining site in Central Java, Indonesia**  
**Abstract n°1512**

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KEYWORDS: groundwater, traditional, mining, mercury, heavy, metals

This study aims to examine mercury contamination distribution in groundwater in traditional gold mining area in Banyumas District, Central Java Province, Indonesia. All groundwater samples were obtained by systematic random sampling method in shallow well located in study area. Mercury concentration and other heavy metals in groundwater sample were measured by using ICP-AES. As source of contamination, concentration of mercury in tailing was measured and the value has range from 37 to 350 ppm and other heavy metals were also detected in this tailing. This value was very high compare to mercury and other heavy metals concentration in natural condition. The mercury concentration in groundwater was detected in range of 0,219 to 1,574 ppm and the average value was 0,867 ppm. The other heavy metals such as As, Cu and Pb also were detected in low concentration. The resume of this study show that groundwater in study area has been contaminated by mercury and other heavy metals. Having analyzed the mineralization process occurred in some rock study area, the presence of mercury and other heavy metals in groundwater in study area was caused can be by natural factor and and also mining activity. Future study and action for remediation of this contaminated site would be highly recommended.



**Groundwater flooding in a lowland karst network in response to extreme rainfall and tidal event synchronicity**  
**Abstract n°1513**

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KEYWORDS: karst, transfer function model, groundwater flooding, tide

The objective of this research was to develop a black box transfer function model of a lowland karst network in order to assess groundwater flooding in the area in response to combinations of extreme rainfall and tidal events. The study has focused on a lowland karst network in the west of Ireland fed by allogenic runoff from low permeability Devonian mountains and discharges into a bay below mean sea level. The temporal dynamics of localised groundwater-surface water interactions have been studied for several years to yield information about the nature of the hydraulic connections beneath the ground. From this a deterministic hydraulic hydrological distributed pipe network model of the system has been developed. This model predicts the outflow from the main spring into the sea which has been validated against discharge estimates using conductivity profiles and radon concentrations. In response to severe flooding events in November 2009 and December 2015, this current research has now characterised the hydrogeology of whole karst network by a single transfer function to investigate the impact of the two main drivers on flooding (rainfall and tidal level) in the area. The data used to develop the black box model was a 12 year time series of flooded storage, rainfall and tide levels (all from monitoring) and the spring outflow discharge (from the calibrated pipe-network model). Frequency analysis of the data sets was then carried out using Fast Fourier transform analysis and a transfer function based upon a discrete wavelet function has been derived to characterise this inherently non-stationary behaviour of the flooding in the karst system. The results suggest that the extent of flooding is related to the synchronicity of heavy rainfall and perigean (i.e. maximum) spring tides. Historical flooding of the area back to the 1900s have then been compared with the predictions of the model. This knowledge can be used to make more reliable flood management predictions in the future in order to help to protect local communities.



# HYDROCHEMICAL ANALYSIS OF GROUNDWATER OF SIDI EL HANI IN TUNISIA AND ITS ASSESSMENT FOR IRRIGATION

## Abstract n°1514

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**KEYWORDS:** Major ion, hydrochemistry, groundwater, geochemical facies, Sidi El Hani.

Sidi El Hani aquifer, located in eastern Tunisia between two endorheic systems such as sabkha Sidi El Hani and sabkha Cherita, has been extensively used to satisfy the increasing demand for irrigation requirements. Nevertheless, this aquifer is generally subjected to groundwater quality degradation by salinisation. A detailed investigation was carried out with the objective to identify hydrochemical characteristics and to assess water quality. Forty nine samples were collected in this study area during April and May 2015 and analyzed for various physical and chemical parameters, such as, Temperature (T), Electrical conductivity (CE), pH, dissolved solids (TDS), Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup>, K<sup>+</sup>, HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup> and Cl<sup>-</sup>. In addition, some indicators of irrigation quality were calculated like SAR, Na%, MAR, RSC and PI. The analyses results are expressed by many hydrochemical methods combined with the Geographic Information System (GIS) to assess the suitability of the groundwater for irrigation. The results indicate that groundwater is brackish and salty-brackish. The general order of dominance of cations is Na<sup>+</sup>>Mg<sup>2+</sup>>Ca<sup>2+</sup>>K<sup>+</sup> while that for anions is Cl<sup>-</sup>>SO<sub>4</sub><sup>2-</sup>>HCO<sub>3</sub><sup>-</sup>. The study area is characterized by a mixed hydrochemical facies- Na-Ca-Cl-SO<sub>4</sub> and the Na-Cl. In addition, the quality indicators for irrigation show that the groundwater was suitable for irrigation in most parts of the aquifer area. However, the SAR and the MAR exceeded the limit permissible in certain wells near the sabkha Sidi El Hani, Sabkha Cherita and wadi Chérta. **KEYWORDS-** Hydrochemistry, groundwater quality, geochemical facies, Sidi El Hani.



**Characterization of an alluvial fan aquifer system in Bolivia by electrical resistivity tomography and induced polarization parameters**  
**Abstract n°1515**

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KEYWORDS: Geo-electrical, conceptual model, alluvial fan

The rapid agricultural development in the alluvial fan of Punata (Bolivia) has caused an increase of demand for water, therefore the drilled wells has increased considerably in the last years. The monitoring of the groundwater level shows a decreasing trend of the water table. Probably the main reason for this decline is due to over-extraction. Additionally, there is a lack of knowledge regarding the geometry and properties of the local aquifer system. Electrical Resistivity Tomography (ERT) surveys coupled with Induced Polarization (IP) measurements were conducted in the alluvial fan of Punata. The aim of these surveys is to obtain detailed information about the geometry of the local aquifer system. A total of 23 ERT surveys were performed covering an approximate length of 22.6 km. Besides ERT surveys, 15 lithology columns and 10 well-loggings were used to support the interpretation of the ERT profiles. The results show a complex structure in the apex region of the fan dominated by fluvial and colluvium deposits, while in the distal area the stratification is smoother and is dominated by lacustrine deposits. The ERT surveys yield valuable information, revealing the existence of two main layers- one is composed mainly by coarse material (boulders, gravel and sand), the other layer has a high clay content. When ambiguities were presented during the ERT interpretation, IP parameters (i.e. chargeability and normalized chargeability) proved to be useful for solving these ambiguities, since the IP response is sensitive to clay content. The results obtained during this investigation provides valuable information for building a conceptual model of the aquifer system in the alluvial fan of Punata. Hence an appropriate estimate of the volume storage, flow direction and recharge discharge process can be done. All this new information can be used for developing policies for a sustainable management of groundwater.



## **Isotopic assessment of groundwater patterns in Challapampa aquifer, Bolivia Abstract n°1516**

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**KEYWORDS:** Stable isotopes, groundwater, highland, Andes, Bolivia

In the Bolivian semiarid highlands, groundwater has become the most important and safe source of water for consumption when rivers and lakes have been reduced due to the effects of climate change. In the Challapampa aquifer, used to supply Oruro city, decades of exploitation combined with the limited information available, represent a challenge for the groundwater management. This study analyses isotopic compositions in different hydrologic cycle stages to assess flow patterns in this aquifer and therefore elucidate processes poorly known in the reservoir. Data records of stable isotopes, tritium, radiocarbon and electrical conductivity, are more abundant in the area of the alluvial fan of River Paria, where a production well-field is located. Previous studies applying stable isotopes have been used in several climate and paleoclimate investigations in the region. However, the scarcity of data, gaps in series and lack of consistent sampling methods are common problems reducing accuracy of the results. This study includes that information and new data collected during 2014 and 2015 to propose a conceptual circulation model. This study estimates about 80 % of the annual precipitation over the region, falling during the summer from December to March, is comprised of the most depleted stable isotopic values. This fingerprint is similar to the majority of the groundwater samples collected in wells. The linear tendency of the isotopic compositions in groundwater, below that in the Global Meteorological Water Line, exposes the effect of evaporation in shallow and intermediate circulation systems. Modern precipitation is the most important recharge source until about 100 m below surface. Conversely, deeper levels seem to be recharged by different processes, possibly at higher altitudes or ancient times. A circulation model comprised of four systems with distinctive characteristics is proposed in the alluvial fan area.



# **The Role of Hydrogeologists as social-scientists in Nigeria- from theory to practice**

## **Abstract n°1519**

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**KEYWORDS:** Hydrogeologists, Socio-hydrogeology, geologists, Social scientists, Nigeria

Socio-hydrogeology is an evolving branch of hydrogeology. The requirement for possessing a multi-disciplinary stance by hydrogeologists is vital in managing the impacts of socio-cultural activities on groundwater resources. In Nigeria and many other countries across sub-Saharan Africa, geology and hydrogeology are still largely mono-disciplinary in nature+ while the need to integrating the dynamic relationship between the scientific and social-cultural dimensions of both geology and hydrogeology remains crucial in the 21st century. The objective of this paper is to evaluate the role of hydrogeologists as social scientists in Nigeria and suggest ways of promoting socio-hydrogeology in the country. This has been achieved by interviewing various hydrogeologists in the academia, independent consultancy sphere, and government agencies between December 2015 and February 2016. Other category of hydrogeologists engaged in the study+ via a survey are students and graduates of geology and hydrogeology. The result show that most of the interviewees see themselves as scientists (hydrogeologists) other than socio-scientists. This opinion was also the same for the survey participants. The majority of respondents are of the opinion that social sciences are not well integrated into hydrogeological research. The paper suggests a much deeper involvement of hydrogeologists in aspects related to socio-cultural issues of water management, facilitation of knowledge exchange programmes among hydrogeologists and social scientists, and the integration of social aspects of groundwater management into the current hydro (geo) logical curriculum in Nigeria. The final outcomes of the study are expected increased awareness among hydrogeologists and other relevant stakeholders. This will ensure the achievement of the Sustainable Development Goal (6) on water.



**Distribution Characteristics and Cause Analysis of Iodine in Groundwater of  
Cangzhou Region, China  
Abstract n°1521**

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**KEYWORDS:** Hydrogeology+ groundwater+ iodine+ cause analysis+ Cangzhou Region

Iodine is an important raw material for the synthesis of thyroid hormones, and iodine deficiency or iodine intake excess can induce thyroid disease. Iodine content in drinking water and daily reasonable edible iodized salt has an important effect on the prevention and treatment of thyroid diseases. This work selected the typical section in Cangzhou Region and had carried out investigation on iodine distribution in groundwater and using of edible salt, collected 61 groups of groundwater samples for iodine content analysis, basically got the space distribution of iodine in groundwater, iodide in deep groundwater has better spatial temporal regularity than that in shallow groundwater, and the iodine content in deep groundwater of Huanghua depression is significantly higher than that in groundwater of Cang County uplift. The uplift of Cang County is in the continental sedimentation zone, while the depression of Huanghua is in the zone of interactive marine and terrestrial deposit. Six transgression movements since Quaternary period result in a tremendous number of marine animals and plants with rich iodine. Influenced by changing environment conditions, iodine changes gradually from molecular state into ionized state, and then enters into water, resulting in increased iodide concentration in deep groundwater. At the same time We found most of the regions mainly use iodized salt, and only Xinghua District (Cangzhou) and Cangzhou Development Zone use non-iodized salt. Many hyperthyreosis patients in regions with high iodine concentration in groundwater were found, but most of the regions are using iodized salt. Based on analysis on iodide concentration of the section, in the regions with high iodine concentration in groundwater (areas in the north and in the east of Zhuzhuangzi Village, Cangzhou) and areas where abnormal groundwater is used as drinking water, people should stop using iodized salt and appropriately use edible salt according to local conditions. It has important significance for protecting the health of the residents and preventing thyroid diseases.



**Using pre-existing stresses to predict impact of new developments- lessons from modelling vertical hydraulic conductivity between a reservoir and a water resource aquifer**  
**Abstract n°1522**

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KEYWORDS: modelling connectivity aquifers

Objective- The nature of coal seam gas (CSG) projects has raised questions about the extent of inter-layer connectivity and the effect of projects on overlying alluvial aquifers used for irrigation. A pump test was undertaken to assess connectivity between a CSG reservoir and an overlying alluvial aquifer and the results of this test were modelled to assess the vertical connectivity between these units. This paper presents the findings from groundwater modelling undertaken to assess the results of the test and presents results and implications for use of pre-existing data on system stresses in assessing impacts of new developments. Design and Method- Prior information on the alluvial aquifer indicated over extraction had occurred with mining of the water table by tens of metres over a wide area, such that in some areas underlying coal seams reported pressures higher than the alluvial water pressure. Test pumping was undertaken from the alluvial aquifer and the underlying units were monitored at several depths. Geological, geophysical logs and core data was also collected. Numerical modelling using Modflow and the "PEST" parameter estimation software with two alternate interpretations of the geology of the intervening zone between the alluvial aquifer and the coal seam were undertaken to assess connectivity. Original Data and Results. Data collected from the test measured upward vertical hydraulic differences of more than 10m over a 15m thickness of intervening material between a coal seam and an alluvial aquifer. The results of modeling indicated vertical hydraulic conductivities in the order of  $1.4 \times 10^{-8}$  and  $8.0 \times 10^{-10}$  m d across the intervening zone. Data supporting conclusion- The major control on results was head difference and suggests that prior regional data can provide an indication of connectivity. The results of this test indicate that pre-existing conditions can provide useful information to assess proposed stresses and inter-aquifer head difference data can be a pre-existing indicator of the potential for future impact.



**INFILTRATION AND RECHARGE IN A FRACTURED, SEDIMENTARY ROCK AQUIFER  
IN A SEMI-ARID REGION  
Abstract n°1523**

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**KEYWORDS:** Groundwater recharge, California, environmental tracers, semi-arid regions

In this study, multiple environmental-tracers were used to estimate the amount of recharge and evaluate its spatial and temporal variability, to investigate the different mechanisms influencing recharge and to quantify groundwater travel times in a fractured sandstone aquifer located in southern California. The study area is 11.5 square km and located on an upland ridge in the Simi Hills about 400 m above the surrounding valley. Because of its morphological and hydrological features, it provides ideal conditions for recharge studies and comparison between different methods. Moreover, this site and its data set is uniquely given the abundance of multi-temporal chemical analysis of groundwater from an incredibly dense network of monitoring wells, multilevel systems, seep piezometers and core samples. The motivation for this study was prompted by the need to understand the rate of groundwater flow and mechanisms affecting transport of contaminants resulting from site operations between 1949 and 2006. Moreover, considering the severe drought that is currently affecting California in the last four years, the estimation of groundwater recharge has increased scientific relevance in this area. Through the application of the Chloride Mass Balance Method for the saturated zone, a site-wide annual recharge of 19 mm (4.2% of the average annual precipitation) was estimated. Given that surface runoff is continuously monitored and represents only 6.1% of the mean precipitation, the resultant average annual evapotranspiration is 408 mm (89.6% of precipitation). These values are corroborated with other site data and consistent with other study sites in semi-arid regions reported in the scientific literature, showing a robust technique for improved water balances and groundwater flow system inputs, especially in regions where water is scarce. This recharge estimate, when used in a 3-D groundwater flow model, imposes limits of the total volumetric groundwater flow rate available to transport contaminants in the plumes in the study area



# **Paleowaters of glacial origin in the northern part of the Baltic Artesian Basin (BAB)**

## **Abstract n°1524**

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**KEYWORDS:** Pleistocene glaciations, paleowaters, isotopic composition

The sedimentary sequences in the northern part of the Baltic Artesian Basin (BAB) contain paleogroundwaters that originate from meltwaters of Pleistocene continental glaciers. Until recently, the paleowaters of glacial origin had only been recognized in the deepest Cambrian-Vendian aquifer system. These waters are characterized by the most negative isotopic composition recorded in continental Europe ( $\delta^{18}\text{O}$  values from -18 to -23.5‰) and low  $^{14}\text{C}$  activities are evidence for their old age. Recent studies in the overlying aquifer systems have shown that the influence of Pleistocene glaciations can also be traced in the confined aquifer systems overlying the Cambrian-Vendian. Thus, it has become important to study the spatial distribution of these paleowaters to understand their formation and to help manage these unique resources sustainably. In this contribution we study the distribution of glacial paleowaters in aquifers of different stratigraphic age in the northern part of the BAB using the chemical and stable isotope (e.g.  $\delta^2\text{H}$ ,  $\delta^{18}\text{O}$ ,  $\delta^{13}\text{C}$ ,  $\delta^{34}\text{S}$ ) composition of groundwater together with  $^{14}\text{C}$  and  $^3\text{H}$  activities. Our first results show that waters with depleted isotopic composition with respect to values found in modern precipitation can be found in all aquifer systems studied. The comparison between spatial patterns of salinity and isotopic composition, and the modern hydraulic head distribution shows that in some aquifer systems these distributions do not coincide, suggesting that the groundwater system in the BAB is still in a transient state recovering from the changes induced by Pleistocene glaciations. Water-rock interaction and mixing between waters of different origin have influenced the geochemical evolution of these waters. The presence of glacial paleowaters in the BAB exemplifies how global climate change can influence the evolution of groundwater systems in areas affected by continental glaciations in the past. The majority of these paleowaters are used today for public water supply. As essentially non-renewable resources, their presence must be taken into account in future decisions concerning groundwater management.



## Urban groundwater model of Bucharest city, Romania Abstract n°1526

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KEYWORDS: urban hydrogeology, groundwater modelling

Bucharest city (1.9 million people 228 km<sup>2</sup> surface) faces two main hydrogeological problems. Both are produced by the interaction between the aquifer system and the underground infrastructure. The first consists of a barrier effect produced by an extensively channelized river, increasing consequently the groundwater hydraulic heads in the surrounding areas. The second, a twofold concern, it is due to the strong hydraulic interaction between sewerage and the groundwater. As result, the seepage into the sewer network increases the influent at the waste water treatment plant. Restoration of its conduits triggers consequently the groundwater hydraulic heads increase. Bucharest city conceptual hydrogeological model has been developed within a research project since 2010. Institutions, companies, and experts participated with data and knowledge to perform this work. A 3D geological model has been developed by stratigraphical litho-correlation (1800 boreholes). It focuses the Quaternary sedimentary deposits of the first 50 m below ground level and it was used to identify, delineate, and describe the existing hydrogeological units. Pumping tests and grain size distribution analysis have been performed to hydraulically characterize them. By intersecting the model with the existing urban infrastructure elements (subway, parking lots, etc.) it has been possible to provide the geometrical parameters needed to quantify their groundwater flow barrier effect and to identify the location of the sewer conduits and their potential hydraulic connection with the aquifer strata. The hydrogeological model englobes the following datasets- hydraulic heads, surface water, groundwater recharge from precipitation and from the water supply system losses, drainage systems and seepage in tunnels. The resulted hydrological water balance identified that about 0.92 m<sup>3</sup>/s wastewater surplus originates from seepage. It has been determined that more than 20% (96.7 km) of the sewer network is completely or partially immersed into the groundwater.



**Contribution of Magnetic Resonance Soundings for characterizing water storage in limestone**  
**Abstract n°1529**

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KEYWORDS: MRS, unsaturated zone, limestone

The Cigéo industrial center designed for the disposal of the most highly-radioactive French wastes is studied at a depth of 600 m in an argillite formation of the Callovo-Oxfordian located near the Bure village in the Paris sedimentary Basin. A comprehensive understanding of the surficial groundwater circulations in the Portland "Barrois" limestones is required for the setting of surface installations for the Cigéo project. Characterizing water storage and flows in both the saturated and unsaturated zones of these fractured and karstified limestones is a challenging task that requires a multidisciplinary approach. In this work we show the specific contribution of MRS soundings for the characterization of water storage in the Barrois limestones. We realized a careful selection of the soundings sites based on the geological setting (lithostratigraphy and outcropping) also as ambient electromagnetic (EM) noise conditions. MRS data acquisition was performed during four campaigns and very different EM noise conditions depending on the site and campaign were encountered. Cautious post-treatment of the data was necessary to ensure the comparability of the soundings. As a final result, MRS soundings allowed a better understanding of the water storage properties of the Barrois limestone. As a perspective of this study, hydrochemical monitoring, in-situ wells characterization and tracing experiments should provide further support of the interpretation of MRS soundings and the conceptual hydrodynamic model of the site.



**Current research in urban hydrogeology- urban underground development confronted  
by the challenges of groundwater flow, quality and temperature  
Abstract n°1530**

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**KEYWORDS:** Urban hydrogeology, underground structures, resource management

Urban subsoil provides space, groundwater, geothermal energy and geomaterials, and the importance underlying the management of this strategic space is well-known. In the context of vertical urban growth, groundwater management, is a crucial issue. First, the aim of this talk is to synthesize the state of the art dealing with the impact of underground structures (US) on groundwater flow. Secondly, feedback on deterministic approaches to the interaction between US and urban groundwater will be presented in order to propose recommendations dedicated to urban planners. Understanding of the role played by numerous types of US is improved at the decision-making scale, resulting in a methodology to define the potential state of an urban groundwater flow. The influences of several kinds of US are assessed. US involving pumping devices are shown to be responsible for the fragmentation of flow systems, which can modify the urban groundwater regime. Under low gradient conditions, impervious structures are confirmed to have a nonsignificant effect on water table elevation. Regarding quality, groundwater age theory is applied to assess the influence of US, integrating the advective and dispersive part of groundwater flow. A dispersive piston effect is shown to occur under the US, favoring the vertical spreading of pollutants via a mixing process between shallow and deep groundwater. Consequently, a 'dispersive trap' under US is described. In addition, the impacts of US on groundwater temperature and, by consequence, on the geothermal potential of urban groundwater bodies are investigated. The annual heat from US is computed deterministically, highlighting the significant thermal affected zones. On the one hand, zones subject to thermal impacts caused by US should be taken into account to avoid conflicts of use with groundwater heat pumps. On the other hand, the relevance of extracting this energy from the zone affected is shown. Finally, the impacts of US on groundwater flow quality and temperatures and on urban groundwater management are investigated to prevent risks and disturbances- flood risk, degradation of groundwater quality, jeopardizing geothermal potential.



**Cluster analysis of time-lapse resistivity data to identify a privileged feed zone within the epikarst of Lascaux Cave (France)**  
**Abstract n°1532**

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**KEYWORDS:** Epikarst, Electrical Resistivity Tomography, Multidimensional statistic, feed zone identification, flow-rate modelling, time-lapse

An experiment using time-Lapse Electrical Resistivity Tomography (ERT) was designed to monitor the hydraulic upstream area of the Lascaux cave which is located within the epikarst. The cave of Lascaux is one of the most important prehistoric cave worldwide that shows Paleolithic paintings. It is therefore necessary to predict the flow rate in its vicinity. Thirty ERT surveys were acquired over three years. It allowed us to identify the temporal variability of electrical resistivity in the area. We used a Hierarchical Ascendant Classification (HAC) to merge the 30 resistivity models into a single model which was then divided into several clusters. The resistivity in each cluster has a similar temporal variation. The resistivity variability was combined to climatic data to provide a hydrogeological interpretation. We identified two singular areas from the HAC of resistivity data. The first area extends from the surface to 2.6-4 meters. Resistivity variations and effective rainfall are correlated with a short-delay response. The rapid response of resistivity shows that the water infiltration is very efficient through the formation, suggesting that it could be a fractured limestone. We observed that the tree coverage also impacts the behavior of water infiltration in the area. The second area has lower resistivity values and appears at the center of the model. In this area, temporal variations of resistivity are correlated with the flow rate recorded inside the cave. The flow rate is recorded inside the cave with a three-month delay after rainfall. We assume that the second area may correspond to the privileged feed zone, that the geometry was determined in 3D. We modelled the flow rate from electrical resistivity data using Archie's law and including an additional term for percolation threshold. This model shows a good prediction of a rapid increase or decrease of the flow rate.



## **Suspended sediments in Pinarbasi karst spring, Central Taurus Belt, Turkey. Abstract n°1533**

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**KEYWORDS:** Hydrogeological conceptual model, karst aquifer, suspended sediments, Taurus belt, Turkey.

Modeling of a karst aquifer has significant challenges. Karst springs are popular with the suspended sediments. From this point of view, creating the hydrogeological conceptual model of Susuz karst aquifer is aimed. Because this is possible to find a relationship between hydrodynamic behaviour and the amount of the suspended sediments in a karst spring. The Susuz aquifer is located in Seydi ehir, Central Taurus Belt, Turkey. There are lots of springs, estavelles, caves, sinkholes, uvalas and other karst structures near Susuz. The most popular one is T naztepe cave in the catchment area. The objective of the study is understanding the relationship between the amount and mineralogy of suspended sediments in Pnarbasi spring and the hydrodynamic and hydrochemical characteristics of Susuz aquifer. Pinarbasi spring is monitored by CTD diver since December 2014. The device recorded water temperature, electrical conductivity and water elevation on Susuz Creek instantly. The recharge elevation of the spring is determined by means of evaluation of stable isotopes of Oxygen18-Deuterium. Water samples are taken during storm events and Total Suspended Solid (TSS) are evaluated by gravimeter method. Every geological unit is sampled systematically and XRD analyzes are carried out. As the beginning of dry period, sediment samples are gathered before the spring and grain size distribution analyses are carried out. 20 liters plastic bottles is used in order to gather suspended solids of spring water. SEM and EDS analyses are carried out on the suspended solids and the mineralogy and dissolution marks are obtained. To sum up, hydrogeological conceptual model of Susuz aquifer is obtained by means of a series of hydrogeochemical and mineralogical analysis methods.



## **Kansa's Multiquadric Based Meshfree Solution for Confined Aquifer Abstract n°1534**

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KEYWORDS: simulation+ Kansa's multiquadric approach+ Radial basis function+

A successful strategy for groundwater management depends upon the adequate estimation of groundwater head distribution over the aquifer region with lesser computational time resource. Most of the groundwater simulation models are based upon certain element (FEM) or grid (FDM) formulation for the interpolation of head values which eventually imparts rising simulation cost. Since management scenarios often demand calling simulation models several hundred times to deliver the acceptable decision scene, it is essential that an efficient system simulation technique is adopted. In this paper a recent Kansa's global approach based meshfree (Mfree) model is developed as a ground water simulation tool. The developed model is maiden tested on two- dimensional homogeneous isotropic confined aquifer flow problem with its solution showing close agreement with the analytical solution. Different time steps and varied pumping schedules were also assessed for a performance check with available solutions. Mfree model also showed better accuracy compared to FEM solution. Later this model is applied to a different synthetic aquifer flow problem analogous to field variability of parameters viz. non- homogeneity, anisotropy and boundary inflow with the irregular computational domain. Mfree solutions are the testimony of accuracy and successful application of the developed model. The proposed model can also work as a first stage simulator before coupling with an optimization algorithm for problems like inverse groundwater modeling, groundwater contaminant source identification etc. for appropriate management of groundwater.



**Geochemical and isotopical analyzes of groundwater in a karst system - the case study of Fez-Meknès basin ( Morocco)**  
**Abstract n°1535**

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**KEYWORDS:** Middle Atlas, Karst aquifer, Sa s basin, Stable isotopes (O-18, D), Radon-222, Transit time, Recharge zones.

The karst Middle Atlas Causses reservoir mainly composed of Liasic dolomitic limestone, overlying Triassic clays, evaporates and basalts, is the main drinking water supply in Fez-Mekn es region (Sa s Basin). Because of the increase in population, the number of drilling for irrigation of agricultural land and some longer drought periods in recent years, the issue of sustainable groundwater management arises. Recent analyzes have shown a decline in its chemical quality and punctually some turbidity problems. In order to enhance understanding of this hydrosystem and the interactions between the different main springs of Liasic and Triassic origin, and their connections to the major spring (Bittit), an integrated hydrogeochemical study was conducted coupled to isotopic analyzes of delta O-18, delta D and Radon-222. Four surveys were performed in fall and spring seasons (2009-2011). Water geochemistry shows two kinds of water- a major Liasic origin along the transition between the Causses and the Sa s basin, and a major Triassic origin for El Mir, Sbaa, and Maarouf springs located at the southern border of Sa s basin extremities. Deuterium excess highlights a local recharge while delta O-18 versus delta D characterize two aquifers with different evaporations. Radon-222, underlined the existence of areas of rapid exchange between waters of Liasic aquifer characterized by low Radon activity (3500 Bq m<sup>3</sup>) and waters in contact with Triassic aquitard characterized by a high Radon activity (> 15000 Bq m<sup>3</sup>). The transit time is less than two weeks to surface. The waters renewal is only conducted by major rainfalls. Four recharge zones of different altitudes have been found and two main mixing zones (limits of Sa s Basin).



**Surface water potabilisation with a horizontal filtering medium elaborated for developing countries- some physiochemical aspects.  
Abstract n°1536**

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**KEYWORDS:** water surface, drinking water, pilot, water treatment, horizontal filtration, sand, adsorption, modelisation

Despite the important resources of water in the Central African Republic, a strong shortage of potable drinking water is observed. Natural waters mainly springs, surface waters, aquifers of low depth are found to be contaminated by anthropogenic pollutants due to a lack of waste water treatments. In this context, a horizontal filtering medium has been designed and set up, allowing for a cost effective treatment process without any pre-chemical treatment for the purification of the overlying water. Sand was chosen as adsorbent because of- (i) its filtering properties+ and (ii) its particular behavior as a natural mineral through hydro-geochemical processes in soils, enabling to produce a good quality in deep aquifers. The filtering pilot was supplied with waters which were collected from Oubangui River by Sodeca Agency. Performance and quality of treated waters were monitored during 18 months, and the data obtained during this experiment met the requirements from the potable-water criteria (with a water production of 400 L h<sup>-1</sup>) and from the water quality norms which were usually recommended before chlorination bleaching. Finally, modeling calculations on the water flow through the pilot were carried out using the mathematical model- MODFLOW. This approach resulted in the optimization of length and slope (which affect both the contact time) of the filtering system in order to get a good quality water. To improve this water-treatment system, kinetic and thermodynamic studies will be important to carry out in the future in order to take into consideration these data in our transport model.



**Multi-model approach to evaluate the impact of a future well field on forest production  
(South-West of France)  
Abstract n°1538**

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**KEYWORDS:** groundwater model, forest growth model, multilayer aquifer system

In Gironde (SW of France), 98% of drinking water comes from the North Aquitaine multilayered aquifer system. It constitutes a strategic water resource considering the great quality of this water and its natural protection against anthropic pollutions. Nevertheless, some of these aquifers are overexploited. In order to manage these resources, a regional planning of groundwater was approved in 2003. It plans the realization of new facilities to improve the spatial distribution of pumping areas in order to minimize groundwater mining impacts on specific sites. Thus, a new well field is planned in the Medoc region at 35 km west of Bordeaux. It will be composed of 14 wells and will produce 10 million cubic meters by year extract from Oligocene aquifer (150 m below ground surface). In this region, most of the surface is occupied by the Landes forest, which corresponds to a monoculture of maritime pines (*Pinus pinaster*). Soils are mainly composed of sand in which a phreatic aquifer (Plio-Quaternary) is in development. In order to evaluate the impact of the future well field on the Oligocene aquifer and the multilayered aquifer system, a hydrodynamic model (PHONEME) was specially built for this with MARHTE (Thiéry, 2014). It incorporates 8 aquifers and 7 aquitards, covering a total surface of 4,430 km<sup>2</sup>. Simulations done with the groundwater model show a maximum impact of 30 m on the Oligocene and an impact between 0 and 35 cm on the phreatic aquifer. Results from the hydrodynamic model were used to evaluate impact on forest production using the INRA forest growth model GO+ (Lousteau et al., 2012 ). This multi-model approach was done in order to gives some answers on the impacts on the growth of trees with the implementation of a well field and to bring solutions to limit use conflicts.



**Evaluation of urbanization on groundwater environment changes in the Tokyo metropolitan area, Japan- long-term monitoring of subsurface temperature and groundwater data**  
**Abstract n°1548**

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**KEYWORDS:** subsurface temperature, groundwater flow, long-term monitoring, urbanization, Tokyo metropolitan area

Human activities in the Tokyo metropolitan area have induced various changes of groundwater environment (e.g., groundwater flow regime and subsurface temperature distribution). In addition, subsurface temperatures have been affected by surface warming caused by not only urbanization but also global warming. Thus, it is required essentially to evaluate the mechanism and process of changes of subsurface thermal environment in this area. Three-dimensional distribution of the subsurface temperature and its secular change have been observed by repeated measurements of temperature-depth profiles at monitoring wells since 2000 to understand the subsurface thermal environment change in this area. We also have conducted subsurface temperature monitoring using high accuracy temperature logger (resolution- 0.001 degrees Celsius) for two or more years to find subsurface temperature change in great detail. In addition, groundwater flow regime was evaluated based on the distribution of hydraulic heads in the wells. Secular subsurface warming was found at shallow depths in the whole study area. Also, subsurface temperature beneath the urban center was particularly high not only at the shallow part but at the deep part. The results of the monitoring showed continuous warming tendency beneath both of the urban center and the suburbs. The warmings at 40m deep beneath the urban center showed fluctuations in a few months interval, and it was considered to be induced by heat supply from underground buildings. Differences of the trends between the urban center and the suburbs suggest the capability to separate effects of climate changes and urbanization in the Tokyo metropolitan area. This study is conducted as a part of joint research projects and is supported by JSPS KAKENHI Grant (No. 25871190).



**Hydrogeological parameters and sustainability of ground water in Uganda. A case of Ankole-Masaka corridor, South Western Uganda  
Abstract n°1549**

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**KEYWORDS:** Parameters, sustainability, hydrogeological, aquifer, regolith, recharge.

Uganda is well endowed with abundant surface water, with notable 162 fresh water lakes and numerous rivers that is not safe for human consumption. Treatment to supply a scattered rural population in Uganda is financially unfeasible+ and thus many people depend on groundwater harvested from deep boreholes in the basement rock aquifer. The study aimed at defining hydrogeological parameters and sustainability of ground water in Ankole-Masaka corridor a semi-arid area in south western Uganda. The study employed a number of methods ranging from surface geophysics, depth sampling, regolith sampling and testing, numerical methods of pumping test analysis, and flow modeling. Other methods employed included observation, opinion surveys, personal interviews and group discussions with representatives of groundwater resource harvesting facilities in the area. The results confirmed bedrock being extremely weak aquifer whose ability to yield water depends on additional contributions from the regolith, the principal aquifer in Ankole-Masaka corridor is not the basement rock but rather the overlying regolith. The present pumping rates in the deep rock might not be sustainable in the long term thus the recharge, storage, and vulnerability of local aquifer is weak, a factor that renders most bore holes and wells dry. The study recommended that land use patterns be monitored to assess their potential impact on water quantity and quality, steps be taken to implement a national monitoring program based on monitoring of wells in both the regolith and bedrock aquifers and laws governing groundwater harvesting facilities be investigated and improved.



**Perchlorates in the chalk aquifer of Northeastern France (Marne, 51) – Preliminary results and perspectives**  
**Abstract n°1550**

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**KEYWORDS:** Perchlorates, Chalk aquifer, World War One (WWI)

Noticeable concentrations of perchlorate ions have been measured since 2011 in numerous drinking water supplies of Northeast of France. Because the consumption of food and water containing  $\text{ClO}_4^-$  is suspected to result in thyroid tumors and mental retardations, authorities issued health recommendations for tap water beyond  $4\mu\text{g/L}$ . Perchlorates have both natural (associated with nitrate in caliche formation, e.g. Atacama Desert, Chile) and anthropogenic (numerous industrial processes use synthetic  $\text{ClO}_4^-$ ) origins. Chilean caliche has been intensively imported in France before WWI since it was the unique nitrate supply for agriculture and nitrogen industry. The increased production of synthetic  $\text{ClO}_4^-$  dates back to WWI because of the widespread uses of trench artillery weapons (mortar bombs, grenades) loaded with chlorated perchlorated explosives, and the production of explosives for shells (TNT...).  $\text{ClO}_4^-$  concentrations largely higher than  $15\mu\text{g/L}$  are observed in groundwater from the chalk aquifer in the Marne French department. A geographical approach allowed to link perchlorate concentrations with WWI and post-WWI activities- shelling and fighting along the former front line, dumping breaking down of ammunition during the war and for several decades after, free and labile explosives still be buried in soil. But this area is also characterized by intensive agriculture. Past use of Chilean nitrate and intensive fertilization during the reconstruction of devastated soils after the Armistice could have resulted into widespread groundwater contamination. Management of this issue requires better constraints on the sources of contamination thanks to the combination of historical archives and measurements of inorganic traces, organic warfare agents, explosives, and isotopic signatures of  $\text{ClO}_4^-$  from groundwater. Perchlorates mobility in the aquifer will be specified by a multi-tracer geochemical survey (major ions, stable isotopes of water molecule, trace elements) and groundwater residence time determination. The links between  $\text{ClO}_4^-$  and other molecules of military origin ( $\text{NO}_3^-$  and other organics) will also be clarified.



## **Impacts on Freshwater Resources Related to CO<sub>2</sub> Storage in Saline Aquifers Abstract n°1551**

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KEYWORDS: CCS, environmental risks, groundwater protection

Injection and storage of CO<sub>2</sub> into deep saline aquifers changes geophysical and geochemical conditions in the storage environment. Such changes in greater depths, however, may subsequently lead to adverse impacts in the shallow subsurface. Here, freshwater aquifers might be influenced during and after injection – indirectly by pressure changes and directly by CO<sub>2</sub> or saline formation water migrating along natural occurring faults and fractures or through faulty boreholes. While pressure perturbations may lead to deformations at the surface in the range of millimeters, the main concern is the vulnerability of shallow freshwater resources. CO<sub>2</sub> entering freshwater not only decreases pH, but may subsequently dissolve and mobilize potentially toxic metals. The mixing of native saline formation water or CO<sub>2</sub>-enriched saline formation water with ambient groundwater increases salinity and electrical conductivity and may result in severe damages and contamination of fresh groundwater. Geophysical, geochemical, and biological parameters, often interdependent, can be used for monitoring strategies. The two main reasons for monitoring shallow aquifers in the vicinity of deep CO<sub>2</sub> storage reservoirs are- (1) provisions for health, safety, and environment, (2) verification of safe injection management and storage operation according to plans. A broad and site-specific monitoring program, operating on different time and spatial scales prior, during, and after injection together with THMC modelling, laboratory and field experiments, are highly recommended for safe geological CO<sub>2</sub> storage and general groundwater protection. Diffusive and localised leakage associated with geological CO<sub>2</sub> storage cannot be excluded, but, by selecting suitable storage locations, potential impacts on the environment can be reduced. This presentation gives a review of possible impacts on freshwater aquifers.



**Approaches to implement the Regional Strategy of the Transboundary Aquifers of the Americas**  
**Abstract n°1553**

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**KEYWORDS:** Aquifers, Americas, transboundary, strategy

Twenty-four countries of the American Hemisphere have come together with a common vision for the assessment and management of transboundary aquifer systems (TAS) under the UNESCO-ISARM Programme. The group of countries from Argentina Chile to Canada developed a regional strategy with a unified mission to identify, assess and manage TAS following a set of principles suggested in the regional strategy, inspired by the recommendations of the UN Draft Articles on the Law of Transboundary Aquifers. The regional strategy emphasizes the linkages between the science (knowledge), social (participation) and legal (policies) domains as a common framework for a shared governance of TAS. This presentation discusses the links and relevance of the UN Law of Transboundary Aquifers on how it might fit into the strategy for TAS of the Americas. Basically, the studies aim at strengthen transboundary water management by facilitating information sharing and knowledge management. Important challenges are identified on how to combine the scientific and technical recommendations of the strategy with the numerous legal and institutional instruments of the 24 countries and the UN's draft articles on TAS. The strategy explains the role of science for the collective understanding, developing, managing, and protecting of the TAS in the Americas. The strategy's main message for decision makers is that a strong scientifically-based strategy should be the backbone for good informed decisions to sustain water resources and reduce potential conflict amongst neighboring countries. A few examples show how the process has begun to develop for selected transboundary aquifers, including the Milk River between the US and Canada, the Rio Grande and Colorado River between the US and Mexico and the Guarani in South America. Finally, it is recognized that a single global convention will be difficult to relate to the wide variations in the TAS of the Americas.



## **Crystalline rock aquifers- The Llano Uplift, Central Texas, USA Abstract n°1554**

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**KEYWORDS:** Crystalline aquifers, permeability, Llano Uplift, Texas

The crystalline rock aquifers of Llano Uplift are locally vital+ they are hosted in Mesoproterozoic granitic and metamorphic rocks that form the core of a broad structural dome. Late Paleozoic normal faulting and fractures, decompressive fractures, and weathering control aquifer properties. Driller report data (n=1530) show that wells in granites have higher median yields (57 litres per minute) and lower total dissolved solids (420 mg/L) than in the metamorphic rocks (30 lpm and 500 mg/L). The more productive wells are associated with thicker regolith and valleys, which reflect increased fracture density. Median regolith thicknesses are about twice as thick over granitic rocks (12m) than over metamorphic rocks. Wells are shallow (generally < 100 m depth with a median of 37 m). Permeability data imply decreased open fracture intensity with depth, although sample bias is a consideration. The decrease in incremental well yield with depth is greater in the Llano Uplift than in other areas of the US. Lithologic descriptions and well-yield data indicate the regolith and the fissured or partially weathered zones provide the greatest permeability. Rock Quality Designation (RQD < 50%) on drill cores, where available, can predict transmissive zones. Consistent vertical fracture orientations create permeability anisotropy. Some near-surface fractures with significant apertures (> 1mm) are filled and fracture skins can be thick with white weathering rinds that can have porosities approaching 14% and iron banding, particularly on the subhorizontal fractures+ subvertical fractures commonly have clay, hematite, and pyrolusite coatings. These affect solute transport in this shallow aquifer. Further needed studies include- better mapping definition of the regolith and weathered zones+ evaluation of open fracture properties with depth+ controls on fracture skin formation and fracture filling+ and quantifying the effects of lithology, climate, and geological history on crystalline rock aquifers.



## ONLINE FLUOROMETRY IN ENVIRONMENTAL APPLICATIONS

### Abstract n°1558

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KEYWORDS: field fluorometer, resazurin, tryptophan

We present four applications of an online fluorometer in which the optics have been adapted for simultaneous measurement of the concentration of up to three naturally-occurring or artificial fluorescent compounds at intervals of 10 s. These compounds are of interest in several environmental applications, whereas in standard usage, this fluorometer is dedicated to dye tracer tests and stream gauging. Smart tracer - Resazurin – Resorufin The “smart” fluorescent compound resazurin was introduced as a reactive stream tracer to quantify hyporheic exchange and metabolic activity of streams. This tracer, together with its reaction product resorufin and an additional conservative tracer (in our case fluorescein), are measured to provide information about transport properties of the stream and its hyporheic zone. Resazurin is weakly fluorescent and can irreversibly be reduced to the strongly fluorescent dye resorufin, indicating exposure of the water to a metabolically active environment. Tryptophan – Indicator of degradation of amino acids in waters The induced fluorescence of this molecule in sewage waters results from microbial breakdown of proteins. It can be measured to quantify human influence on water quality. The multiple optics of the fluorometer allows for real-time separation of tryptophan from humic-like fluorescence and simultaneous sampling of water turbidity and temperature. Real-time detection of fecal pollution in drinking water supplies The ability of the instrument to detect and broadcast in real-time the DOM-associated fecal pollution by grazing livestock allows for immediate reaction of the operators of the water distribution, avoiding further contamination to reach the network. PAH detection in water With UV excitation light at smaller wavelengths, real-time detection of dissolved PAH in water is of great interest. In all four applications, the dissolved compounds behave as short-lived tracers. Collecting discrete samples at frequent time intervals during days or weeks by mechanical samplers is not practical and the samples may not reflect the real content of the water. Therefore online measurement and in situ fluorescence analysis is the method of best choice.



**Impacts of irrigation on groundwater recharge, mixing and quality- sandy aquifer of the Limagne Bourbonnaise (central France)**  
**Abstract n°1560**

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**KEYWORDS:** Irrigation, environmental tracers, groundwater quality

In the context of global change, understanding the long-term evolution of groundwater resources in irrigated regions is essential for water and food security in the face of multiple pressures on the aquifers (increases in water demand, urbanisation and climate change). This project explores effects of the pumping and irrigation cycles on both groundwater quality and quantity in a region in France exposed to a strong growth in groundwater irrigation over the past 20 years. The scientific challenges in irrigation regions include the need for a deeper understanding of the temporal and spatial variability in recharge from rainfall and irrigation waters. Secondly, defining the origins and mixing of waters from multiple sources (rain, surface water, irrigating waters, shallow and deep groundwater) that eventually contribute to the groundwater resource is essential for sustainable use. Furthermore, a comprehensive understanding on the links between the hydrodynamic variability and agrochemical contaminant transfers in heterogeneous hydrogeological systems is required. In this project, dating tracers ( $^{14}\text{C}$ , CFCs,  $\text{SF}_6$  and  $^3\text{H}$ ) are coupled with environmental tracers ( $\delta^{18}\text{O}$ ,  $\delta^2\text{H}$ ,  $\delta^{13}\text{C}$ , and major and minor ions), water quality parameters (nutrients and pesticides), and physical and chemical models to investigate shallow groundwater in an unconfined sand and clay aquifer in the Allier Department, central France. Due to the limited historical hydrogeological data for this aquifer, the use of dating and environmental tracers is essential to understand hydrosystem dynamics. Results highlight a groundwater resource that rapidly recovers from seasonal declines in hydraulic heads of up to 27.5 m due to pumping for irrigation. This recovery is associated with variable chemical responses depending on the tracers+ highlighting the influence of water from diverse sources. The evolution of nutrient (e.g.  $\text{NO}_3$  10-24 mg L) and herbicide (e.g. atrazine 0.05 to 0.17 micro g L) concentrations during variations in groundwater drawdown indicates a shallow system vulnerable to rapid vertical transfers of contaminants.



**Importance of the unsaturated zone in understanding nitrate and pesticides trends in a fluvioglacial aquifer of the eastern part of Lyon, France**  
**Abstract n°1562**

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KEYWORDS: nitrates, pesticides, groundwater, unsaturated zone

**Objectives** The Meyzieu fluvioglacial aquifer located at the eastern part of Lyon is intensively exploited and of multiple pressures (urban, industrial, agriculture). Nitrate concentrations are quite high while pesticides contamination is low considering the past and today's pressure. A project was initiated in 2011 with the objective of determining the role of the unsaturated zone of a maximum depth of 80 m in the transfer of NO<sub>3</sub> and pesticides. **Design and methodology** Monthly monitoring of major elements, some pesticides, and stable water isotopes is carried out at three sampling points located along the flow lines. Additional information such as hydrogeological functioning, pressure inventory was gathered and additional data from two water and one soil sampling campaigns was collected. **Original data and results** The temporal variation of NO<sub>3</sub> is quite different at the three monitoring points. At the sampling point located upstream, where the unsaturated zone is of about 40m, the nitrate concentrations are comprised between 20 and 40 mg.l<sup>-1</sup> from 2004 to mid-2013. From mid-2013 nitrate concentrations are increasing regularly and are now reaching 70 mg.l<sup>-1</sup>. The monitoring indicates a threshold value equal to 30 mg.l<sup>-1</sup> from where the relationship between Cl and NO<sub>3</sub> evolves. The linear relationship between NO<sub>3</sub> and Cl indicates that the changes in concentrations can be described by a mixing scheme. Assuming that chloride behaves conservatively in the studied system, the decrease of Cl NO<sub>3</sub> ratio reveals a change in the end-members when the NO<sub>3</sub> concentration increases. **Conclusions** The year 2013-2014 was particular concerning rainfall, leading to a higher recharge during this time period compared to the previous one. In consequence, we hypothesized that the changes in the Cl NO<sub>3</sub> reveals remobilization of NO<sub>3</sub> stocks present in the unsaturated zone during the period going from June 2013 to nowadays. This schema was compared to the pesticide variation pattern.



**Multifrequency electromagnetic method for the hydrogeophysical characterization of hard-rock aquifers- the case of the upstream watershed of White Bandama (northern Ivory Coast)**  
**Abstract n°1564**

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KEYWORDS: Hard rock Aquifer, Electromagnetic sounding, Ivory Coast

In West Africa, for drinking water supply, we refer to the hard rock aquifers. In Ivory Coast, the population growth together with climate changes patterns make groundwater resources vulnerable. The upstream watershed of White Bandama, northern Ivory Coast, is located on a poorly known hard rock aquifer, especially for the precise geometry of the reservoirs. This poor knowledge, combined with a high heterogeneity and difficulties for the classical hydrogeological exploration methods, leads a lack of the exploited water resources. Further spatial knowledge of the aquifer geometry, is first required for the achievement of a sustainable management of this resource. To further investigate weathered hard-rock aquifer of White Bandana catchment, we coupled electromagnetic measurements to lithological data to refine the geometry of the aquifer and to better constrain the choice for future well locations. This study therefore presents a new hydrogeophysical approach to improve the knowledge of the regionally or locally important resources in a hard-rock aquifer by the use of the PROMIS frequency electromagnetic system coupled with lithologs from boreholes. The interpretation of the results leads to propose multi-layer models consistent with lithological structuring and geological discontinuities in place, and to the location of the aquifer and its geometry, roof and base interfaces. This method is efficient to improve hard rock aquifer characterization, as the results revealed good agreement between the soundings (1D), the resistivity section (2D) and the boreholes and geological structures. A detailed knowledge of the local aquifer geometry constitutes the first and crucial step before going further into a complete hydrogeological study.



**What uses of piezometric network's data in hard-rock aquifers ? Example of Brittany's network 10 years after its implementation.  
Abstract n°1565**

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KEYWORDS: piezometric network, hard-rock aquifers, Brittany

Targeted provisional session N°8.03 For a long time ago considered as a region devoid of big aquifers, Brittany's region has a piezometric network since 10 years contrary to other regions equipped since the 1970s. Its implementation was financed by Loire-Bretagne Water Agency, BRGM, Regional Council of Brittany, and Regional Department for the environment. Since 2008, network's supervision and follow-up is financed by ONEMA and BRGM. Brittany's piezometric network is constituted by 52 boreholes equipped with automatic acquisition of water level and with data's remote transmission. Among these points, 48 are settled in hard-rock aquifers (4 others follow alluviums or tertiary aquifers). Their location has been carefully cogitated, and it allows to cover main geological and hydrogeological formations existing in Brittany and takes into account weather conditions very contrasted from west to east and between coast and the inland. After check and validation, data are stored and put at the public's disposal on the French national groundwater database called ADES. 10 years after its implementation, piezometric network's basic data of Brittany are useful for various valorisations and plenty of different uses - evaluation of groundwater bodies quantitative status, bulletins of groundwater's level situations, elaboration of indicators piezometric dedicated to the departmental management of the drinking water, contribution of groundwater to rivers flows, diagnosis of floods by water table rise, interactive dashboard... Acquired data have also allowed to better understand Brittany's hard-rock aquifers - dynamics and slowness, cycles of data variation, memory effect, overflowing, time of water table's drop, and blocking high levels.



# The Impact of the Last Glaciation on Groundwater Flow in Estonia- A Numerical Study. Abstract n°1566

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KEYWORDS: Groundwater flow, glaciation, numerical modelling

In northern Estonia, groundwater from the Cambrian-Vendian aquifer is the most depleted in 18O in Europe (about - 21‰) and is further characterized by low salinity, high excess air and cold recharge temperatures inferred from noble gases. 14C dating indicates ages ranging from 30 to 19 ky BP. Based on these observations, it was suggested that the Cambrian-Vendian aquifer was recharged by subglacial meltwater beneath the Fennoscandian ice-sheet during the last glaciation. The Cambrian-Vendian aquifer is a major source of drinking water in Estonia and the sound management of this resource requires more information about its origin and its long-term evolution. For this purpose, a numerical model was built, simulating transient groundwater flow and solute transport. It consists in a 2D cross-sectional model that crosses Estonia along a NW-SE direction. The model was run over the last 25 ky in order to include the Last Glacial Maximum (LGM), during which the entire country was covered by the Fennoscandian ice-sheet. Subglacial recharge is simulated by prescribing hydraulic heads at the land surface that are proportional to the overlying ice-sheet thickness. Calibration of the model is performed using water levels, as well as delta18O and salinity data. First, the preliminary results of this model show that subglacial recharge is indeed a possible mechanism explaining the presence of fresh water in the deep subsurface even though several thousand years have elapsed since deglaciation. Secondly, inverse modelling was performed using a probabilistic approach to determine the most probable value of some key variables such as the ice-sheet thickness, the initial time of the LGM, the initial delta18O composition of meltwater and the hydraulic diffusivity of the confining layer overlaying the Cambrian-Vendian aquifer. Finally, we discuss whether the present-day hydrodynamics is at equilibrium or still reflects the perturbation of the last glaciation.



## **Linkages between groundwater and agricultural production in a Ugandan wetland Abstract n°1567**

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**KEYWORDS:** agriculture, conceptual models, Uganda, water quality, wetlands

The use of East African freshwater wetlands for agriculture has increased in recent decades. Agricultural production is highly depending on water quality and quantity and vice versa. Thus, a sound knowledge of the hydrogeological behavior of wetland systems is required providing boundary conditions for sustainable management decisions. Therefore, the presented study aims at a) identifying and explaining hydrogeological processes, b) evaluating the status quo of water quality, and c) assessing the influence of agricultural production on water quality in an inland valley wetland in central Uganda. Based on geological mapping, drilling surveys, determination of hydraulic conductivity, geochemical analyses, and data acquisition from literature hydrogeological maps, cross-sections, and standard sections were created. Hydrochemical and isotopic analyses of shallow and deep groundwater, stream water, soil water, and precipitation, and groundwater level data, derived from various field campaigns, resulted in a sound understanding of the origins and interactions between different water compartments and water quality aspects. Two aquifers were identified, the lower part of the alluvial sediments covering the valley itself, and the lower part of the deeply weathered bedrock underlying the sedimentary cover. While regional groundwater flow takes place in the basement aquifer, local groundwater flow in the confined alluvial aquifer is determining wetland hydrogeology. Water quality of the different water compartments is good in terms of drinking water and irrigation purposes. Shallow groundwater is not derived from direct recharge and therefore not vulnerable to water quality deterioration of flooding water due to fertilizer input. Furthermore, no increased amounts of nitrate and potassium were detected in soil water after fertilization (NPK). Complex hydrogeological processes were successfully visualized in a conceptual model. Moreover, major hazards to water quality related to inputs of fertilizers were outlined. These results can help stakeholders with little hydrogeological knowledge to integrate hydrogeological aspects into agricultural management decisions.



**Seismic amplitude anomalies revealed by the monitoring of underground CO2 injection**  
**Abstract n°1569**

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**KEYWORDS:** seismic monitoring, CO2 injection, saline aquifer

Multiparameter geophysical monitoring of shallow depth gas injection experiments in a saline aquifer have been conducted over a 4 years period at the Maguelone site, situated on a Mediterranean lido, near Montpellier (France). The aim of these experiments concerns the behavior with time of the water-CO2 mixture in the context of long-term CO2 underground storage as a possible solution to reduce atmospheric concentration. At Maguelone, the gas is injected into two clastic reservoirs located at depth 8-9m and 13-16 m. These reservoirs are interbedded in a clay-rich sedimentary sequence, and saturated with saline fluids. Subsurface biogenic gas production also takes place in this environment. The experimental setup includes both surface and downhole, electrical and seismic, baseline and injection-time, monitoring in order to follow possible changes of formation physical parameters (porosity, density, conductivity, velocity, reflectivity), together with In situ temperature, pressure as well as pH and chemical composition of the saturating fluids. This presentation is focused on the seismic measurements results, obtained using an impact source at the surface, and recorded by a combination of 20m vertical and 40m surface antennas. The baseline monitoring reveals that natural changes of the site seismic response can occur due to changes in the surface climatic conditions on the one hand, but also due to induced biogenic gas release on the other hand, triggered by the seismic impact source. Nevertheless, after correction of these effects, a clear seismic response, linked with the gas injection experiments, can be retrieved. Due to the thin thicknesses of the reservoirs, time delays and their associated velocity changes cannot be demonstrated. However, significant transmitted and reflected seismic amplitude modifications, synchronous with the gas injections, can be established. A physical model is presented to link these amplitude anomalies with the involved physical parameters (saturation, porosity, velocity, density). As a result of these investigations, we emphasize the usefulness of an adequately designed seismic surveying method as a tool for underground gas storage and induced hydrological interactions monitoring.



## **Protecting Critical Groundwater Resources above Coal Seam Gas Operations- The Roles of Chemistry and Isotopes Abstract n°1570**

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**KEYWORDS:** aquifer connectivity, Great Artesian Basin, coal seam gas, Gunnedah Basin, stable isotopes, hydrochemistry

The Great Artesian Basin (GAB) in Australia is an iconic groundwater resource providing water for the environment and for stock, domestic and industrial users across one fifth of the Australian continent. In SE Queensland, coal measures within the GAB are targeted directly for coal seam gas (CSG). In northern NSW, Santos Limited (Santos) extract CSG from coal measures in the underlying (older) Gunnedah Basin. Minimising impacts from CSG extraction on any critical overlying groundwater resources places stringent controls on CSG extraction and on-going monitoring and evaluation is undertaken to ensure critical groundwater users and receptors are not compromised by CSG extraction activities. Santos has installed a network of nested monitoring bores across the Narrabri Gas Project region that augments existing State and private bores. Targeting multiple formations, the Santos bores are equipped to monitor pressure and chemistry and this data helps us understand hydrogeological processes whilst providing baseline data for potential future CSG development. The characterisation, patterns and trends seen in the chemical and isotopic data demonstrate an isolated coal measures sequence and identify critical parameters that may be used as indicators of any inter-formational connectivity. Groundwater chemistry is strongly influenced by biogeochemical processes operating along different flow-paths and stable isotopes of carbon and water provide the greatest distinction between different sources+ provide a means to distinguish the deeper groundwaters from those in the GAB and highlight the hydraulic separation between formations.



# **Managed Aquifer Recharge with Highly Polished Treated Effluent in the Malta-South Regional Aquifer**

## **Abstract n°1571**

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**KEYWORDS:** Managed aquifer recharge, aquifer protection, regulatory framework

The Maltese islands are one of the most water-stressed countries in the world, where the annual mean national water demand is around double the sustainable naturally renewable water supply. As part of the implementation of the EU's Water Framework Directive Malta is considering wastewater treatment and re-use as one of the main measures required for the environmental objectives of the Directive. Three polishing plants have been commissioned with a production capacity of 7Mm<sup>3</sup> year (12% of national demand). The water treatment (polishing) strategy adopted in Malta is centered on a four barrier process supplementing conventional treatment with membrane technology. The intended primary use of this water is its supply to the agricultural and commercial sectors. However within a comprehensive water management framework, the use of this highly polished water is also being considered for managed aquifer recharge (MAR) in periods of low water demand. In preparation for the availability of this new water resource, a pilot MAR scheme was developed around the main Malta-south wastewater treatment plant. This pilot enabled the assessment of the quality of the polished wastewater, an assessment of the potential significance of MAR for aquifer protection purposes and the development of a regulatory framework based on the requirements of the EU's Water Framework and Groundwater Directives. Initial results from this pilot project show that the quality of the highly polished water is sufficient to achieve the prevent and limit objectives of the EU's Groundwater Directive and thus permit its use for direct MAR purposes. The process of replenishing groundwater with high quality treated wastewater also proved beneficial at the pilot level when it comes to aquifer protection from saline intrusion. It is envisaged that the results of this pilot project will enable the replication of the MAR scheme along a 2 km corridor in the southern region of the Malta Mean Sea Level aquifer for the development of a seawater intrusion barrier for the increased protection of this regional aquifer system.



**PROPOSED TWO DIMENSIONAL MATHEMATICAL MODEL FOR GROUNDWATER  
MANAGEMENT OF AL HASHIMYIA AREA -BABYLON GOVERNORATE-IRAQ  
Abstract n°1572**

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**KEYWORDS:** Keywords- Groundwater Modeling, heterogeneous media, Iraq.

Abstract- During the last decades there is low flow in the Euphrates River then consequently low flow in Hilla River which is branch of Euphrates River, Iraq. The Tyass Barrage constructed to lift the hydraulic head upstream in Hilla River raised the groundwater table above ground surface. Environmental problems have been occurred in Hashimiyia Area, Babylon Governorate, causing flooding an area of about 9 km<sup>2</sup> called the TYASS SECTOR and drought of some other local streams. The Hashimiyia Area is flat area located in the Mesopotamian plain which is consisting of Tigris and Euphrates rivers recent deposits. Prevailing sediments are sand, silt and clay forming alternative beds of Flood Plain sediments. To reconstructing the water managements within the area and rehabilitating the natural water resources, a two dimensional mathematical model has been developed to overcome such problem. Sixteen wells were drilled within the Hashimiyia area to achieve the pumping test and to calculate the Transmissivity values, evaluating of the safe yield of the bearing layer to assign withdrawal rates to lower the water table and to analyze the groundwater characteristics. The low withdrawal rate of Tyass sector is attributed to shallow and horizontal extent water bearing layer. The designed model is proved total pumping discharge of 68 liter sec that can deplete the bearing layer within Tyass sector and produces a maximum drawdown of 4.25 m at the center. The current model will provide the scientific platform for decision maker to execute any environmental application and water management.



## **The governance of groundwater and the state-community comanagement continuum Abstract n°1573**

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**KEYWORDS:** Groundwater governance, community management, management tools, participation, co-management

Governing groundwater is one of the thorniest issue in water management. It is generally recognized that governance systems only relying on state authority on the one hand or, on community management, on the other, are only successful in very particular and rare cases. This presentation offers a review of various cases from around the world situated along the state-community continuum+ it first illustrates the diversity of arrangements and then tries to identify contextual conditions conducing to a degree of success, understood as the stabilization of abstraction at a level which is environmentally sustainable. This leads us to distinguish between different types of aquifer, groundwater use, political economy and state-citizenry relationships.



## Use of Shallow Groundwater in Sprinkler Irrigation Abstract n°1574

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**KEYWORDS:** Groundwater, Simulation techniques, CROPWAT, Epanet, Sprinkler irrigation systems.

The study area is located in the desert region to the west of the road to Karbala-Najaf cities. The unconfined Dibdibba aquifer in this area is considered as a source of water. The storage of the aquifer is about 46.8 mcm. Two different sites were selected+ the first site is the front field which includes 4 wells, while the second site is the back field which includes 20 wells. Basins have been suggested to be constructed with volume of 3000 m<sup>3</sup> in the back field and volume of 1500 m<sup>3</sup> for farm C in the front field. The results of EC of GW samples indicate that the range of EC values are 3420 to 7090 ls cm, and it is suitable for wheat, barley, maize, and sugar beet. Simulation models have been used at two phases for two specified areas with an area of 51 donums for each of farm A and farm B in the back field and 33 donums for farm C in the front field. The first phase is to find crop water requirement and irrigation requirements for wheat and barley as a winter crops and maize and sugarbeet as a summer crops by using CROPWAT8.0, while the second phase includes irrigation network design by using EPANET2.0 simulation model. This study has revealed that the final designed semi-permanent sprinkler system capacity in this research is 321 m<sup>3</sup>/hr to irrigate area of 51 donum, within 4 days of 7 hours per day for the back field, while the capacity in the front field is 164 m<sup>3</sup> hr to irrigate area of 33 donum, within 5 days of 8 hours per day. Thus, the application of sprinkler irrigation will assist to increase of cultivation by about 2.5 times. The suggested layout configuration has showed that the results showed that the operation time of wells has been reduced about 40%. Crop yield produced by donum for each crop was increased by about 50%.



## Medical Hydrogeochemistry of Iraqi Sulfurous Springs Abstract n°1575

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KEYWORDS: Balneology, Mud Therapy, Hydrochemistry, Springs, Medical Hydrology

Medical Hydrogeochemistry of Iraqi Sulfurous Springs Salih Muhammad Awadh Department of Geology, College of Science, University of Baghdad, [Iraq\\_Salihauad2000@yahoo.com](mailto:Iraq_Salihauad2000@yahoo.com)

Abstract This work aims to assess some of the Iraqi sulfurous springs for balneology and mud therapy. Seventeen sulfurous springs located along the Abu-Jir Fault Zone were investigated during 2011 in terms of hydrogeochemistry. Physico-chemical parameters including color, taste, odor, hydrogen number (pH), total dissolved solid (TDS), electrical conductivity (EC), temperature (T), total suspended solid (TSS), major cations ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ), major anions ( $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$ ,  $\text{HCO}_3^-$ ,  $\text{CO}_3^{2-}$ ), secondary ions ( $\text{NO}_3^-$ ,  $\text{PO}_4^{3-}$ ),  $\text{H}_2\text{S}$ , Trace elements (Pb, Cd, Ni, Co, Zn, Fe, Mn, Cu, Cr, Hg, As, Mo, Se, Ag, Br, F, Li, Sr, Ba, B, Be, and Th) are measured. Sediment samples that have been collected from the spring bottom are analyzed for  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ,  $\text{TiO}_2$ ,  $\text{MnO}$ ,  $\text{P}_2\text{O}_5$ ,  $\text{BaO}$ ,  $\text{SrO}$  and L.O.I). Dissolved oxygen (DO), biological oxygen demand (BOD) is also determined along with the microbiological analyses for bacteria and algae. The sulfurous springs are almost valid for the balneology as therapeutic uses according to the global guidelines of the European Union, 2009 and USA and Iceland spas, Dead Sea and the Hungarian sediments.



## **Balneo-Mud Therapy of Iraqi Sulfurous Springs Abstract n°1576**

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**KEYWORDS:** Mudtherapy, Balneology, Sulfurous spring, Hydrochemistry, Iraq

The sulfurous springs in Iraq were investigated for therapeutic uses (balneology and mud-therapy). Sixteen springs as well as the Sawa Lake were investigated in terms of medical geochemistry. In water samples, cations, anions and trace elements (Al, As, Br, Ba, Cd, Cr, Co, Cu, Pb, Li, Ni, Mo, Zn, Hg, Fe, Mn, Sb, Be, Se, Th, V, and F) are analyzed in the Global ALS Laboratory Group in the Czech Republic-Prague Laboratory using ICP-MS. Spring sediments were investigated mineralogically and chemically analyzed for SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>, CaO, MgO, Na<sub>2</sub>O, K<sub>2</sub>O, TiO<sub>2</sub>, MnO, P<sub>2</sub>O<sub>5</sub>, BaO, SrO and L.O.I using ICP-MS in ALS Laboratory Group, Seville, Spain. The springs are described as exclusively mineralized of weakly alkaline pH belonging to the tepid class (25-34°C). They were originated from partial mixing of connate and meteoric waters. Mineralized water, crustal salts, natural tar and bitumen along with mud effect of absorbing the sunlight, moisturizing the skin and activates the blood circulation of the muscles and joints and work as anti-inflammatory agent against skin allergies. Bacterial species such as Pseudomonas, Bacillus subtilis, Staphylococcus and Lactobacillus capable of secretion enzymes inhibit the effectiveness of the other harmful bacteria that may be available in the mud. The spring water are compared with the global famous guidelines (The European Union and US spas), while the spring sediments are compared to the Dead Sea Mud. The springs are considered as potential sources of health spas for therapeutic uses. Despite, they could be as natural heritages in Iraq, but also they are considered as medicinal sites for massage and fitness, beauty treatments, weight-loss spas and spending time during vacation and Athletic camps and tourism.



# **Sustainable Management of Surface & Subsurface Water of Hashyimia Region by a Hydrogeologic Solution Under Social Contradictions and Terroristic Extremism in Iraq**

## **Abstract n°1577**

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**KEYWORDS:** - SWR- surface water resources, confining layer, conjunctive use, SY- safe yield, WD- water demand, WL- withdrawal, WU- urban water.

Corresponding to many social problems arisen in Iraq such as population growth, political problems of controlling terroristic croups on the water dams of Tigris and Euphrates Rivers and even collapsing of Al Mosul Dam the biggest in Iraq (happening now in 2016), construction of Aliso Dam in Turkish to prevent surface water (SW) allocations entering Tigris causing a declining of water heads which led to stopped electrical hydropower stations leaving Iraq with a sharp leakage to electricity , people migration, in addition to worse administration politics, calls for new and effective water resources management were promoted. A hydrogeologic solution was issued by using 2D groundwater (GW) and conjunctive use models to optimize a conjunctive study for Hashyimia Region of 110km<sup>2</sup>. Saving a SW as possible is a main objective among other available water resources such as rainfall and GW exploitation provided that water requirements are completely satisfied. Unsteady groundwater modeling process based upon the solution of finite difference approach of Laplace`s Equation required mesh design of a model domain, aquifer properties determination by pumping test analysis, model calibration to evaluate the safe yield of aquifer bearing layer whereas the conjunctive use model required an assessment of meteorological elements, local plant diversity and water demand estimation, population counting and urban water needs to adapt an integrated water resources management. The hydrogeologic management study based firstly upon consuming a rainfall and GW resources to satisfy the total water requirements and secondly is integrated by SW if it is needed. The current hydrogeologic study paved the solution to many social and ecosystem problems and encourage the opposite people immigration through satisfying people water requirements and overcoming the local environmental problems such drying of swamped lands, and saving of 66,099,456mcm year of SW. The study revealed that previously a 3.76 cumces of SW is specified to cultivate 48% of the total area whereas the current study showed a 3.467 cumces enough to cultivate the total area.



## **Proving 'Urban Karst' as a Mechanism for Basement Flooding in a Till Aquitard Abstract n°1578**

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**KEYWORDS:** Leaking sewers, Aquitards

Increasing impermeable surfaces in urban settings and installation of storm sewers and other urban infrastructure can affect groundwater flow patterns in urbanized watersheds. Although interaction between storm sewers and the groundwater system is widely recognized in the literature, there are few studies describing quantitatively how the storm sewer system 'karstifies' an aquitard groundwater system. This paper presents a unique study of an urban community in North America that has proven a wide-scale interaction through a groundwater pathway in the storm sewer bedding material between storm sewers and the foundation drainage collection (FDC) system that were designed to operate as hydraulically separate entities. The work was part of a larger study to assess the cause of community wide basement water infiltration for the City of Mississauga, Ontario, Canada. The main problem of the study was to identify the mechanism for FDC surcharging under storm conditions that caused clear water to infiltrate into basements. The study team designed a series of storm sewer leakage tests based on the integration of water level and temperature data from groundwater monitoring wells, the FDC system, storm sewer and surface water gauges, footage from FDC CCTV and the original engineering designs. The storm sewer leakage tests comprised blocking and filling of storm sewers and the use of classical karst dye tracing methods to track the pathway of the leaking waters. Clear breakthroughs were recorded in the FDCs only hours after dye release. The coarse granular fill material within cross-connecting sewer trenches was identified as the flow path, with the surrounding till aquitard acting to focus flow within the utility trench. The data obtained, including measured estimates of storm sewer leakage, were a key input to the system modelling to better understand and inform the overall community storm sewer system behaviour and ultimately solving the problem.



## **Contrast of groundwater ages around saltwater-freshwater mixing zone Abstract n°1579**

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**KEYWORDS:** saline and freshwater mixing zone, carbon-14, helium-4

This presentation reports the subsequent investigation on the last presentation “Carbon-14 age of groundwater in freshwater-saltwater mixing zone” in 42nd IAH Congress, AQUA 2015 in Roma. The aim of the study is to check the stability of saltwater-freshwater mixing zone below active groundwater flow in Quaternary unconsolidated fan deposit, which locates the coastal area on the foot of Mt. Fuji. The unique feature of this study is to obtain the vertical profile of groundwater age from fresh water to saltwater water through freshwater-saltwater mixing zones at the distance of 50m from shoreline. We carried out a drilling up to 350 m in depth with taking groundwater samples at several depths. The groundwater chemistry and resistivity log indicate that saltwater-freshwater mixing zone ranges from 125 to 150 m depth. Below the 150 m depth, saltwater distributes. The ages of freshwater and saltwater have contrasting characters- freshwater age ranges from modern to several hundred years, while the saltwater has 10000 years. On the other hand, the Helium-4 age do not agree with the carbon-14 ages for the water in saltwater-freshwater mixing zone.



# **Towards Integrated Transboundary Groundwater Management in Southern Africa - The Case of the Ramotswa Aquifer Shared between South Africa and Botswana Abstract n°1580**

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KEYWORDS: transboundary, groundwater, management

Water is essential to economic development, resilience of ecosystems, biodiversity conservation, and human health and welfare in the Limpopo River Basin. Linked to the surface water resources of the Basin, major internationally shared groundwater reserves exist in the region that could support sustainable development, drought and flood resilience, urban expansion as well as small-scale agriculture if properly and conjunctively developed, shared, recharged, and managed as part of ongoing joint collaboration between the states. The Resilience in the Limpopo Basin- the Potential Role of the Transboundary Ramotswa Aquifer (RAMOTSWA) project focuses on one of the most important shared aquifers in the Limpopo Basin – the Ramotswa Aquifer. The project supports equitable access to water that balances urban and rural needs with ecosystem requirements under a changing climate and a growing demography to reduce climate vulnerability of both population and ecosystems by promoting adaptation strategies for integrated, transboundary water resources management and by building the management capacity of river basin organizations, national authorities and local communities. Through a multidisciplinary methodology with multi-stakeholder involvement and a transboundary diagnostic analysis including socio-economical and hydrogeological studies, the project intends, in particular, to (1) improve the understanding of the socioeconomic importance of the aquifer area and the inequalities in water security across the population, (2) improve the knowledge of the extent of the transboundary aquifer resources and the hydrogeology by conducting an airborne survey, (3) develop tools for shared and harmonized management and monitoring of the groundwater resources (Joint Information Management System) and (4) develop human and institutional capacity for shared and harmonized sustainable management. The presentation introduces the multidisciplinary approach of the project, to highlight the challenges faced and to present the results and outcomes of the socio-economical and hydrogeological baseline assessment.



**Mapping irrigation potential from renewable groundwater in Africa – a development perspective**  
**Abstract n°1581**

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KEYWORDS: groundwater, irrigation, Africa

Groundwater provides an important buffer to climate variability in Africa. Yet, groundwater irrigation contributes only approximately 1% of the cultivated land as compared to 14 % in Asia. As opposed to previous country-based estimates, this study derives a continent-wide, distributed (0.5 degree resolution) map of groundwater irrigation potential, indicated in terms of fractions of cropland potentially irrigable with renewable groundwater. The method builds on an annual groundwater balance approach using 41 years of model data, allocating to groundwater irrigation the groundwater recharge in excess after satisfying other current human needs and environmental requirements, while disregarding any socio-economic and physical constraints in access to the resource. Due to high uncertainty of groundwater environmental needs, three scenarios, leaving 30, 50 and 70% of recharge for the environment, were implemented in a conservative estimate of the potential. In addition, current dominating crops and cropping rotations and associated irrigation requirements in a zonal approach were applied. Results show an inhomogeneously distributed gross groundwater irrigation potential across the continent, even within individual countries, reflecting recharge patterns and extent of cropland. Results further show that average annual groundwater available for irrigation ranges from 708 to 1669 km<sup>3</sup> depending on scenario. The total area of cropland irrigable with groundwater ranges from 44.6 to 105.3 million hectares, corresponding to 20.5% to 48.5% of the cropland over the continent. To extend this assessment, the results are compared with socio-economic and physical parameters in a composite mapping analysis in order to identify the areas where agricultural development of groundwater irrigation is most feasible. It appears that only 70% of the area identified with the groundwater irrigation potential approach are in socio-economic favorable areas for groundwater development for agriculture. Accounting for existing groundwater irrigation, residual irrigation potential remains high and relevant for poverty alleviation in the Sahel and Eastern Africa region.



**Pollution of alpine ponds and groundwater by de-icing chemicals (Serra da Estrela,  
Central Portugal)  
Abstract n°1582**

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KEYWORDS: alpine ponds, mountain aquifers, de-icing chemicals

The ecological and socioeconomic importance of mountains is being increasingly recognised. Such regions provide key ecosystem services, namely, water supply which benefits local as well as lowland human populations. Besides mountain aquifers and rivers, alpine lakes and ponds are crucial for water resources management but are also important in hydroecological and wildlife conservation terms. This study aims at comparing the pollution of surface and underground water bodies by de-icing chemicals in a mountain environment. The influence of geological, geomorphological, pedological, climatic and anthropic conditions is taken into account. The study region is the highest part of the Serra da Estrela, a Mediterranean mountain located in Central Portugal. In this area there is a hydrological system which encompasses water-table aquifers and number of alpine ponds of glacial origin situated between 1500 m a.s.l. and the summit (1993 m a.s.l.). In the study area, the alpine ponds and springs were inventoried. Water sampling campaigns were carried out for hydrogeochemical characterisation of alpine ponds. These results were compared with hydrogeochemical data from water springs obtained in previous studies. Concentration of the following analytes were determined- total organic carbon (TOC), metals (Pb, Zn, Fe, Cu, Ni, Cd, Cr, As, Mn), cations ( $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ), anions ( $\text{F}^-$ ,  $\text{Cl}^-$ ,  $\text{NO}_3^-$ ,  $\text{SO}_4^{2-}$ ), silica ( $\text{SiO}_2$ ) and nutrients (N, P). Additionally, parameters such as pH, conductivity, turbidity and alkalinity were also measured. The hydrogeochemistry of ponds and water table aquifers affected by de-icing chemicals is clearly different from the one showed by non-polluted water bodies, due to the influence of different physical settings as well as to the spatial distribution of the anthropic influence. The pond and aquifer contamination affects water quality but may also disturb the local highly sensitive aquatic ecosystems.



**The Agreement of the Guarani Aquifer. A regional adaptation to the Law of Transboundary Aquifers  
Abstract n°1583**

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KEYWORDS: Legal – Tools- Transboundary Aquifers

The interesting peculiarity which has the Agreement of the Guarani Aquifer (2010) - as regional adaptation to the Law of Transboundary Aquifers (U N A Res 63 439)- is that it turns out to be a valid international legal tool to articulate and strengthen local legal and institutional frameworks, concerning the functioning of the aquifer system, their recharging and discharge zones, the checking or monitoring activities , which have - or may have- direct or indirectly negative impact in the short or long term, either on the surface or underground. Through its articles - even though the Agreement is still not current due to lack of total ratification of all the signatory countries – it is estimated that it would be a useful legal tool to reach a sustainable and integrated management through the principles of- equitable and reasonable utilization, the obligation to prevent and not to cause significant harm to other aquifer State, general obligation to cooperate and regular exchange of data and information. In this sense, the agreement is an invitation to the signatory countries to effectively implement cadastres and registers of waters, as technical tools to meet the proposed purposes.



**Relationships between natural fluorescence and organic matter content based on sampling and in-situ monitoring of groundwater. Application to the karst systems of the Lez and Fontaine de Nîmes springs**  
**Abstract n°1585**

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**KEYWORDS:** Natural fluorescence, Organic carbon flow, Continuous monitoring

In karstic aquifers, changes in organic content are now commonly used to track the arrival of water from rapid infiltration (Blondel et al., 2010). Along with physico-chemical and hydrodynamic monitoring, the continuous monitoring of Total and Dissolved Organic Carbon (TOC DOC) can thus be used to enhance our understanding of karst flows processes and karst vulnerability to pollution. In addition to laboratory TOC analyzer, different optical approaches have been proposed to measure organic contents in waters, based on fluorescence or absorbance properties of the organic compounds (Coble, 1996). First studies dealing with fluorescence spectroscopy on karstic aquifers highlighted two distinct compounds of fluorescent organic matter, denoted humic-like and protein-like (Mudarra et al., 2011+ Quiers et al., 2013). This approach however requires analyses on water samples, and is consequently limited to punctual monitoring. Other studies focused on continuous measurements of natural fluorescence by using field fluorometers, initially designed for continuous measurement of artificial dye tracers. Recent results highlight that field fluorometers can be used to measure humic-like substances, while protein-like compounds need further developments (Durepaire, 2014). Based on such in situ monitoring, correlation between TOC DOC and natural fluorescence data is not straightforward and show seasonal variations (Savoy, 2007+ Tissier et al., 2013). Our study aims at better understanding the relationships between fluorescence, absorbance and organic content in karst groundwater from two karst systems with contrasted environmental contexts, the Lez spring and the Fontaine de Nîmes spring. These two sites are equipped for physico-chemical and hydrodynamic monitoring, and also with field fluorometers and a submersible UV VIS spectrometer. Field sampling campaigns are also carried out in order to compare in situ measurements with laboratory analyses and also to sample different types of water that contribute to karstic flows to characterize the origin of the GW organic compounds. All these data will be gathered to explore and discuss the relationship between TOC DOC and fluorescence using samples analyses and in situ monitoring during the hydrological cycle.



**The Contribution of the ISARM initiative to international cooperation and its role regarding SDG Goal 6.5.2 on water cooperation  
Abstract n°1586**

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KEYWORDS: Transboundary aquifers+ SDG6 monitoring+ international law

2016 is an important year for the scientific community addressing the challenges of transboundary aquifer governance. On the one hand, the UN General Assembly (UNGA) will again discuss the set of Draft Articles on the Law of Transboundary Aquifers+ on the other hand, the SDGs indicators framework will be adopted by the UNGA. The presentation will first address the issue of transboundary aquifer governance. Responding to the calls of the UNGA made in 2008, 2011 and 2013 (A RES 63 124, 66 104 and 68 118), the UNESCO International Hydrological Programme (UNESCO-IHP) continued its contribution in the field of transboundary aquifer governance by offering scientific and technical assistance to interested Parties or States through the activities of the International Shared Aquifers Resources Management (ISARM) Initiative. Since its launch in 2000, ISARM has achieved outstanding results by developing and applying innovative methodologies for a global assessment of transboundary aquifers, mapping their location worldwide and enabling concrete cases of cooperative management mechanisms in different regions of the world. However, further ISARM efforts will be needed to encourage interested States to consider using the Draft Articles as “guidance” when considering agreements or arrangements for the management of transboundary aquifers as provided for in A RES 68 118. In the 2030 Agenda, progress towards operational arrangements for water cooperation will be tracked by the indicator on target 6.5.2 of the SDG 6. The work of ISARM, and UNESCO as one of the entities responsible for its global monitoring, will be crucial for providing relevant data, as well as for developing the monitoring methodology and for its testing in pilot countries. The inclusion of a stand-alone indicator for SDG 6.5 that captures a transboundary water cooperation element brings together the discussion on transboundary aquifer governance and SDGs. In fact, SDG 6 will be fully met only if more countries start looking into ways of cooperating over transboundary aquifers using also the Draft Articles as “guidance”.



**When Groundwater Input Results in Reduced Pool Persistence- Isolated Waterholes in an Arid Environment**  
**Abstract n°1587**

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**KEYWORDS:** environmental resilience+ stable isotopes+ refugia+ intermittent rivers+ baseflow indices

The presence of groundwater inflows to rivers and creeks is generally presumed to result in increased and prolonged flow in ephemeral systems, with groundwater inputs maintaining baseflow during dry spells, particularly where seasonal potential evaporation significantly exceeds precipitation. In a dryland river environment in western Queensland, Australia, however, where river flow is intermittent and where surface water during dry times is limited to isolated in-channel pools, termed waterholes, we found a different pattern of interaction between groundwater and surface water. Two waterholes, of 15 we investigated, showed evidence of groundwater input during periods of high flow. These waterholes, however, also proved to have the greatest rates of water loss during extended periods without surface flow. Analysing a time sequence of stable isotopes in this system confirmed that waterholes that received groundwater-augmented flow also drained faster than those that did not, while those with no groundwater input exhibited a purely evaporative reduction in water volumes during periods of no flow. We surmise, therefore, that a rise in shallow groundwater tables during periods of rainfall resulted in preferential input to two waterholes only (possibly related to faulting). These waterholes also exhibit hard bedrock associated with local igneous intrusions. Waterholes that did not receive groundwater input exhibit fine-sediment river beds that remain sealed by fine-grained clays, inhibiting downwards leakage. As the river recessed and waterholes became isolated, those that were augmented by groundwater drained faster than those that did not receive groundwater input and the combined drainage and evaporation in groundwater-fed pools exceeded the evaporation only in surface water fed waterholes. The use of baseflow indices to indicate stream resilience of ephemeral systems, therefore, should be used with caution in arid areas with variable and shallow water tables.



## Stakeholder Engagement and Groundwater – A practical approach Abstract n°1588

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KEYWORDS: Groundwater Stewardship, Stakeholders

Water is a common good and an emotive subject. Facing an ever increasing water scarcity more and more companies must take into account and pro-actively manage the needs, perceptions and desires of stakeholders to avoid restrictions on their ability to use water. Stakeholder engagement needs to happen at the local level – literally in the basin. However, stakeholder engagement at this local level is very different from what is currently the norm in many companies. Acts of charity and philanthropy are necessary, but do not amount to a serious engagement activity. A centralized approach, driven from headquarters is also not an optimal approach. It is vitally important to engage with the right stakeholders at the right level of effort. Bad stakeholder engagement or ill-prepared stakeholder engagement is worse than no engagement. Stakeholder engagement, when done well, however, will significantly improve companies' chances of continued and uninterrupted production. Practical approach to stakeholder identification and mapping must be outlined in order to help companies to design the right, fit for purpose, stakeholder engagement plan. Identifying the stakeholders is only the beginning. The stakeholders need then be scrutinized and assessed for a number of key criteria. These criteria will depend on the company's own strategic objectives. Once this is done, a stakeholder map can be constructed to provide an overview of all stakeholders in such a way that in the next step, planning, an approach for each stakeholder that is in line with company strategy will be designed. Only then can we work together with stakeholders on a more sustainable use of water in each basin.



## Diagnostic Analysis of the Pretashkent Transboundary Aquifer Abstract n°1589

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KEYWORDS: TRANSBOUNDARY AQUIFER, DIAGNOSTIC

Pretashkent transboundary aquifer (PTBA) is a unique source of deep lying fresh groundwater in Central Asia, located within the territories of Kazakhstan and Uzbekistan. The population of 463.4 thousand people on the Kazakhstani segment of the aquifer greatly depends on groundwater of PTBA. The mineral water of PTBA is widely used for SPA and bottling in Kazakhstan and in Uzbekistan. Given the importance of the groundwater resources to the region a multidisciplinary study of the PTBA has been conducted in 2014-15. The study and subsequent diagnostic analysis of main problems and risks for the Pretashkent transboundary aquifer was performed in accordance with UNESCO GGRETA project's methodology of indicator based assessment of groundwater resources, based on the DPSIR methodology. The analysis demonstrated the importance of development and implementation of complex and urgent management measures especially at the interstate level. During the assessment two main transboundary problems were distinguished, both linked to the decrease in groundwater level in the PTBA - 1. depletion of PTBA's groundwater storage+ 2. potential deterioration of PTBA's groundwater quality (increase in mineralisation). The study identified two main groups of causes contributing to the changes of groundwater resources of PTBA - Group 1. Socio-economic drivers (or root-causes)- 1) growth of population size+ 2) economic development. Group 2. Environmental driver (1) and indirect (pressures (2 and 3)- 1) climatic+ 2) depletion of groundwater resources of overlying non-transboundary aquifers+ 3) pollution of surface water and groundwater of overlying non-transboundary aquifers. It's been observed that, there are conflicts of interests between the countries concerning the use of groundwater resources of PTBA as well as local conflicts of interests between individual users of the aquifer's groundwater. As a result of the diagnostic analysis the recommendations for the optimization of the further exploitation of groundwater resources of PTBA (Kazakhstan part) have been prepared. The methodology of such diagnostic can be used in the implementation of the Syrdarya' project (UNESCO).



# Hydrogeological GIS-Mapping of Runoff Basins as a Basis for Information Support of Integrated Groundwater Resource Management

## Abstract n°1590

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KEYWORDS: hydrogeological GIS-mapping, groundwater management

Integrated water resource management, including management of groundwater resources, is based upon the modern and constantly changing information support. Hydrogeological map of runoff basin on a scale of 1-500000 for information support of subsoil and water use management related to the groundwaters is created on the basis of GIS-technology. Thus, GIS-map is a part of workplace for specialist hydrogeologists. The standard legend for hydrogeological map of runoff basin contains the following sections- 1) Hydrogeological subdivisions and their distribution along the area+ 2) Hydrogeological zoning+ 3) Groundwater reserves and their use+ 4) Water exchange characteristics+ 5) Natural and technical manifestations of groundwater (wells, springs, etc.)+ 6) Mineralisation, chemical compositions of groundwater+ 7) Natural bodies and processes of hydrogeological meaning and their parameters+ 8) Technogenic bodies and systems affecting hydrogeological conditions+ 9) Technogenic changes of hydrogeological conditions. Hydrogeological subdivisions (aquifers, aquifer complexes, aquitards) are shown with the solid colour or with the colour of outlines with hachures of specific form in accordance with the type of the reservoir and its water abundance. Besides, the GIS-map enables displaying the hydrogeological cross-section in a separate window. In pop-up windows, the following information is displayed- 1) Hydrogeological structure in any point of the map+ 2) Hydrogeological characteristics of hydrogeological subdivision of any area of its distribution+ 3) Groundwater well-fields with approved exploitable resources of groundwater+ 4) Groundwater abstraction+ 5) Geological and technical logs of hydrogeological boreholes+ 6) Observational stations and points of the state groundwater-monitoring system+ 7) Groundwater contamination sites, etc. The features of GIS-map compilation and functioning are illustrated with the example of the GIS-map of the Lake Balkhash basin of runoff, area of 350,000 km<sup>2</sup>, in Kazakhstan. The suggested map shall be a new powerful tool for provision of groundwater resources management at the territorial and basin level.



**Linear Infrastructure Development Project – Vulnerability assessment using PaPRIKa Method**  
**Abstract n°1592**

Topic 8 - progress in conceptual models, tools and methods Accepte Poster, sylvain.anus@anteagroup.com,  
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KEYWORDS: vulnerability assessment, karstic aquifer

The multi-criteria method PaPRIka has been developed for the assessment of intrinsic vulnerability of carbonate aquifers. The acronym signifies “Protection of carbonate aquifers based on Protection, Reservoir, Infiltration and development of the karst network” and considers in its name the four principal criteria used to identify the vulnerability. Protection and infiltration relate to the infiltration zone (vertical water transfers), reservoir and development of the karst network refer to the saturated zone (horizontal water transfers). These factors are either describing the structure of the aquifer or the functioning of the aquifer system. This method has been mainly developed to identify the vulnerability of a global carbonate aquifer system or a water catchment. In the first case, the factors describing the infiltration zone and the saturated zone represent both between 40 to 60 % of the final note. In the second case, the factors describing the saturated zone are more important and represent between 65 and 100 %. In the case of linear infrastructure projects, the principal constraint at the moment of an accidental discharging is not to contaminate the groundwater. Therefore, two adaptations have been developed in order to improve the vulnerability maps. In that case, the factors characterizing the unsaturated zone are much more important than the criteria describing the saturated zone. Therefore, the weight of these criteria has been increased to represent between 65 to 100 % of the final note. In order to improve the factor infiltration, two categories are distinguished in the case of a linear infrastructure project- the direct infiltration and the deferred infiltration. Direct infiltration refers to swallow holes and their catchment areas as well as other spots where absorption particularly occurs. Deferred infiltration is the combination of the criterion “protection” with the combination of slopes and superficial carbonate phenomena except from swallow holes.



## **ASTRIDE - Aquifer flow direction variation Abstract n°1593**

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KEYWORDS: Rose diagram, flow direction

In environmental diagnostics, knowledge of underground flow is of special importance since it is the vector of contamination and thus determines the potential risk within the site boundary, and sometimes outside. The information is generally issued from regional hydro geological records and or piezometric maps which include in the most favorable case high and low levels data. This approach provides only a vision at a given time and does not take account of the fact that these underground flows can vary up to be reversed according to natural parameters and or anthropogenic factors. Furthermore, groundwater quality monitoring on a site shows quite often inconsistencies regarding the location of monitoring well impacted from known contaminated soil sources. In this context, it is essential to have a good understanding of the aquifer's dynamic with an automatic monitoring of the up and down movement of the water table (tides), flow direction and flow velocity. A specific methodology has been developed to assess and quantify the aquifer flow direction changes. It is to calculate for each time step, orientation (azimuth) and slope (gradient) of the plane normal vector passing through three monitoring wells. The aquifer is assumed to be continuous and flat between the three points. A statistical treatment of the data is made to calculate the frequencies by range of directions. The results are plotted on a rose diagram. A second statistical treatment is made by considering the flow passed by range of directions. The hydraulic flow is equal to the product of permeability by the gradient and flow section ( $Q = K.i.A.$ ) Permeability being an intrinsic parameter of the aquifer and the variation of aquifer section considered as negligible, a balancing can be performed directly, in first approach, on the slope of the water table with the Darcy formula.



## **Modular TDR for real-time automated soil water content profile analysis Abstract n°1594**

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**KEYWORDS:** Time Domain Reflectometry (TDR), soil water content, dielectric permittivity

Time Domain Reflectometry (TDR) is a valuable technique for investigation of the vadose hydrological zone and the contained water through the unsaturated column. In this work we present an integrated system that uses a modular TDR wave guide as a probe to obtain high resolution soil water content profiles through the entire unsaturated zone, for the real time continuous monitoring of soil water content fluctuations. The major design requirements are analysed and a solution based on Commercial Off-The-Shelf (COTS) components is presented, characterised by low power consumption, minimal size and very fast on the field deployment and installation. Robust automatic shape analysis of the measured TDR waveform and calculation of the waveform characteristic feature points and statistical parameters are performed automatically. The apparent relative dielectric permittivity and relevant soil water content profile of the surrounding medium along the TDR sensor length is calculated using the inverse modeling approach. All measurements and processed data are stored onboard. The correlation in time of waveforms, other measurements and meta-data, enables adaptive system sleep time between measurements, according to changing environmental weather conditions. The use of open source software (Linux, C++) and System on a Chip (SoC) based hardware, ensure a flexible and expandable system that is vendor neutral, has minimal cost, can integrate data from a variety of other sensors (eg. temperature, pressure) and offers a multitude of user interface, storage and communication options. The integrated system, which has been evaluated in a laboratory setup using a soil column and at a Managed Aquifer Recharge (MAR) application site, is a valuable tool for analysing the mechanisms of water fluxes through significant depths within the unsaturated zone.



**Characterisation of antibioresistance of bacterial communities in a mediterranean karst system- impact of hydrogeological functioning during the hydrological cycle**  
**Abstract n°1595**

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**KEYWORDS:** Karst groundwater, environmental tracers, culturable antibiotic resistant bacterial communities

Karst aquifers are a major water resource supplying more than 25 % of the world population and up to 50 % of the population in the Mediterranean basin. However, karst groundwater is particularly vulnerable to anthropogenic contaminations due to fast transit from the surface through direct flow pathways. Karst features thus play a crucial role in interconnecting surface and subsurface ecosystem, which contribute to the circulation of antibiotic-resistant bacteria. Microbial community in karst groundwater as well as the impact of groundwater for emergence and dissemination of antibioresistance is still few documented despite the relevance for human health. This project focus on the role of karst as reservoir for antimicrobial resistance in Mediterranean area submitted to a high water demand. The Lez aquifer is a typical Mediterranean karst aquifer, which supplies drinking water to the city of Montpellier. The aim of this study is (1) to evaluate the diversity and the antibiotics resistance of bacterial communities in contrasted hydrological conditions, and (2) to establish relations with the hydrogeological structure and the hydro-chemical characteristics of waters. Since April 2014, the Lez spring was sampled during high, low and normal flows, for hydrochemical (major and trace elements, Total Organic Carbon, dissolved gases) and microbiological analyses. We develop an original mixed method associating i) study of the culturable bacterial community according to diverse antibiotics concentrations, and ii) taxonomic affiliation of resisting bacteria by 16S rRNA gene PCR-Temporal Temperature Gradient Gel Electrophoresis (TTGE) and sequencing. Minimal antibiotic concentrations inhibiting 50%, 70% and 90% of the whole culturable community were determined. We observed that resistance level to antibiotics (Amoxicillin, Ceftazidime and Cefotaxime) varies according to the sampling period, thus according to the residence time of water in the karst aquifer and to the mixing between different types of fluxes. Thereby, these considerations are important to elucidate how hydrogeology and human practices can impact on diversity and dynamics of microbial communities in karst groundwater.



## The implications of climate change on water resources in India Abstract n°1596

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KEYWORDS: glacier+ groundwater+ renewable energy

Scientists agree that rising concentrations of anthropogenically produced greenhouse gases in the Earth's atmosphere are leading to changes in the climate. The local observations of climate change in India are witnessed by fact that the entire Himalayan Hindu Kush ice mass has decreased in the last two decades. Hence, water supply in areas fed by Himalayan glacier melt, on which hundreds of millions of people in India depend, are negatively affected + precipitation decline and droughts in most regions of India due to warmer climate have resulted in drying up of wetlands and severe degradation of ecosystems + the gross per capita water availability in India is likely to decline from  $\sim 1820 \text{ m}^3$  year in 2001 to as low as  $\sim 1140 \text{ m}^3$  year in 2050. Serious and recurrent floods and droughts + sea-level rise leads to intrusion of saline water into the fresh groundwater in coastal aquifers and thus adversely affects groundwater resources. The thickness of freshwater lens was computed to decrease from 25m to 10m and from 36m to 28m, respectively, for a sea level rise of only 0.1m for two small and flat coral islands at the coast of India, India is now following the key strategies for cutting greenhouse gas emissions to zero are resource efficiency backed up by the substitution of renewable energy for fossil fuel sources. The major drawing down of CO<sub>2</sub> is to be achieved by using natural carbon sinks and deliberate human capture and sequestration of this gas such as growing biomass (Jatropha) for use as biofuel and capture the CO<sub>2</sub> when the fuel is combusted and then geosequester it and by growing forests that create water dynamics that efficiently capture heat from the land surface and redistribute it to the upper boundary of the troposphere where it can more easily radiate into space.



**Assessing the potential impacts of CO<sub>2</sub> leakage on fresh groundwater- from experiments to predictive models**  
**Abstract n°1598**

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KEYWORDS: CCS, groundwater quality

Geological storage of CO<sub>2</sub> in deep saline aquifers is one of the options considered for the mitigation of CO<sub>2</sub> emissions into the atmosphere. A deep geological CO<sub>2</sub> storage is not expected to leak, however, potential impacts of CO<sub>2</sub> leakage into aquifers overlying deep storage site have to be addressed. . A better understanding on how it could affect groundwater quality, aquifer minerals and trace elements mobilization is necessary to fully characterize a future storage site. Moreover, this characterization is required to evaluate monitoring and remediation plans. As part of the collaborative project CIPRES co-funded by the ANR, we present reactive transport works dedicated to the impact assessment of CCS on fresh groundwaters. In a 3D model using ToughReact v.3, we perform different CO<sub>2</sub> leakage scenarios in a confined aquifer. This study focuses on the Albian aquifer that is a strategic water resource in the Paris Basin. The model is based on groundwater and rock chemistry of the Albian green sand layer (i.e. Quartz, Glauconite, Kaolinite) at 700 m deep. The geochemical model was elaborated from experimental data (Barsotti et al. 2016 and Humez et al. 2014) taking into account kinetics for mineral dissolution, ion exchange and surface complexation processes. The numerical mesh consists of 200 m x 500 m x 60 m. A grid refinement near the leakage point is considered to focus on local phenomena e.g. secondary precipitation, surface processes. The total mesh comprises 21600 cells. The results highlight the importance of sorption processes on trace element mobilization and transport (As, Zn and Ni) in fresh groundwater. Moreover, we distinguish different geochemical behavior (CO<sub>2</sub> plume shape, secondary precipitation, desorption...) occurring at different depth and length scale according to the horizontal flow rates and density effects that are influenced by hydrodynamic properties (regional gradient). Coupling geochemical processes and regional flows influence on water chemistry evolution allows to strengthen monitoring and verification plan as well remediation perspectives.



**Use of  $^{222}\text{Rn}$  and  $^{18}\text{O}$ - $^2\text{H}$  isotopes in detecting origin of water and in quantifying groundwater inflow rates in an alarmingly growing Lake  
Abstract n°1599**

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**KEYWORDS:** Radon-222,  $^{18}\text{O}$ - $^2\text{H}$ , lake-groundwater interaction, expanding lake, seismicity induced fractures, Ethiopia

Dual Radon ( $^{222}\text{Rn}$ ) &  $^{18}\text{O}$ - $^2\text{H}$  isotopes have been utilized to a) detect the origin of water, b) pinpoint groundwater inflow zones and c) determine rates of groundwater inflows in an expanding lake in central Ethiopia. The lake expanded from 2 km<sup>2</sup> in to 50 km<sup>2</sup> over the 60 years causing serious engineering & socio economic challenges (inundation of urban utilities, inundation farms, inundation of railways and roads, ecological changes, and threatening water quality salinization for water users downstream). Commensurate with the changes in volume there quality changed from a hypersaline (TDS 50g/L) to a brackish water (3 g/L) condition. Presence of multiple interplay of mechanism (deformation related to seismicity, irrigation, neo-fractures, change in river stage) that could increase water volume make it difficult to take management measures. Radon isotope is powerful in pinpointing sites of groundwater inflows and determining groundwater inflow rates in a system with non-hydrologic steady state. However radon was not capable in detecting the source of the groundwater as shallow or deep, local or regional, cold or geothermal. This limitation in the capability of the radon method is complemented by use of  $^{18}\text{O}$ - $^2\text{H}$ . The  $^{18}\text{O}$ - $^2\text{H}$  has been used to discriminate the source of the groundwater responsible for expansion of the Lake. The results show that the main source of water responsible for expansion of the lake is irrigation excess water joining the lake through subsurface flow paths. The fast and voluminous flow is aided by dense network of faults and by seismically induced modern ground-cracks that enhance the transmissivity to as high as 10 000 m<sup>2</sup>/day. The radon mass balance shows the groundwater inflow amounts to 5.4 m<sup>3</sup> s. This is comparable with the 4.9 m<sup>3</sup> s annual seepage from three large farms. This work adds to the growing literature in use of radon in lake-groundwater interaction studies by demonstrating the capability of the method in solving a practical engineering challenge. Proposed engineering measures shall be discussed.



**Impact of on-site sanitation systems on groundwater sources in a costal aquifer in  
Chennai, India  
Abstract n°1600**

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**KEYWORDS:** On-site sanitation, Groundwater pollution, Nitrate, Faecal coliform, Coastal aquifer.

On-site sanitation is the most preferred mode of sanitation due to expensive off-site sanitation. The increasing population especially in the peri-urban areas has led to increasing use of on-site sanitation systems in India. However, the habitations in the vicinity of these systems do not have centralised water supply and are dependent on groundwater sources. However, there is concern about leaching of faecal coliforms and nitrate from the septic tanks to the underlying aquifer. The present study is attempted at two sites in the coastal city of Chennai where on-site sanitation is prevailing. The sample locations (16 Nos.) are selected in such a way that groundwater sources are situated in the vicinity of on-site sanitation systems. The groundwater sources are the bore wells installed by the Private agencies. It is observed that parameters considered key parameters to study the impact of the on-site sanitation systems, namely  $\text{Na}^+$ ,  $\text{Cl}^-$ ,  $\text{NO}_3^-$ , faecal coliform and total dissolved solids exceed the concentration limits recommended by the Bureau of Indian Standards. The Piper diagram analysis identifies that the predominant cations and anions are respectively  $\text{Na}^+$ , and  $\text{Cl}^-$ ,  $\text{SO}_4^-$ ,  $\text{HCO}_3^-$ . The Gibbs plot shows ground water quality is dominated by the evaporation process in both the seasons. The  $\text{Cl}^-/\text{HCO}_3^-$  ratio in many samples confirms the sea water intrusion in the study area. Elevated concentrations of faecal coliforms in all 16 samples confirm the significant amount of groundwater pollution from the on-site sanitation systems. It is desired that policy planners and implementation agencies have detailed scientific and hydrogeological studies of the region in order to examine the feasibility of implementing on-site sanitation systems.



**Pharmaceuticals in wastewater and its interaction with groundwater- a case study of  
wastewater infiltration locality in Czech Republic  
Abstract n°1601**

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**KEYWORDS:** pharmaceuticals, wastewater, groundwater

Micropollutants in the environment are becoming a topical water management issue. Some pharmaceuticals are not effectively eliminated in most of current wastewater treatment plants. This specific type of pollution is therefore transferred from wastewater to surface water and successively to groundwater. Their effect on environment and human health is still uncertain, but we can expect more and more calls for concentration limits and standards for such substances in coming decades. Better understanding of occurrence and behavior of emerging pollutants like pharmaceuticals is our priority issue. The purpose of our study is to evaluate the removal of pharmaceuticals in conventional wastewater treatment plants in Czech Republic and describe the occurrence and fate of pharmaceuticals on locality with infiltration of treated wastewater. Our complex monitoring system provides samples of wastewater, infiltrating surface water, infiltration ponds sediments and groundwater in different distances from source of pollution. The samples are analyzed for a range of 32 pharmaceuticals. The results reveal that wastewater treatment plants remove some of the analytes very efficiently (e.g. Paracetamol, Ibuprofen, Atenolol) while other pass the facility to a considerable extent (e.g. Carbamezepin, Diclofenac, Hydrochlorothiazide). The efficiency of different wastewater treatment plants is very variable. The samples of sediments confirm high sorption rate of most pharmaceuticals. After infiltration the concentrations of majority of detected micropollutants in groundwater gradually decrease, but species like e.g. Carbamezepin seem to be very persistent and decrease only due to dilution of infiltrated water. We can conclude that current wastewater treatment plants are not able to remove a range of pharmaceuticals. The soil and unsaturated zone play an important role in natural attenuation of pharmaceuticals in case of infiltration of pretreated wastewater. The processes in aquifer efficiently remove the residues of majority of pharmaceuticals, but not without exceptions.



## **Karst genesis modelling of a regional Mediterranean aquifer (Lez, France) Abstract n°1604**

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

The exploitation of karst aquifers is a risky activity as far as the drilling of the main conduits of the karstic network is not systematically successful. However, a better knowledge of the karst development along time could help to predict the preferential areas in which the karstic drains occur. Several attempts have tried to understand how the drains are growing along time. These studies concern either –(i) geological studies on the field+ or –(ii) numerical modelling. Combining both the field observations and the numerical modelling appears as a promising solution for a better forecast of the preferential zones of karst development. However, such a combination is still a challenging objective. For the last few millions years, the aquifer of Lez (Montpellier, France) has been developed in a Mediterranean setting. However, several evidences show that other previous karstification stages affected this aquifer. The problem is to weight the impact of each of these stages on the present-day karst network. For example, the Messinian crisis is considered as mainly driving the architecture of the karst conduits, but how to quantify its impact compared to the ones of the previous and following stages? In order to provide quantitative arguments and elements of responses to these questions, a numerical modelling of diagenetic overprints (using an in-house TOTAL S.A. modelling toolbox) has been applied. This study shows that the main conduits of the present-day karstic network were created during the early karstification stages, and then used again during the Messinian. A preferential karstic area, located at the top of the Jurassic layer (jurassic epikarst), developed during the earliest period of karstification (late Jurassic). The karstification during the Messinian crisis emphasized and increased the dissolution in this superficial zone, but also created a new and deeper karstic network. For the first time, such a study has been carried out at the regional scale. Results are so exciting that the same methodology shall be applied in other locations and other reservoirs.



**Specific yield comparison between the two layers of a hard-rock aquifer model with  
Advar, a new quality-of-fit criterion  
Abstract n°1605**

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KEYWORDS: Two-layer numerical model, Quality-of-fit criterion, Specific yield

Hard-rock aquifers (HRA) have long been considered to be two-layer systems, with a mostly capacitive layer just below the surface, the saprolite layer, and a mainly transmissive layer underneath, the fissured layer. Although this hydrogeological conceptual model now attracts a wide consensus within the scientific community, it is difficult to prove that it can be efficient in terms of deterministic modelling, especially with an equivalent porous medium model, which would not be the first choice for “fractured aquifers”. In order to investigate the storage capacities of both layers and the recharge, a deterministic hydrogeological model was used on a HRA to calibrate the specific yield of each layer. The application site is the Plancoët migmatitic aquifer located in north-western Brittany, France, with piezometric data from 40 observation wells surveyed every two weeks for eight years. When the variance, the most common quality-of-fit criterion used in inverse calibration methods, was found to be inefficient for calibrating the specific yield and the recharge together, Advar , a new quality-of-fit criterion based on the seasonal piezometric amplitude variation, was developed and calculated for a set of 512 simulation results. Contrary to the variance, it is able to define the best values for the recharge and the specific yield in each layer. Adding to the conclusion that this two-layer model is well suited to such a HRA, it is demonstrated that the saprolite is about 2.5 times more capacitive than the fissured layer.



**Evaluation of groundwater ages in a layered aquifer system using analytical and numerical models**  
**Abstract n°1606**

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**KEYWORDS:** groundwater age, nitrate contamination, lumped parameter model, numerical simulation

Groundwater age can provide valuable information related to flow mechanism, migration of solute and aquifer vulnerability to contamination. Generally, water pumped at a groundwater well is a mixture of different ages of water particles not having a single age component. To avoid misinterpretation of the groundwater age derived from environmental tracers, it is important to consider mixing and dispersion processes occurring in the aquifer system. In this study, we estimated groundwater ages from 3H-3He environmental tracer data with application of analytical and numerical models to account for the groundwater mixing process. Tritium (3H) and noble gas dissolved in groundwater were sampled in two aquifer systems (shallow perched and deep regional aquifers) of the Gosan agricultural area, Jeju volcanic island. From the interpretation of environmental tracers, the apparent 3H-3He ages for the perched groundwater showed younger ages as 4.4 ~ 11.3 years than that of the regional groundwater, which has ranges of 22.1 ~ >60.0 years. Lumped parameter model estimated that dispersion mixing occurred for the perched aquifer and binary mixing between young perched groundwater and old regional groundwater can be explained for the age of regional groundwater contaminated by nitrate. Regional scaled numerical modeling of groundwater age showed that the importance of full age distributions for better characterizing the nitrate contamination in the complex aquifer system. Our combined evaluation of the analytical and numerical approaches was useful to delineate the dynamics on water and solute mixing in groundwater of the study area.



**Estimation of rock mass permeability using RQD and variation in hydraulic conductivity with depth**  
**Abstract n°1609**

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**KEYWORDS:** hard-rock aquifer, RQD, hydraulic conductivity, rock mass, injection test

The determination of the permeability of fractured rocks is one of the focal points in engineering projects concerning dams, tunnels, quarries and mines. The complexity of the topic is related to the heterogeneity and anisotropy of rock masses. Many methods have been developed for the direct in-situ determination of the hydraulic parameter, which are not always easy to perform because of their high costs and long times. Therefore, sometimes, especially in the preliminary stages of the rock mass characterization, empirical correlations are used to estimate the permeability of rocks and its variation with depth. The present study is addressed to derive a relationship between RQD, depth and permeability of rock mass. For this purpose, data of boreholes drilled in hard-rocks of western Turkey were considered, analyzing the results of core drilling by relating them with the results of injection tests. The approach used in this study considers the cubic law to calculate the hydraulic conductivity of the rock mass and its variation with depth. The parameters of the cubic law, i.e. aperture and discontinuity frequency, are obtained considering RQD measured during drilling, the depth of the section for which RQD was determined and empirical correlations with the results of injections tests on the same section. It is evident a decrease of rock mass permeability with depth in accordance with what is already known in the literature. On the contrary, it is not evident a significant relationship between RQD and depth. The relationship found between RQD and discontinuity frequency is in accordance with that reported in the literature. Based on these results, it follows that the parameter that mainly affects the decrease of the hydraulic conductivity with depth is precisely the aperture of discontinuities. In the end, the empirical relation found for the hydraulic conductivity of the rock mass as a function of the RQD and depth can be considered locally significant and very useful for a first characterization of rock masses.



**Origin and dynamics of spring flows during flood events inferred from innovative tracers**  
**Abstract n°1610**

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**KEYWORDS:** karst floods, multi-tracing, flow pathways

Understanding the dynamics of flow and recharge processes is crucial information for managing water resources. However, this is challenging in heterogeneous systems, e.g. karst, due to the strong spatial variability in flow pathways. In addition, the evolution of mixing at the event-scale is rarely characterized with sufficient details to constrain or validate hydrodynamic models. The objectives of this study were to (1) identify event-scale variations in contributions from different flow pathways to a karst spring, and (2) better constrain the response of spring dynamics to the spatio-temporal variability of flood events. The study focuses on the main spring (Lez spring) of a Mediterranean karst aquifer near Montpellier (SE France), which is subject to intense autumn rainfall events. We used innovations in (1) the continuous and high frequency monitoring of tracers ( $\delta^{18}\text{O}$ ,  $\delta^2\text{H}$ , and natural fluorescence+ humic and proteic-like compounds), and (2) the types of tracers monitored (natural and anthropogenic dissolved gases, radon and radium isotopes, 3D-fluorescence and total organic carbon). Three rainfall events highlighted distinct spring chemical responses. The first event was characterized by a contribution of deep groundwater flow (low CFC contents, low ( $^{228}\text{Ra}$   $^{226}\text{Ra}$ ) ratios and low organic carbon concentrations) resulting from a piston flow effect due to heavy rainfalls at the basin margins. The second event showed a proteic peak associated with a sharp decline in DO concentrations and an anomalous peak in  $\delta^{18}\text{O}$ . The third event was characterized by a dilution effect by subsurface waters (CFC contamination, high turbidity and radon peak) due to high local rainfall. The simultaneous monitoring of these tracers during multiple rainfall events provides an innovative approach in spring dynamics analysis, and improves our understanding of a complex hydrogeological system. The Lez spring supplies drinking water for Montpellier, therefore understanding the variability of water origins and potential contamination pathways during intense storm events is essential.



## Sources and sinks of sulfate in an urban aquifer – Berlin, Germany Abstract n°1611

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**KEYWORDS:** sulfur species, sulfate, atmospheric deposition, sulfur dioxide, groundwater, sulfur retardation, unsaturated zone

Occurrence of sulfur species in the urban water cycle of Berlin and deposition of sulfur compounds in the aquifer lead to elevated sulfate concentrations in the urban water resources. To mitigate the risk of increased sulfate concentrations in drinking water production wells, it is necessary to identify sources and sinks of sulfur species and to quantify the input of sulfate into the groundwater. The main concern is the sulfate load of surface waters discharging the lignite mining district of Lusatia, Brandenburg. The input of sulfate into the rivers Spree and Havel compromises the drinking water supply based on bank filtration. Additional sources of sulfate within the investigation area are debris deposits, organogenic sediments, discharge from sewage farms, oxidation of sulfides, mobilization of geogenic sulfur species, ascending groundwater from deeper aquifers as well as emissions from combustion processes (atmospheric input). Within the Grunewald forest (southwestern part of Berlin) some low moors are able to reduce high sulfate concentrations of the effluent of the Teufelsberg, which is a deposition of construction waste. These moors serve as sinks for high sulfate concentrations. Another source of sulfur, investigated in this study, is the input due to atmospheric deposition of sulfur dioxide from times when flue gas desulfurizing plants were not existing, i.e. from the seventies and eighties of the last century. Using batch experiments it was possible to detect sulfate peaks within the unsaturated zone in depths of about 16 m which could be traced back to an atmospheric deposition of the late eighties. Further investigations, including reactive transport modeling, will quantify the sulfate input into the groundwater regarding the different sources and sinks. The results will support the water supply companies in improving well management strategies.



## Abbé Paramelle's Method for Finding Groundwater in Karst Abstract n°1615

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KEYWORDS: Paramelle, karst, springs, observational method, conceptual model

In 1856 Abbé Paramelle published a best-selling book entitled *The Art of Finding Springs* that played a major role in promoting groundwater in France. Paramelle started searching for shallow water on the Jurassic karst plateau, the Causses de Quercy, in the Dept. of Lot in the 1820s. He identified the terrain of Lot as clay, granite, and limestone+ recognized that rainfall formed streams on clay and granite but not on limestone+ and observed that runoff infiltrates limestone and forms underground rivulets that issue as springs or flow into rivers. He estimated depth to water by measuring the elevation difference between sinkholes and springs and the distance between them. Success finding water in Lot launched Paramelle's career as a hydrogeologist. By 1854, he had evaluated 30,000 localities in person and predicted the probability of groundwater at 10,000 places, with a 90% success rate. His fame was such that Henry Darcy favorably reviewed Paramelle's method in *The Public Fountains of the City of Dijon*. Paramelle refined his methods as he prospected in 39 French departments. He noted that linear depressions host streams either at or beneath the surface and he estimated karstic spring discharge to be proportional to the length of a dry valley. He also hypothesized that aligned dolines mark out an underground water conduit that rests on an impermeable layer and that water erodes conduit walls and roofs to create dolines. By estimating runoff and evapotranspiration, he calculated a 1-12 ratio of spring discharge to rainfall at potential sites for wells and springs. Paramelle's model served the Dept. of Lot until the 1970s when dye tracing and cave surveys revealed groundwater flow through deep karstic conduits along tectonic features. This example shows how direct observational methods coupled to new technologies (e.g. remote sensing, geophysics) improve conceptual models for evaluating karstic systems.



## **Offshore aquifers- an answer to water scarcity? Abstract n°1618**

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**KEYWORDS:** offshore, aquifer, hydrogeology, policy, scarcity, hydrocarbon

During the last two decades mounting evidence has indicated that vast amounts of fresh to brackish water lie in confined aquifers under continental shelves around the world. Indeed, these aquifers have been discovered along the coast of every continent, and their genesis dates back to the last glacial maximum, when sea levels were much lower than they are today. Sheltered for thousands of years, these waters should not contain any modern pollutants, and extracting and transporting them should not be much more difficult than similar operations for offshore oil and gas. Indeed, the hydrocarbon industry has invested enormous human and financial resources into producing state of the art exploration and extraction technology that could be very helpful for developing offshore aquifers. Assuming that predictions of vast offshore water reserves are accurate and that development is financially and technically feasible, these aquifers could serve to meet critical needs in times of global water scarcity. However, several questions will have to be answered first. To date, none of the offshore aquifers has straddled an international marine boundary. In the event that transboundary offshore aquifers are discovered and targeted for development, ownership of the reserves will have to be agreed by the nations concerned. Further, selecting between competing agricultural, industrial, domestic and ecosystem needs in a water-scarce world will require thoughtful analysis, careful deliberation and skillful diplomacy. Hydrogeologists and policy-makers will doubtless play major and collaborative roles in crafting solutions. This presentation will show compelling evidence of the existence of offshore aquifers, will describe the technical and legal challenges to be addressed in conjunction with their development, and will discuss how competing needs should be weighed in a world where fresh, clean water has become scarce enough that it must be sought from the global seabeds.



## Management of irrigation-induced groundwater salinity - a novel approach Abstract n°1619

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KEYWORDS: Groundwater management, over-allocation, salinity

The Tintinara-Coonaplyn Prescribed Wells Area (PWA) is located in the upper South East of South Australia approximately 200 km southeast of Adelaide. Managers of the groundwater resources in the PWA are dealing with a number of complex issues, including groundwater salinisation, groundwater level declines due to below average rainfall and over-allocation in some management areas. Groundwater extracted from a shallow Quaternary limestone aquifer is applied to Lucerne (alfalfa) by flood and pivot irrigation, resulting in increasing groundwater salinity due to the recycling of the irrigation drainage water. Over 50% of irrigation wells sampled show an increase due to this process. In 2003, the first Water Allocation Plan (WAP) for the Tintinara-Coonaplyn Prescribed Wells Area was adopted to provide a management framework for the groundwater resources. Problems arising from over-extraction from aquifers are managed by reducing such extractions to sustainable levels. However, the degradation due to recycling is caused by application of water to the crop rather than the physical removal of water from the aquifer, and hence a new approach was required. A buffer zone method was instigated to prevent concentrations of irrigation (and salt accessions) in any given area and allow dispersion and dilution of the salt added to the aquifer by rainfall recharge. This method will also prevent excessive drawdowns in water levels caused by pumping which may prevent lateral groundwater flow through the aquifer which removes salt from the region. Theoretical crop irrigation requirements (TCR) were used to determine the volumetric allocations for irrigators. An area limitation was also imposed so the area irrigated could not be increased. Metered data subsequently showed that actual extractions were only about 45% of the TCR for the same area of irrigated crop. The over-allocation issue was successfully addressed by recalculating the TCRs using more recent information, setting a reduction target for allocations and involving the 40 irrigators in determining the methodology for meeting that reduction target.



**Geotechnical Centrifuge Modelling of Variably Saturated Flow at the Soil-Rock Interface**  
**Abstract n°1621**

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KEYWORDS: Physical modelling, soil-rock interface, variable saturation, fracture flow, flow regimes geotechnical centrifuge

Unsaturated flow from soil into fractured bedrock is investigated by means of geotechnical centrifuge modelling. Modelling of the development of a dispersion plume in soil showed good accordance between scaled dispersion plume dimensions and numerical methods in soil. Confirming the viability of the centrifuge in replicating natural soil conditions, subsequent experiments incorporate a single inclined clean smooth parallel fracture. This showed the development of a perched water system and saturated wetting front along the interface, supporting capillary-dominant conceptual models for fractured vadose zone where breaching through the interface occurred from preferential feeding pathways in the soil as multiple point sources in the fracture. Film flow is shown to play a significant role through the presence of droplets, tendrils with droplet formation, and numerous types of rivulets. Intermittent influx provides larger saturated wetting fronts along the interface while continuous influx promotes flow instability within the fracture through oscillating and meandering of rivulets. Full saturation is never achieved within the fracture and only 5-30% cross-sectional area contributes to flow, which further decreases with depth. Non-vertical fractures showed decreasing droplet flow and the formation of a capillary barrier, while conversely increasing flow instability within the fracture. Contrasting support for both conceptual models, regardless of fracture inclination, indicates capillary flow dominating in soil material and film flow in fractures. Current challenges include understanding film and capillary forces within a fracture such that a combined conceptual model is capable of correctly replicating numerous field implications and characteristics observed at the soil-rock interface. Applications to preferential flow, groundwater recharge, aquifer vulnerability and dewatering are envisaged.



**The influence of aquifer mineralogy and trace gas composition on the potential impact of a CO<sub>2</sub> leakage on groundwater quality**  
**Abstract n°1622**

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KEYWORDS: CCS, natural CO<sub>2</sub> leakage, groundwater impact

One concern regarding CO<sub>2</sub> geological storage is the potential impact a leak of gas, or reservoir-associated brines, may have on groundwater quality in overlying potable aquifers. Sites where geological CO<sub>2</sub> is naturally leaking into near-surface aquifers provide opportunity to study large, long-term processes in different geological settings. We present results from two locations in Italy- i) the Latera caldera has silicate mineralogy with gas leakage (CO<sub>2</sub>, trace H<sub>2</sub>S, CH<sub>4</sub>)+ ii) the San Vittorino site has carbonate mineralogy with leaking gas (CO<sub>2</sub>, trace H<sub>2</sub>S, CH<sub>4</sub>) and groundwater. At both sites shallow boreholes were augered parallel to the hydraulic gradient. Samples were analysed on-site for physical-chemical parameters and in the lab for major and trace elements. A significant difference between the response of the two aquifers was observed. The low buffering capacity of the silicates at Latera result in pH values as low as 3.5 compared to minimum pH values of only 6 in the San Vittorino carbonates. Redox was found to be equally important in controlling mineral stability and associated ion mobility. H<sub>2</sub>S is particularly important due to its oxidation and the formation of sulfate ion complexes, yielding species and processes not unlike those in acid mine drainage. Different elements were anomalous in the leakage areas of the two sites, such as very high aluminum values in Latera silicates or elevated magnesium in San Vittorino carbonates. Down gradient attenuation processes lower the concentrations of most elements, although this is more evident at the Latera site due to the longer transect. This work highlights the importance of aquifer mineralogy and trace gas composition on the potential impact of leakage from a CCS storage reservoir on groundwater quality. The utility of studying natural leaking sites is also illustrated.



**Coupled thermo-hydro-mechanical modeling of geological CO<sub>2</sub> storage at In Salah,  
Algeria  
Abstract n°1623**

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**KEYWORDS:** geologic carbon storage+ induced seismicity+ geomechanics+ caprock

Geologic carbon storage (GCS) has emerged as an option to significantly reduce carbon dioxide (CO<sub>2</sub>) emissions and thus, mitigate anthropogenic climate change. Several questions related to GCS remain open and some of them have been controversial lately, such as the likelihood of GCS to induce large seismic events and the potential for CO<sub>2</sub> to leak. In spite of the fact most of the modeling studies suggest that a proper pressure management may lead to a safe CO<sub>2</sub> storage, i.e., without inducing earthquakes and without causing CO<sub>2</sub> leakage, demonstration projects are required to turn GCS into a reality. The In Salah Gas Project, in Algeria, was an industrial scale GCS project that permitted to test the geomechanical response of the subsurface to CO<sub>2</sub> injection at high pressure. Furthermore, the injected CO<sub>2</sub> reached the storage formation at a temperature around 45 OC colder than the rock. We numerically investigate the thermo-hydro-mechanical (THM) couplings that take place during cold CO<sub>2</sub> injection at In Salah. Simulation results show that cooling decreases fracture stability, which may be the cause of a portion of the induced microseismic events that were measured, most of them occurring within the storage formation or below it. The region affected by cooling is much smaller than the CO<sub>2</sub> plume and concentrates around the injection well. Cooling causes the contraction of the rock matrix, which opens up existing fractures, leading to an increase in injectivity. We found that the solution of coupled THM processes is required to explain some of the observations reported at In Salah.



**SOWAMO – Sowing Water in Monchique Mountain in Algarve, Adapting Portugal do  
Climate Change  
Abstract n°1624**

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**KEYWORDS:** Climate change, MAR (managed aquifer recharge), hard rocks

SOWAMO project, financed by the EEA grants, addresses the vulnerability of Monchique Mountain water resources, in the context of climate change scenarios, where water supply for over 6000 inhabitants is assured by gravity groundwater intakes. Monchique discontinued aquifers occur in two main subsystems- i) an epidermal subsystem constituted by weathered syenite rocks, with direct recharge ( 5% precipitation) and an estimated porosity and permeability of about 5 to 15% and 10-1 m d, respectively+ ii) a deep fractured subsystem recharged directly and by vertical drainage from the upper system, with an estimated porosity of around 1 to 5% and permeability around 10-2 m d. A first approach to the local water balance predicts 60 mm of annual infiltration, 670 mm of evapotranspiration and 484 mm runoff, from a total average annual precipitation of 1215 mm. SOWAMO aims at potentiate groundwater recharge and improve the municipal springs and wells' productivity, prevent future drought situations and increase the resilience of the current municipal water supply system, which stands out for its simplicity, efficiency and sustainability. Recharge will be developed through a hydraulic system composed by two retention reservoirs coupled to two infiltration channels, which will lead water surplus to an infiltration basin, upstream the target existing galleries and wells. The infiltration channels, with an infiltration rate of about 1.44 to 3.6 m d, are expected to have a maximum infiltration capacity of about 1000 m<sup>3</sup> d. The major challenge is to understand the local hydrogeology and implement a storage and MAR system and a management protocol that assures its maximum efficiency. The main foreseen difficulties lie on the groundwater model calibration to develop after infiltration permeability tests and precipitation and groundwater data analysis. As the impacts of the project extend to the local biodiversity, ecosystems and its services, native forest and aquatic systems, are also being studied. The project has a good potential to be replicated in Portugal, were similar hydrogeological conditions occur, and in equivalent Mediterranean areas.



**Global-scale assessment of groundwater stress in transboundary aquifers under climate and water use change**  
**Abstract n°1627**

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**KEYWORDS:** Transboundary aquifers, groundwater stress indicators, climate change

Within the framework of the Transboundary Waters Assessment Programme (TWAP), initiated by the Global Environment Facility (GEF), we contributed to a comprehensive baseline assessment of transboundary aquifers (TBAs) by quantifying different groundwater indicators under current (2010) and projected conditions in 2030 and 2050 using the global water resources and water use model WaterGAP 2.2. The set of indicators included per-capita groundwater recharge, groundwater depletion, dependency on groundwater, and groundwater development stress (groundwater withdrawals to groundwater recharge, GWDS). Projected indicators were quantified using climate scenarios of five global climate models (GCMs) for the high-emissions scenario RCP 8.5 and two alternative water use projections consistent with SSP2. According to our assessment, aquifers with the highest current groundwater depletion rates worldwide are not transboundary. Exceptions are the Neogene Aquifer System (Syria) and the Indus River Plain aquifer (India). For current conditions, we identified 20 out of 258 TBA-CUs (CU- country unit) suffering from medium to very high GWDS. Per-capita groundwater recharge is projected to decrease in 80-90% of all TBA-CUs until 2030 2050. Due to the strongly varying projections of the global climate models, we applied a worst-case scenario approach to define future hotspots of GWDS, taking into account the highest computed increase of GWDS until either 2030 or 2050 among the ten GCM water use scenarios. Based on this approach, the number of TBA-CUs under at least medium GWDS increases from 20 to 58, comprising all hotspots under current conditions. New hotspots are projected to develop mainly in Sub-Saharan Africa, China and Mexico. The study provided a globally-consistent analysis of groundwater quantity-related stress in TBAs under current and future climatic and water use conditions. By applying a worst-case scenario analysis with a focus on the high-emissions scenario RCP 8.5, its results are appropriate for informing adaptation to climate change under a precautionary approach.



## **Etude de Régularisation du Système Hydraulique du Haut et Moyen Drâa (MAROC) Abstract n°1629**

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**KEYWORDS:** la simulation – Mike Basin – Gestion – Satisfaction –Déficits – Scénarios.

Le présent travail consiste en étude de la simulation des consignes de gestion du complexe hydraulique de Haut et Moyen Draa en vue d'assurer une protection maximale contre les inondations et la satisfaction des besoins actuels en eau à savoir les demandes en eau potable et en eau d'irrigation. Pour schématiser l'ensemble des composantes du système étudié (apports, barrages et demandes) et pour atteindre les objectifs fixés par cette étude + le modèle de gestion a été développé sous MIKE BASIN, outil de planification et de gestion des ressources en eau. Les modalités de gestion que nous proposons restent aussi proches que possible des réalités de terrain et du fonctionnement actuel. La logique suivie consiste, en chaque début de cycle hydrologique, à se projeter dans le futur, à l'horizon d'une année, afin de prévoir l'évolution du stock. La démarche s'appuie simplement sur "Le bilan volumétrique annuel des retenus, qui intègre la variable aléatoire des apports naturels" Les objectifs du gestionnaire, à savoir le contrôle du déstockage des retenus, en mettant en adéquation les allocations aux usagers, les niveaux minima de stock d'eau qu'il faut garder... Les simulations ont été effectuées à l'échelle mensuelle pour les deux scénarios d'apports d'eau suivants, et ce pour différentes réserves d'eau stockées en début de la simulation. Tous les scénarios présentent une garantie suffisante en ce qui concerne la demande en eau potable. La demande en eau d'irrigation connaît des déficits arrive jusqu'à 50 % pour la PMH pour le cas d'une année décennale sèche et réserve initial faible. Pour les autres scénarios les demandes sont généralement satisfaites à 100 %, cependant la réserve de soudure pour l'AEP Industriel et l'irrigation fluctue d'un scénario à un autre.



## Hydrogeology education- University courses, core skills and the role of IAH Abstract n°1630

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KEYWORDS: Education, training

Over half of the world's population obtain their drinking water from groundwater and groundwater provides more than 40% of all agricultural water. Future groundwater reserves are under threat from climate change, intensification of land use and pollution. In this context, the proper education and training of hydrogeologists is now more important than ever. The next generation of hydrogeologists will face difficult challenges in attempting to quantify and manage this precious resource. This paper will review topics that form an essential part of the hydrogeological curriculum, requiring a balance between teaching the fundamental principles whilst at the same time giving hydrogeologists an appreciation of topics that lie at the interface between groundwater science and other disciplines – for example, the role of groundwater in integrated catchment management, or how hydrogeologists must have an understanding the sociological issues that are key to sustainable development. The different roles of universities and the IAH in education and training will be discussed. In the United Kingdom and Ireland, aspiring hydrogeologists have traditionally received their hydrogeology education through specialised masters courses. However, the numbers of such courses have declined, and some of the remaining courses are under threat owing to the priority given by the funding agencies to supporting doctoral research. Although an organisation like IAH cannot provide a university style degree course, it can play an important role in life-long learning, and current IAH proposals in relation to short courses, webinars, thematic papers and mentoring will be presented.



## Water chemistry and carbon flux in a storm event in a karst river Abstract n°1632

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KEYWORDS: water chemistry, carbon flux, storm event, karst river

Rainfall (P), discharge (Q), water temperature, pH, and specific electrical conductivity (EC) of the karst surface river (Li river) in Yangshuo transect (surface layer), and Fuli transect (surface layer and -2m layer) in Guangxi Province, Southwest China were continuously monitored during a period 50 hours from 7 to 9 in April, 2015 using high-resolution data loggers. Water samples were collected at 2-h sampling interval, which were analyzed in the laboratory for major parameters. Continuous karst-related carbon sink fluxes (CSFs) were also estimated through continuous Q and HCO<sub>3</sub><sup>-</sup> concentrations in each site. The primary goal of this study is to assess the intensity of chemical weathering at the storm event, and estimate end-member contribution to geological carbon flux in study catchment. Results show that 1) The EC and pH in Yangshuo transect increased before peak flow, indicating the weathering was enhanced by the quick water-rock interaction in storm event while it was diluted during peak flow period. Meanwhile, the EC in two Fuli transects both increased while the pH decreased, which suggested the continuously precipitation was beyond the maximum capacity of water-rock interaction or the rain flowed into river through the surface flow+ 2) The variation of HCO<sub>3</sub><sup>-</sup> indicated that the weathering which was predominant during the peak flow instead of dilution. Furthermore, the increase of Ca<sup>2+</sup> and the decrease of Mg<sup>2+</sup> indicated the limestone weathering was the main type of weathering+ 3) The CSFs of Yangshuo, Fuli and Fuli(-2m) was 4122.29 tCO<sub>2</sub>, 4322.14 tCO<sub>2</sub>, and 4324.91 tCO<sub>2</sub>, respectively in monitoring time. The proportion of carbonate weathering were account for 75.23%, 71.42% and 72.72%, respectively, of the 3 sites while the portion of silicate weathering were 3.2%, 3.06% and 3.11%, respectively. The proportion of weathering with the allogenic acid taking part in were 21.58%, 25.52% and 24.18%, respectively, which caused the distinctly carbon loss.



**Nitrate contamination of groundwater and health effects due to unhygienic sanitation practices in rural India**  
**Abstract n°1633**

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**KEYWORDS:** Keywords- On-site sanitation, Groundwater contamination, Nitrate, Cancer

Developing countries like India lack access to facilities for safely disposing human waste and maintaining hygienic conditions. On-site sanitation and open defecation practiced in various parts of India has raised concern to the impact on groundwater quality. This waste directly leaches to the nearby groundwater and contaminates the drinking water sources leading to increase in concentration of contaminants like nitrates posing threat to human-health. Higher concentration of nitrates in drinking water has been positively associated with the increasing risk to several types of cancers. As a part of research work in NEERI+ drinking water samples from different rural settings in Nagpur were collected. In villages, Isapur (85.59 mg l), Tarodi Khurd (50.71), Gumthala (53.02), Jakhegaon (98.8), Bina (54.43), Sillori (205.26), Parsodi (54.28), Shivani (49.38), Shegaon (63.44), Wahi (133.67), Khairna (164.06), Pimpalgaon (71.86), Sakoli (67.96), Garanda (62.08), Mahadula (53.8) nitrate concentration in drinking water was found to exceed the permissible limit. A detailed health survey emphasizing on the sanitation practices, storage of water, filtration techniques used and the waterborne diseases prevalent in the area was carried out in these villages. Also, the prolonged exposure to nitrate contaminated water could lead to carcinogenicity. Using a case-control study design a population of 234 persons in Nagpur and Bhandara district of the Indian subcontinent was studied for 1 year. In this respect a survey of cancer patients in three of the cancer hospitals in Nagpur was performed. A detailed survey of 16 predictor variables through formhub software was carried out. Drinking water and vegetable samples were collected from these locations to identify the risk from nitrates and consequent occurrence of cancer. Statistical analysis suggested that nitrate concentration in drinking water was found significant in predicting cancer risk and the unhygienic sanitation practices enhanced nitrate contamination of groundwater.



# **Sustainability of Environmental Topology & Water Resources management of Enclosed Land by Vertical Irregular Geotechnical Barriers**

## **Abstract n°1634**

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**KEYWORDS:** Enclosed, Geotechnical Barrier, Water Table Level -WTL, Discharging Well, Recharging Well

A hydrogeologic study has been developed to adapt a conjunctive use study of (2508 donams) for Tyass area in the middle of Iraq. The government bounded the entire area by Hillah River which causing a soil water logging and swamps elsewhere. To solve this drawback, it was planned to enclose Tyass by an impermeable geotechnical barrier penetrating the full depth of 4.25 bearing layer to prevent the seepage water. Consequently the barrier will produce a serious environmental disaster such soil salinity rise, contamination, and non-renewing of groundwater storage which may force a population immigrating their lands. To rehabilitate Tyass again a management study was developed depending basically upon estimating the water demand (WD) and a formulating a 2D mathematical model for Tyass area. After the model has been calibrated and verified it was firstly used to lower the water table levels (WTL) 2.43m, testing the discharging and recharging capacity of the wells which was found to be (5L s). Two hydrogeological solutions have been adapted+ the first is by satisfying the (WD+20%WD) by surface water (SW) releases from the old river reach by using a small ditches and then discharging the extra 20%WD from the aquifer into the new river reach. (19 wells) is a maximum number should be drilled to achieve this purpose whereas the second solution is satisfying the 1.2WD by recharging SW into the aquifer by (104wells) a maximum No. of injection wells on MAY and using (86 discharging wells) scattered over the entire area to satisfy the WD of farmers in range of (30donam well) and (18 discharging wells) to discharge the 20%WD into the new river reach. The extra water is used for renewing and sweetening the groundwater. The study added a strategic role and strong platform to rehabilitate any surrounded area by anticlines of mountains from all sides or by artificial geotechnical and no flow barriers. A feasible study showed that the first solution is preferred.



## **Water Markets, Regulation and Groundwater- Insights from Australia Abstract n°1635**

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**KEYWORDS:** Markets, Regulation, Governance

**Objectives-** With over 20 years of market inspired governance, and with substantial trade now occurring within the Murray Darling Basin, it is timely to examine the achievements and challenges of water markets in Australia. While this is a topic about which governments, practitioners and academics have produced considerable work, they have predominantly done so from the perspective of economics, management and geography. This paper seeks to build on this work, but shed new insights into areas where far less attention has been directed, namely to legal and regulatory issues of water markets in practice. **Design Methodology-** To identify the achievements and challenges of regulating water markets in practice, the article draws on available studies, original survey data (n 3,978+ response rate of 22%) collected from agricultural water users, as well as interviews (n65) with agencies, industry bodies, farmers and NGOs from three Australian states. **Original data results-** The paper identifies and weighs up both achievements and challenges of water markets in practice. **Achievements include-** (1) more flexible responses to droughts+ (2) efficiencies that contribute to economic and environmental benefits+ and (3) increasing market functionality. **Challenges include-** (1) effective regulation of markets+ (2) accuracy in water accounting+ (3) addressing universality of impact and source particularly in the context of groundwater trades+ (4) delivering expected environmental benefits+ (5) accounting for social impacts+ (6) addressing windfall gains+ and (7) markets operating equally across Australia. **Data conclusion-** While achievements are evident and many of the above challenges are not fatal to the future success of water markets, the data suggests that markets appear to face fundamental limitations, not least dealing with non-universality of impact and source regarding groundwater. In such situations water regulators need to turn their attention to supplementary policy approaches that can plug the gaps in market operation by providing flexible and decentralised management of groundwater, integrating quality and quantity and drawing on local knowledge and expertise to account for social, economic and environmental impacts.



## Volcanogenic Karst Systems Abstract n°1639

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**KEYWORDS:** volcanogenic karst, Mexico, Australia, Turkey, Europe

Hypogenic karst forms from water flowing upward from depth. Several geologic conditions facilitate hypogenic karstification by sourcing acids that dissolve carbonate rocks at depth. Hydrothermal, deep-seated karst is now documented, but the processes are not commonly applied in geologic evaluations. Shallow magmatic and volcanic activities provide conditions that can dissolve large voids deep below the Earth's surface. Volcanogenic karstification has produced some of the Earth's deepest underwater cave systems. Volcanogenic karst systems (VKS) in Mexico (Sistema Zacatón), Australia (Mt. Gambier), Turkey (the Obruks), Italy (Pozzo del Merro), the Czech Republic (Hranice Abyss) and Russia (Blue Lake) have commonalities. Volcanogenic karstification needs four components to initiate and develop deep, subsurface voids- 1) thick carbonate strata+ 2) preferential groundwater flow paths (fractures fault zones)+ 3) volcanic igneous activity that releases acids, and 4) flux of groundwater through the system. Components 1, 2, and 4 are common to most karst, but component 3 can accelerate dissolution processes. The high fluxes of carbonic, sulfuric, and other acids can create hyper-aggressive subsurface conditions that can rapidly dissolve carbonates. The Hranice Abyss differs in that the CO<sub>2</sub> is from a deep source not associated with shallow volcanic activity. Compared to adjacent epigenetic karst, VKS can be somewhat isolated from surrounding epigenetic karst both physically and chemically+ have different speleothems and water chemistries+ and, when actively forming, the waters have higher temperatures and uniform characteristics with depth. Differences in the durations and magnitude of volcanic emissions, whether or not the processes are currently active, and geologic controls (i.e., fracture systems, etc.) create variations. With time, epigenetic processes can overprint the VKS. Volcanogenic karstification can produce deep solution porosity and high permeability where older carbonate rocks are juxtaposed to younger volcanic rocks+ we infer that there remain undiscovered VKS at depths.



**Sub-Basin Valuation of Agriculture- A Framework for Sustainable Groundwater Management Facing the California Drought**  
**Abstract n°1641**

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KEYWORDS: GIS, agriculture, groundwater, economics

California's booming agricultural industry, valued at over \$20 billion in 2014, relies heavily on groundwater. The California Statewide Groundwater Elevation Monitoring program prioritizes groundwater basins for monitoring. Currently, this prioritization method does not include the value of crops irrigated by each sub-basin, thereby disregarding the financial incentive and impact of conserving groundwater. In the absence of this information, current approaches to groundwater management rely on models and simulations, with varying degrees of uncertainty. Accounting for the value of agriculture at the sub-basin scale allows for a better representation of regional agricultural economies and their dependence on groundwater. The presented methodology combines agricultural remote sensing products with county-level crop price indices to derive a sub-basin level agricultural value for 2007 – 2014. This agricultural value is combined with a crop water footprint for improved understanding of the revenue and water demands of agriculture in each groundwater sub-basin. This spatiotemporally variant sub-basin valuation of California's agriculture has extensive potential to guide the Groundwater Sustainability Agencies created by the 2014 Sustainable Groundwater Management Act for comprehensive groundwater resources management across California.



# GROUNDWATER SURFACE WATER INTERACTION IN ESKERS

## Abstract n°1642

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**KEYWORDS:** groundwater, hydrogeology, ecosystems, peatlands, eskers, isotopes, modelling

Eskers are postglacial sand and gravel deposits that constitute one of the main aquifer types of Northern Europe. Eskers are typically connected to surface waters and often discharge to streams, lakes, wetlands and springs. Such important ecosystems are in many cases dependent on stable groundwater discharge. Protection of groundwater dependent ecosystems is often required against extensive water abstraction and different types of land use including forestry in the recharge and discharge areas. A summary of 10 years of experience in esker hydrology will be presented. The role of forestry and other land uses, water abstraction and climate change will be discussed and compared. Different methods to observe complex processes in discharge zones and ecosystems will be presented including examples from traditional flow, water level and pressure measurements, isotope techniques and infrared imagery surveys. Recent effort in numerical modeling using fully integrated models such as HydroGeoSphere will be presented showing analysis of flowpaths in a complex hydrogeological setting with many groundwater-surface water interactions.



**The importance of heavy rainfall to groundwater recharge in the southwestern Chad basin- evidence from isotopic observations  
Abstract n°1643**

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KEYWORDS: Rainfall, Groundwater, Recharge, Isotope, Chad basin

The southwestern Chad basin is situated within the Sahelian belt of Africa where annual rainfall is generally less than 500 mm and evapotranspiration exceeds 2000 mm. Surface water in rivers is seasonal so groundwater is the only perennial source of water for domestic and other purposes such as irrigation. Understanding groundwater recharge is therefore fundamental to assessing the sustainability of groundwater use, especially in the context of climate change. Stable-isotope ratios of O and H together with carbon-14 data demonstrate that active recharge of groundwater is taking place regionally.  $\delta^{18}\text{O}$  values observed in shallow groundwaters near river channels range from -2‰ to +2‰ (relative to Vienna-SMOW), which may reflect the impact of evaporation as these values exceed the weighted mean average  $\delta^{18}\text{O}$  for precipitation. Stable-isotope data are considered to trace focused recharge via river channels. Groundwater remote from the river channels is characterized by more depleted  $\delta$  values of -4‰ and -7‰, similar to that of heavy rainfalls and reflect direct, diffuse recharge through the deep unsaturated zone. Therefore, in this region, groundwater recharge is dominantly from heavy rainfalls. Carbon-14 data sampled from some of these wells are consistent with 'modern' water with average percent modern carbon of over 100 pmC. The dominance of heavy rainfall in recharging the groundwater in this region has implication, especially in view of the climate change projections that global warming will lead to intensification of rainfall and thus will probably result in increased groundwater recharge.



**Can we Manage Groundwater? A statistical assessment of management plan effectiveness.  
Abstract n°1644**

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**KEYWORDS:** groundwater management, testability, analysis.

Regulation of groundwater through the use of management plans is becoming increasingly prevalent as global groundwater levels decline. But seldom are plans systematically and quantitatively assessed for effectiveness. Instead, the state of an aquifer is commonly considered a proxy for plan effectiveness despite being a combination of many drivers, such as climate, extractions and management techniques, and not an indicator of the effectiveness of the plan. Groundwater management under uncertainty is challenging, often provisional and experimental, and for this research, was structured as a systems control problem. This enabled development of an assessment rubric to determine whether groundwater management plans have the required features that allow plan effectiveness to be quantitatively tested. Using systems control methods, seven components of a management plan representing the primary elements of a control loop were determined, then weighted and rated, allowing calculation of a numerical testability score. This enabled different plans to be rated and compared. Component importance varied, but, a measurable objective or acceptable impact, such as water level, was found to be necessary in order for plans to be testable. The rubric was applied to 15 Australian groundwater management plans and approximately 50% were found to be testable. Testability does not however, indicate plan effectiveness and testable plans do not necessarily achieve planned objectives. To numerically quantify the effectiveness of groundwater management, the impact of extraction restrictions was probabilistically assessed by simulating management of a highly connected, semi-confined, two dimensional groundwater system. Water managers were privy only to head levels in a varying number of grid cells assigned as monitoring wells, and used that limited information to infer aquifer properties and make allocation decisions at each time step. Extraction rates for each simulated management period were determined based upon observed heads from the previous management period and adjusted depending upon triggers outlined in the plan. The effectiveness of water restrictions as a management technique to maintain supply reliability under various decision making frequencies, aquifer response times and climate scenarios was explored.



## **Making Australian groundwater data accessible- managing “big” data Abstract n°1645**

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**KEYWORDS:** groundwater+ data management, data visualisation

In Australia groundwater is major source of water for many urban and rural communities, as well as industry and agriculture. In some places it is the only water available. Groundwater also sustains many rivers and wetlands during dry periods. Nationally consistent groundwater information is needed to underpin national decisions. However, it has been difficult to depict a seamless national picture of groundwater resources and frame groundwater issues at a national scale. This is due to the distributed nature of groundwater management across the various levels of government as well as private agencies. In recent years the Bureau of Meteorology has been tasked with collating, standardising and analysing water (including groundwater) data from across Australia. The Bureau has adopted a collaborative approach and worked closely with State and Territory governments and other agencies to develop a consistent representation of groundwater accessible and downloadable to all. When groundwater data is submitted to the Bureau by water agencies, it is standardised for terminology and format, and then ingested in the National Groundwater Information System (NGIS) resulting in a standardised groundwater data for more than 800,000 bores. Time series of groundwater level, salinity and entitlements are ingested into a SQL database and a bore-by-bore analysis of groundwater level and salinity is also undertaken. This data is available to be visualised and downloaded through the Groundwater Information Suite. The suite comprises four products- a) the Insight, a mobile-friendly map portal designed for non-experts+ b) the Explorer, a sophisticated mapping portal+ c) the NGIS database of spatial information for GIS experts+ and d) the Groundwater Dependent Ecosystems Atlas, a national inventory of groundwater dependent ecosystems. For the first time, decision-makers in industry, government and the community have easy access to comprehensive, nationally consistent information on groundwater across Australia.



**Field experiments for designing controlled CO<sub>2</sub> release and leakage detection monitoring in a shallow aquifer of K-COSEM site, Korea**  
**Abstract n°1646**

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**KEYWORDS:** CO<sub>2</sub> storage, controlled release, shallow aquifer

K-COSEM (Korea-CO<sub>2</sub> Storage Environmental Monitoring) site is a field experimental site intended for studying shallow-depth subsurface and surface environmental impacts caused by artificially injected CO<sub>2</sub>. Main objectives of this study is to construct and operate efficient groundwater monitoring network appropriate for hydrogeological characteristics in field-scale transport of CO<sub>2</sub> originated from artificially injected CO<sub>2</sub> at the K-COSEM site in Eumseong, South Korea. Various hydraulic tests were performed to identify the hydraulic characteristics such as hydraulic conductivity, effective porosity, and groundwater flow direction. Hydraulic tests and electromagnetic flow meter tests were conducted to estimate groundwater flow direction by well to well scale, which was compared with regional groundwater flow direction and velocity estimated from hydraulic head distribution. This comparison indicated local variations in flow direction and velocity exist that could generate variations in CO<sub>2</sub> monitoring results. Push-and-pull tracer tests using chloride and SF<sub>6</sub> were conducted at different depth intervals of the shallow-depth aquifer in the K-COSEM site. By analyzing the breakthrough curves and the mass recovery percentage of tracers, the groundwater velocity and effective porosity were computed. Recovery ratios of tracers were estimated as 90–96 % for chloride while much lower 47 % for SF<sub>6</sub>. The exact reason of the difference in recovery ratios was not clarified yet, but it indicated that, for a volatile tracer, not only dissolved phase in groundwater but gaseous phase in groundwater and vadose zone should be examined for a complete mass balance analysis. Based on this idea, multi-level groundwater monitoring wells linked to multi-level soil gas monitoring facilities were installed at the K-COSEM site. Before CO<sub>2</sub> injection to shallow aquifer, preliminary tracer tests were performed by using aqueous and volatile tracers.



## Numerical determination of water fluxes from soil temperature measurements Abstract n°1648

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**KEYWORDS:** infiltration, unsaturated soil, numerical methods, Pt100 thermistors, temperature

Soil water fluxes may be determined from the temporal and spatial variations of soil temperature field, provided the heat redistribution effects of water movements are properly quantified. This requires both measuring the temperature fluctuations accurately enough and deriving methods to handle the coupled water and heat advection terms in the heat equation. Nevertheless, a strong interplay exists between the quality of temperature recordings and the numerical methods relevant to solve the inverse problem for the unknown water fluxes. A general trend is that cheap, limited-quality source data dictate the use of sophisticated, indirect and multistage resolution procedures. Moreover, these necessitate hypotheses on the form (e.g. sine variations only seen through their amplitude and phase) or origin (e.g. successive Heaviside-type heat pulses transmitted from the soil surface) of the temperature signal to allow appropriate numerical processing (e.g. Fourier transform of the heat equation to work with periodic signals, Laplace transform to work with transient hydro-thermal events). From the above numerical processing, the magnitude and phase of the temperature variations (or soil's propensity to transmit heat pulses -its transfer function) depend both on the water movements and on soil's thermal diffusivity, the latter well correlated to soil's water content. Finally the sought water movements are these that ensure the best match between the modeled and the observed temperature fields. Conversely, high-quality temperature data allow direct numerical schemes for the heat equation, in which the water movement and thermal diffusivity terms explicitly appear- only the last, fitting stage is needed to solve the problem. This contribution reviews how to lean on the differences between temperature signals, at various sites, locations and depths, for the determination of water fluxes, placing emphasis on high-resolution approaches (0.001 K accuracy for Pt100 probes vs. 0.1 K for classical probes) and the news avenues offered for agricultural applications.



## Heavy metal contamination risk in Pinarbasi karst spring Abstract n°1649

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KEYWORDS: Pinarbasi spring, Heavy metal contamination, Bauxite deposits, Central Taurus Belt

Pinarbasi karst spring is located in Seydisehir, Central Taurus Belt, Turkey. The catchment area is covered with highly karstic limestones and the area is highly tectonic. The Jurassic limestones overlap Triassic Seydisehir schists. Mortas Bauxite deposits is located upwards of Pinarbasi spring in the catchment area. Oxygen18-Deuterium analysis results show that the recharge elevation of the Pinarbasi spring is almost the same as Mortas Bauxite deposits. The study area is highly karstic and it is possible to see lots of sinkholes and dolines. This is because point recharge is dominant and heavy metal contamination risk is available in Pinarbasi spring. Pinarbasi spring and other water points are sampled in different seasons. Three water samples from Pinarbasi spring and four water samples from different sampling points are gathered in wet season of 2015. Pinarbasi spring is sampled in January, February and March, other points are sampled just in January 2015. Pinarbasi spring is sampled again in both wet and dry seasons in 2016. Water chemistry and ICP-MS analyzes are carried out at Hacettepe University Water Chemistry and Environmental Isotopes Laboratories. The analysis results are evaluated as both WHO and TSE-266 drinking water standards and the results show that water chemistry and minor element concentration varies between seasons. The more precipitation becomes the more heavy metal contamination increases in spring water. Aluminum reaches 132 ppb, Iron 156 ppb and Strontium reaches 165 ppb in January 2015. As a conclusion, by means of point recharge, the spring water contains much more heavy metal in the wet season but the spring water is suitable for agricultural irrigation and susceptible to drink and alluvial borehole water is not suitable for a drink.



# Hydrogeochemical and isotopic constraints on the origin and evolution of groundwater from a Quaternary aquifer in the Shule River Basin, Northwest China

## Abstract n°1650

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**KEYWORDS:** Groundwater, Stable isotopes, Recharge sources, Geochemical evolution, Northwestern China

Stable isotopic ( $\delta D$  and  $\delta^{18}O$ ) and major ions were employed to constrain the geochemical evolution and sources of groundwater recharge in the arid Shule River Basin, Northwestern China, where extensive groundwater extraction occurs for irrigation and municipal use. A total of 54 specimens were collected in 2014 to 2015 from upstream to downstream in the watershed which can be divided into three parts according to geographical characteristics, the Changma unit (Qilian Mountains area), the Yumen unit (the piedmont alluvial basins) and Guazhou plains unit. The quality of groundwater in Changma was generally good with low salinity and depleted in heavy isotopes, with mean values of  $-12.1\text{‰}$   $\delta^{18}O$  and  $-74\text{‰}$   $\delta D$ . It mainly originated from precipitation in the Qilian Mountains because their isotopes were very similar. Lateral flow from Changma acted a primary source of groundwater recharge in the Yumen unit, while direct recharge by infiltration of local precipitation can be neglected. Dissolution of minerals within the aquifer material (e.g., halite, calcite, dolomite, and gypsum) was mainly source of groundwater salinity. Therefore, strong linear relationships were found between  $Na^+$  and  $Cl^-$  and between  $Ca^{2+}+Mg^{2+}$  and  $SO_4^{2-}+HCO_3^-$ , with stoichiometry ratios of approximately 1-1 in both cases. Groundwater in Guazhou unit may be recharged by seepage of the Shule River water. The ion-exchange reaction played a dominant role in hydrogeochemical evolution and causes a good linear relationship between  $(Ca^{2+}+Mg^{2+})-(SO_4^{2-}+HCO_3^-)$  and  $(Na^++K^+)-Cl^-$  with a slope of -0.89 and also results in positive CAI 1 and CAI 2. At last, a conceptual model was developed based on hydrogeochemical and isotopic analysis. and the hydrologic circulation process in the Shule River Basin has been initially identified. The results should facilitate integrated management of groundwater and surface water resources in the study area.



## European maps of habitats, bioregions, and species in groundwater Abstract n°1651

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**KEYWORDS:** groundwater, Europe, bioregion, habitat, biodiversity, mapping, groundwater fauna, Crustacea,

Since the second half of the 20th century, groundwater ecology has established itself as a mature research field of limnology embracing concepts on the evolution, distribution and functional role of biodiversity. However, ecologists have comparatively been less successful in promoting the implementation of environmental policies that truly integrate life in groundwater as an essential component of groundwater resources. Part of the problem might have come from the difficulty among groundwater ecologists to provide knowledge-based information and operational tools that truly meet the needs of policy makers at national to continental scale. Here, we describe three such tools that have recently been developed as part of several research collaborative efforts. The groundwater habitat map of Europe (GHME) is derived from the international hydrogeological map of Europe- it shows the areal extent of 13 habitat types that are classified based on groundwater flow type, permeability and pore size. The groundwater bioregional map of Europe (GBME), in which 15 biogeographical regions are delineated, is based on the species compositions of groundwater crustacean assemblages. The European groundwater crustacean dataset (EGCD) contains a total of 21,700 georeferenced occurrence data of 1,570 species and subspecies of Crustacea, representing 12 orders, 46 families, and 165 genera. Covering virtually all groundwater of Europe, these habitat and bioregion maps together with their associated species dataset provide an effective European-scale knowledge base to detect factors shaping patterns of species richness and geographic range size. They also provide useful tools for integrating the maintenance and management of groundwater biodiversity into national and EU policies for the conservation and sustainable use of groundwater resources and ecosystem services.



**3D Conceptualization and Numerical Model Analysis, and its Impact on Drawdown, in the Bulgarene Borefield, Port Hedland WA  
Abstract n°1654**

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KEYWORDS: Bulgarene, conceptualisation, numerical modelling

The Bulgarene borefield (BB) is situated between the De Grey and Ridley Rivers, 60km east of the town of Port Hedland in Western Australia. The BB has substantial ecological and indigenous heritage values, and there was concern that abstraction from this borefield could significantly drawdown water levels within the culturally sensitive Muccungarra Pool along the Ridley River. In 2013 the Water Corporation engaged SKM to undertake a drilling and aquifer testing program with the aim to stress the aquifer and observe any impacts to the water table. A total of five monitoring bores were drilled in strategic locations within the upper alluvium aquifer to capture accurate drawdown data. Two separate 14 day aquifer tests were undertaken at 81 s on bores 21 96 and 18 96 with drawdown readings collected from both the newly installed bores in the upper alluvium and several existing bores in the lower alluvium aquifer. A numerical model was built after the field programme indicating, with a 2G1 yr. abstraction, a maximum drawdown at Muccungarra of 0.1m. This is a significantly smaller estimation in maximum drawdown at Muccungarra Pool, compared to the two previously completed numerical models for the borefield. This investigation involved reviewing all existing data sets, including bore lithological logs, EM surveys, hydraulic testing data, current and previous 2D conceptual models. This information was then used to create three 3D conceptual models using Leapfrog<sup>TM</sup> modelling software. These conceptual models were then used to compare the three depositional environments used in the previous hydrogeological investigation work undertaken at the BB. The second part of this investigation involved comparing all three conceptual models and their corresponding numerical models to determine what had the biggest influence on the drawdown results. The conceptualisation, or the revised hydraulic parameters and numerical modelling.



## **Management of aquifer recharge in arid zones under coastal constraints Abstract n°1655**

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**KEYWORDS:** Artificial Recharge, Water Management, Stressed Coastal Aquifers

The Managed Aquifer Recharge (MAR) is a broad collection of practices for water resource management, aiming at underground water recharge and storage for its recovery. Climate change, population growth and economic development may be behind the acute tension over water resources, particularly in arid and semi-arid areas. In these areas, recourse to new sources of water has to be considered in order to secure water supply for drinking, irrigation, tourism and domestic using. Artificial groundwater recharge using different water resources (desalted waters, river waters, treated wastewater, etc.) appears as one of major solution to the recurrent issue of water scarcity and supply security. Artificial groundwater recharge is potentially a pragmatic way to store and restore water in the environment allowing to- i) maintain necessary water supply levels, ii) alleviate salt water intrusion into coastal aquifers, iii) store water avoiding evaporation as it happens for dams, and iv) make it available at any time for all needs. Joint research projects were developed by BRGM and VEOLIA for more than 8 years aiming to develop concepts and transferable technology based on the control of the key physical, microbiological and chemical processes. Though the MAR technology is deployed worldwide, and especially in arid countries, great care has to be made to ensure the success of any given MAR scheme because the successful establishment of a particular aquifer cannot be reproduced elsewhere due to different hydrogeological and geochemical settings, climate conditions and economic contexts. Every aquifer recharge design is highly specific, and must encompass a number of scientific disciplines (geology, hydrogeology, geophysics, geochemistry...). The challenges emerged by the environmental security issues and the water quality improvement preserving were taken into account. Indeed, the reactive transport modelling is often carried out in order to identify the relevant processes controlling the filtration capability (permeability) of the soil, the compatibility of injected water with soil mineral reactivity (i.e., favorable water - rock interactions).



**Assessing the Managed Aquifer Recharge through Village Intervention project with groundwater dependent communities in rural Rajasthan and Gujarat, using the Comparison of Participatory Processes diagnostic framework.  
Abstract n°1657**

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KEYWORDS: Participatory processes, community management, managed aquifer recharge, India

Literature based insights suggest participatory processes have clear advantages over “traditional” or non-participatory processes when the coordination of individual groundwater users is characterized by complex and contested decision-making and planning situations. Hassenforder et al. (2015) have developed the Comparison of Participatory Processes (COPP) diagnostic framework to describe and compare participatory processes. A series of selectable variables describe three COPP dimensions- context, process and outputs outcomes and impacts. The Managed Aquifer Recharge through Village Intervention (MARVI) project was conducted with groundwater dependent communities in rural Rajasthan and Gujarat. There is a current imperative to promote and facilitate community and local administrative responsibility for groundwater management, recharge and rainwater harvesting, ensuring that groundwater reliant households and interests are involved in the design and implementation of such schemes. The MARVI project deployed a trans-disciplinary approach to assist local communities coordinate individual well operations and recharge, involving community aquifer monitoring, multiple science disciplines and community engagement processes. We systematically describe the MARVI participatory processes according to the COPP framework and attempt to test three hypotheses formulated by Hassenforder et al. (2015) intended to improve the robustness of the COPP framework. These were- 1) that multilevel engagement is more likely to lead to specified outcomes+ 2) there is a high potential for method substitution+ and 3) whether a minimum engagement period of two years, with regular events and local coordination, is more likely to lead to the achievement of project objectives.



**Designing participatory processes based on subjective well-being and groundwater attitudes and practices of groundwater users in rural India**  
**Abstract n°1658**

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**KEYWORDS:** subjective wellbeing, India, participatory processes, community management, managed aquifer re=charge

Failure to effectively coordinate opportunistic extractions by individual well owners with groundwater recharge has led to increasing groundwater scarcity, affecting future opportunities for improved rural livelihoods and household wellbeing. Investigation of the relationship between groundwater institutions and management attitudes and household wellbeing of Indian rural households has substantial potential to reveal initiatives that jointly improve aquifer sustainability and household well-being, yet has received limited attention. Respondents in the Meghraj and Dharta watersheds, India, selected subjective wellbeing factors from an array of economic, environmental and social relational wellbeing dimensions. Subjective wellbeing was calculated as an index of dissatisfaction (IDS), revealing ranked importance and the level of dissatisfaction of individual wellbeing factors. The distribution of IDS wellbeing scores was estimated across four statistically distinct clusters reflecting attitudes towards groundwater management and practice. Decision tree analysis identified significant correlates of overall wellbeing specific to the cluster membership. The study found that the array of factors comprising subjective wellbeing was not consistent across the watersheds nor across groundwater management clusters. High income IDS scores were weakly correlated with actual total household income ( $r < 0.25$ ) consistent with international studies. The array of variables correlated with subjective wellbeing are specific to each cluster, comprised of differing combinations of willingness to adapt, household assets and life guiding values. The results suggest a singular reliance on initiatives to improve household income is unlikely to manifest as improved individual subjective wellbeing for the Dharta and Meghraj watersheds. In conclusion, correlates were tabulated into a systematic decision framework to assist the design of participatory processes at the village level, by targeting specific factors likely to jointly improve aquifer sustainability and household wellbeing.



**INTEGRATED USE OF GEOELECTRICAL IMAGING AND HYDROCHEMICAL METHODS  
IN ASSESSMENT OF THE IMPACT OF SOLID WASTE ON THE GROUNDWATER AT  
ABULE-EGBA DUMPSITE, LAGOS, NIGERIA  
Abstract n°1664**

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**KEYWORDS:** geoelectrical parameters, leachate, groundwater, water sample

Solid waste dumpsites usually pose a serious threat of polluting the surrounding groundwater. To this end, the Abule – Egba solid waste dumpsite in Lagos, Southwestern, Nigeria, was investigated by using geoelectric resistivity methods to ascertain leachate plume generation , migration and its impact on the surrounding soil and groundwater. 2-D resistivity imaging using Dipole-Dipole array was carried out along the major profile in the site in order to delineate the plume and possible trend of migration. Six VES locations were also occupied along the 2-D resistivity imaging profile. The 2-D resistivity imaging data were interpreted by Dipro software while VES data were interpreted by partial curve matching and 1-D computer modeling. The results of the 2-D resistivity imaging revealed very low resistivity values ranging from 13 ohm-m to 72 ohm-m , which is diagnostic of a medium that is saturated by conductive fluid presumably a medium polluted by leachate. This result correlates well with results of the VES technique that show resistivity values varies from 5 ohm-m to 25 ohm-m at the leachate affected zones. The geoelectrical parameters are compared to results of groundwater samplings at the site and to results from the borehole logs, which confirmed that the low resistivity layer is sand formation that is highly polluted by leachate generated from the dumpsite. In addition to this, the results of geochemical analysis from the groundwater samples are above the World Health Organisation (WHO) permissible limits for potable water.



**Location of saltwater wedge using electrical recognition- An application in the aquifer of Chaouia coastal (Morocco).  
Abstract n°1670**

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**KEYWORDS:** aquifer of Chaouia coast, electrical resistivity tomography, vertical electrical sounding, saltwater wedge.

The aquifer of Chaouia coastal is the only water resources exploitable for social and economic development of the region between Casablanca and Azemmour. It is a free groundwater, dandruff, discontinuous which feeds by infiltration of rainwater and discharges at sea. It develops in a Paleozoic basement fractured and altered surface, mainly in sandstones, shales and quartzites. Agricultural irrigation, excessive in places, is made exclusively from the waters of the aquifer, causing a drop in water table and intrusion of saltwater into the aquifer at the coast. The result is reflected in the abandonment of some wells contaminated by seawater. This study proposes to locate the penetration of saltwater wedge from the coastal strip to the interior, by the joint use of the electrical resistivity tomography (ERT) and vertical electrical sounding. The interpretation of 36 electrical tomography profiles and 296 electrical soundings after calibration with existing lithological boreholes in the zone, and the wells measured near profiles has divided the study area into two parts • Part I- Azemmour - Tnine Chtouka, characterized by the presence of Cretaceous ground where the attenuation of seawater intrusion was observed beyond 2000 m of the coast • Part II- Bir Jdid - Casablanca, characterized by the rise of sounds shales overlain by altered, where seawater intrusion is limited to 400 m of the coast.



**Horizontal groundwater Darcy velocity estimation from underground temperature distribution- a focus on the City of Turin (NW Italy)**  
**Abstract n°1673**

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**KEYWORDS:** Thermal profile, subsurface temperature distribution, Quaternary deposits.

We propose an application of a methodology to obtain a quantitative estimation of the horizontal component of the Darcy velocity by using analytical models of interpretation of heat transport by advection and conduction in permeable horizons. This study is based on the collection of groundwater temperature data, recorded in boreholes, in which the heat transfer is affected by both advection and conduction, with an important contribution by the seasonal climatic oscillations on temperature distribution in the first several meters of the subsurface. The thermometric measures were collected in boreholes, with an average depth of approximately 30 up to 50 meters, by the means of a probe equipped with sensors of depth and temperature, with 0.01 degree Celsius sensitivity. Thermal logs show a trend characterized by temperature fluctuations linked to seasonal climatic change in the first depth meters, while the slightly concave profiles suggest a preferential horizontal groundwater movements of relatively warmer water, for greater depth. We select the City of Turin (NW Italy) where an important shallow aquifer occurs, as an example of application of the methodology. The shallow subsoil of Turin city essentially consists of Pleistocene outwash sediments linked to Alpine watercourses forming wide fans, consisting of gravel and sand. These fans are cut by erosional scarps linked to the present incision of the Po River, partially filled by Holocene fluvial sediments. The shallow aquifer, that generally follows the topographic surface, shows a thickness ranging between 20 and 50 meters. The application of this method to thermometric data only affected by seasonal fluctuation returns groundwater velocities with differences up to 4 orders of magnitude, suggesting this method is not applicable. On the contrary, the application of the analysis of the data collected below the seasonal fluctuations depth range, returns groundwater velocities of about  $10^{-5}$  –  $10^{-6}$  m/s.



# **Intensive surface and groundwater use and salinity impacts in Rechna Doab, Pakistan**

## **Abstract n°1674**

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**KEYWORDS:** groundwater, canal irrigation, salinity, NDVI, modelling

The Rechna Doab covers 2.98 million hectares of intensively irrigated land in Punjab, Pakistan. A dense network of canals supplies water from the Chenab River. Over the past three decades groundwater use has increased from a few hundred tubewells to over 200,000. The increase in farmer owned tubewells was largely driven by inequity in the surface supply system and the drive for increased cropping intensity. Farmers in the mid portions of Rechna Doab have to cope with scarcity of irrigation water as these areas are underlain by saline groundwater resulting in increased salinity and sodicity of soils. Thus management of surface and groundwater in Rechna Doab is an important instrument for increasing crop productivity and improving livelihoods of smallholder farmers. A regional flow and solute transport model was developed to assess availability of groundwater resources and interaction of surface and groundwater in Rechna Doab. Spatial and temporal assessment of groundwater use, availability of surface water supplies, and climatic variability were modelled to assess risks to existing groundwater supplies. Spatial variability of actual evapotranspiration was estimated at pixel scale for the entire Rechna Doab. The approach involved using MODIS NDVI data from 2008-13 to prepare crop maps and to derive crop coefficients for various crops in Rechna Doab. Spatial and temporal estimates of recharge and actual ET were used to assess groundwater use on a monthly basis, as there are no recorded usage data for the vast majority of farmer-owned and operated tubewells in Rechna Doab. The modelled scenarios showed that if groundwater pumping was reduced by 10 percent and surface water availability was increased by 10 percent then an estimated total water savings of 900 GL yr is possible. Thus greater effort needs to focus on significantly enhancing the level of groundwater management. The project outcomes will support planning and implementation of more equitable, economically efficient and hydrologically sustainable canal and groundwater management options in the study areas.



**CARTOGRAPHY OF INTRINSEQUE VULNERABILITY OF GHISS - NEKOR  
GROUNDWATER AGAINST POLLUTION (NORTH EAST OF MOROCCO)  
Abstract n°1675**

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**KEYWORDS:** Vulnerability of groundwater, piezometric level, Permeability of the aquiferous formation.

The assessment of groundwater vulnerability against pollution is a crucial procedure for land settlement. The cartography enables decision makers to better manage and analyze information necessary for the delineation and or identification of areas where groundwater is vulnerable to pollution. Within this context, and considering the strategic role of the Ghiss - Nekor groundwater in the socio-economic development of the North East of Morocco, a map of the aquifer vulnerability using the PRK approach has been drawn. This approach, based on the parametric methods of class system, aims primarily at designing an index map of the intrinsic vulnerability of the hydrogeological system through gathering the overall indices by classes. It is grounded on the multiplying combination of the information layers relating to three parameters - 1. (P) - topographic slope, 2. the ratio (R), combining variation of the amplitude of the fluctuations of the piezometric level compared to the thickness of the unsaturated zone and 3. (K)- permeability of the aquifer, whence the generic term PRK taking the initials of these parameters. In the framework of this communication, we present the results related to the application of this multicriterion method thus adopted at the Ghiss – Nekor groundwater, using the Geographic Information System (GIS). This tool allowed the multiplicative combination of the layers of information relative to each criterion retained by superposition space set of themes. The overall indexes acquired by this combination vary within a range of values. They are distributed into six classes corresponding to degrees of vulnerability fluctuating from “very less” to extreme .



**SENSITIVITY OF GHISS - NEKOR GROUNDWATER AGAINST POLLUTION (NORTH  
EAST OF MOROCCO)  
Abstract n°1676**

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**KEYWORDS:** Groundwater, sensitivity against pollution, Geographic Information System, remote sensing...etc

The concept of groundwater sensitivity against pollution makes conscious that groundwater is not immune to pollution loads. The variability of natural conditions makes waters unequally protected. Whence, different sensitivity degrees to identify and map. In this context, this study developed a sensitivity index of shallow groundwater against contamination, based on the superposition of the intrinsic vulnerability map generated following the P.R.K. approach and the land use map. This index is composed of different intermediate indices of individual sensitivities, developed for the different steps through which a pollutant is supposed to cross from surface soil to water table. These indexes marks by a color code corresponding areas on a sensitivity map which will be used to designate targets areas where protective measures should be adopted strictly. It will provide a support tool decision for the developer. This new approach is applied to Ghiss - Nekor groundwater, using a Geographical Information System (GIS) and remote sensing.



**THE PROBLEM OF As NBL DEFINITION IN THE DRAINAGE BASIN OF VENICE  
LAGOON (DBVL), NE ITALY  
Abstract n°1679**

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**KEYWORDS:** Arsenic, LNBLs, CoKriging, DBVL

In northern Italy, especially into the alluvial aquifers of the Po and Venetian Plain, high concentration of arsenic is found in reducing environments and it often is associated with the presence of organic matter. Our study concerns the area of the Drainage Basin to the Venice Lagoon (DBVL), a densely populated area affected by the groundwater arsenic pollution, extending on approximately 2038 km<sup>2</sup> on the provinces of Venice, Padua and Treviso. The UE's Groundwater Directive (GWD 2006/118/EC) suggests an arsenic Contamination Threshold Values (CTV) equal to 10 µg/l. In addition, the UE BRIDGE project proposes to use the 90th percentile of the concentration data for the estimation of the Natural Background Level (NBL). Nevertheless, this method provides only a NBL value for the whole area. The dataset used in this work comes from the "A.Li.Na" study (founded by the Regional Environmental Agency) aimed to define the NBLs of As, Fe, Mn and NH<sub>4</sub><sup>+</sup> into the DBVL's groundwater. Hydro-geochemical parameters were collected by 50 piezometers during four seasonal surveys from 2013 to 2014. The aim of this study is to improve the NBL concept using a sensitive case where the NBL is higher than the CTV. A geostatistical prediction of the arsenic spatial distribution appears a good procedure to point out the zones exceeding the CTV. The relations among As, Fe and NH<sub>4</sub><sup>+</sup> suggested a cokriging method to spatialize arsenic distribution in the DBVL. The results allow highlighting different zones of arsenic concentration- i) areas with values lower than the CTV+ ii) areas with values between the CTV and the median, calculated on the values over the CTV+ iii) areas exceeding the median. Subsequently, the 90th percentile is applied to calculate a local NBL for each zone following the BRIDGE suggestions. In addition, if necessary (n° piezometers < 30), in these three classed areas the "A.Li.Na" sampling network should be increased to calculate the LNBLs.



**Improved groundwater management from in-situ geophysical monitoring of the  
Chatelaillon coastal aquifer  
Abstract n°1685**

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KEYWORDS: saltwater intrusion, coastal aquifer, geophysical observatories

Chatelaillon is a touristic seaside resort in western France where the water supply is provided by a coastal limestone aquifer exploited from two wells. Every summer, due to high touristic demand, groundwater extraction is strongly increased, leading to a progressive aquifer salinization and constraining the city to buy water from inland. In order to document the saltwater intrusion dynamics into the Chatelaillon coastal aquifer, and better constrain groundwater extraction, a downhole (in-situ) monitoring network was installed in January 2015. Based on 3 downhole geophysical observatories installed in 30m deep piezometers, daily to hourly EC profiles with 70cm electrode spacing are recorded in an automatic and remote controlled mode. The three observatories are installed respectively at 50m, 1000m and 2000m from extraction wells. Automatic electrical conductivity measurements of the extracted water are also recorded. Over the past year, this subsurface monitoring network has provided daily to hourly saltwater intrusion geophysical pictures of conductivity versus depth and time. The saltwater intrusion location, shape and ionic content is detailed on an hourly basis, then confronted to boundary conditions such as rainfall and groundwater extraction. A saltwater intrusion maximum is recorded from mid-June to the beginning of August with the piezometer located close to the shore, with a decrease as soon as the recharge occurs. Regarding the two other observatories, rainfall events and groundwater extractions both lead water conductivity changes. For the observatory located within the pumping zone, the pore water conductivity steadily increases (from 800 to 1100microS cm) at bottom of the hole from July to the beginning of September. During this period, when the water level stays bellow 0,20mNGF (the productive upper part of the aquifer is then dewatered), the pumped water comes from the salinized bottom, leading to water contamination. In summary, automatic and high frequency EC profiles recorded at Chatelaillon with autonomous and automatic downhole geophysical observatories lead to a better understanding of aquifer contamination process by saltwater and provide data for a more precise water management.



**Oxygen and hydrogen isotopes of different water types present in the Demänovská dolina Valley mountain karst system (Slovakia)**  
**Abstract n°1686**

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**KEYWORDS:** isotopes, karst water, monitoring

In 2011-2012, 32 sampling places for regular observation of delta  $^{18}\text{O}$  delta  $^2\text{H}$  and tritium were established around the Demanovska dolina Cave system (Slovakia). This monitoring was performed in 7x2 months interval and included precipitation, waters in the surface streams, underground hydrological system and the dripping seepage of the cave system. Altitudinal extent of the area was from 800 to 2024 m a.s.l. High variability of isotopic composition was found in precipitation ( $^{18}\text{O}$  from -17.5 permil to -5.7 permil+  $^2\text{H}$  from -125.5 permil to -32.7 permil+  $^3\text{H}$  from 4.0 to 19.1 TU). In the case of surface waters, streams in underground, groundwater in boreholes as well as the dripping seepage waters of the cave system many similarities were found. In the whole "non-precipitation" dataset,  $^{18}\text{O}$  were found from -12.4 permil up to -9.1 permil+  $^2\text{H}$  from -80.2 permil to -64.0 permil+  $^3\text{H}$  from 1.5 to 15.9 TU. No significant differences were observed between surface streams, running from the crystalline mountain range (median values of  $^{18}\text{O}$  -11.2 permil+  $^2\text{H}$  -74.8+  $^3\text{H}$  8.3 TU), smaller "autochthonous karstic" surface water streams formed in the side valleys of the main karstic canyon (median values of  $^{18}\text{O}$  -10.7 permil+  $^2\text{H}$  -72.3+  $^3\text{H}$  9.3 TU), waters running in the underground karstic system ( $^{18}\text{O}$  -10.8 permil+  $^2\text{H}$  -73.5+  $^3\text{H}$  8.7 TU) and stagnant waters in the lakes of underground karstic system ( $^{18}\text{O}$  -10.2 permil+  $^2\text{H}$  -69.8+  $^3\text{H}$  9.3 TU). Slightly, but not too different was groundwater in boreholes ( $^{18}\text{O}$  -10.8 permil+  $^2\text{H}$  -74.1+  $^3\text{H}$  7.4 TU) and groundwater in springs ( $^{18}\text{O}$  -11.0 permil+  $^2\text{H}$  -73.9+  $^3\text{H}$  8.7 TU). The most different were autochthonous seepage waters (slow circulation through the fissures) with isotopically enriched waters ( $^{18}\text{O}$  -9.8 permil+  $^2\text{H}$  -66.7) but with quite similar  $^3\text{H}$  (8.7 TU) median.



**WATER STORAGE CHANGES IN HARD-ROCK BASEMENT AREAS USING HYBRID GRAVIMETRY+ RESULTS FROM TROPICAL AND TEMPERATE SETTINGS**  
**Abstract n°1687**

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KEYWORDS: hybrid gravimetry, water storage changes, topography

Time-lapse gravimetry is known to be a powerful non-invasive integrative tool to monitor mass redistributions near the Earth's surface and particularly water storage changes (WSC) within the critical zone. WSC are important variables in highly heterogeneous hard-rock aquifers, as they provide insights in recharge discharge mechanisms. Hybrid gravimetry relies on the combined use in a specific study of different types of instruments measuring the earth's gravity changes i.e. relative spring gravimeters and superconducting gravimeters, as well as ballistic absolute gravimeters. Hybrid gravimetry is able to provide new constraints on underground WSC and we will focus here on two hard-rock aquifers with distinct topography, climate and hydrological settings to illustrate the interest of the technique. The first site is the Ara catchment near Djougou (Benin) in West Africa. This catchment with low topography is located in the humid zone and was investigated in the frame of the GHYRAF (Gravity and Hydrology in Africa) project. The space-time patterns of seasonal WSC as revealed by EOF decomposition is the result of lateral redistribution processes occurring mostly in the saturated zone, as confirmed by water table depths and space-time soil moisture patterns. Such observations bring additional information on recharge-discharge processes. The second site is the Strengbach catchment in the Vosges Mountains (NE France) with large topographical changes (880-1150m). One issue that is investigated is the role played by the topography on WSC. Another point is to compare the WSC inferred from surface gravity observations to the ones deduced from hydrological measurements such as soil moisture content, piezometric data, RMP exploration for inferring the behavior of the saturated zone.



**Anticancer Drugs as Water Environment Contaminants- Data Needs for Quantitative Risk Assessment.  
Abstract n°1689**

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**KEYWORDS:** Anticancer Drugs, Emerging Contaminants, Groundwater protection, Risk Assessment

Anticancer Drugs are receiving increasing interest by environmental scientists due to improved analytical methodologies allowing for concentration detection on the order of ng l (or less) in environmental samples. The mode of action of these compounds is consequently raising concerns about potential risks posed to sensible receptors (both human and ecosystems) for long-term effects low-concentration (environmental) exposures. Risk Assessment (RA) is defined as a procedure in which site specific and contaminant specific parameters are used to evaluate risks posed by known hazards to selected receptors. With extant knowledge is not possible undertake a reliable RA for Anticancer Drugs using well-established procedures because some fundamental data, like in example toxicity and carcinogenicity thresholds, are not been studied in deep neither for human nor for bio-receptors. Few papers have been recently published about long-term effects of environmental exposures on selected macro-organisms finding measurable and not negligible impacts, but data on human are still missing. Even environmental fate and transport processes are not well known thus models are based on estimations and assumptions rather than real measurement. Here we highlight that the methodologies used so far to evaluate risk posed by Anticancer Drugs are based on questionable assumptions and call for a dedicate approach to evaluate such pharmaceuticals. Without a reliable evaluation there is no scientific context for decision makers and regulators.



**Involving stakeholders in the design of a groundwater trading scheme. An empirical analysis in France.**  
**Abstract n°1690**

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**KEYWORDS:** groundwater trading+ irrigation+ foresight workshop+ policy instrument+ water scarcity

In France, water allocation policy has recently been reformed with the introduction of a global cap specifying the maximum volume of water that can be abstracted from each water resources facing overexploitation problems. Individual volumes have generally been allocated among irrigating farmers based on historical uses. As water scarcity increases, these volumes are progressively reduced leading to inefficient water allocations from an economic point of view. Groundwater trading has been advocated as a possible tool to increase the economic efficiency of irrigation water use. The design and the implementation of such schemes may however raise a number of issues in France, where water is culturally and legally considered as a national public trust. In this paper, we propose an institutional set up adapted to the French institutional context, by the development of a scenario introducing groundwater trading in the agricultural sector at the 2035 horizon. We investigate the operational feasibility of groundwater trading by adapting this scenario to five basins, considering local agricultural and hydrological conditions. We then analyze the perception of this scenario by organizing 16 foresight seminars involving a total of 44 experts and 80 farmers. Results show that there is still a long way to go before the preconditions to water trading are met- water scarcity has not reached a critical level+ scientific knowledge is perceived as insufficient to establish the cap+ individual water entitlements and rules to allocate initial volumes still need to be defined+ farmers oppose vehemently to water trading, based on ethical grounds. Moreover, groundwater trading schemes are expected to have a limited potential with trade taking place only in large and homogeneous groundwater units, and where farming systems are highly diversified. Lastly, there will be a real challenge to choose the optimal regulation level of the trading mechanism, with a trade-off between (i) many trading rules to limit economic, social and environmental risks and (ii) as few regulation as possible to propose a realistic and manageable scheme and to enhance trading activity.



**Geochemical modelling as a tool in the assessment of potential geological reservoirs  
for CO<sub>2</sub> storage in Hungary  
Abstract n°1693**

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**KEYWORDS:** CO<sub>2</sub> storage, water-rock interaction, PHREEQC

Based on the EU 2009 31 EC Directive the Geological and Geophysical Institute of Hungary screened potential CO<sub>2</sub> storage structures in the country. An initial assessment closed in 2014 including basic screening, assessing geological and technical viability, estimation of storage volume and basic environmental aspects of selected structures. A second assessment started in 2015 with the dedicated aim of carrying out detailed studies on the whole of the storage complex including the question of geochemical reactivity for reservoir and cap rocks. Geochemical modelling on CO<sub>2</sub> escape and brine displacement to shallower drinking water aquifers was carried out using PHREEQC in order to estimate the impacts which might be caused by CO<sub>2</sub> storage activities. These risk assessment studies assume a much stronger regional effect of CO<sub>2</sub> injection than planned. Dissolution of escaped CO<sub>2</sub> into pore water of a shallower aquifer may significantly reduce its pH, inducing dissolution and precipitation of different minerals in the aquifer rocks leading to changes in water composition and even rock porosity. The essential input parameters of these models are the aquifer rock composition, the original ground water composition of the aquifer and a range of gas-phase CO<sub>2</sub> replacement ratio. Another aspect to consider is brine escape and replacement in shallower drinking water aquifers due to pressure increase as a consequence of CO<sub>2</sub> injection in the reservoir. Modelling assumes mixing of brine and aquifer water chemistries as input parameters as well as the shallower aquifer rock composition. Ranges of water displacement ratio are considered in the models. Equilibrium and kinetic batch reaction simulations and preliminary 1D reactive transport models have been tested. Output from modelling provides the possibility of identifying the most suitable parameter to monitor in groundwater wells, which can indicate even minor water displacement. This parameter may show detectable and early changes as predicted by different models even at some distance from the source. The possible long-term consequences on aquifer and water composition of these worst-case scenarios have also been studied.



# **Application de la Modélisation à des Situations Futures et Performances Comparées des Modèles - Sous-bassins du Haut Niger à Koulikoro**

## **Abstract n°1695**

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KEYWORDS: Niger, Modélisation, GR2M, SimulHyd, Tarissement

Nous présentons la performance comparée des modèles GR2M et SimulHyd, successivement, à simuler des débits maximum, à faire des projections futures à trois horizons différents (2010-2039, 2040-2069, et 2070-2099), et à reproduire un coefficient de tarissement sur deux périodes contrastées (hautes et basses eaux). Sur un échantillon de quinze sous-bassins versants du haut Niger à Koulikoro (inclus), deux approches complémentaires sont adoptées, l'une dite régionale où la valeur la plus élevée de la série de débits observés de chaque exutoire est considérée, et l'autre dite ponctuelle, et qui concerne quinze valeurs de débits maximum à la station de Koulikoro sur la période 1907-1999. Le constat, partant de la première approche (régionale), est que la différence relative entre les débits maximum observé et calculé par les modèles est au plus 36 % + et cette différence entre les résultats de simulation des modèles GR2M et SimulHyd par rapport à l'observation est au plus 8%. Ces pourcentages obtenus partant de la deuxième approche (ponctuelle) sont successivement de 50% et 6%. Le modèle SimulHyd simule mieux le débit maximal que le modèle GR2M + l'exception est faite à la station de Baranama où les deux modèles surestiment le débit maximal. Cette situation de surestimation du débit maximal est constatée lors de l'approche ponctuelle en Septembre 1985 et 1991 à la station de Koulikoro. Les projections sont faites partant d'une simple hypothèse de baisse pluviométrique de 10%, sans une étude des sorties des Modèles de Circulation Générale (MCG). De cette hypothèse, les modèles GR2M et SimulHyd produisent les mêmes saisonnalités sur un horizon considéré, seulement que le concept d'interchangeabilité de jeu de paramètres entre versions de modèles induit des différences de comportement entre ces deux modèles. Les projections des modules de débit aux horizons 2020 et 2050 sont quasiment les mêmes en amplitude, avec les versions non-distribuées des modèles GR2M et SimulHyd+ et les amplitudes des débits (hautes-eaux) sont loin plus faibles à l'horizon 2080 qu'aux horizons 2020 et 2050.



# **Temporary Sensor Deployments- a New Method for Assessing Transient Hydraulic Perturbations in Boreholes and Improved Design of Permanent Multilevel Installations**

## **Abstract n°1696**

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**KEYWORDS:** Fractured Rock, Hydro-physical Testing, Multi-level Design

Detailed investigations of groundwater flow through fractured rock are consistently progressing towards an increased focus on hydraulic characterization of both large and small aperture fractures, the latter having an important role on matrix diffusion processes influencing plume transport and fate. Often fractured rock investigations identify abundant fracturing in continuous core and or geophysical imaging techniques. When complementary rock core chemistry sampling and or advanced thermal techniques are available, these usually indicate numerous zones of ambient groundwater flow. With increased frequency, the next stage of investigation is the installation of a multilevel monitoring system (MLS). Inevitably the choice of which commercially available MLS to use and the details of its design (i.e. port and seal intervals) is a compromise between- the number of available ports, borehole condition and potential for blending hydro-stratigraphic units or missing key flow zones. The importance of these choices is heightened when the MLS is to be used as a sentry well or for monitoring a tracer test without adequate data to prioritize critical flow zones. We present a temporary removable and reusable installation to monitor pressure and temperature at numerous (10 or more) discrete depth intervals in a borehole as a tool for improved understanding of the hydrodynamics surrounding rock mass and planning a permanent MLS installation. Rock core and geophysical data are used to design sampling intervals of variable length, wherein pressure transducers are deployed within spacers and then a temporary liner is used to hydraulically isolate the intervals. The transducers can be twinned with high sensitivity (0.0001 C°) temperature sensors for increased resolution of thermal variations. Once the system is hydraulically stressed, either naturally or artificially, the resulting data is used to confirm and refine the design of a permanent MLS. The temporary system is entirely reusable and reconfigurable as appropriate for another location. Data from sites in California (US) and Ontario (Can) are presented to demonstrate the process, the detailed resolution of the system, and the utility of the approach.



**CONNECTION ZONES, SURFACE WATER – GROUNDWATER- AQUIFERS  
ASSOCIATED TO NIGER CENTRAL DELTA, IN MALI  
Abstract n°1701**

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KEYWORDS: Surface water, Groundwater simulation, hydraulic relation.

Surface water infiltration recharging Mali aquifers occurs through, underlying perched hydrogeological networks, lacustrine zones of the Central Delta or inundation valleys. The mapping of both the Surface water and the Groundwater, their types and availabilities, are briefly presented, and the focus of the study is on the types of hydraulic connections between these water bodies. The aquifers hydraulically connected to the Niger Central Delta flows systems are Continental Terminal Quaternary, and they concern some areas where either inundation or perennial surface water flow occurs. These aquifers belong to the hydrogeological Unit of Central Delta where the recharge by surface water is estimated to be five percent of the flow loss between the entry and the outlet of this hydrological system. Some attempts of simulation along with a review based on the first studies synthetized in “Synthese Hydrogeologique du Mali” would permit to pave the way to other studies on these hydraulically connected zones in Mali. A previews simulation study, about mapping the potential rate of pumping capacity, corroborates some observed structural characteristics and leads to subdivide the area in two hydrogeological sectors, and the present simulation studies focus on the sector “Macina –Diaka” where surface water are in hydraulic relation with groundwater.



**Groundwater storage variations in the North China Plain from GRACE and ground observations**  
**Abstract n°1702**

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**KEYWORDS:** GRACE, groundwater, North China Plain, GNSS

Extensive anthropogenic activities in the North China Plain (NCP), such as agricultural irrigation and urbanization, are consuming the unrecoverable groundwater resource in the region. Since its launch in 2002, the Gravity Recovery and Climate Experiment (GRACE) satellites provide a powerful tool to monitor regional groundwater storage (GWS) variations. In this study, we provide a detailed assessment of spatiotemporal variations of groundwater storage in the NCP from two independent methods, i.e., GRACE satellite measurements and ground well observations. Based on GWS estimates from GRACE and ground observations, seasonal groundwater variations in the NCP respond to the additive effect of anthropogenic irrigation (discharge of groundwater aquifers from spring to summer) and natural precipitation (recharge of groundwater aquifers from summer to winter). On inter-annual timescales, groundwater changes from GRACE and ground observations agree well with year-over-year precipitation anomalies. However, for the whole period of 2002-2014, the spatial pattern of GRACE-based long-term groundwater depletion rates indicates significant mass loss in the piedmont and central plain regions of NCP, while ground well observations only indicate the groundwater level decrease of shallow unconfined aquifers in the piedmont region, i.e., the western part of NCP. The difference in groundwater depletion rate estimates from GRACE and from ground observations indicates the significant contribution from deep aquifers in the central plain of NCP, which was underestimated until now. Furthermore, the GNSS network in the NCP observes the significant ground subsidence in the central plain of NCP, which results from the groundwater depletion in confined aquifers. Although GRACE cannot distinguish the different GWS variation behavior between the shallow and deep aquifers in the NCP, we still successfully isolate these two contributions to the long-term GWS depletion by combining GRACE, ground well observations and GNSS measurements.



# **A Holistic Approach to Sustainable Groundwater Development in Africa**

## **Abstract n°1704**

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**KEYWORDS:** Domestic Water, policy, awareness-raising, boreholes, professionalizm

Groundwater provides about 45% of global domestic water demands, is the main source of domestic water supply in several African countries, and is the most common supply of water demands in of sparsely populated areas. Where groundwater is shallow, hand dug wells play a major role in Africa's domestic water supply in rural, as well as peri-urban areas. Over the past two decades, Africa has witnessed a significant increase in boreholes - financed through investments by development programmes, water users and local businesses. They are used for handpump and piped water supplies. The Sustainable Development Goals strive for universal realisation of the right to safe and affordable drinking water by 2030. Ensuring that everyone has access is a momentous shift from the MDGs, particularly for rural and peri-urban Africa, where access is low. Without doubt, groundwater supplies, and boreholes in particular, will play a tremendous role in reaching the SDGs. Developing sustainable groundwater supplies and managing the resource is a highly skilled endeavour. The wider socio-economic, institutional and political environment, as well as the way that projects are designed affects groundwater development. If boreholes are not well sited, designed, contracted and installed, the supplies cannot be sustained, and investments are wasted. If groundwater resources are not properly managed, there is risk of pollution and failure of the water supplies. Unfortunately, there is growing evidence that there are major weaknesses in the way in which drilling projects are being undertaken in many African countries. If there is to be any chance of meeting the SDGs for water, this must to change, including-

- Improved design and implementation of drilling and rehabilitation projects
- Raised capacity
- Dialogue & exchange
- Civic awareness of groundwater
- Improved, policies, regulation, standards and procedures
- Increased consideration of water resources



## Recharge processes in karstic systems at different time scales Abstract n°1705

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KEYWORDS: karstic flows, natural tracing, recharge

In karstic systems, the heterogeneity of the transfer processes within the different compartments of the critical zone (soil, epikarst, and saturated zones) controls the recharge-discharge relationship. The MEDYCYSS observatory (Multi scalE observatory of flooD dYnamiCs and hYdrodynamicS in karSt, belonging to OSU OREME and SNO Karst network) has been set up to better understand these transfers under a Mediterranean climatic context. On the Lez karst catchment (South of France), being part of MEDYCYSS, a 333 m deep borehole has been equipped with the PMPS Multi-level monitoring system (SolExperts) in the framework of the CRITEX project. The borehole is located 100 m from an intermittent river and 500 m from the main outlet (Lez Spring) of the aquifer where an intense pumping is performed. Continuous pressure and temperature monitoring is realized at 5 depth levels, isolated by packers, where discrete water sampling are also regularly achieved. The main objective of this monitoring is to assess the different mechanisms of the recharge process at various time scales. The collected data implement the existing spatio-temporal monitoring of the hydrodynamic and geochemical variations followed in bore-holes, karst features (caves and sink-holes), perennial and temporal springs of the karstic aquifer. In this study, we aim at specifying the contribution of the different karst compartments, from the recharge zone towards the main outlets. The results obtained during a one year monitoring show a contrasted hydrodynamic response and underline a pressure transfer between compartments, surface water and karst flow. Assessed by temperature monitoring, the hydrochemistry shows a stable water composition for each compartment of the bore-hole, in contrast with the high variability and water mixing identified at the Lez spring. These new data are essential to better assess the recharge processes and specify the role of the vadose zone in the flow organization at short and long timescale.



**Mapping the soil water content variations in a torrential environment using Slingram electromagnetic technique (EM31)  
Abstract n°1706**

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**KEYWORDS:** runoff distribution, torrential environment, geophysical measurement

Soil water content is a key parameter that controls runoff processes at the watershed scale. Recent studies showed that changes in soil's water storage was needed to understand the distribution of water residence time and the shape of flood's hydrograph (Davies and Beven, 2015). Identifying the spatial and temporal distribution of soil water content is still challenging especially in sloppy regions with high changes in soil properties and land cover. Hydrogeophysical methods can help to better understand the distribution of runoff generation by mapping soil water holding capacity using the apparent electrical conductivity measurements (Martini et. al, 2016). The present study has been carried out in a 0,86 km<sup>2</sup> sub basin of the torrential Draix-Bléone's experimental catchment. Water content changes presents high spatial and temporal variability, controlled by site properties (soil texture and structure, topography, vegetation cover) and climate. The mapping process is complicated because of steep slopes coupled with high erosion rates resulting in a significant gully network. Since the summer 2015, four geophysical surveys were conducted in various moisture conditions and following the same pathway using the Slingram electromagnetic technique (EM31) in horizontal dipole to identify changes in soil properties until 5m. Owing to the marl's structure stability beyond 1m depth (Maquaire et.al 2002), we assume that variations in the soil electrical conductivity between surveys are mainly due to water content variation in the subsurface. First measurements comparison between field campaigns show significant differences between areas with higher values and signal variations in marly's valley bottom and on the footslope than in forested areas. Clay content, soil texture, evapotranspiration and drainage rate are amongst the variables that could explain those changes. A discrete high frequency soil water content monitoring from a set of capacitive sensors is also available to validate the EM signals. Eventually, an integrative hydrogeophysical approach will be proposed to map soil water content over the whole catchment area.



# Surface area change detection of the Aguelmam Sidi Ali Lake in the Middle Atlas of Morocco, using water indices- an empirical analysis using Landsat TM and OLI data Abstract n°1708

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KEYWORDS: Aguelmam Sidi Ali Lak, water Index, spatiotemporal changes.

The Lake Aguelmam Sidi Ali is an endorheic depression located in the volcano-karst environment of the Middle Atlas known as Morocco's water tower . At an altitude of 2078 m, this permanent depression of about 44m depth is mostly fed by karst springs and meteoric runoff waters and some intermittent streams. The regular observations for more than ten years from the lake's banks has found that a very sensitive withdrawal of their level of submersion during the dry years. This study modeled the spatiotemporal changes of Lake Aguelmam Sidi Ali in the period 1985–2015 using the multi-temporal Landsat 5-TM and 8-OLI images. In doing so, the applicability of different satellite-derived indexes including Normalized Difference Water Index (NDWI), Modified NDWI (MNDWI) and Water Ratio Index (WRI) were investigated for the extraction of surface water from Landsat data. The Overall Accuracy and Kappa Coefficient were calculated to assess the accuracy of the results showing that the MNDWI was found superior to WRI index and hence it was used to model the spatiotemporal changes of the lake. The results indicate a direct relationship between the importance of the meteoric waters intakes (rain and snow) with the extent of the lake. As well, the dry period 1985-1995 recorded a strong tendency towards the reduction of the size of the Lake, but in the wet period 1995-2015 shows a progressive increasing trend of the level of reference covering about one third of its surface.



**Examining the Hydrogeochemical parameters of a multilayer karst system using high-resolution auto-monitoring. The case of Toulon springs (Dordogne, France)  
Abstract n°1709**

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**KEYWORDS:** Multilayer karst aquifer, hydrogeochemistry, high-resolution auto-monitoring

Toulon springs, one of the main springs in Dordogne, are located in Périgueux (Dordogne, France), at the northern edge of the Aquitaine Basin. Toulon springs are the main perennial outlet of the Turonian aquifer, with annual average discharge of 0.45 m<sup>3</sup> s. These springs are fed by a multilayer karst aquifer from the upper Cretaceous and upper Jurassic. The objectives of the current study are to delineate the degree of participation of reservoirs (Santonian, Coniacian, Turonian, Jurassic). A new methodology based on high-resolution auto-monitoring of hydrogeochemical parameters of a karst system will be employed to the karst system. It is possible with the aid of the automatic sensors allowing monitoring of several parameters such as temperature, EC, pH, redox potential, dissolved oxygen, turbidity. Another advantage is that there is a spectrophotometer which measures absorbance across the UV-Vis range (200-750 nm, at 2.5 nm intervals). These can lead to a precise measurement of DOC, TOC, and nitrate. These are immersed and installed at the outlet of the Toulon karst system. Interpretation from high-resolution auto-monitoring chronicles enable identification of quick flow condition during flood events (flushing effect from storage, water with low residence time, or nitrate responses of the karst system (mobilisation or dilution). At annual scale, time-series data are analyzed to show correlations between several parameters (flow dissolved oxygen turbidity + temperature EC + NO<sub>3</sub><sup>-</sup> COT). This analysis by signal confirms the participation of waters from several reservoirs (Santonian, Coniacian, Turonian, Jurassic). Use of high-resolution auto-monitoring based of several parameters improve characterization of quick responses of karst aquifers to rainfall. This auto-monitoring enable to focus on the changes in hydrogeochemical processes. Results of this current study will help to improve knowledge of conceptual models of flow and transport in karst aquifers.



# Estimation of the base flow characteristic time scale for global scale applications

## Abstract n°1712

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KEYWORDS: base flow characteristic time scale, global coverage, high-resolution

Base flow from aquifers to rivers is a key element of the water cycle, and is particularly important to drought resilience. The base flow characteristic time scale ( $\tau$ ) is an important variable to estimate base flow in regions with no discharge measurements, in simple groundwater models such as the ones embedded in global-scale land surface models, and it can provide an indirect index of groundwater vulnerability.  $\tau$  represents the mean amount of time the groundwater will take to reach the stream in a given catchment. Here, we estimate  $\tau$  using a long-term solution of the Boussinesq equation in an exponential form. It depends on effective porosity, effective transmissivity, and the mean distance from the stream to the divide (estimated based on drainage density). Global porosity and estimated transmissivity used in this work are derived from GLHYMPS (high resolution porosity and permeability data). Global drainage density was calculated using global high-resolution river network extracted from HydroSHEDS data at 15 arc-seconds, constrained by lithology, climate, and observed drainage density.  $\tau$  results are presented as means within 7.5' x 7.5' grid-cells with a global coverage, and compared with alternative estimates, at multiple scales. We also show that the main uncertainty factor of  $\tau$  is the drainage density, which was improved, and significantly reduced, by our methodology compared to state-of-the-art estimates from available global DEMs.



**Spatial and temporal reconstruction of the temperature distribution to assess the water circulation in the Euganean Geothermal Field (NE Italy)  
Abstract n°1713**

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**KEYWORDS:** thermal logs, temperature mapping, thermal water circulation

The Euganean Geothermal Field (EGF) represents one of the biggest thermal areas of Europe extending on a plain band of 25 km<sup>2</sup> in Veneto region (NE Italy). Approximately 14x10<sup>6</sup> m<sup>3</sup> of water with temperature from 65 to 86°C were exploited in 2014 from fractured layers located in Mesozoic to Oligocene formations. The hydrogeological setting of the 300-600 m deep aquifer is elucidated through transmissivity and temperature maps, while the 800-1000 m deep aquifer is less exploited and investigated. The exploitation influences the natural regime of the aquifers causing seasonal fluctuations of the level related to the variation of the extraction. In 2014-15, five surveys were conducted to measure the potentiometric level and the water temperature in approximately 130 wells (depth up to 1064 m) during periods of high and low exploitation. The data are used to perform temperature maps of both aquifers outlining the spatial and temporal variations of the temperature. The maps of the shallow aquifer evidence two areas with temperature higher than 84°C and an outward decrease. The higher temperature is comparable with the 100°C reservoir temperature calculated with geothermometers suggesting a quick ascent of deep fluids through open fractures with a small loss of heat, while a longer path causes the decrease. The maps of the deep aquifer show higher temperature than the shallow one, but the few available data do not allow a detailed analysis. Small variations of temperature among the surveys are depicted, but the distributions are slightly comparable. In addition, the temperature collected during 30 vertical thermal logs are examined evidencing a correspondence with the maps, although the logs are performed in inactive wells. Therefore, the correlation of the areal variations depicted with different methods suggests that the geological setting controls the temperature distribution in the EGF. In conclusion, the performed spatial and temporal reconstruction improves the knowledge of the hydrogeological setting of the thermal area providing useful data for the management of such resource.



**Evaluation of major factors influencing the geochemistry of groundwater in the Berrechid basin, central Morocco**  
**Abstract n°1714**

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**KEYWORDS:** Groundwater+ Hydrogeochemical processes+ Isotopes+ Evaporation.

Located in semi-arid regions of central Morocco, Berrechid basin is a tectonic zone with subsidence and sedimentation, where groundwater is the most important source for water supply. Hydrogeochemical processes affecting the chemical composition of groundwater are evaluated with various methods such as correlation analysis, saturation index, Piper diagram, Gibbs diagrams, and stables isotopes relationship. The mode of study includes analysis of major ion contents and other chemical parameters such as pH, and electrical conductivity of seventy one groundwater samples. Results indicate that groundwater is highly mineralized. In term of TDS and TH, the majority of groundwater is very hard-brackish and only few represent fresh. Groundwater is saline magnesium sodium chloride type facies and changes to sodium chloride type. The main processes influencing the groundwater chemistry are evaporation, mineral precipitation and dissolution of carbonates and evaporate minerals, with significant contribution of the cation exchange with clay minerals and anthropogenic activities. The isotopic data reinforce chemical data in identifying the role of the evaporation as main process controlling the ground water mineralization, and ensuring that the Berrechid aquifer is mainly recharged by evaporated waters, including the return flow of irrigation water also reflected by the high nitrate concentration. Knowledge of the processes regulating the hydrochemistry would constitute an essential tool in the management and preservation of the environmental characteristics of this system.



**Shallow groundwater dynamics in hyper-arid Gobi-Desert- quantitative analysis on surface water–groundwater interactions  
Abstract n°1715**

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**KEYWORDS:** surface groundwater interaction, water table fluctuations+ evapotranspiration, riverbank filtration

The objective is quantitative analysis on surface water–groundwater interactions for water management in hyper-arid environments. Shallow groundwater is an important source of water for the maintenance and restoration of ecosystems in arid environments, which necessitates a deeper understanding of its complex spatial and temporal dynamics driven by hydrological processes. This presentation explores the dominant hydrological processes that control the shallow groundwater dynamics in the Gobi Desert-riparian-oasis system of the lower Heihe River, a typical arid inland river basin located in northwestern China. The methodology is model-oriented analysis of ground surface water monitoring data. The dynamic behavior patterns of the groundwater level at most sites are characterized by a declining trend during the period from spring to autumn and a slightly increasing trend in the winter months. The seasonal variations of the water table are determined by the rate of evaporation and lateral groundwater recharge via riverbank filtration. Further, the water table fluctuation (WTF) method was used to investigate groundwater evapotranspiration (ET<sub>g</sub>) processes at two sites dominated by phreatophytes (*Tamarix ramosissima* and *Populus euphratica*). The average ET<sub>g</sub> rate during the summer months (June–August) of 2010-2012 was estimated to be 0.63-0.73 mm d at the site dominated by *Tamarix ramosissima* and 1.89-2.33 mm d at the site dominated by *Populus euphratica*, depending on climatic conditions, vegetation status, and depth to water table. Additionally, a coupled river-aquifer numerical model of water flow and heat transfer was used to calculate the river leakage in the main stream of natural rivers from April 20, 2010 to April 21, 2012. The results showed that the amount of river water leakage was about  $2.51 \times 10^8$  m<sup>3</sup>, which accounted for approximately 32% of the amount of river flow. The river filtration rate is mainly determined by the streambed vertical hydraulic conductivity, which is highly dependent on the river water temperature that varies from 0 to 20 °C.



**Socio-hydrogeology- enhancing the role of hydrogeologists as advocates for public engagement in water management and governance**  
**Abstract n°1716**

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KEYWORDS: Socio-Hydrogeology, public participation, transdisciplinarity, science for society

A new approach to groundwater investigation is proposed. Socio-hydrogeology aims at providing management practices with better support, coupling hydrogeology with a more comprehensive assessment of the socio-economic implications of the (ground)water problem in question. In practical terms this means not only to study the mutual relations between people and groundwater (i.e., the impact of human activities on the baseline characteristics of an aquifer and the impact of groundwater on human wellbeing), but more generally to foster the inclusion of the social dimension in hydrogeological investigations. Only in this way hydrogeologists can ensure that the results of scientific investigations are both based on real needs and local knowledge, and also adequately disseminated to water end users. Indeed they can act as mediator between theory and practice, hence between the problem and the (potential) proposed solution. The key aspects of socio-hydrogeology are- (i) assessing the impact of human activities on groundwater resources+ (ii) evaluating the (socio-economic) impact of groundwater resources (and its changes in terms of both quality and quantity) on human life and wellbeing+ (iii) identifying the stakeholders involved in a specific groundwater issue, their relations (e.g., power, knowledge flux, financial transfer) and possible existing conflicts+ (iv) promoting better use of the outcomes of a hydrogeological investigation+ and (v) attempting to bridge the gap between science and practice. The last point is fundamental because only trust in scientific outcomes can lead to successful and conscious cooperation, with water end users being fully aware of the implications of new science-based policies and that their real needs are taken into account while new measures are being decided upon. Through its application socio-hydrogeology will not only create room for future public participation activities (supporting the design of a framework where participation results are really taken into account in decision-making processes), but it will also allow science and groundwater scientists to be demystified, facilitating the promotion of groundwater-user networks supported by experts.



# Guidelines for aquifer monitoring programs within the frame of CO2 geological storage

## Abstract n°1717

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KEYWORDS: geological storage of CO2, aquifer monitoring, impacts, groundwater quality, guidelines

While France is committed to reduce greenhouse gas emissions, the regulatory environment requires that future geological storage sites are chosen so as to ensure environmental protection. Regulations and guidelines are available for geological storage of CO2 but guidelines towards groundwater resources are limited to brief and general recommendations. The collaborative CIPRES project (2012-2015, co-funded by the French Research Agency) was dedicated to the characterization of the potential impacts of CO2 leakage on the groundwater quality in the framework of CO2 geological storage. One main objective aimed at giving clues for the improvement of the existing guidelines in terms of freshwater aquifers monitoring methodology. A guide has been issued, summarizing the existing regulations and guidelines towards aquifers overlying geological storage of CO2 and providing a focused monitoring methodology on groundwater resources. This methodology proposes global aquifer monitoring practices, but also, for each stage of the life cycle of a geological disposal site - basic parameters to be monitored (pH, electrical conductivity, alkalinity, major ions, DOC, dissolved CO2 groundwater level, temperature, redox potential), recommended for all aquifer in the area of review of the CO2 storage complex+ - specific parameters, which will have to be customized according to the specific context of the assessed case (based on composition of deep fluids, regional geology and hydrogeology, microbiological and geochemical parameters)+ - minimum recommendations in terms of- a) duration- prior to any storage operation, at least two years to acquire the baseline as a reference for monitoring+ b) frequency- at least 2-4 times per year for the baseline acquisitions, and 1-2 times per year during the operation monitoring+ c) and location- in the control aquifer (first aquifer above the geological storage) and vulnerable aquifers (aquifers that may suffer damages).



**Bacterial community structure and biogeochemical activity in an aquifer contaminated with pesticides**  
**Abstract n°1721**

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**KEYWORDS:** community structure, nitrate reduction, herbicides, groundwater quality

Our objective was to assess the effect of cocktails of pesticides on groundwater community structure, microbial abundance and denitrifier abundance. We used two complimentary approaches- a 2-year in situ monitoring at a rural alluvial plain (France) (n = 37) and microcosms with groundwater with contrasted contamination history spiked with selected herbicides having a high occurrence in this aquifer, atrazine (ATZ), desethylated atrazine (DEA) and ATZ+DEA (n = 50). Abundance of the universal marker (16S rRNA) and of nitrate-reducing bacteria (narG and napA) was assessed by qPCR. Biodiversity was assessed using a fingerprinting technic (CE-SSCP). Pesticides in water were analyzed by LC-MS MS. In microcosms, biodiversity was higher in historically contaminated water than in pristine-like one. The community structure was affected by the concentration of the incubation with community different from the control at 1 ug/L in the pristine-like water and 10 ug/L in the historically contaminated one suggesting a community tolerance to triazine induced by its chronic exposure. The time duration of the incubation also affected the community structure, however, the triazine type had similar effect on the community structure. Biomass was higher at 10 ug/L than at 1 ug/L or in control, especially at 30-d incubation in both water types. This was surprising since triazine degradation was not observed during the 4-week incubation. During the two-year in situ monitoring, triazine affected the community structure, while denitrifier abundance slightly but significantly increased when chloroacetanilide concentrations increased. A significant relationship was not observed between nitrate concentration and microbial biomass or denitrifier abundance. Microbial end points based on molecular indicators should be proposed to complete the biodiversity objective under the European water directive framework with the microbial compartment.



**Hydrogeochemistry of the intertidal zone and beach slope in a shallow aquifer on the North Sea coast – example of the central coastal plain of Belgium**  
**Abstract n°1722**

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**KEYWORDS:** hydrogeochemical processes, dune water outflow, tidal influence

The upper groundwater reservoir in the central coastal plain of Belgium consists of Quaternary sediments with thickness around 30 m, overlying the Tertiary, mainly clayey substratum. Quaternary sediments in general comprise a lower thick sand layer (~ 20 m thick), overlain by a clay-loam-peat complex of variable thickness. The upper layer consists of sand, and is mostly limited to 5 m thickness. Groundwater flow and chemistry have been studied in six profiles perpendicular to the coast line. Deep boreholes with resistivity logging were executed and equipped as multi-level wells, with piezometers and mini-screens at different depths. Piezometric measurements were executed to determine groundwater flow. Groundwater was sampled from deep and shallow piezometers and from shallow hand-augered holes. There is general outflow of fresh(er) groundwater recharged in the dunes (or sometimes more landward in the polders) towards the sea, mainly occurring in the lowermost sandy layer. At shallow depth, a salt water lens is infiltrating at high tide in the intertidal zone, and intruding further landward. The tides, with important tidal amplitude of around 5 m, however, are complicating groundwater flow and chemistry throughout the whole aquifer. The presence of the clay-loam-peat complex is also influencing groundwater flow, the fresh salt-water distribution and chemical reactions. Whereas the fresh salt-water distribution has been studied before in part of this system, hydrogeochemical processes have not been studied in detail. This paper discusses chemical reactions and governing processes that are determining the composition of deep and shallow groundwater in the Quaternary system. Next to major parameters, also redox parameters and nutrients are studied, as well as halogenide ratios. The major chemical reactions occurring are cation exchange, pyrite oxidation, sulfate reduction, calcite dissolution and precipitation. Redox reactions are affecting iron and manganese concentrations. The deepest, highly saline part of the groundwater reservoir close to the clay substratum, seems to have preserved oxidizing conditions with high sulfate and rather high nitrate, while somewhat above, conditions are reducing.



## **The Impact of ENSO on Ground Water Variability in Iran Abstract n°1723**

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**KEYWORDS:** Groundwater table, ENSO, El Nino, La Nina, Iran, Teleconnection

In this study, the impact of ENSO atmospheric and oceanic phenomenon on the groundwater table (GWT) changes was investigated using the Southern Oscillation Index (SOI) in Iran. For this purpose the information of 30 piezometric wells selected from different points of the country were used. Pearson correlation analysis conducted on relationship between SOI and GWT. Results showed that minimum GWT changes occurred in La Nina phase at 37 % of stations. On the contrary, the maximum GWT changes occurred in El Nino phase at 80% of the stations. Application of Pearson correlation analysis revealed that a negative correlation exists between SOI and GWT fluctuations at more than 93% of the stations. Furthermore, variation of GWT in La Nina phase to neutral phase was 207.3 % which was comparable with 6.8% for the average GWT changes in El Nino phase to neutral phase. Results showed that the percentage changes of GWT in La Nina phase is more than El Nino phase.



# **Challenges to sustainable management of urban groundwater in Nairobi County, Kenya**

## **Abstract n°1725**

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**KEYWORDS:** Groundwater, Historical Data, GIS, Spatial Analysis, Management Practice

This paper presents the challenges in managing groundwater resources in Nairobi County, Kenya, a rapidly growing urban centre. The Water Resource Management Authority (WRMA) estimates water demand for Nairobi is 650 000 m<sup>3</sup>/day compared to production of 482,940 m<sup>3</sup>/day. This difference between production and demand has been widening over time due to population growth, inadequacy of the carrying capacity of the distribution network, and climate shocks. Groundwater continues to be exploited to fill the gap. We mapped licensed boreholes developing spatial discrimination maps and assess changes in borehole locations and drilling depths. Further we interviewed staff of regulatory agency (i.e. WRMA) on compliance and challenges they face. 2,632 boreholes were mapped and analysed to elucidate statistically significant borehole density and water abstraction 'hotspots'. Proximity analyses also showed a 6% increase in the number of boreholes that lie within 100 m from each other from 2011 to 2013 whereas analyses on drilling depths indicated that an average increase of 170 m from 1930 to 2013. This substantial increase in drilling depth is attributed to both pollution of the upper aquifer and perceived competition for groundwater. This study also reveals policy and practice shortcomings that contribute to the poor management of groundwater in Nairobi. Lack of a publicly available groundwater database for decision making+ unclear legal framework+ low capacity of the regulator+ access to groundwater that permits unlicensed (and thus unrecorded) groundwater use. The county's population increase drives other exigent contributing factors such as poor enforcement of supportive regulations, increased water demand, and intermittent piped supply. A low level of compliance to, and awareness of, regulatory processes among residents and borehole owners was also noted. Based on these findings, we propose a series of recommendations to improve groundwater management in Nairobi County. Under a new 5-year project, AfriWatSan, we are extending our analyses of urban groundwater to Kisumu County.Kenya, where we will explore growth in groundwater use and its relation to current management policies



**Estimation of specific yield of porous aquifer in Anthemountas River basin (North Greece) using geoelectrical methods**  
**Abstract n°1726**

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**KEYWORDS:** Groundwater, Hydrogeophysics, Electrical resistivity, Specific yield

Specific yield of an unconfined aquifer is essential for groundwater exploitation management. Coupling specific yield with hydraulic parameters such as hydraulic conductivity and transmissivity allows quantitative prediction of the exploitable amounts of groundwater. Specific yield represents the storativity of an unconfined aquifer and is the ratio of the total amount of the solid matrix and the amount of water yielded by gravity drainage, after being saturated. Therefore, the value of this parameter determines an aquifer's storage capacity, a useful tool for the sustainability of groundwater reserves. In this study, geoelectrical methods were applied in the porous aquifer of Anthemountas river basin to estimate its safe yield. The studied aquifer is located in northern Greece, covers an area of 181.5 km<sup>2</sup> and is developed in Quaternary and Neogene sediments. In total 37 vertical geoelectrical soundings (VES) were adopted from previous studies so as to determine the electrical resistivity of the aquifer and the vadose zone. Additionally, groundwater resistivity was calculated from the electric conductivity which was measured in seventy (70) wells. The sites of the geoelectrical soundings were close to existing boreholes and lithological profiles, covering the highest possible area of the porous aquifer. Finally, the specific yield (Sy) of the unconfined aquifer, which is actually the storage term, was calculated from Frohlich's & Kelly's equation considering the resistivity of the saturated and unsaturated zone, as well as the groundwater resistivity. The aquifer's specific yield ranges between 1.9% and 25.2%, with a mean value of 9.5%. Comparing these values and the specific yield obtained from pumping tests it is concluded that the results are similar, indicating the reliability of the applied method.



## **Mechanism and control measures of land subsidence in Cangzhou, China**

### **Abstract n°1728**

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**KEYWORDS:** Cangzhou Land subsidence Groundwater model

The development and utilization of groundwater bring great benefits in Cangzhou, and at the same time have led to severe land subsidence, which has become an important environmental factor hindering regional sustainable development. This paper focuses on issues associated with mechanism and control measures of land subsidence in Cangzhou. The analysis shows that multi-layer aquifer systems with deep confined aquifers and thick clay layers are the key of geological and hydrogeological conditions favorable for the development of land subsidence in this area. The land subsidence volume approximately represents the amount of water released from compression of deep aquifers and aquitards in that most land subsidence is triggered by excessive groundwater withdrawal in deep aquifer system. The ratio of the cumulative land subsidence volume to the amount of deep groundwater abstraction was estimated as 57.6% in Cangzhou. This great ratio is controlled by the local lithological structure and groundwater recharge and discharge conditions. The hydrogeological conditions in this area determine that the water released from compression of deep aquifers and aquitards may be the main source of deep groundwater abstraction, and belongs to the depletion of the storage. The hysteresis of land subsidence is also discussed and the results reveal that the time for completing the primary consolidation ranges from less than one year to tens of years. A transient 3D groundwater model was constructed with MODFLOW to analyse groundwater flow systems and to explore the optimal groundwater abstraction scenario for alleviating land subsidence. Among the four proposed abstraction scenarios, scenario S4 consists of merits of reduced abstraction and increased recharge scenarios, and may lead to a sustainable development of groundwater resources in Cangzhou.



# **Prediction of Short Ranged Groundwater Level Trends by Using a Non-Linear Auto-Regressive Model**

## **Abstract n°1731**

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**KEYWORDS:** Groundwater levels, Trend prediction, Non-linear auto-regressive model

The prediction of future groundwater levels is a difficult task in all hydrogeological settings due to many factors including but not limited to climate-related variable precipitation patterns, poorly defined interactions with surface waters and adjacent aquifers, geologic discontinuities and human interventions. Despite the large uncertainties associated with these factors, the use of non-linear auto-regressive models can provide satisfactory results when accurate precipitation input is available and the external forcing functions are not strongly influential on the overall hydrogeological character of the system. Based on this premise, this research investigates the use of a non-linear auto-regressive model on the prediction of groundwater levels in an alluvial surface aquifer when local precipitation data is available, surface subsurface interactions are at minimum and groundwater extraction is not a major factor in the overall water budget of the aquifer. The model is a feed forward neural network that use antecedent groundwater levels as the main input and precipitation series as an exogenous predictor. The model has nonlinear transformation capabilities that is trained by Levenberg–Marquardt algorithm. The developed model is tested in a surface aquifer in western Anatolia. The alluvial aquifer is fairly isolated from external influences and natural interactions and has historic level data that can be used to train and calibrate the model. The results of model application revealed that the groundwater level trends in the aquifer can be captured well within a short range of time. The extent of validity is a function of total system non-linearity and the relative influence of external forcing functions. Thus, unless the prediction time frame is set too long, the model can accurately predict the general trend of groundwater level change and can create future level time series. With the attained level of prediction capability, the proposed model can serve as a potential tool for the management of groundwater resources and assist the decision makers and planners on future status of groundwater reserves.



**Coupling groundwater residence time and isotopic ratios ( $^{234}\text{U}$   $^{238}\text{U}$ ,  $^{87}\text{Sr}$   $^{86}\text{Sr}$ ) in a granitic catchment (Vosges Eastern France)  
Abstract n°1732**

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**KEYWORDS:** granitic catchment, CFC,  $^{234}\text{U}$   $^{238}\text{U}$  isotopic ratios, residence time

Weathering processes are active in surface waters but groundwater also represents no negligible chemical fluxes. As residence-time in groundwater are high, silicate weathering might take place and control Si, Ca and C fluxes. Weathering processes can be deduced from U isotopic ratios but the kinetics of these processes remain relatively poorly constrained. In order to better characterize these processes, residence-times deduced from anthropogenic gases (CFC and SF<sub>6</sub>) analysis and isotopic ratios determination ( $^{234}\text{U}$   $^{238}\text{U}$ ,  $^{87}\text{Sr}$   $^{86}\text{Sr}$ ) have been coupled. Water samples were collected in the Strengbach catchment (Hydro-geochemical Observatory OHGE, Vosges, eastern France). Two campaigns were carried out in May and August 2015 during two highly contrasted hydro-climatic periods. Both springs and boreholes down to 80 m depth have been sampled. A very clear geochemical distinction is observed between groundwater from surface springs and deeper groundwater from boreholes. Springs show much lower residence-time (few years) and specific chemical composition. Deeper groundwater have residence-time of several decades and different geochemical composition. The campaign of May is characterized by highly groundwater levels and spring fluxes. All groundwater show low residence time, except in the boreholes at depth greater than 40 m. Conversely, during low groundwater-level period in August, the residence times are much higher and CFC concentrations indicate a large mixing process between surface groundwater and deeper levels. The  $^{234}\text{U}$   $^{238}\text{U}$  isotopic ratios confirm this vertical zonation in the boreholes, with much higher activity ratios in the deep ground-waters from borehole than in the surface and spring waters+ Such high U activity ratios are indicative of long water-rock interactions, which is consistent with the long residence times deduced from the CFC and SF<sub>6</sub> data.



**Simulation of groundwater indirect recharge in a volcanic aquifer system using a probabilistic method - Tadjourah region, Republic of Djibouti.  
Abstract n°1733**

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**KEYWORDS:** hard rock aquifers, arid climate, GLUE approach, groundwater modeling, uncertainty assessment

The combined effects of chronic drought known in East Africa and demographic growth exacerbate the demand of water supply of the Republic of Djibouti. Moreover, the main water supply is from hard rock aquifers, and due to the scarcity of data and the lack of knowledge about the hydrogeological properties and aquifer geometry, the quantitative assessment of the available water resource is a tricky issue, related to a high level of uncertainty. For identifying the main flow processes occurring in the volcanic aquifer system of Goda mountain range (Tadjourah region, 1600kmC, 52 surveys), groundwater flow simulations were carried out using an approach based on of the Generalized Likelihood Uncertainty Estimation (GLUE). This resulted in an ensemble of probably density functions describing the parameters and the corresponding uncertainties rather than a unique combination of parameters. An estimation of the indirect recharge could be proposed, that corresponds to a major advance for the understanding of this crucial aquifer system, in particular its renewability. In addition, this work contributed to the development of an efficient numerical tool to assess impact of climate variability on the groundwater resources in arid zone.



## Geometrical structure and hydrogeological properties of Hard-Rock aquifers Abstract n°1736

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It is frequently assessed that aquifers in crystalline rocks are caused by weathering of hard rocks. As proposed by Lachassagne (2008), a typical weathering profile which develops in such rocks under stable geodynamic conditions is composed of stratiform layers following the paleotopography. Below the upper unconsolidated layer (saprolite), the permeable layer is a fissured zone where horizontal fractures are generated by tensile stress induced through by hydration by swelling of some minerals (particularly biotite). This chemical reaction is clearly exothermic which would result in a temperature increase+ once the reaction is complete, the density of heat  $E$  released per unit volume of intact rock is on the order of  $0.5 \text{ GJm}^{-3}$ . The purpose of the present 1D thermal model is precisely to discuss the conditions under which a substantial temperature increase can develop. Since the enthalpy of the weathering reaction  $E$  (in  $\text{Jm}^{-3}$ ) is finite, at any point the heat is generated only during a limited time ( $Dt$ ) at an average rate  $A$  (in  $\text{Wm}^{-3}$ ) =  $E / Dt$ . This time period  $Dt$  is imposed by the kinetics of the chemical reaction (until it is complete) and the heat dissipation is supposed constant during this period  $Dt$ . The continuing nature of the reaction requires that the chemical front propagates downward into intact rock which furnishes new fuel. Call  $V$  this downward velocity. The thickness  $a$  of the active zone is related to  $V$  and to  $Dt$  by the relation  $a=VDt$  and the volumic heat generation rate becomes  $A=EV/a$ . Using the conductive 1D heat equation, the relevant parameter for evaluating the effect of this weathering is the "integrated heat" given by  $Aa=EV$  which has the dimension of a heat flow and where  $Dt$  is absent. Only when  $EV$  is comparable with the natural geothermal heat flow  $q$  (about  $10^{-1} \text{ Wm}^{-2}$ ), does its thermal effect become significant. According to the value of  $V$ , two cases are considered- the value of  $V$  is low and consistent with the erosion rate of the surface so that a steady state is maintained. A value of  $V=10 \text{ m My}^{-1} = 3.10^{-13} \text{ ms}^{-1}$  leads to  $EV=1.5 \cdot 10^{-4} \text{ Wm}^{-2}$  ( $\sim 0.0001q$ ) and induces negligible thermal effects. the velocity  $V$  of the front is 1000 times larger, say  $1 \text{ mm y}^{-1} = 3 \cdot 10^{-10} \text{ ms}^{-1}$ . This leads to  $EV=1.5 \cdot 10^{-1} \text{ Wm}^{-2}$  ( $\sim 0.1q$ ) and corresponds to a 10% increase of the temperature gradient. Such extreme  $V$  value can only occur only during a very limited time. Therefore we can state that any thermal disturbance associated with weathering is the result of a very transient and or local phenomenon.



**Estimation des potentialités de renouvellement et de recharge naturelle d'un aquifère alluvial en zone semi-aride, approche multidisciplinaire - cas de l'aquifère de la plaine du Haouz (Marrakech- Maroc)**  
**Abstract n°1738**

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**KEYWORDS:** recharge naturelle, eaux souterraines, Haouz Marrakech, approche multidisciplinaire

Depuis de nombreuses décennies, la nappe du Haouz (Marrakech), sollicitée pour répondre aux besoins en eau sans cesse croissants de la population et des activités locales, est sérieusement menacée par la surexploitation et la sécheresse. Le climat (global, local) et les oueds jouent un rôle important dans la variabilité hydrologique de la nappe ainsi que sur la qualité des eaux. L'analyse en ondelettes continues, a révélé quatre modes de variabilité (1-2y, 2-4y, 4-7y, 8-12y). La variabilité hydrologique de basse fréquence indique que l'aquifère est contrôlé par les fluctuations climatiques globales, alors que pour la variabilité hydrologique haute fréquence, elle serait contrôlée par les fluctuations climatiques locales des précipitations. L'irrégularité temporelle des précipitations a été décrite (sur 40 ans) et la distribution spatiale de l'indice standardisé de précipitation (ISP) a montré une diminution en direction des zones montagneuses, en lien avec une diminution des précipitations (en moyenne de 10 mm an) ce qui se répercute sur la progression de la sécheresse. L'évolution piézométrique spatio-temporelle, sur 20 à 45ans d'observation, sur base des cartes piézométriques et les piézomètres de contrôle, a ressorti les tendances piézométriques de cet aquifère. L'approche basée sur SIG et une base de données géospatiale, indique des fluctuations piézométriques irrégulières et une baisse généralisée de la nappe (par endroit 1m an). Un modèle empirique pour estimer la recharge diffuse, basé sur une analyse multicritère réunissant les facteurs déterminant l'infiltration potentielle, basé également sur le SIG et la télédétection, a permis de générer des couches de données thématiques relatives à la variation spatiale des différents paramètres déterminant la recharge afin d'estimer cette recharge potentielle spatialisée de l'aquifère. Le taux de recharge diffuse de l'aquifère (6200 kmC) varie entre 3,5 et 19%. Une méthode hydrochimique basée sur l'équation d'Eriksson et Khunakasem (concentration en chlorures des eaux souterraines et des eaux pluviales des années 2011 et 2012) a permis de valider le modèle empirique avec toutefois des marges d'erreur comprises entre 3 et 10 %.



**Tracer test to determine natural groundwater recharge at Pirna, Germany and comparison with simulation tools**  
**Abstract n°1739**

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**KEYWORDS:** tracer test, groundwater recharge, unsaturated flow model

The first step in the development of sustainable water management strategies is the accurate quantification of all components of the hydrological cycle. Among them, the natural percolation rate through the unsaturated soil zone is of great importance but often difficult to determine due to soil heterogeneity and the influence of vegetation. Different methods to estimate the spatial and temporal distribution of natural groundwater recharge are available including field measurements and hydrologic modeling. Field investigations (mostly tracer tests) are time-consuming and site-specific but allow a detailed assessment of processes in the unsaturated soil zone. Modeling tools cover different scales (point, catchment) and complexities (empirical, numerical) but need a variety of climatic and soil parameters as input. A combination of these two methods shall lead to the best understanding of water flow dynamics and provide the most reliable estimates of flow parameters. Therefore, a tracer test was conducted for the estimation of water percolation rate through the unsaturated soil zone at Pirna, Germany. Ten liters of 10 g/L KBr solution was applied once on a one m<sup>2</sup> surface area. The electrical conductivity, soil water content and temperature were measured by Hydra probes installed in a trench at different depths below surface (0.25 – 0.8 m). Additionally soil water probes were taken to determine Br concentrations at specific times and depths using suction cups (ceramic head). Grain size distribution was determined using soil probes. An unsaturated flow and transport model (HYDRUS-1D) was set up using the soil parameters and field boundary conditions and calibrated using the water content measurements of the Hydra probes. Results indicate that due to high soil heterogeneity and preferential flow paths, a tracer test is not suitable to quantify the percolation rate at the chosen field site. Nevertheless, water content measurements and soil probes are valuable to calibrate an unsaturated flow model, which was used to estimate the groundwater recharge rate without taking into account soil heterogeneity.



**Determination of clogging during managed aquifer recharge operation by laboratory experiments and mathematical models**  
**Abstract n°1740**

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**KEYWORDS:** infiltration basin, managed aquifer recharge (MAR), clogging, lysimeter, modeling

Clogging represents one key issue during the operation of managed aquifer recharge (MAR), especially relevant when recharging an aquifer with treated wastewater or surface water. The accumulation of suspended solids and biomass in the soil pore space leads to a decrease in the soil hydraulic parameters and hence a performance reduction of infiltration systems. As a result, costly restoration measures need to be applied to recover the infiltration capacity. Minimizing clogging can therefore increase the overall performance and bring down the operative costs of MAR facilities. The specific objective of this work is to investigate the correlation between clogging formation and operational parameters of surface infiltration systems (hydraulic loading cycle, infiltration rates, water quality) and to identify the optimal boundary conditions at which clogging can be minimized. For this aim, mathematical models were identified which can quantify clogging processes taking place during MAR operation and selected models were applied exemplary for laboratory experiments. The laboratory set-up consisted of a 3D, rectangular-shaped stainless steel lysimeter (1.5 x 1.0 x 1.0 m) with an infiltration basin (0.45 x 0.3 x 0.06 m) installed in the center of its surface. River water with 25 mg l dissolved organic carbon and 15 mg l total suspended solids was infiltrated in the basin with a hydraulic loading rate of 146 m a and a hydraulic loading cycle of 1-3. The spatial and temporal distribution of soil moisture was measured by an array of tensiometers and TDR probes in two different depths at 0.28 m and 0.68 m below surface. The clogging rate was estimated taking into account tensiometer data and soil water content measurements. Mathematical models chosen to calculate the clogging rate during the laboratory experiments cover different complexities and range from simple empirical equations to numerical flow and transport modeling. Results of the different models were compared to evaluate which methods work the best for the specific cases studied.



**Groundwater salinisation in arid area hydrochemical and isotopic evidence, an  
exemple from Bahira plain central Morocco  
Abstract n°1742**

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KEYWORDS: Groundwater salinisation, Cl Br, Fluoride, Stable isotope, Bahira, Morocco

Groundwater salinization resources pose one of the major pressures for sustainable utilization of groundwater in arid and semi-arid regions. Hydrogeochemical investigation of groundwater samples collected in the Bahira aquifer highlighted that the aquifer is characterized by three kinds of water- (i) freshwater, separated from the whole system and located at the Ganntour plateau which is the recharge area+ (ii)+ Waters had moderate salinity highlighting the influence of Ganntour water, and suggesting the occurrence of mixing processes. (iii) High groundwater mineralization acquiring salinity from different sources. This latter, is located especially in Zima lack and Sed Elmajnoun depression and at ridgeline in east part of the plain. Upon integration of multiple geochemical and isotopic techniques, it was shown that the original dissolved salts in the Bahira plain were derived from dissolution of Triassic evaporites in the plain. Also, it is proposed that leaching of Jurassic formation salts in Mouissate Mountain through natural flows and agricultural water irrigation under arid conditions has resulted in accumulation of salts in the unsaturated zone within the Bahira basin. Cl/Br ratios increase gradually with Cl concentration from dissolution of natural halite. When groundwater is affected by extreme evaporation Cl/Br ratios may increase up to 1900. High-fluoride concentrations in groundwater are identified in phosphatic plateau of Ganntour (recharge area) linked to dissolution of fluoro-apatite ( $\text{Ca}_5(\text{PO}_4)_3\text{F}$ ). The high concentration in the rest of plain is explained by the spreader of fluoride over the area following the flow path. The overwhelming contribution of evaporitic rock weathering processes and evaporation to the groundwater salinity is an important finding for decisions regarding how to manage groundwater resources in Bahira region under arid climate.



## **Study of Pore Pressure in Sukowati Field, East Java Basin, Indonesia Abstract n°1745**

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**KEYWORDS:** overpressure, loading, East Java Basin

The study area is focused in Sukowati field, Bojonegoro Regency, East Java Basin. The geology formation is consisted by very thick claystone and characterized by many drilling events. Pore pressure prediction is very essential to reduce drilling uncertainty, determine safe and efficient mud window to prevent a blowout. One of pore pressure cases that often occurred was overpressure. People traditionally use a pressure diagram against depth to predict an overpressure phenomenon. A method that used to predict pore pressure in this research area is Eaton quantitative estimation. Further analysis shows that overpressure in the research area is mostly affected by disequilibrium compaction which is explained by sedimentation rate. This mechanism is existed in Mundu Formation. Moreover, this study also noticed the possibility of clay diagenesis which played a role to generate overpressure that explained by geothermal gradient and cross-plot between log sonic against density.



**Behavior of Radium isotopes in a karstic spring (Lez) and a Mediterranean stream (Vidourle) in the South of France**  
**Abstract n°1747**

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KEYWORDS: Radium isotopes, karstic systems, water origins

Radium quartet ( $^{226}\text{Ra}$ ,  $^{228}\text{Ra}$ ,  $^{224}\text{Ra}$  and  $^{223}\text{Ra}$ ) is largely used in coastal karstic systems as tracer of fresh- and sea-water interactions. Ra isotopes have also been applied to the study of water-rock interactions, residence times and mixing of different waters in geothermal systems or groundwaters. The aims of this work were i) to study the relationship between the ( $^{228}\text{Ra}/^{226}\text{Ra}$ ) activity ratios and the lithologies through which the water is flowing (especially their Th/U ratios) in the Vidourle River, because it drains terranes from the crystalline basement of the Cévennes to the Mesozoic marl and calcareous series with sinkholes resurgences and karstic tributaries. ii) to monitor the time variation of Ra quartet in karstic springs emerging through the Mesozoic limestones near the Lez spring, and to decipher how the activities of these isotopes are linked to mixing of different waters, and to the hydrodynamic conditions. Ra quartet was measured simultaneously by gamma spectrometry, using a new system for in situ sampling of large amounts of water with low Ra activities (typically 1 to 4 mBq/L). A general decrease of the ( $^{228}\text{Ra}/^{226}\text{Ra}$ ) ratios (from 1.4 to 0.9) and of the ( $^{226}\text{Ra}$ ) activities along the Vidourle River is in agreement with the transition from U-rich rocks of the crystalline basement with high Th U ratios, to mainly calcareous Mesozoic rocks with lower U contents and low Th/U ratios. The four karstic springs of the Lez area display lower ( $^{228}\text{Ra}/^{226}\text{Ra}$ ) ratios (0.5 to 0.7), but ( $^{226}\text{Ra}$ ) activities similar to those found in the Vidourle. These lower ratios are probably related to the low Th U ratios of the Upper-Jurassic Lower Cretaceous limestones through which the karst system has developed. Significant temporal variations of this ratio at the Lez spring show the participation of different water masses according to the hydrodynamics. Short-lived Ra isotopes are particularly influenced by water-rock interactions (with alpha-recoil processes) in the epikarstic zone.



**Investigation of irrigation return flows in a coastal karstic aquifer in the Jaffna Region (northern Sri Lanka)- evidence from solutes and water stable isotopes  
Abstract n°1749**

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**KEYWORDS:** water isotope enrichment, carbonate aquifers, irrigation return

Groundwater in Miocene karstic aquifers in the Jaffna Peninsula of Sri Lanka is an important resource for mainly agriculture. The subsurface in this area is characterized by highly productive limestone aquifers that are used for drinking water and agriculture. A comprehensive hydrogeochemical study was carried out to determine processes that may affect water quality in this region. For this purpose major and trace element composition and environmental isotope ratios of oxygen and hydrogen ( $\delta^{18}\text{O}_{\text{H}_2\text{O}}$  and  $\delta^2\text{H}_{\text{H}_2\text{O}}$ ) were determined in 35 groundwater samples. The ion abundance of groundwater in the region was characterized by an anion sequence with the following order of abundance-  $\text{HCO}_3 > \text{Cl} > \text{SO}_4 > \text{NO}_3$ . For cations, average  $\text{Na}^+ + \text{K}^+$  contents in groundwater exceeded those of  $\text{Ca}^{2+} + \text{Mg}^{2+}$  in most cases. Ionic relationships of major solutes indicated open system calcite dissolution while seawater intrusions are also evident, however only in close to shore locations. The solute contents were also enriched by agricultural irrigation returns and associated evaporation. This was confirmed by the environmental isotope composition of groundwater that deviated from the local meteoric water line (LMWL) and formed its own regression line denoted as the local evaporation line (LEL). The latter can be described by  $\delta^2\text{H}_{\text{H}_2\text{O}} = 5.8 \times \delta^{18}\text{O}_{\text{H}_2\text{O}} - 2.9$  ( $r^2 = 0.98$ ). Increased contents of nitrates (up to 5.8 mg/L), sulfate (up to 430 mg/L) and fluorides (up to 1.5 mg/L) provided evidence of anthropogenic inputs of solutes from agriculture. Fluoride contents that are problematic in some parts of the metamorphic terrain of Sri Lanka were low and varied from 0.08 to 1.54 mg/L. Reference Chandrajith, R., Diyabalanage, S., Premathilake, K.M., Hanke, C., van Geldern, R. and Barth, J.A.C. (2016) Controls of evaporative irrigation return flows in comparison to seawater intrusion in coastal karstic aquifers in northern Sri Lanka- Evidence from solutes and stable isotopes. Science of the Total Environment 548-549, 421-428.



**Morphology and distribution of dolines on ultramafic rocks 1 from airborne 2 LIDAR data- the case of southern Grande Terre in New Caledonia (SW Pacific)  
Abstract n°1750**

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**KEYWORDS:** pseudokarst, ultramafic rocks, dolines, New Caledonia, chemical weathering

Dolines are closed geomorphological depressions which are surface manifestations of karstic systems. Usually developed on limestone, they also typify the morphology of the New Caledonian landscape, particularly on the southern massif of the main island (known as Grande Terre). These dolines are evidence of subsidence, suffosion and collapse phenomena resulting from dissolution weathering of peridotites. However, extensive underground drainage systems are still not yet recognized. Semi-automatic mapping of dolines is carried out on a 148 km<sup>2</sup> area of the Massif du Sud from a high accuracy LIDAR digital elevation model. 8,601 dolines ranging from 1 m<sup>2</sup> to 2 km<sup>2</sup> are identified and morphologically characterized with precision. The majority of them are small, shallow and round-shaped, yet more complex shapes are locally observed. Size distribution analysis allows the setting of a threshold of 20,000 m<sup>2</sup> above which surface processes rather than chemical weathering control doline evolution. Doline density analysis reveals high concentrations on flat areas where ferricrete overlies the complete weathering profile, especially in the case of elevated, rainy watersheds. Dolines are aligned and elongated along a N 135 A 5° major fracture direction, which is inherited from the obduction of the Pacific Plate upper mantle in the Late Eocene. Finally, we propose a pioneering morphometric typology of dolines that provides important clues as to pseudokarstic activity. We define collapse, bowl-shaped and flat bottom dolines. Collapse and bowl-shaped dolines are assumed to denote active pseudokarst. They may widen and deepen, or eventually be filled by sediments. They are distinguished from flat bottom dolines that are partially to completely filled, which suggests that they are associated with paleo-pseudokarsts. However the groundwater flow paths associated with the genesis and evolution of dolines must be clarified, and collapse and bowl-shaped dolines should be hydrologically monitored.



## Uniwater Abstract-New University Programs in a Modern Africa Abstract n°1755

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KEYWORDS: Msc, education, university, curriculum, sub-Sahara-Africa,

In response to an identified need for many more trained groundwater professionals in sub-Saharan Africa if the SDG are to be met by 2030, a new MSc program has been developed by UniWater Education for adoption by universities where there are teaching resources but there is a lack of curriculum. The program consists of a combination of hydrogeology (60%), hydrology (10%) and water supply (30%) modules. It is practical in nature and is supported by a 2 week field school. Each host program is partnered with a mentoring university where a similar program is currently offered, thus opening doors for inter-university collaboration, and professor student exchanges. An important aspect of the program is the involvement of industry, consultants and government in the program so that the graduates learn to solve problems that they will face in their communities in the near- and long-term. On-going support is also offered by UniWater, particularly with regards to hosting of the field school or initiating industry-student events to increase the probability of employment for the graduates. An initiative taken to address the lack of text books and reference material is to redistribute books from western countries to these universities where they are badly needed. Our first programs are beginning in September 2016 in Tanzania, Nigeria and Kenya. It is our goal to work with interested universities to initiate 3 to 5 new programs each year. We expect to graduate 30 to 50 students for each new series of programs. By the year 2024, we estimate close to 1800 new professionals will be added to the water sector. While this falls short of the need, it is a long way on the road to progress from where Africa is today.



**Multi-modelling approach to estimate episodic groundwater recharge in a semi-arid environment**  
**Abstract n°1756**

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**KEYWORDS:** Multi-model approach, pedotransfer functions, episodic recharge, arid environment

Recharge in arid and semiarid regions is hypothesized to be highly intermittent and related to extreme precipitation and associated flooding events. Previous tracer-based studies have indicated that precipitation events of at least 150 – 200 mm are required to generate significant recharge throughout the semi-arid Ti-Tree Basin, Central Australia (Harrington et al., 2002). In this study, the vadose zone simulator HYDRUS-1D was used to estimate groundwater recharge in the Ti-Tree Basin for a 130-year time series of daily meteorological data. Hydraulic properties for the 11-m deep unsaturated regolith were generated from a set of 10 pedotransfer functions (PTFs) that used grain size and bulk density data collected from an 11-m long core as predictor variables. Multiple PTFs were used to account for conceptual model uncertainty in generating hydraulic properties. The multi-modelling approach consisted of running HYDRUS-1D multiple times with different sets of hydraulic properties, assuming each PTF is equally likely. To test the effect of vegetation on recharge, simulations were performed for bare soil and for a savanna-type vegetation. The influence of vegetation on hydrologic fluxes in shallow desert soils and thick unsaturated zones was demonstrated by Garcia et al. (2011), Scanlon et al. (2003). In the current study, root water uptake for the predominant Mulga (*Acacia aneura*) savanna vegetation was incorporated in the recharge estimation. Analysis of the 130-year precipitation records revealed extreme events (linked to monsoonal thunderstorms during the summer months) have an average return period of 3 years for a 100 mm rainfall event and 7 years for a 150 mm event. Analysis of the simulated recharge for bare soil indicated most of the extreme rainfall events yielded recharge events of 10.2 mm averaged across PTF and extreme events (ranging from 1.2 – 41.4 mm).



# Optimisation of water quality for sustainable irrigation with coal seam gas produced water

## Abstract n°1757

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**KEYWORDS:** coal seam gas produced water, irrigation, water quality optimization, salinity, sodium adsorption ratio, soil and plant health

Coal seam gas produced water is generally high in total dissolved solids and has a high salinity which may affect soil and plant health if used untreated for irrigation. For example, irrigation waters with a high sodium absorption ratio (SAR) will result in salt accumulation in the soil profile, potentially killing off crops. Use of irrigation water with high SAR values may further result in dispersion of the soil clay minerals making the soil loose structure and become erodible, restricting water entry and reducing hydraulic conductivity. We here simulate coupled processes of variably saturated water flow, plant water uptake and coupled transport of multiple major ions in soils irrigated with produced water featuring different water qualities. By coupling major ion soil chemistry to unsaturated flow and plant water uptake, and by explicitly incorporating effects of salt concentrations on soil hydraulic properties and on root water uptake (so-called salinity stress), critical soil processes required for salinity risk assessment associated with coal seam gas produced water are effectively included in our analysis. Simulations with different irrigation water qualities provided detailed results regarding chemical indicators of soil and plant health, i.e. SAR, EC and sodium concentrations. By comparing such indicators in the soil profile with permissible ANZECC values, an assessment was made of the risk to soil and plant health. We also evaluated the effect of high salt concentrations in the soil profile on plant salinity stress, a condition which reduces the capacity for plants to uptake water causing yield reduction. Finally, the simulations also allowed to test if soil hydraulic properties, in particular the hydraulic conductivity, are negatively impacted by high salt concentrations, especially by the accumulation of the monovalent cations sodium and potassium.



**The Development of MATA PERSADAA, Assessment Tools for Groundwater Protection Practices.  
Abstract n°1758**

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**KEYWORDS:** groundwater protection, Indonesia, industries

During the last decades, as the result of the increase of water needs, a progressive shift from surface water to groundwater has occurred in Indonesia. Groundwater thus has become a strategic water source in the country, with some critical impacts on its status such as overexploitation and degradation of its quality. In addition, the Law of Republic Indonesia which regulated the management of groundwater resources in Indonesia, were cancelled in February 2015 since both were considered not to be compliant with the 1945 Indonesian Constitution. In order to cope with this challenging context, the GroundWater Working Group (GWWG) of Gadjah Mada University of Jogjakarta and industrial groundwater users took initiative to develop a self-evaluation tool for groundwater management to be used by industries, namely the Matriks Penilaian Perlindungan Sumber Daya Air Tanah (MATA PERSADA, &ldquo+The Eye of Mother Earth&rdquo+ in the Indonesian language). The method is inspired by the SPRING (Sustainable Protection and Resource ManagING) methodology, developed by Danone Waters since 2011 and implemented in all its bottling sites worldwide. MATA PERSADA assesses the groundwater management performance through 49 parameters distributed in five groups- data and information, conservation, utilization, controlling, and partnership and institution. The overall performance is determined using a point-count system method then translated into one of the five qualifiers, ranging from poor to outstanding management. MATA PERSADA is expected to become an official assessment standard for groundwater management by industries across Indonesia. Hence, the implementation of the tool aims at contributing to a more sustainable water resources management in Indonesia. These kind of methodologies (MATA PERSADA, SPRING) will surely be a key driver in the future to encourage industries to improve their good practices as regards management and protection of groundwater resources, especially if their score is recognized as an environmental key performance indicators by local authorities.



**Groundwater in hard rock aquifer and resources evaluation base on field observation  
in Sudetes (SW Poland)  
Abstract n°1760**

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**KEYWORDS:** hard rock, water - bearing zone model, groundwater resources , intakes

Results on groundwater resources evaluation in crystalline massif in Sudetes Mts. (SW Poland) composed mainly of gneisses and schist has been presented. The field observation in local catchment consist of network of springs, rivers and well in crystalline massif rocks. In group of springs under observation, four indicates average discharge over 1 l/s and relatively low variability (in range 3-16) and other showed lower outflow as 0.07-0.9 l/s. Groundwater runoff evaluated with base flow method in rivers, showed value in upper part of catchment ( 3.5-6. 5l/s km<sup>2</sup>), when in lower part,value ( 6.5 -7.5 l/s km<sup>2</sup>) due to direct drainage to river valley. Groundwater in such region is low mineralized, low value of pH and high radon concentration (up to 220 Bq/l). Horizontal intake are the best way to provide groundwater resources. As a result a three-layer model of hydraulic properties water-bearing zones in hard rock have been developed based on geological observation and groundwater occurrence. Scheme is associated with spring discharge measurements, water temperature records and water level fluctuation. Model includes the top layer of a weathering zone, mostly composed by clay or sandy clay with thickness from 2m, up to 20 m + the second one is formed of dense fracture network in massif rocks and is extended up to 50 meter below land surface. The third one is formed by deep fracture system, reaching the depth of 300-500 m. The top zone is characterised by high water storage (capacity) and relatively low permeability. The second zone shows low storage ability but high transmissivity. The lowest storage and hydraulic parameters are typical of the deep fractured zone, which is the bridge between fresh and mineral water and is reported up to a depth of 500-700 m. Best condition for groundwater occurrence of the first water-bearing level show two upper zones i.e. alterites covers and fracture zone of the rock massif.



## **Web-based decision support system for planning and management of MAR sites Abstract n°1761**

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**KEYWORDS:** managed aquifer recharge+ modeling+ decision support system

Effective planning and operation of managed aquifer recharge (MAR) schemes require a thorough understanding of the site-specific conditions as well as the processes characterizing the particular recharge methods. To support MAR management a tool is being developed to provide assistance to users with different levels of knowledge in groundwater recharge assessment and MAR specific applications. The core of the tool is a web-based decision support system comprising a compilation of common public domain models and instruments for data acquisition, storage, processing and visualization. A knowledge base will hold data including soil properties, lithology and land surface properties maps as well as meteorological and hydrological time-series data provided by internal (user-defined) and external (e.g. remote sensing) sources. The selection of a feasible approach to assess MAR-related issues is complex and requires a profound understanding of analytical and numerical models. To guide the user through this model selection, applications have been formulated that consider MAR objectives as well as issues related to the operation and maintenance of MAR schemes. These applications include operation and design optimization, geochemical processes during MAR, assessment of water quality and quantity improvement, recovery efficiency evaluation, and restoration of groundwater levels. These applications consist of up to four integral steps- a) estimation of groundwater deficit considering drivers of global change+ b) GIS-based selection of suitable sites and of MAR techniques+ c) assessment of MAR efficiency+ and d) MAR operation design. Simulation tools of various degrees of complexity are allocated to these four steps and the MAR specific applications. Thus the users are provided with a ready-to-use, web-based approach for their MAR related challenges. This paper depicts the tool selection for the decision support system, the allocation of tools to MAR specific applications and a case study showing the applicability of the decision support system.



**MANAGEMENT OF BAI HASSAN UNCONFINED AQUIFER , LESSER ZAB RIVER BASIN  
USING GROUND WATER MODELING SYSTEM, KURDISTAN REGION, IRAQ.  
Abstract n°1763**

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**KEYWORDS:** Keywords- Groundwater Modeling, BAI Hassan Unconfined aquifer, Iraq.

**ABSTRACT** Groundwater is vital for most villages far of the Lesser Zab River, Kurdistan region, IRAQ. Decreasing of groundwater recharge is expected due to the global climate change and human consumption. Uses groundwater for drinking, agriculture and municipality are from the unconfined aquifer of BAI Hassan Formation, the Lesser Zab River Basin. Therefore, predict future groundwater flow conditions, and pumping rate is needed. Ground Water modeling system is used for BAI Hassan unconfined aquifer management. Bai Hassan Formation (Pliocene – Pleistocene) is exposed and appears as a large potential source of water in the study area. Depending on the monitoring of about 175 wells in the area during 2014, boundary conditions are determined to simulate the water enters or leaves the model domain. Three different boundary conditions are identified in groundwater modeling+ these are specified head, specified flow and mixed type (head dependent) boundaries. After running two simulations for every five years, the mathematical model shows that there will be a decrease in hydraulic head of the unconfined aquifer in the modeled area on the two sides of the Lesser Zab River. The recommended solution to prevent more depletion is to reduce groundwater utilization especially in the middle and south parts of Bai Hassan unconfined aquifer. As well as, it is recommended to drill 500 wells within the next 10 years, with discharge rate equal to 20 l sec and with pumping rate of 8 hours daily.



# Hydrogeological and Hydrogeochemical Investigation of the Coastal Aquifer of Sabratah Basin, NW Libya

## Abstract n°1765

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KEYWORDS: seawater intrusion+ overexploitation+ gypsum dissolution

Sabratah Basin at the northern central part of Jifarah Plain, NW Libya, is a typical area where the contamination of the aquifer in the form of saltwater intrusion, gypsum anhydrite dissolution and high nitrate concentrations is very developed and represents the major consequence of human activities. The objectives of this study are to evaluate groundwater resource, to identify and investigate the extent of seawater intrusion and groundwater pollution in the Sabratah Basin. For this purpose, 50 groundwater samples were collected from the study area and analyzed for certain parameters that indicated salinisation of the aquifers. Specifically, water chemical analysis were conducted and hydrochemical profiles and maps were compiled using Arc-GIS, spatial distribution of parameters was assessed, in conjunction with calculation of the ionic deviations of the conservative fresh seawater mixture and saturation indices using the PHREEQC 2.16 software. The results demonstrated increased values of the parameters  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$   $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  which can be attributed to seawater intrusion. Irrigation with nitrogen fertilizers, domestic sewage and movement of contaminants in areas of high hydraulic gradients within the drawdown cones probably are responsible for the high  $\text{NO}_3^-$  concentration towards the south of the region. The large  $\text{SO}_4^{2-}$  anomaly observed in groundwater near the coast was explained by the presence of seawater intrusion and upconing of deep saline water resulting from the intensive extraction. This conclusion is based on high chloride concentrations, the inverse cation exchange reactions, and the lower piezometric level compared to sea level. Inland, the high  $\text{SO}_4^{2-}$  values are related to gypsum dissolution from the Upper Miocene Formation in the lower part of the upper aquifer. High  $\text{SO}_4^{2-}$  concentration is also related to the effect of the scattered sebkha deposits along the coast.



**The research of the nitrate migration in the regional recharge area of water supply  
aquifers (Wielkopolska region, Poland)  
Abstract n°1766**

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KEYWORDS: Groundwater contamination, Nitrate, Denitrification, Buried valley aquifer

In the regional recharge zone of a Quaternary groundwater flow system distinct groundwater contamination was investigated, reflected mainly by high nitrate concentration. The main objectives of presented study were the investigation of the behaviour of nitrate in relation to the flow system and the documentation of the denitrification processes. The examination of groundwater chemistry was performed using data from dedicated groundwater sampling and studies, measurements of the gaseous N<sub>2</sub> dissolved in the groundwater and also tritium analyses. The distinct groundwater contamination was detected in the near-surface zone of the unconfined aquifers, indicated mainly by high nitrate concentrations (>70 NO<sub>3</sub>mg/l). These contaminants migrate to the deeper parts of the flow system at the regions of intensive groundwater exploitation, where concentration of nitrate at depth of 80 m exceed 10 NO<sub>3</sub>mg l. In the regions where the water extraction is not performed the nitrate concentrations are low, even if in the shallow part of the aquifer the concentration of nitrate exceed 70 NO<sub>3</sub>mg/l. Low nitrate concentrations occur also in the regions of confined aquifers occurrence. It was detected with use of gaseous N<sub>2</sub> measurement that denitrification is the process of nitrate removal from groundwater. The potential for denitrification is higher in the confined conditions and leads to an overall decline in nitrate in the deep aquifers. Based on research performed the conceptual model of groundwater circulation was formulated. It was documented that the recharge areas are extremely vulnerable to pollution by nitrate. It was also concluded that the monitoring of groundwater chemistry should be performed for both shallow and deep parts of the flow system, even though the shallow part is not used for water supply purposes. This work was made possible by the financial support of the Ministry of Science and Higher Education (grant no. 2164 BT02 2007 33) and by support of the National Science Centre Poland (grant no. 2014 15 B ST10 00119)



# Fluid Flow in the Faulted Crystalline Basement of the Ore Mountains (Germany) Abstract n°1769

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KEYWORDS: fault zone hydrology, water flow structure ,3D geologic modelling

Groundwater flow in fractured basement rocks on aquifer scale and processes involved in the creation of fracture network permeability are poorly understood even though they have been studied for decades. A unique hydrogeological dataset consisting of 1030 discrete inflows (corresponding to preferential groundwater pathways) to the Poehla Ore Mine (Ore Mountains) of the SDAG Wismut has been compiled and quantitatively interpreted. Transmissivities were calculated for individual inflows using analytical equations. The Variscan basement at Poehla Mine was modelled in 3-D, covering a volume of 14x4x1 km<sup>3</sup> with 14 metamorphosed litho-stratigraphic units and 131 faults separated in 6 main strike directions. Mesoscale fractures mapped at inflows points, i.e. locally conductive fractures, show a weak correlation with fault orientation, and a large orientation scattering, which could be related to small scale mechanical heterogeneities. Inflow points were spatially correlated with major faults considering two distance criteria. The inflows are usually situated within multiple fault zones which overlap each other. The orientations of transmissive faults is highly dispersed close to the surface. The depth transition to more focused flow through NE-SW and NW-SE striking faults aligns with the elevation of the valley bottom of the Ohře- (Eger-) Rift which is at about 350 to 400 masl. The trace length (extent) and width of the core and damage zones of the modelled faults were compiled in order to investigate the flow distribution and permeability profiles in directions perpendicular to fault strike. It can be shown that 90% of all inflows are located in damage zones. Cumulative flow distribution functions within damage zones are non-linear and vary between faults with different orientation. 75-95% of the flow occurs in the inner 50% of the damage zone. The flow rate distribution for all faults decreases exponentially from the fault center to the protolith and may be correlated to decreasing exponentially decreasing fracture count.



## Present Day Fluid Flow Around Variscan Intrusions in the Ore Mountains (Germany) Abstract n°1770

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KEYWORDS: permeability, crystalline basement, contact metamorphism

Groundwater flow in fractured basement rocks and processes involved in the creation of fracture network permeability are poorly understood even though they have been studied for decades. An outstanding dataset has been compiled from mines and ore fields prospected and mined by the former Soviet-German Stock Company Wismut supplemented by construction reports of galleries describing the hydrology of faulted basement rocks in the Ore Mountains (SE Germany). It consists of more than 5000 detailed descriptions of groundwater inflows to about 660 km of tunnels and 57 km of drillings. Inflow measurements (recorded between  $1E-8$  to  $1E-1$   $m^3/s$ ) have been converted to fracture transmissivities using a simplified analytical solution. Discarding site specific effects, the median transmissivity decreases from  $1E-8$  to  $1E-10$   $m^2 s$  within the studied depth interval (0-2000 mbgs) and conductive fracture spacing increases from a 10th to 2500 m. This general trend is overprinted at 3 mining sites by a clear reversal of transmissivity which is caused by contact metamorphic aureoles around intrusions of Variscan granites. It is hypothesized that this transmissivity increase is caused by hydrothermal fracturing, contact metamorphic transformations of greenschist and amphibolite facies metamorphic sediments to hornfelses, metasomatic dissolution reactions in and around carbonate lenses, granite shrinking, and hydro-thermal alteration. The radius of these hydraulically efficacious aureoles is higher in lower grade metamorphic schist than in higher grade metamorphic gneisses. Rock mass equivalent continuum conductivities have been estimated by simple arithmetic averaging of fracture and matrix transmissivities over 100 m intervals. Matrix transmissivities were estimated from ventilation rates and vapor water contents in two mines. For the entire data set a log-linear decrease of median equivalent rock mass conductivity with depth is observed following . This trend is caused by the increasing influence of matrix conductivity due to a non-linear increase of conductive fracture spacing with depth. Matrix conductivity controls the bulk conductivity below about 1000 mbgs and is independent of the occurrence of contact metamorphic aureoles.



## **Micro-organic groundwater contamination in the Indo-Gangetic aquifer system Abstract n°1771**

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**KEYWORDS:** Emerging contaminants, drinking water, India

Groundwater abstracted from aquifers underlying urban centres across India provide a vital source of domestic water. Abstraction from municipal and private supplies is considerable and growing rapidly with ever increasing demand for water from expanding urban populations. This trend is set to continue. The vulnerability of deeper aquifers (typically >100 m below ground) used for domestic water to contamination migration from often heavily contaminated shallow aquifer systems has not been studied in detail in India. This paper focusses on the occurrence of micro-organic contaminants within sedimentary aquifers beneath urban centres which are intensively pumped for drinking water and domestic use. New preliminary results from a detailed case study undertaken across Varanasi, a city with an estimated population of ca. 1.5 million in Uttar Pradesh. Micro-organic groundwater quality status and evolution with depth is investigated through selection of paired shallow and deep sites across the city. These results are compared with surface water quality from the Ganges which is also used for drinking water supply. Broad screening for >800 micro-organic compounds was undertaken. Age dating tools were employed to constrain and inform a conceptual model of groundwater recharge and contaminant evolution within the sedimentary aquifer system.



**The effects of land use change on the surface water groundwater interactions in the coastal lakes and wetlands of eastern South Africa.**  
**Abstract n°1772**

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**KEYWORDS:** Coastal aquifers, conceptual modelling, surface-groundwater interactions, lakes, wetlands

The east coastal plain of South Africa is one of Africa's most outstanding wetland and coastal sites, and as a result has been given world heritage site status. A series of complex and dynamic wetland, estuary and lake systems are sustained by both groundwater and surface water which are strongly linked in this environment. The increased demand for water from the lakes and their associated groundwater systems has resulted in a significant impact. Moreover, extensive Eucalyptus and pine plantations in the catchment areas transpire large quantities of groundwater, adding extra pressure on the already stressed water resource. This study uses integrated modelling of both the surface water and groundwater resources sustaining the lakes to determine the impacts of current and planned Eucalyptus and pine plantations. The model outcomes were calibrated against groundwater and lake level measurements. This paper will focus on Lake Sibaya which is the largest freshwater lake in South Africa. A series of high dunes separates the lake from the ocean, with a palaeochannel forming the only linkage. The increased demand for water from the lake and associated groundwater system combined with decreasing rainfall has resulted in a significant reduction in lake levels over the past decade. The water balance of Lake Sibaya shows that lake levels fluctuate in response to varying amounts of groundwater and surface water inflow, direct rainfall onto the lake, seepage loss through the coastal dune, abstraction, and evaporation from the lake. Although increases in the rate of water abstraction from the lake together with rapidly increasing pine plantations have had a significant effect on lake levels, it appears that decreasing precipitation is responsible for the recent severe drop in lake levels. Nevertheless, the results indicate that proposed new plantations would impact the already stressed environment significantly.



**Emerging contaminants in rainwater as a possible source of groundwater contamination- How to carry out a robust rainwater assessment ?  
Abstract n°1773**

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**KEYWORDS:** Rainwater, emerging contaminants, sampling methodology

The objective of this study is to better understand the potential contribution of emerging contaminants (e.g. pesticides, perfluoroalkyl substances, artificial sweeteners) in groundwaters via dry and wet atmospheric deposition. This can help assessing the possible transfer of organic contaminants in the water cycle and more precisely their introduction pathways at the interface rainwater soil-groundwater. The achievement of this objective requires to select and to implement robust methodologies regarding sampling and analysis. The two major difficulties to face are (1) the representativeness of samples due to the heterogeneity of the considered acidic matrix (inorganic compounds, metals, microbial activity) and (2) the potential risk of external contamination. In this study, two types of semi-automatic rainwater collectors were chosen to sample bulk deposition (i.e. dry and wet depositions simultaneously) and dry and wet depositions separately. This strategic choice is linked to a lack of knowledge regarding occurrence of emerging contaminants in dry atmospheric deposition, whereas it has been shown to be non-negligible for pesticides [1]. Both devices have a refrigerated cabinet to ensure the good preservation of samples. The collectors are composed of well-known inert materials (i.e. PTFE, glass) to avoid any external contamination. The use of an innovative wireless system for data communication allows a remote continuous monitoring of the device, and more flexibility in the collection protocol. Robust sampling methodologies which ensure reliable results are achieved with the use of a wide range of blanks at each step of the protocol, from the installation of the device to the shipment of samples. In this study, we focus on atmospheric deposition in 6 sites with distinct geographical and climatic characteristics, depending on the local rainwater seasonality, which reinforce the spatial and temporal representativeness. It finally enables to anticipate the risks undergone by groundwaters when considering rainwater as a possible source of contamination. [1]Sauret, N.+ Wortham, H.+ Streckowski, R.+ Herckès, P.+ Nieto, L. I. Environmental Pollution 2009, 157, 303.



## **Influence of groundwater on surface water pollution with nitrates**

### **Abstract n°1774**

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**KEYWORDS:** surface water, nitrates, the impact of groundwater on surface water quality

Groundwater is often polluted by nitrates. This not only causes degradation of the water resources but also affects pollution of surface water which is largely fed by groundwater discharge. In order to evaluate this phenomenon and its changes over a longer period of time the variability of nitrate concentration in the water of the Warta river in the last 65 years was analyzed. Investigations were carried out on the Poznan gauging section closing catchment area of 25083 km<sup>2</sup>. In the catchment direct groundwater discharge to the river represents 65.5% of the whole river outflow. It was found a noticeably increasing trend in the maximum concentrations of nitrates marked in the winter periods from approx. 2 mg/L N-NO<sub>3</sub> to more than 8 mg/L N-NO<sub>3</sub> in recent decades. This trend is correlated with the agricultural use of nitrogenous fertilizers in Poland. It shows that nitrates in surface water comes mainly from agricultural lands through groundwater. It was also found that graph of nitrate concentration exhibits a distinct maxima (up to 18 mg/L N-NO<sub>3</sub>), which can be correlated with the occurrence of prolonged periods of droughts. During the droughts nitrates loads are accumulated in the soil and unsaturated zone, and then after the drought accumulated nitrates recharge groundwater and further flow into surface waters. The phenomenon of nitrates accumulation during the four-year drought in 1989-1992 was also demonstrated on the basis of nitrates tests in groundwater in several wells and observation wells in the valley of the Warta river. The results demonstrate the usefulness of nitrate concentrations research in surface waters in order to assess the state of groundwater pollution. They also have a high educational value showing the relationship between groundwater and surface water, as well as the need for effective protection of groundwater in order to protect surface waters quality.



**Hydrogeological responses to intense groundwater pumping in the Indo-Gangetic Basin- Evidence from environmental tracers  
Abstract n°1775**

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**KEYWORDS:** Indo-Gangetic Basin, tracers, groundwater quality, security

Groundwater is a critical resource for hundreds of millions of people in the Indo-Gangetic Basin (IGB) who rely on it for drinking water, agriculture and industry. Intense exploitation for irrigation and domestic water supply is widespread across the IGB, where deeper (typically 100-200 m below ground level) aquifers are generally considered secure long term sources of drinking water. The water quality at depth is generally of superior quality compared to shallow sources which are affected with a range of issues including arsenic, fluoride, nitrate and pathogens. The security of deep groundwater sources are contingent on a range of factors including regional scale geological controls, local and site scale pumping histories and trajectories as well as site specific borehole design and completion. Chemical properties of groundwater can be used as environmental tracers to provide important insights on its hydrogeochemical evolution, origin and residence time. This paper brings together new environmental tracer data from case studies within sedimentary aquifer systems of the IGB where profiles of groundwater residence time and hydrochemistry have recently been collated. Age tracers and hydrochemical depth profiles are compared from areas with contrasting subsurface lithology and pumping histories. These are used to characterize pumping induced changes in age-depth profiles and water quality and understand the regional scale anisotropy of the IGB aquifer system. This new empirical evidence informs the current dialogue regarding the complexity of the IGB aquifer system and the long term security of deep groundwater resources in this region.



**Characterization of sub-surface heterogeneity with electrical resistivity tomography-  
new insights gained on hydrological functions in the Weierbach catchment  
(Luxembourg)  
Abstract n°1777**

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**KEYWORDS:** subsurface hydrological processes, regolith, electrical resistivity tomography

While being of highest relevance in catchment studies, subsurface regolith observations remain severely measurement limited. There is a pressing need for detailed information on the structure, properties and weathering states of the soil to bedrock continuum. Groundwater plays a key role in the fundamental hydrological functions of catchments, i.e. water storage and release. This subsurface information is indeed a prerequisite for a better understanding and prediction of water flow paths and transit times. However further progress is stymied by the “point-scale” character of most conventional measurement protocols. Given their proven potential for investigating the subsurface, geophysical methods have received increasing attention in recent years within the hydrological sciences community. They inform on variations in physical properties and states that are of interest to hydrological investigations. For instance, electrical resistivity tomography (ERT) is now commonly used for mapping electrical resistivity in depth and space and, more recently, through time. In many studies, it has revealed static properties such as subsurface lithological structure and hydraulic pathways, as well as temporal changes in water content or solute concentration. The Weierbach headwater experimental catchment (0.45 km<sup>2</sup>) is a slate forested area of interest, representative of the Ardennes massif in northern Luxembourg. Previous studies have shown that shallow subsurface regolith plays a major role in runoff generation in this catchment. However a detailed understanding of this hidden compartment was still missing until very recently. In order to fill this knowledge gap, the Weierbach catchment has been extensively investigated, using ERT. Different types of ERT investigation were strategically deployed- catchment scale mapping to grasp the overall catchment structure, plot scale profiles to accurately characterize specific landscape units, as well as time-lapse survey to image dominant processes controlling subsurface flow. Through our case study, we illustrate how ERT investigations offer considerable potential for gaining new insights on fundamental catchment functions of water storage and release.



**INFLUENCE OF LITHOLOGICAL AND HYDRODYNAMIC CONDITIONS ON  
GROUNDWATER QUALITY IN RIVER VALLEYS AND ICE MARGINAL VALLEYS  
Abstract n°1780**

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**KEYWORDS:** river valleys and ice-marginal valleys, groundwater quality, groundwater quality changes during pumping

In the valleys of big rivers and ice-marginal valleys are located aquifers that contain large groundwater resources in Poland. These waters are characterized, however, in some areas by very poor quality (high concentration of iron, manganese, ammonia nitrogen, COD and colour). Furthermore deterioration of groundwater quality during pumping is observed in these areas. In order to identify the occurrence of zones characterized by unfavorable geochemical environment the hydrochemical and hydrodynamic conditions were examined including determination of lateral and vertical variation of parameters. In addition geochemical tests of aquifer sediments focusing on organic matter, carbonates and sulfides were done. Performed research shown that the zones of low groundwater quality are located in the regions of the flood terraces, where a young Holocene sands containing dispersed organic matter of plant origin is deposited. Extremely bad geochemical conditions are observed, however, in those parts of the floodplains where the absence of hydrodynamic gradient cause lack of groundwater outflows. In areas where palneohydrogeological groundwater flow occurred, gradual improvement of water quality is observed as a result of leaching of the reactive organic matter. Studies have also shown that in such areas deterioration of groundwater quality may occur as a result of oxidation of organic matter and the associated sulfides. Process is being developed, above all in conditions of lowering the water table during pumping and leads to high concentrations of sulfate, iron, manganese and the total hardness in the water. The results indicate unsuitability of these zones to locate groundwater well fields. They also point to the need to provide detailed hydrochemical and hydrodynamic research during design and construction of the new groundwater captures located in the river valleys and ice-marginal valleys.



**Flow-adapted parametrization of subsurface heterogeneity - Estimating aquifer statistics from transient pumping tests**  
**Abstract n°1781**

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**KEYWORDS:** transient pumping, aquifer heterogeneity, parameter estimation

A novel concept is presented for interpreting transient pumping tests in heterogeneous transmissivity fields to infer the geostatistical parameters of the medium. The methodology bases upon the upscaling method Coarse Graining which provides a theoretical framework for a flow-adapted parametrization of subsurface heterogeneity. Simply expressed, the heterogeneity of transmissivity is filtered according to the characteristics of well flow tests. The filter is chosen small in the vicinity of the pumping well and increases with increasing distance. The application of the concept to well flow - called Radial Coarse Graining - provides an effective description of transmissivity for pumping tests in heterogeneous media. It was used to derive an Effective Well Flow Solution for transient flow conditions including not only the parameters storativity, but also the geometric mean, the variance, and the correlation length of log-transmissivity. Parameters of aquifer heterogeneity, in particular variance and correlation length, can be inferred from simulated pumping test drawdowns by combining the Effective Well Flow Solution with inverse estimation techniques. A sampling strategy - comprising pumping tests at multiple locations within an aquifer - is presented in order to show that the parameters of aquifer heterogeneity can be inferred under field conditions. Pumping test field data is analyzed in the same procedure, showing promising results in comparison to other geostatistical methods for aquifer analysis.



**Discriminating sources of nitrate pollution in groundwater of Piedmont plain (NW Italy)  
using stable isotopes of nitrate and boron isotopes  
Abstract n°1784**

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KEYWORDS: nitrate, sources, stable isotopes

Diffuse nitrate pollution in groundwater is currently considered one of the major causes of water quality degradation. Determining the sources of nitrate contamination in groundwater is an important first step for a better management of water quality. Thus isotopic composition of nitrate and boron isotope were used to evaluate nitrate contamination sources and to identify geochemical processes occurring in the shallow and deep aquifers of the Turin-Cuneo Plain (NW Italy). The study area is essentially an agricultural zone+ also livestock farming are highly developed. Moreover in the small towns domestic waste water is locally not connected to sewerage. A groundwater sampling campaign was performed in October 2014 on 34 wells in the shallow aquifer and 8 wells in the deep aquifers. In the shallow aquifer 26% of monitored points have nitrate concentration between 0 and 25 mg/L, 50% between 25 and 50 mg/L, 24% superior than 50 mg/L, up to 177 mg/L. In the deep aquifers all water samples have nitrate level inferior than 50 mg L, ranging between 5 and 40 mg/L. The boron concentration is generally inferior than 15 lg L, except four samples of shallow aquifer in which the concentration ranges between 20 and 86  $\mu\text{g/L}$ . The  $\delta^{15}\text{NNO}_3$  values of Turin-Cuneo Plain samples vary between 4.00‰ and 20.00‰. The  $\delta^{18}\text{ONO}_3$  values vary between 4.2‰ and 14.9‰.  $\delta^{11}\text{B}$  swings between 8‰ and 18‰. Isotope data of nitrate indicate that nitrate contamination in the Turin-Cuneo Plain originates from synthetic fertilizers, mixtures of synthetic and organic sources, slightly denitrified, manure or septic tank effluents. Moreover boron isotopes were used to try to discriminate further among the main anthropogenic sources of pollution. The analyses confirms that both domestic sewage and animal manure contributes to the nitrate contamination. At last a significant denitrification process was highlighted especially in the shallow aquifer of Poirino Plateau, that is the most contaminated part of the study area.



**Multi-isotope systematics on the Dogger brines of the Paris Basin – Preliminary results.**  
**Abstract n°1785**

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KEYWORDS: isotopes, Dogger, brines

The franco-canadian ANR-NSERC project G-BASELINE aims at constraining the potential effects of exploration and exploitation of unconventional hydrocarbon resources by defining a geochemical baseline for impact assessment. In France, the Lower Jurassic of the Paris Basin is investigated as potential shale oil reservoir. The parent rock are the black shales of Lower Jurassic. The oil migrates either upwards in the Dogger (Middle Jurassic) limestones, or downwards to the Upper Triassic sandstones. These conventional reservoirs have been exploited for centuries, and extraction is still active in some places. Associated high temperature Dogger brines are also exploited for low-enthalpy geothermal energy. They are investigated in the aim of identifying their migration or leakage, potentially triggered by non-conventional hydrocarbon exploitation, on the background of existing salinity anomalies in overlying freshwater aquifers, particularly the Albian aquifer. Several studies that were carried out during the 90's have emphasized the complex origin of both Triassic and Dogger brines. In addition, it is not clear whether the Dogger brines could originate from the upward migration of the Triassic brines (in Millot et al., 2011). These latter have a heavy B isotopic composition (Millot et al., 2011), that is identical to the heaviest boron isotopic signature of the dilute Dogger formation waters from the eastern Paris Basin (Innocent et al., in prep.). Strontium isotopic compositions obtained on some Dogger brines (in Rojas et al., 1989) cluster at 0.7078-0.7079, slightly higher than dilute Dogger formation waters of the eastern Paris Basin (0.7073-0.7074, Rebeix et al., 2011). Such values reflect the isotopic composition of the aquifer material, but are largely lower than the isotopic compositions of oil-bearing Triassic brines (0.7104 to 0.7112, Millot et al., 2011). Thus, on the basis of Sr isotopes, the different brines do not seem to be completely geochemically homogenous. A multi-isotopic study is underway on new samples of Dogger brines. The preliminary results are discussed.



**HYDROGEOLOGY - THE KEY PREREQUISITE FOR OPTIMAL WATER MANAGEMENT  
AND REGIONAL DEVELOPMENT IN KARST  
Abstract n°1786**

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**KEYWORDS:** Karst+ groundwater resources+ sustainable management+ transboundar+ engineering works.

At a number of karst regions in the world water potential is the only natural source relevant for socio-economic development. In spite of abundant rainfall, access to water is a challenge because hydrogeological properties of karst aquifers are extremely complex and unpredictable to be optimally utilized in a simple way. In contrast to the limited surface water resources, it is known that there is considerable amount of groundwater available. The nature of karst presents a great variety of risks associated with any kind of human activities. As a consequence, the people for centuries emigrate from karst regions in searching of a better life. The optimal strategy of water resources development in karst areas is a key requirement for socio-economic development. Application of common basic hydrogeological rules and investigation methods, has in karst, a number of limitations. Elemental hydrogeological volume (EHV) in karst does not exist. Construction of different structures (dams, reservoirs, tunnels) is the only way for optimal water management and socio-economic development in local and regional scales. In the first part of the 20th century geology, and particular hydrogeology, were not fully accepted as an important base for water management in karst. As a consequence of inadequate knowledge of hydrogeological properties a number of failures occurred. The risk of constructing in karst still cannot be eliminated completely, even when best engineering practice are followed, but it can be minimized to an acceptable technical and economical level. Hydrogeology has a crucial role in protection of sensitive karst environments, rich with endemic species, natural rarities and historical monuments. At many karst areas with transboundary problems, hydrogeology plays a key role. Successful solutions require a good hydrogeological base and close co-operation of a wide spectrum of scientists and engineers to define causes and consequences between human activities and resulting impact.



**Assessing groundwater flow pattern in the Bara volcanic aquifer system, Republic of Djibouti**  
**Abstract n°1787**

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**KEYWORDS:** arid climate, geochemistry, isotopes

Located in the semi-arid Republic of Djibouti, the Bara area mainly relies on fractured volcanic aquifers for its water supply. Sustainable water management therefore requires a comprehensive understanding of groundwater flow pattern. This paper aims at characterizing groundwater flow inside and between the compartments of the aquifer system composed by basaltic rocks and by alluvium using geochemical and isotopic tracers, including major ion chemistry,  $2\text{H}$ ,  $18\text{O}$ ,  $13\text{C}$ ,  $14\text{C}$  and  $3\text{H}$ . Geochemistry shows an evolutionary trend from alluvium aquifers located in wadi-valleys and deltaic formations bordering the two sedimentary basins, with low salinity and Na-Cl- $\text{HCO}_3$  water type, to a more saline and intermediate water type in the basalts and finally to a Na-Cl- $\text{SO}_4$  water type in the most mineralized groundwaters. Decreasing TDIC and increasing  $\delta^{13}\text{C-DIC}$  reveal the absence of an active deep  $\text{CO}_2$  contribution to the groundwater system. Different recharge conditions for the alluvium and basalt aquifers are revealed by  $2\text{H}$  and  $18\text{O}$ , with no evidence of evaporation effects. Alluvium groundwaters are found to be modern according to radiocarbon and tritium, while basalt groundwaters are dated to the early to mid-Holocene. These features reveal a common evolutionary pattern, with a significant recharge from the alluvium, transmitted downward to the basalt aquifer through major faults in the wadi valleys or through the sediments of the alluvial fans, followed by mixing with an ancient Na-Cl water. Finally, the two basaltic aquifer compartments located below the main endorheic plain are found to form one single aquifer flowing northeastward.



## Potential Impacts of Rock Mining from a Karstic Aquifer on a nearby Wellfield Abstract n°1788

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KEYWORDS: Karst, Rock mining, Tracer tests, Aquifer protection

Water to the city of Miami and other communities in Miami-Dade County, Florida, USA is supplied by several wellfields, including the Northwest Wellfield. The water is produced from the Biscayne Aquifer, a karstic limestone. This limestone is also the source of rock aggregate for construction and is extensively mined in the vicinity of this wellfield. Mining of the rock occurs below the water table and man-made lakes, hydraulically connected to the aquifer, remain at the completion of mining+ because of the abundance of such lakes, the area is called the Lake Belt Area. Depth of mining is controlled by regulations based on travel-time distances from the wellfield. There were, however, concerns that these regulations were not adequate for protecting the wellfield from pathogens and other contaminants that could enter the aquifer through the mining lakes. To address these concerns, several tracer tests were conducted in the vicinity of the wellfield by County and Federal agencies. Previous evaluations of these test data compared travel velocities without considering the relative position of the test location with respect to the wellfield. This presentation summarizes the results of an analysis of these test data using a simple model that considers test location, and presents an evaluation of the adequacy of the existing mining regulations with respect to the test results. It is concluded that travel-time distances specified in the regulations were flawed because their calculation did not correctly consider the pathways between the lakes and the wellfield, ignored the effects of regional gradients, and used data that were not consistent with the results of tracer tests.



**Sustainable use of the subsurface and groundwater- Identifying opportunities and bottlenecks using the ecosystem services concept  
Abstract n°1789**

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KEYWORDS: groundwater, ecosystem services, assessment framework

In densely populated areas like the Netherlands, the use of groundwater and the subsurface for functions such as groundwater extraction, aquifer thermal energy storage and infrastructure is increasing. National and regional governments need tools to take informed decisions on the sustainable use of the subsurface and groundwater. For this purpose a technical assessment method was developed based on the concept of ecosystem services (ESS) and its relations with economic activities. The method discloses in a systematic way how activities in the subsurface and aboveground depend on ESS and what the activity's impact is on the ESS, whether it is a positive or a negative impact. It finally shows what activities can be combined or have an adverse impact on each other. Eleven relevant ESS of the Subsurface and Groundwater and 30 activities are described in the method. The ESS are clustered according to The Common International Classification of Ecosystem Services (CICES) into provisioning services, regulating services and cultural services. The activities are related to abstraction of groundwater, storage of water and other substances, reservations, extraction of resources (other than water), groundwater level management, aboveground activities and subsurface spatial occupation (spatial claim). Two sets of factsheets summarize key knowledge about these activities and ESS, and their interrelations. The factsheets give preliminary guidance for local and regional authorities for decision making. The method was tested on a case in the municipality of Utrecht and a case in the Province of Noord-Brabant (the Netherlands) involving all stakeholders from the private and public sector. For both cases, the method is used to create a common knowledge base on current and future activities in the first and second aquifer with the purpose to jointly identify opportunities and bottlenecks with respect to the sustainable use of the subsurface. The method proved to be an adequate tool to build a common picture of important win-win situations and trade-offs, which in a next step need to be further elaborated.



**Hydrochemistry study to determine an active hydrodynamic in hydrocarbon trap system**  
**Abstract n°1790**

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**KEYWORDS:** hydrogeochemistry study, modern groundwater, active hydrodynamic

High water resistivity value in shallow, friable-to-loose sandstone reservoir characteristics below oil-water contact is a rare condition in oil and gas field in Indonesia. Water samples from several wells have been analyzed and showed Na-bicarbonate water type. Low TDS values of the water clearly indicated fresh water characteristic and tritium isotope analysis showed that the water has young age range from 23 to 47 years. These conditions are similar to modern groundwater. Therefore, the water in water zone of the reservoir was not originated from sedimentation process and still affected by modern groundwater movement. The presence of groundwater movement indicated that water in the reservoir could be supplied from recharge area close to study area. Pressure conditions in some wells of the study area are known had a supernormal dynamic pore pressure regime which means that the wells are located in discharge area. All of the analysis yield conclusion that the fresh water from recharge area enter the reservoir and flowing into the wells. The water flow caused the hydrocarbon trapping mechanism in the study area as active hydrodynamic system.



**Core model-based practices for investigating conjunctive use opportunities-  
description and evaluation for two cases in the Murray-Darling Basin  
Abstract n°1791**

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**KEYWORDS:** conjunctive use, water management, participation, integrated modeling

The presentation will introduce integrated modeling case studies of two catchments in the Murray-Darling Basin. The studies are being undertaken with key stakeholders, with the aim of identifying opportunities to attain improved water management in terms of socioeconomic and ecological outcomes. The opportunities are focussed on innovative conjunctive use options for surface and groundwater, derived from workshops with stakeholders. In the Campaspe study, the conjunctive use options are generally at a smaller scale, which means a more detailed model is required to explore the smaller scale issues (e.g. groundwater trigger levels and the impact on saline intrusion of water, or on-farm managed aquifer recharge and water use efficiency improvements), while in the Murrumbidgee study the greatest interest tends to be at a system scale, with large government water holders (i.e. Commonwealth Environmental Water Holder). Both case studies have different characteristics (e.g. modelling purpose, data collection, scales, stakeholder engagement) which will influence the modelling practices (i.e. technical and participatory) to be employed throughout the project. The aim of the presentation is to reflect on the practices that were used in the modeling process, from stages of problem framing to evaluation of the models and conjunctive use alternatives. This reflection will be against the background of a new framework for determining effective model-based practices for integrated water management projects. We will use the two case studies to explain differences in practices being used, especially in the way (1) interactions with water managers and users were engaged in the problem framing, (2) the conceptual modeling was developed with stakeholders, and (3) the ensuing numerical modeling platform and components were selected. It is hoped that this analysis will contribute to demystifying the process of model-based identification and assessment of water management improvements and clarifying the selection of practices that are appropriate to a given problem setting.



**Groundwater flow and saltwater intrusion modelling in the Continental Terminal (CT) aquifer near the Saloum inverse estuary in Senegal**  
**Abstract n°1792**

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**KEYWORDS:** Groundwater modelling, Saloum, Inverse estuary, Salt water intrusion, Climate change

The Saloum River hypersaline estuary (Senegal) is an ‘inverse estuary’ showing a salinity increasing from the river mouth towards inland. This salinization process is mainly driven by a net loss of freshwater due to intense evaporation. In this context, interactions between the river and the surrounding aquifer of the Continental Terminal (CT) may lead to local and progressive salinization of this groundwater main resource for water supply. Our study, based on available data and new measured data in 2012 and 2013, is focused on the southern part of the Saloum basin. It confirms that the groundwater resource is threatened by local saltwater intrusions in the vicinity of the Saloum River and along the western coastal part of the aquifer. For a long term water resources management, it is thus essential to predict the future evolution of this process in a context of increasing groundwater pumping rate together with climate variability and changes. A groundwater flow model is developed using MODFLOW. Starting from a conceptual steady-state situation corresponding to the CT aquifer state in 1973 before development of pumping, a transient calibration of the groundwater flow model is performed on data from 1974 to 2012. Despite the low number of measured data, the model can be considered as the current best assessment tool for future predictions. Using the particle tracking technique (MODPATH), a first assessment of the saltwater intrusions in the aquifer is simulated (neglecting the density effect on the hydraulic conductivity) confirming the measured data. Results, for an increased pumping of 20% in 2050 combined with different climatic scenarios, are useful to assess how the saltwater intrusions will evolve in the next years.



**Hydrodynamics of the chalk aquifer- a new hydrogeological experimental site of  
LaSalle Beauvais (Picardie)  
Abstract n°1795**

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**KEYWORDS:** chalk aquifer, experimental site, hydrodynamic, LaSalle Beauvais

The groundwater represents a major factor in the economical and social development in the northern part of France (Oise department, Picardie). In the last decade, industrial, agricultural activities and the development of the Beauvais-Tillé airport have continued to increase with an intense stress on the alluvial aquifer. So, environmental and water offices were led to search new and deepwater resources in the Picardie and to setup groundwater protection zones. The construction of a new hydrogeological experimental site in the campus of the "Institut Polytechnique LaSalle Beauvais" can help in making a groundwater policy. This site aims to-

- Understand the groundwater recharge in the Cretaceous chalk formations. Many hydrogeological wells have been realized and equipped with automatic probes of the groundwater levels, temperature and electrical conductivity.
- Monitoring the evolution of the hydrodynamic characteristics of the chalk aquifer. These parameters are rarely studied in the Picardie and the experimental site offers an opportunity to estimate the transmissivity, hydraulic conductivity and water content by using the powerful hydrogeophysics methods (RMP- The Magnetic Resonance Sounding).
- Understand the behavior, structure and the chalk aquifer functioning. The core drilling will be the subject of an extensive study accompanied with the analysis and the interpretation of cuttings resulting from the core well.
- Characterize the petrophysical parameters of the chalk aquifer by using the well logging technics in order to follow the variation of the gamma ray, electrical conductivity.



**Carbon sequestration flux and its annual dynamic variation in watershed systems of Yangtze River Yellow River and Pearl River China  
Abstract n°1797**

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**KEYWORDS:** geological carbon sequestration, dynamic change, Yangtze River, Yellow River, Pearl River, China

**Objective-** Continual locating monitoring made at the controlling hydrological sections on Yangtze River, Yellow River and Pearl River respectively during 2011 to 2012. The purposes are to calculate the annual DIC flux formed by geological processes and to make estimation calculation of annual amount CO<sub>2</sub> absorbing from atmosphere through geological processes. **Methodology-** The monitoring items include as following, discharge, HCO<sub>3</sub><sup>-</sup>, Ca<sup>2+</sup>, pH, EC, DOC, rainfall, water temperature and so on. Analyzed hydrochemical indexes include K<sup>+</sup>, Na<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, HCO<sub>3</sub><sup>-</sup>, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, SiO<sub>2</sub> etc. **Original data and results-** The output flux of DIC in Pearl River and Yellow River watershed is 5.34x10<sup>6</sup> tCO<sub>2</sub>/a and 20.69x10<sup>6</sup> tCO<sub>2</sub>/a respectively, the carbon sequestration intensity is 16.34 tCO<sub>2</sub> km<sup>2</sup>.a and 27.10 tCO<sub>2</sub> km<sup>2</sup>.a in 2011. Similar results in Pearl River and Yangtze River watershed in 2012 are calculated as following, the output flux of DIC is 7.18x10<sup>6</sup> tCO<sub>2</sub>/a and 43.81x10<sup>6</sup> tCO<sub>2</sub>/a respectively, the carbon sequestration intensity is 21.96 tCO<sub>2</sub> km<sup>2</sup>.a and 25.69 tCO<sub>2</sub> km<sup>2</sup>.a. The DOC concentration of Pearl River, Yangtze River and Yellow River water is 2mg/l, 4mg/l and 6~8mg/l, respectively. **Conclusion-** (1) The hydrochemical components of river water are mainly formed by rock weathering processes. The discharge is the main control factor of carbon sequestration flux. (2) The monitoring sections of three watersheds control an area of 2.78x10<sup>6</sup> square km, the output DIC is about 70.00x10<sup>6</sup> tCO<sub>2</sub> in total. The DOC concentration of Pearl River, Yangtze River and Yellow River water is 2mg/l, 4mg/l and 6~8mg/l respectively. Therefore, the annual output carbon sequestration flux should be greater than 91.88x10<sup>6</sup> tCO<sub>2</sub> during 2012. This value will be a little difference during the years. (3) Thus shows that the carbon sequestration effect formed by geological processes in a global scale is a considerable sum.



**Genevese transboundary aquifer management as a model for the establishment of a water community in the Geneva region (Switzerland and France). Highlights on the technical aspects to be implemented**  
**Abstract n°1798**

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**KEYWORDS:** transboundary aquifer, aquifer use agreement, aquifer recharge

The Genevese aquifer is a transboundary aquifer. While this groundwater provides around 20% of the total drinking water supply, for over 35 years the artificial recharge system has made it possible for 560 million metric cubes of water to be used. Transboundary groundwater management, coupled with the technical success of the aquifer recharge system, have guaranteed safe drinking water for Geneva and the surrounding region by diversifying and optimising the quantitative and qualitative potential of existing water resources. An agreement relating to the use, recharge and monitoring of Franco-Swiss Genevese groundwater was signed between local French communities of Haute Savoie (Upper Savoy) and the State of Geneva in 2007. This new agreement succeeded the 1978 arrangement and entered into force on January 1, 2008 for 30 years. The agreement is an extremely rare example of a bilateral agreement on the management of a transboundary aquifer system. Due to the radical change in demographics over the past seven years and the economic attractiveness of the Geneva region, there is an ever greater trend towards establishing a cross border approach. A committee on a transboundary water community was even formed in 2007. At the end of 2009, the Geneva Cantonal Statistical Office projected that the population of the Franco-Valdo-Genevese area would grow to approximately one million by 2030, representing a 20-30% increase. The demand for water would therefore also rise as a consequence, requiring a clear technical vision for meeting such future demand. Finally, an agreement protocol for cross border cooperation in water management was signed on December 3, 2012. This Water Community is a real shared program between French communities and Geneva canton, in which an actual transboundary cooperation is successfully implemented. This regional project will seek to create a common strategic environmental vision across the territory and will include patrimonial, social and economic aspects.



## **The Study and assessment of prospects of groundwater use in transboundary areas Abstract n°1799**

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**KEYWORDS:** transboundary states, groundwater, socio-legislative and natural aspects, groundwater attraction

At present transboundary problems don't lose its relevance, but also acquire greater significance. This is due primarily to the growing economic activity in a number of border areas, which raises the question of the assessment of possible and prospect ecologic safety of the use of some components of the environment. The study and assessment of the prospects of the use of certain components of the environment in the border area of neighboring countries has two aspects- socio-legislative and natural. The first one is based on adherence to a number of legislative acts, both international and domestic, governing the conditions for the use of all components of the environment in the border area. The second determines the internal and external factors determining the possibility and prospects of their rational use. With regard to groundwater, transboundary issues include assessment of the mutual hydrodynamic influence under the joint exploitation of transboundary aquifers, i.e., the so-called problem of attraction of water from the territory of neighboring state, as well as changes in the quality of groundwater under the influence of their exploitation. The report is focused mainly on hydrogeological aspects of the problem- estimation of present-day and prospect groundwater resources use for water supply and irrigation+ protection of groundwater from pollution and deterioration, quantitative assessment of groundwater natural protection+ assessment of the interaction of groundwater abstraction in the border areas of neighboring states. The basic methodological approaches addressing these issues and the basis for future groundwater management of transboundary aquifers accounting environmental restrictions are formulated. The report provides some examples of possible and existing transboundary problems and describes some ways of their solutions.



**IDENTIFICATION OF GROUNDWATER NATURAL RECHARGE AREAS IN THE  
PRODUCTIVE THIAROYE URBAN AQUIFER (DAKAR, SENEGAL)  
Abstract n°1800**

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**KEYWORDS:** Urban aquifers, Groundwater quality, Recharge, Environmental isotopes

Urban groundwater remains a major source (~47%) of the freshwater supply to Dakar, Sénégal despite steadily rising water demand and observed degradation in groundwater quality. We apply hydrochemical and isotopic tracers to characterise groundwater low regimes (i.e. recharge, discharge) in the infrabasaltic and Thiaroye aquifers exploited in Dakar. Our results show a predominance of present-day recharge occurring mainly in the Thiaroye watershed coinciding with the peri-urban area with tritium data ranging from 1.1 and 3.5 TU (78% of samples), close to the input signal of 2.2 TU. Low values of 0.8 TU measured in the south-eastern part are considered to indicate older groundwater recharged prior to 1960. Sites with tritium values of between 4 and 5.3 TU (16%) are located in the “niayes” where water tables are shallow and reflect recent groundwater replenished within the last 15 to 20 years. Values are similar to the 3H activities in groundwater from previous studies. These sites in the “niayes” represent rapid discharge zones from the shallow aquifer. The relative ages of the sampled groundwaters and associated recharge zones are in good agreement with their origins given by the  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$  groundwater compositions and hydrochemical zones. This research builds on previous evidence based on stable isotope ratios of O and N in nitrate and mapping of trace elements (B, Br, Sr). These hydrochemical and isotopic studies provide a framework for more detailed site and modelling investigation studies under a new 5-year research project, AfriWatSan that seeks to inform a new adaptive strategy of using polluted urban groundwater for irrigation in peri-urban areas of Dakar.



**Geo-fluid-dynamic models of the oil-and-gas accumulation zone's forming in uniclinal and synclinal conditions within the oil-and-gas bearing basins**  
**Abstract n°1801**

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**KEYWORDS:** Ground waters, geo-fluid-dynamic unhomogeneity, oil-and-gas bearing basin

Hydrodynamic factor's influent to location of hydrocarbons deposits are studying well actively in recent times. Expelled water and hydrodynamic water junction leads to geo-fluid-dynamic unhomogeneity forming, which could be more complex externally influenced, at first by the geo-dynamic stress nature. In the passive geo-dynamic conditions, by the expelled water and hydrodynamic water junction on the uniclinal and troughs onboard slopes and bowls such conditions are created when the oxygenate infiltration waters contact with organic matter enriched expelled waters and with the phase-isolated hydrocarbons which are migrated along with it. In these conditions are formed for example the Dualetabad-Donmezscoe gas-condensate field (Turkmenistan), Sorochinskaya gas accumulation zone (Ukraine) and others. In the geo-dynamic stretch conditions the hydrodynamic inverting forming is possible. In addition to the above, gas is osuperposedO by oil and oil is osuperposedO by water. These processes are noted by different terminology- ocontinuous type gas accumulationO, ogas under waterO, obasin-centered-gasO, odeep basin gasO, osincline oilO. The last two terms largely explained by that the same feature of geo-fluid-dynamic field is found in the syncline's axial region specifically. In specific cases a ocontinuous type gas accumulationO term includes the group of non-traditional oil-and-gas accumulation zones (hydrocarbons in the formation pressure deficit zones, hydrocarbons in the low-permeable reservoirs, hydrocarbons in the fracture-shaly zones).



**Monitoring of micro-organic pollutants in groundwater by means of passive sampling-  
case study Dravsko polje, Slovenia  
Abstract n°1803**

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**KEYWORDS:** Persistent organic pollutants, Groundwater monitoring+ Passive sampling

Organic compounds are nowadays used in large amounts in different human activities. Their number is additionally increased by several millions of metabolites and degradation products of parent compounds. The presence of micro-organic pollutants (MOs) in the environment results also in an increasing demand for sensitive and reliable monitoring tools to determine these contaminants in groundwater. One such method is passive sampling. Contrary to grab sampling, passive sampling is less sensitive to accidental extreme variations of the organic pollutant concentration in natural waters and a large range of contaminants can be detected at once. A passive sampler can cover a long sampling period, integrating the pollutant concentration over time. Compared to conventional monitoring, the use of passive samplers can reduce analytical costs substantially. This study presents the application of passive sampling for MOs monitoring in the Dravsko polje coarse gravel aquifer. This Quaternary aquifer lies in north-east Slovenia and is one of the largest and most important drinking water resources in Slovenia, extending in an the area of 293 km<sup>2</sup>. Intensive agriculture covers 70% of the study area. Settlements and industrial areas are the main urban pollution sources. All these impacts are factors that affect the quality of groundwater. Passive sampling devices with activated carbon fibers were applied into 19 observation wells. Four sampling series covered the period of two years. Samples of groundwater were analyzed by gas chromatography mass spectrometry (GC-MS). For the interpretation of chromatograms, the AMDIS deconvolution was used. The deconvolution was covered by GC-MS library with retention times for 921 organic contaminants from Agilent USA, and also the NIST 2008 library of mass spectra. GC-MS chromatographs were interpreted with estimate of peaks intensities with ranking scale. The results are evaluated according to the probability of identification and to the potential relevance of signal intensity. In four sampling series, ca. 370 organic compounds were identified. Most often detected MOs were classified in different pollutant groups with respect to their origin (urban source, agriculture or industry). Based on the intensity and frequency of selected MOs in groundwater and land use, a spatial analysis was performed. Passive sampling was proved as an appropriate way of monitoring MOs in groundwater.



# QUANTIFICATION OF RUNOFF AND RECHARGE FROM RAINFALL IN THE GAZA STRIP

## Abstract n°1806

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KEYWORDS: CN method, CMB method, SMB approach

Groundwater is the only water source in the Gaza Strip, where more than 1.8 million inhabitants are living within 365km<sup>2</sup>. The groundwater is being exposed to salinization as a result of aquifer exploitation and unbalance between recharge and abstraction in the past decades. The groundwater level has dropped more than 10m below mean sea level in the southern part of the Gaza Strip which exposes the groundwater to seawater intrusion. The only fresh water source recharging the aquifer is from rainfall, hence it is essential to estimate the annual recharge volume from rainfall. Previous studies have estimated the average annual recharge in wide range from 35 to 64 MCM. This paper is focusing on recharge estimation based on collected historical daily rainfall data for the past 41 years. An estimation of surface runoff was made using SCS Curve Number Method. An estimation of groundwater recharge has been calculated using two different methods- Thornthwaite and Mather Soil Moisture Balance approach and Chloride Mass Balance method. Four land use maps and data have been used for the entire estimation period, three of them based on actual survey carried out in 1994, 2004 and 2010, while the fourth map was developed based on the population expansion trend to cover the period before 1993. It was found that the built up and the sand dune areas have inverse relationship, where built up area expanded from 7.6% in 1982 to 25.2% in 2010, while sand dune areas showed shrinkage from 32% in 1984 to 8.7% in 2010. The results show only 10.78% error percentage for long term average recharge between SMB and CMB within the same areas and time, hence SMB approach can be used as a reliable recharge calculation method for the Gaza Strip. The results estimated the long term average for runoff is 8.3% and for recharge, it is 21.5% of the rainfall quantity, where using long term average is conservative to be used due to yearly variance changes according to rainfall quantity, intensity, land use activity and soil textures of the Gaza Strip.



**Development of a method for prioritizing the interventions of Seine-Normandie Water Agency for the restoration and preservation of water quality of drinking water wells  
Abstract n°1807**

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KEYWORDS: nitrates, pesticides, water well vulnerability

Diffuse pollution by nitrates and pesticides is the main cause of groundwater quality degradation in France. To orient its assistance for the restoration of groundwater used for drinking water, Oise Delegation of Seine-Normandie Water Agency wanted a methodology for evaluating the capacity of a degraded resource to regain a satisfactory quality in a reasonable time. Using information from the 781 water wells of the Oise basin, a consortium of four engineering firms (Calligee, Hydriad, Agristem, Ecodecision) has developed a practical methodology to analyse the potential of qualitative recoverability of drinking water wells taking into account hydrogeological, agronomic and socio-economic considerations. This methodology is based on a decision tree comprising a sequence of analysis steps- - Characterization of the degradation level of the resource using nitrate and pesticide concentrations+ - Delineation of the preferential water catchment area of the drinking water well taking into account the type of aquifer (continuous, fractured or karstic)+ - Evaluation of the global vulnerability of the preferential catchment area+ - Estimation of agricultural pressures+ - Test of consistency between observed degradation, vulnerability and agricultural pressures+ if required, changes in initial assumptions and parameters+ - Analysis of the socio-economic acceptability of the changes that can be recommended to regain the water quality (agricultural context, local political context, market channels)+ - Evaluation of the resource renewal rate (resilience)+ - Quantitative and strategic importance of the water well. This methodology has been developed on a sample of 60 water wells and tested and refined on two additional samples of 20 water wells each. This original method is fast and applicable to all types of groundwater resource (automated processing from easily accessible data+ requested additional expertise in a targeted way only). The goal of the Seine-Normandie Water Agency is to extend its use to all 4215 water wells of the Agency's territory.



# Hydrogeological heritage in the Languedoc, and Roussillon- the role of the National Inventory of the French Geological Heritage Abstract n°1810

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KEYWORDS: hydrogeological heritage, National inventory, Languedoc-Roussillon

Since the law of February 27th 2002 in France, the geological heritage is an integral part of the great natural heritage inventory established for the entire land territory, fluvial and marine (Article L. 411-5 of the environmental code). The geologic heritage of the Languedoc and Roussillon is one of the richest in France, by its diversity and its abundance. 253 remarkable geological sites representing 3 580 km<sup>2</sup> (13 % of the regional territory) were listed+ they restore the history of the Earth over the past 600 million years. This inventory constitutes a scientific, educational, cultural, economic and tourist asset. More than 20% of these sites have been identified for their hydrogeological relevance and associated phenomena (thermalism, karst process, fluvial erosion...). These are springs, swallow holes, caves, canyons, karst systems, poljes, potholes... essentially located on mesozoic carbonate rocks. However, some of them such hot springs along the Têt River valley emerge along a polyphased fault in paleozoic granitic units or are in paleozoic cover. The diversity of hydrogeological heritage in Languedoc and Roussillon reflects the exceptional geological diversity of this territory. The inventory of geological heritage is an essential tool to enhance knowledge, develop educational actions preserve and sustainably manage our regional territory.



**Recharge areas of deep aquifers- a simplified approach for the assessment in  
Piedmont Region (NW Italy)  
Abstract n°1811**

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**KEYWORDS:** deep aquifer, recharge area, flow system

The deep aquifers represent one of the most important supply of drinking water. They are involved in intermediate and regional flow systems and are characterized by a different chemical composition compared to shallow one. Their groundwater are constantly renewed in the recharge areas of the deep aquifer (shown below as RADAs), where groundwater flow is downward directed, from the topographic surface to the deep aquifer, passing through the shallow one. This flow is able to transfer not only water but also pollutants from the ground surface to the deep aquifer. Consequently, the identification and safeguard of RADAs represent one of the most important prevention measure against the damage of water quality. Whereas the recharge areas of the shallow aquifer correspond with all the topographic surface, the RADAs are represented by a limited sector of it. Unfortunately their identification on a regional scale is not easy because it requires many hydrogeological and chemical data. These data are lacking in most of the Piedmont Region (NW Italy)+ thus a methodology for mapping RADAs was proposed, based on easily available data. More specifically the evaluation of the length of regional flow system, from its starting point to the discharge area of deep aquifer, was used. Indeed the size of the RADAs can be considered as a percentage of the length of the regional flow system. The size of these areas was modified in a second step according to including and excluding criteria, e.g. the water head difference between the shallow and the deep aquifers and the outcropping of the hydrogeological units hosting the deep aquifer. After the identification of RADAs in the Piedmont plain using this simplified approach, RADAs distribution and size were compared with recharge areas identified in a large portion of the plain (Vercelli plain) by previous studies that used hydrogeological data. The comparison highlighted that the differences of size of RADAs are very little, thus supporting the validity of this approach.



**Migration of nitrates in groundwater (Picardie)- experimental and analytical approaches**  
**Abstract n°1812**

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**KEYWORDS:** Nitrates contamination, saturated zone, pollutant transport modeling, chalk aquifer, Picardie, France, groundwater system

The prevention and reduction of the groundwater pollution caused by nitrates from agricultural sources is a priority for the European Council Directive of 12 December 1991, and an important objective defined in the European Water Framework Directive. In Picardie, in the northern part of France, this problem concerns almost 90 percent of groundwater bodies and involves a sustainable management of these resources for the coming years. In this context, the Institute of LaSalle Beauvais was commissioned by the Water agency of Seine-Normandie to study the nitrates transport in groundwater of the three extractions of drinking water located in the Thelle country (Oise department). The first part of this project consists to- i) realize a state of the art synthesis of the global context previous studies on nitrates transport in the saturated zone. It is supported by the information collected during a geologic investigation to understand the aquifer system functioning. li) characterize the hydrodynamic conditions and model the groundwater transport by using MODFLOW software iii) conduct the sampling campaigns in several hydrogeological wells which are used for water supply. The hydrochemical monitoring of the nitrates concentrations is realized in a vertical profile following a metric stratification. The analysis results will be used to support and validate the groundwater model. Finally, the path monitoring of the pollutant in the saturated zone will be determined on 2D or 3D sections issued from simulations and could serve to estimate the rate of nitrates transport. The integration of heterogeneous geological structures, which eventually impact parameters, will be used for the characterization of vertical zonation. These results are intended to serve as a basis for further water agency studies to better understand the hydrodynamics of the region.



**SIGES**  
**Abstract n°1813**

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KEYWORDS: SIGES, website, groundwater

A SIGES is a website that allows publicizing and valorizing information related to groundwater. This information concerns either a specific administrative region or a geographical division based on watersheds. The utilization of SIGES started 10 years ago at BRGM. The Aquitaine region was the first to use this technology, and now SIGES projects are being developed on the whole territory for diverse regional needs. Collected information has been registered in databases in order to reunite, process and manage these data. SIGES also assure the permanence of information. The development of Internet has permitted to publicize data, for instance with ADES website (Accès aux Données sur les Eaux Souterraines) and with BRGM's website Infoterre. However, these national databases don't allow responding on their own to all concerns about groundwater. Thus, SIGES aim to share means and information in order to answer those concerns. A server coupled to databases have been developed to constitute SIGES, a portal access to groundwater information, with the following aims- - Increase the availability of information about groundwater+ - implement a tool made of geo-referenced databases , and related cartographic materials + - facilitate data access to help the management of groundwater , while promoting consultations and treatment of information+ - facilitate the use of data for assessments, diagnoses, etc. Free of charge and accessible to everyone, SIGES is built to be easy to understand and manipulate by users of different level. Committed to a local regional development, SIGES respond to the needs and motivations of groundwater managers. This website is a unique portal which gives access to compiled data on a regional scale.



**Methodologies and best IWRM practices for joint management of groundwater and surface water at basin level**  
**Abstract n°1814**

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KEYWORDS: IWRM, capacity building, groundwater, surface water

INBO has published methodological handbooks on the conjunctive management of groundwater and surface water through IWRM at basin level- - “Toward a Joint Management of Transboundary Aquifer Systems” (2010), - “Integrated Water Resources Management in the Basins of Transboundary Rivers, Lakes and Aquifers” (2012), - “Water and Climate Change Adaptation in Transboundary Basins- Lessons Learned and Good Practices” (2015). These documents designed with expert partners (UNECE, UNESCO-IHP, GEF, GWP, AFD, etc...) promote methodological guidelines and share practical experiences on each step required for a joint management. The key principles of surface water management are demonstrated to be also relevant for groundwater management, especially in the case of transboundary aquifers- - Monitoring, water information and knowledge, - Institutional capacity building, - Professional training of stakeholders of all levels of qualification, - Design and implementation of basin management plans and programs of measures. This review include concrete case studies, illustrating successes in implementing the provisions of the 2008 Draft articles on the Law of Transboundary and IWRM principles- cooperative management of the French-Swiss Genevois aquifer, Mexico on the involvement of all users (farmers, industries, municipalities and state governments) in “technical committees for groundwater” (COTAS) created within basin councils, Sahara and Sahel Observatory on water-saving agricultural practices in the North-Western Sahara Aquifer System and on the development of a water information system covering the Niger river basin and its related lullemeden-Taoudeni-Tanezrouft aquifer system, Guarani transboundary aquifer and the involvement of the Intergovernmental Coordinating Committee of La Plata river or the Russian-Estonian Lake Peipsi aquifer system on the use of mathematical modeling to understand hydrological relations between groundwater and surface water. In conclusion, these methodologies and case studies are highly valuable capacity building tools for institutions in charge of implementing IWRM of both groundwater and surface water at basin level. They deserve to be broadly disseminated.



**Numerical simulation of managed aquifer recharge into a karst groundwater system at the Wala reservoir, Jordan**  
**Abstract n°1823**

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**KEYWORDS:** Managed aquifer recharge (MAR), karst aquifer, hydraulic anisotropy, groundwater modeling

<p>A successful example of managed aquifer recharge (MAR) into karst is the Wala reservoir in Jordan, where storm water is captured and infiltrates naturally into the carbonate aquifer and supplies a wellfield 7 km downstream. Sedimentation in the reservoir successively clogged the infiltration path and reduced the storage capacity. To predict the impact of sedimentation on the recharge rate and to characterize the hydraulic properties of the underground, a numerical assessment was conducted using the finite element approach with specific adaptation for karst aquifers. The 3D model domain was projected onto a 2D vertical cross-section. An independent calibration of the recharge and abstraction processes was achieved by dividing the cross-sectional model into a recharge model and an abstraction model. To account for the heterogeneity and anisotropy of the aquifer, both models were subdivided into horizontal zones of different permeability. The simulation of groundwater table fluctuations, as a result of the karst characteristic flow pattern of fast flow and slow depletion, were achieved with the fitting of high permeability zones and with a large anisotropy of permeability. Strong water level fluctuations at the wellfield could be assigned to changes in the abstraction depth. Climate scenarios for a dry period of low reservoir inflow and a wet period of high reservoir inflow, each 10 years (2013-2023), predict a lowering of the average groundwater table of around 2.7 m downstream the reservoir as a consequence of sedimentation in the reservoir. An average groundwater table decrease of 2.7 m and 6.3 m at the wellfield was computed when two different abstraction depths were applied to the wet scenario. Stronger influences of 9.0 m and 12.0 m, respectively, were calculated for the dry scenario. Flow quantities and water balance were not examined with this modeling approach. The numerical model can support the management of the reservoir and the wellfield and demonstrate an approach how MAR can be evaluated in karst regions with similar hydrogeological conditions.



**Geoelectrical Investigation of Seepage beneath Tailing Dams- case study in Miduk  
Copper Mine (Iran)  
Abstract n°1824**

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**KEYWORDS:** Seepage, Tailing Dams, ERT-SP

A hydrogeophysical survey is performed at tailing dams of Miduk Copper Mine (Iran). The surface topography is mounded, and groundwater discharges from this zone periodically. We use self-potential (SP) and electrical resistivity tomography surveys (ERT) to investigate the hydraulic connection between the reservoir and the seepage zone to determine whether there exists a potential for this success to be undermined. The hydro-stratigraphy is mapped with the electrical resistivity tomography data and groundwater flow patterns are determined with self-potential data. The groundwater flow pattern is controlled by the geological and tectonically history of bedrock and preferential flow pathways exist beneath the dams.



# Sea Level Rise, Groundwater and the Future of Agriculture in Oman

## Abstract n°1826

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**KEYWORDS:** MODFLOW simulations, Climate Change, Salinization, Economic impact

Oman's agricultural sector depends totally on irrigation from small coastal alluvial aquifers that are recharged temporally and sporadically. Most of these aquifers are already stressed. Expected sea level rise due to climate change will exacerbate seawater intrusion and the consequent salinization of the aquifers. Fifty percent of Oman's agricultural activity is located in the coastal region of Batinah. This paper estimates the effect of sea level rise on the water salinity of two aquifers Jamma and Suwaiq located in the Batinah. Two extreme scenarios are presented RCP2.6 and RCP8.5, where the sea level rise will range between 24 cm and 63 cm by 2050 and 2070 respectively. The groundwater simulation model MODFLOW-SEAWAT is used to assess the extent of the irrigated area that will be affected by salinity in the next 35 to 55 years. Results showed that around 64% to 75% of the cropped area will have to be abandoned due to excessive salinity in the groundwater, in the absence of adaptation measures. The economic losses due to climate change on the agricultural sector are estimated assuming no increase in current rates of pumping from wells given the limits on wells' yields. A crop production function was used to determine the effect of deficit irrigation on the value of crop productivity. It is expected that the present value of losses will vary from \$38.5 Million by 2050 to \$65 Million by 2070, assuming a 2% discount rate. The gross profit will fall from a current 100% to 40% by 2050 and 22% by 2070 considering 2015 constant prices and no discounting. The alarming results show the urgent need for determining the best combination of adaptation measures to reduce the impact on farmers' communities.



## Assessment the groundwater quality using the model of Grey Relational Analysis Abstract n°1827

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KEYWORDS: Groundwater+ karst+ assessment+ Grey Relational Analysis

**Objectives-** Karst groundwater resources are particularly important in karst areas. Heqing Basin, a classical karst dam agriculture area in Yunnan Plateau, Southwest China. As the other karst area, both daily lives and crops irrigation depend mainly on karst spring water. In the last few decades, excessive exploitation of groundwater and other human activities have caused serious environmental problems in this area. Hence, it is essential to assess the quality of karst groundwater in the area.

**Design and methodology-** A total of 42 water samples from 21 springs in Heqing Baisn were collected in the summer and winter, which was analyzed for the major ion chemistry and nitrates. The hydrochemical characteristics were assessed using the method of piper diagram. The comprehensive model of water quality was established on Grey Relational Analysis (GRA) to assess the groundwater quality.

**Original data and results-** From summer to winter, the concentration of  $Mg^{2+}$  showed litter change, the concentration of  $Ca^{2+}$ ,  $Na^{+}$  and  $HCO_3^{-}$  decreased, while the concentration of  $SO_4^{+}$ ,  $K^{+}$  and  $CL^{-}$  increased. Piper diagram revealed that all the water samples belonged to the  $Ca-Mg-HCO_3$  type of groundwater facie. The comprehensive evaluation indicated that most of these water samples are fit for class in winter. However, it decreased to class in summer.

**Conclusion-** The hydrochemical characteristics were influenced by precipitation and human activities. The groundwater in summer is not suitable for drinking, but can be used for other daily lives and crops irrigation. This study can provide references for rational utilization of the groundwater resources in karst area.



**Reverse modeling - a simple and robust method for modeling and forecasting the piezometric level discharge of a pumping well. A case study in a Hard Rock Aquifer  
Abstract n°1828**

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KEYWORDS: Session 8.10, Reverse modelling, Hard rock aquifer, discharge, piezometric level, well losses

Forecasting the piezometric variations at a well as regards both its discharge, and the characteristics of the pumped aquifer, including its replenishment, is of high practical interest. Such a medium term approach is not straightforward, particularly in complex small size aquifers (a few square kilometers) as in hard rocks. We thus present a simple but original approach that uses the time series of discharge piezometric level (D PL) available at the well, and the piezometric level available at the “present date”. This data set is used to “reversely” compute the piezometric level from the present date towards the beginning of the time series. The parameters of the model are calibrated to accurately reproduce the piezometric chronicle. Then, as with any model, the calibrated model is used to forecast the future. This approach was developed in a weathered-fractured metamorphic aquifer pumped by a unique well. The diagnosis of the early months of the D PL chronicle allowed to characterize its hydrodynamic parameters (T, S), but also the distance to the 4 orthogonal impervious boundaries limiting the aquifer. The model then computes, with a MSExcel sheet the water budget of this aquifer with the efficient porosity and the well losses revealed by the pumping test. A recharge flux was introduced to ensure the calibration. No vertical variation of the specific storage with depth was necessary, nor variation of the recharge rate with the drawdown. The forecasting was then performed on the basis of the four seasonal recharge fluxes defined during the calibration. This approach is very efficient and cost effective, particularly in such a context where water budgeting of the aquifer finally appears to be quite easy. The model is not accurate to compute short term discharge variations but its improvement would complexify it without a great added value for longer term computations.



## Quantitative interactions between forest and the water resources Abstract n°1829

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KEYWORDS: Session 5.02, Forest, evapotranspiration, runoff, recharge

Afforestation is often considered as “the” solution to manage issues such as desertification, or even the local decrease of water resources. A comprehensive corpus of hydrological research on the relationships between the forest cover (or the forest cover changes, or, by extension, landcover changes) and water resources is available. It is however rarely used by afforestation (or deforestation) promoters. First of all, from the local to regional scales, forest has no influence on the amount of rainfall falling on a given watershed. Second, forest has a very significant influence on the fate and the hydrological distribution of rainwater and thus on water resources. Two main antagonistic – and usually successive – effects come up against one another- 1. Negative effect on water resources- compared to other types of land cover, forest intercepts and transpires a considerable portion of precipitation (evapotranspiration) as a consequence of both the large water needs of trees and their deep root exploration capacity- they can suck and then evapotranspire water from soils at a greater depth than other types of plant cover+ 2. Positive effect on water- forest locally reduces runoff and there improves aquifer recharge. Evapotranspiration occurs just after the precipitation event (rainfall). Recharge and replenishment of the water resource comes next, through infiltration of the residual water. In most hydrological configurations, overall the effect of additional uptake by a forest cover (evapotranspiration) is not fully offset by reduced runoff to the benefit of infiltration. Consequently, forest decreases the available water resource. However, not all forests and not all watersheds have the same hydrological functioning. Case by case study, for instance through modelling, is required to assess the impact, and also, what is more, the sensitivity of the watershed in question, especially that of its water resource, with regard to a modification (decrease) of the recharge.



**Geological and anthropogenic constraints of uranium behaviour in the RecifeEs groundwater (Pernambuco, Brazil)- Monitoring and modelling investigations  
Abstract n°1831**

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**KEYWORDS:** Uranium, Brazil, Speciation, Geochemistry, Contamination

It is uranium in water that controls our daily exposure, especially if drinking water is obtained from groundwater. Therefore in area strongly dependent from groundwater exploitation such as in warm climate contexts, the understanding of geological, geochemical and anthropogenic processes involved in U mobility is strongly required. This study aims at characterizing U concentrations and mobility in the RecifeEs groundwater (Pernambuco state, NE Brazil.), exploited from a multi-layered sedimentary aquifer system. Due to population increases and climate change impacts, groundwater resources are highly strategic for the coming decades and their quality needs to be evaluated. In this perspective, chemical analyses of major and traces elements, including U, were performed within the superficial and deep aquifers. The results show a high variability in mobile U, implying heterogeneity of sources and processes. Coupled with a lithological description of the area, geochemical modeling was carried out, aiming at evaluate possible speciation processes. It appears that the different lithologies, inherited from plutonic, metamorphic and sedimentary rocks may primarily explain the presence of U. In addition, immobilization by hydroxyferrous oxydes may occur, controlled by pH and pE and amount of iron present in the system. When these parameters are affected, U may be mobile in the form of Uranyl ions (low pH) or associated to free carbonate complexes (high pH). As these preliminary conclusions are still based on hypothesis about the abundance of iron, this study highlights the importance of a detailed knowledge of aquifer mineralogy to better understand U mobility constraints in groundwater. This should permit to better manage the resource of increasing importance in this kind of hotspot of climate and anthropogenic pressure.



# **Global Scale Assessment of Groundwater Contribution to Environmental Flows and Sustainable Groundwater Abstraction Limits for the Sustainable Development Goals**

## **Abstract n°1832**

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**KEYWORDS:** Groundwater, environmental flows, SDGs, sustainable groundwater abstraction

Goal 6 of the Sustainable Development Goals (SDGs) has at least three targets that explicitly or implicitly cover issues of sustainability of water resources development and freshwater ecosystem maintenance. To incorporate sustainability, environmental flows (EFs) and sustainable groundwater abstraction have to be an integral part of the SDG discourse, but there is a lack of awareness and application of EFs at multiple levels. If countries are to accept and implement EFs over the next 15 years in the context of achieving the SDG targets, some initial EF information is in high demand. In this work, the global EF assessment carried out by International Water Management Institute from 2004 is modified, specifically to provide initial EF information useful for the calculation of SDG target indicators. The spatial resolution of the analysis has been improved from 0.5 to 0.1 degrees and enables assessment at any larger aggregated scale. Importantly, the EFs are also split into the surface runoff contributed EFs and groundwater contributed EFs. The groundwater-contributed EFs help in defining sustainable groundwater abstraction from renewable sources. The desired conditions of rivers are defined by four environmental flow management classes (EMCs). The EF (as percentage of flow required relative to the pristine conditions) and volume of groundwater abstractable without impacting the EFs are calculated for each EMC. The EFs are determined based on modifying synthetic pre-development natural flows (derived from the global hydrological model PCR-GLOBWB). In reality, the current flow and environmental condition of the rivers vary globally. A modified Index for Global Threat to River Biodiversity determined globally by other researchers were used to link the current condition of the rivers to the desired EMC. The results suggest that total accumulated global EFs vary from 42% to 80% of natural flows, from the lowest to highest EMC, and the groundwater contribution ranges from 39% to 77% of natural base flows. Globally, 149 to 376 km<sup>3</sup> yr<sup>-1</sup> of groundwater can be abstracted sustainably, depending upon the EMC



# **A path towards aquifer management through the empowerment of water stakeholders**

## **Abstract n°1833**

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**KEYWORDS:** groundwater resources, management, information transfer, indicators

Regional aquifer assessments produce a wealth of scientific and technical information that is essential for the sound management of groundwater resources. However, generally regional water stakeholders are not groundwater specialists and they cannot be expected to readily handle specialized hydrogeological maps and data. This presentation provides an overview of the path being followed in Quebec to ensure that the knowledge developed about aquifers ends up being used to protect and manage groundwater resources. This path includes knowledge development, transfer to stakeholders, information translation, and the development of aquifer management plans. In 2009, a law made groundwater a common good in Quebec, which required the state to take care of groundwater and thus develop the knowledge needed to manage the resource. A systematic aquifer assessment program (PACES) involved projects carried out by universities with the participation of regional stakeholder, mainly watershed organizations (OBV) that are mandated to ensure water governance and regional municipalities (MRC) responsible for land use planning. From 2009 to 2015, the PACES assessed groundwater resources over about 70% of the Quebec municipal territory. A structured knowledge transfer program was created to ensure that OBV and MRC personnel were able to comprehend and use the data produced through the PACES. Further efforts were also made "translate" the specialized technical knowledge produced by PACES projects. Conceptual hydrogeological models were used to synthesize and illustrate the functioning of aquifer systems. Furthermore, indicator maps were derived to provide representations of conditions needed for the sustainable management of groundwater resources- preserve quantity, preserve quality, ensure socioeconomic well-being, protect ecosystems, and support sound water management. Another pilot study is building on previous steps to develop a mechanism allowing the development of regional groundwater management plans. Such management plans would then guide specific actions, notably through land use planning, in order to protect and sustainably use groundwater resources.



**Global Food Production - Share from Sustainable and Unsustainable Groundwater Use**  
**Abstract n°1834**

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**KEYWORDS:** Groundwater, global crop production, unsustainable groundwater use, food security

Groundwater is crucial for global food security. At the same time, its contribution to global food production is largely unknown. Even more critical is the fact that groundwater depletion is occurring at an alarming and ever-increasing rate – mainly due to irrigated agriculture, progressively threatening global food security. Here we present for the first time estimates of the global food production derived from groundwater and in particular depleting groundwater. Based on an integrated GIS analysis combining global distributed datasets on groundwater depletion, irrigated areas, and food production for the year 2005, we show that 44% of global irrigated food production is derived from groundwater. Furthermore, depleting aquifers account for between 14 and 17 percent of global groundwater-irrigated food production, between 6.0 and 7.0 percent of global irrigated food production, and between 1.8 and 2.2 percent of total food production (including rainfed). In total, between 124 and 150 mill. tonnes per year are produced unsustainably. This production occurs primarily in arid and semi-arid areas with good sub-surface water storages, with the South Asia, East Asia, Near East North Africa and OECD regions as dominating. Crop-wise, we found that while cereals and sugar crops exhaust most groundwater, crop groups like roots and tubers, non-food crops (mostly cotton), leguminous crops, and vegetables and fruits are disproportionately and preferentially grown by depleting groundwater due to their higher value linked to the reliable irrigation source provided by groundwater. The findings imply the critical importance of analysing and developing congruent policies at multiple levels that account for the nexus between groundwater, groundwater depletion, and global food security.



**Hydrological and Geochemical Processes during Managed Aquifer Recharge with  
Desalinated Seawater  
Abstract n°1837**

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KEYWORDS: Infiltration Recharge rates, Clogging, Remineralization

attached as a doc file Abstract\_1837\_IAH\_2016.doc



**Estimation of Underground Water Flows in the Shallow aquifers Using Artificial Neural Networks (ANN) in North of Algeria  
Abstract n°1840**

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**KEYWORDS:** geomorphological data, precipitation, shallow aquifers, artificial neural network, groundwater.

Rational management of water resources cannot ignore the monitoring of the most important geomorphological factors and studies on lithology, especially in arid and semi-arid regions and high precipitation variability. The technical support and the communication of geo-meteorological information is crucial for a sustainable management of water resources and to improve the quantity and the quality of the agricultural production. Often, geomorphological and meteorological information are not punctual, that are relative to a certain region, and the data are not treated to supply indications and provide useful indications concerning water reserves in the shallow aquifers for technicians and farmers. This work aimed to develop a model of artificial neural network for estimating the water reserves from the geomorphological data watersheds of northern Algeria under the effect of precipitation contrasting, in order to determine automatically the flow rates of underground water available for agriculture in the shallow aquifers, to have better control of groundwater.



**HYDROGEOCHEMICAL-MULTIVARIATE ANALYSIS OF UNDERGROUND WATER IN  
THE MIDDLE MAGDALENA VALLEY REGION - COLOMBIA- STUDY AT A REGIONAL  
SCALE  
Abstract n°1841**

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**KEYWORDS:** Hydrogeochemistry, Multivariate Statistics, Underground Water, Geochemistry Evolution

The Middle Magdalena Valley region - VMM, Colombia, is one of the areas with the densest population and industrial growth. To heed the growing water demand it is necessary to raise the knowledge in regards to underground water resources to achieve a sustainable use of those. While the amount and availability of underground water in the region is generally better characterized and understood due to hydrogeological studies made by national and regional environmental authorities, the issue of quality, and more specifically the processes and hydrogeochemical evolution of underground water, it is poorly studied and understood. Agricultural, industrial and mining-energetic development in the area, are activities that could potentially alter the quality of underground water. The VMM is one of the areas in the country with the greatest prospect for the use of hydraulic fracturing as a technique for exploration and production of non-conventional reservoirs YNC and hypothesis derived from different studies associate pollution and conflicts in underground water with the development of this type of projects. Therefore, this research was aimed to identifying the main processes responsible for the quality and hydrogeochemical evolution of underground water through the use of multivariate statistical techniques (Factor Analysis, Principal Component, and Conglomerates). They were compiled and analyzed all the underground water samples reported in the Environmental Impact by oil companies which explore and exploit hydrocarbons in the area of study for the period 2010-2014. As a result, hydrochemical classification of underground water was established, the processes controlling its composition, and a conceptual model was proposed to explain the geochemical evolution in the area of study.



## **Towards a sustainable water resources management for Qatar Abstract n°1842**

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**KEYWORDS:** water resources management, arid zones, aquifer storage and recovery

Qatar is an arid country with harsh environmental conditions and little rainfall. With a long term average rainfall of only 80 mm per year and no surface water, aquifer is the only natural source of water. The sustainable yield of the aquifer is insufficient to support the population so the country is relying entirely on desalination of seawater to meet municipal demand, whereas groundwater is used for agricultural development. The abstracted groundwater is many orders of magnitude the natural recharge from rainfall. As a result, the groundwater level dropped more than 10 meters over the last 30 years, and seawater intrusion advanced further inland up to more than 10 km. In addition, the phenomenon of upconing is very common in many wells as the deeper brackish groundwater flows into these wells because of high pumping. This highlights the need to take an urgent action to stop deterioration of water quality and aquifer depletion. Despite the limited water resources, water consumption in Qatar is the highest in the world with an average of 500 liters per capita per day. Many social and economic factors contribute towards this high consumption. In the light of the National Vision 2030 for Qatar, water security was identified as one of the main challenges that the country faces. Although desalination production meets the entire municipal demand, no storage facility exists to enhance the water security. The produced water from the plants meets only two days of consumption. Aquifer Storage and Recovery (ASR) was identified as an appropriate solution to increase water security and to counter the adverse environmental impact of aquifer over-exploitation. This study outlines the major challenges that Qatar is facing in terms of water security and discusses different means to overcome the water scarcity problem. This includes artificial recharge, increasing reuse of treated wastewater and reducing losses.



## **Groundwater Monitoring Using a Community -Science Approach Abstract n°1843**

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**KEYWORDS:** Citizen Science, groundwater, water resource management

In addressing groundwater depletion, it is important to develop evidence base so to be used in assessing the state of its degradation. Groundwater data is limited compared to meteorological data, which impedes the groundwater use and management plan. Monitoring of groundwater levels provides information base to assess the condition of aquifers, their responses to water extraction, land-use change, and climatic variability. It is important to maintain a network of spatially distributed, long-term monitoring wells to support groundwater management plan. Monitoring involving local community is a cost effective approach that generates real time data to effectively manage groundwater use. This paper presents the relationship between rainfall and spring flow, which are the main source of freshwater for drinking, household consumptions and agriculture in hills of Nepal. The supply and withdrawal of water from springs depends upon local hydrology and the meteorological characteristics- such as rainfall, evapotranspiration and interflow. The study offers evidence of the use of scientific method and community based initiative for managing groundwater and springshed. The approach presents a method to replicate similar initiative in other parts of the country for maintaining integrity of springs.



**Natural Mineral Water quality protection- the main principles of the 25 years Evian experience**  
**Abstract n°1844**

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**KEYWORDS:** Session 7.06, Natural Mineral Water, protection policies, Evian

The natural mineral water (NMW) aquifers exploited for bottling in France by the Water Division of the Danone Group (Evian, Badoit, La Salvetat, Volvic) all benefit from the technical protection offered by the springs borewells completion and from an efficient geological protection. In order to ensure their long term protection, Danone Waters developed, since the 80ties, a public-private partnership, grounded on a participative, concerted, and self-willed approach with the local players. The experience feedback on these protection policies shows that, overall, an in-depth knowledge of the local "ecosystem" (hydrogeological but also socio-economic, regulatory, agronomic, environmental, etc.) is mandatory. From this, an open mind approach is required to propose and implement not only protection policies, but also an organizational scheme, adapted to the local specificities. Of course, a financial scheme must be organized in order to fund the projects, but technical and financial engineering skills and also manpower for the animation process are also required. In France, the scheme comprises- an association created for each NMW, gathering the bottling company, the communities where the spring is located, who benefit by law from a specific tax on NMW, and the communities from the watershed, who do not benefit from this tax. The association is funded for two thirds by the bottling company and for the rest by the communities where the NMW spring is located. This mechanism thus constitutes a downstream upstream redistribution process of the incomes from the NMW. This association defines and funds the protection policies- wastewater collection and treatment, securing of heating oil tanks, value-creation from agricultural effluents (methanogenesis), preservation and promotion of the local patrimony, among which wetlands, etc. The main principles of this approach inspire other Danone Waters' sites worldwide (Indonesia, China, Argentina, etc.). These principles can also serve as a model to protect potable water resources.



# **Influence of Bedrocks on Hydraulic Characteristics of Weathered Basement Aquifers- A Case Study from South-Western Nigeria Abstract n°1846**

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**KEYWORDS:** Basement aquifer, Bedrock type, Pumping test, Sludge test+ Hydraulic characteristics, SW-Nigeria

Analyses and interpretation of aquifer tests carried out on 21 boreholes drilled into the basement aquifers within Ibadan metropolis, SW-Nigeria were carried out with emphasis on aquifer characterization and assessment of the influence of bedrock types (banded gneiss, augen gneiss, and quartz-schist) on the hydraulic characteristics. The study approach involved assessment of borehole data inventory as well as evaluation of pumping and sludge tests data, based on which principal hydraulic properties (such as transmissivity, hydraulic conductivity, and specific capacity) of the weathered regolith fracture aquifer were estimated. The borehole data revealed varied regolith thickness of 21.6 – 60m (mean 36.2m) in banded gneiss, 12.1 – 68m (mean 47.7m) in augen gneiss, and 60 – 87m (mean 66.4m) in quartz-schist. The average saturated thickness varies from 30m in banded gneiss to 42.2m in augen gneiss and 62.6m in quartz-schist, while the observed yield is generally low with average value of about 80.8m<sup>3</sup> d in all the three bedrock settings. The estimated average specific capacity (Sc), range from 5.6m<sup>3</sup> d m in the banded gneiss to 13.8m<sup>3</sup> d m in the augen gneiss and 5.2m<sup>3</sup> d m in the quartz-schist. However, the estimated transmissivity (T) range from 1.1 – 4.2m<sup>2</sup> d (mean 2.8m<sup>2</sup> d) in banded gneiss, 0.76 – 27.2m<sup>2</sup> d (mean 7.3m<sup>2</sup> d) in augen gneiss, and 0.41 – 10.6m<sup>2</sup> d (mean 2.7m<sup>2</sup> d) in the quartz-schist. Further evaluation of overall measured and estimated aquifer parameters show that the augen gneiss setting exhibits higher hydraulic potentials compared to banded gneiss and quartz-schist settings. Nonetheless, weak correlations ( $R = <0.1$ ) of the yield and Sc with respect to saturated aquifer and total regolith thicknesses are indications of the dominant influence of the interplay of bedrock geology and hydraulic characteristics on the infiltration process and aquifer recharge characteristics of the weathered basement aquifer.



**Monitoring of water drilling exploitation as a tool of rationalization of agricultural irrigation**  
**Abstract n°1847**

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KEYWORDS: monitoring, groundwater, irrigation, agriculture, water drilling.

Groundwater represents an important part of Moroccan water resources. Its management and policy decisions was improved in recent decades regarding the huge increase of water demand to meet objectives fixed by the national development programs, mainly in agricultural domain. The aim of Morocco Green Plan “Maroc vert” is to modernize agriculture by developing many sectors across the country. This issue requires the valorization of large irrigated lands by implanting big water volumes consuming projects, mainly from groundwater. Therefore, most moroccan aquifers storage decrease continuously with a large deficit. Good management of agricultural projects based on irrigation requires a mastering water resource knowledge. Also the sustainability of groundwater resources requires more rationalization and good monitoring, to guarantee a medium-term visibility and to anticipate probable dysfunctions in the future. The purpose of this communication is to show across a case study the importance of good monitoring of water drilling exploitation. The study was done in an agricultural farm of 600 hectares area with high-density olive trees on fifteen water-operating structures. This monitoring allows the quantification of the water and energy consumption from an agricultural season to another one+ to better constrain the relationship between the rainfall importance and distribution with water production+ and to anticipate decisions to guarantee the good operation of the irrigation system.



**A pan-African inter-comparison of the relationship between precipitation and groundwater recharge from in-situ observations and large-scale models**  
**Abstract n°1848**

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**KEYWORDS:** groundwater recharge, global models, Africa

Global coverage of groundwater-level monitoring networks is limited so assessments of groundwater recharge and storage changes in many regions rely upon output from - (1) global-scale hydrological and land-surface models (GHMs, LSMs) and (2) GRACE satellite observations in which groundwater storage changes are isolated using model data. Such models are also the primary source of information on projected climate change impacts on groundwater resources. There has, however, been a paucity of studies examining the robustness of terrestrial water balances including estimates of groundwater recharge simulated by LSMs and GHMs in Sub-Saharan Africa and other regions where observational records are limited. Such comparisons require careful consideration given the inherent differences between gridded data and point observations+ our inter-comparison aims to improve conceptual and numerical models of groundwater recharge. We report on preliminary analyses that assess the relationship between precipitation and groundwater recharge indicated by both LSMs and GHMs and observational records of groundwater levels collated under The Chronicles Consortium and stable-isotope ratios collated by the IAEA and published sources. Initial results derive from the analysis of the relationship between monthly precipitation and subsurface runoff (i.e. proxy for groundwater recharge) from four 1°x1° global-scale GLDAS LSMs (CLM, NOAH, MOSAIC, VIC) across Africa and at 9 locations across Sub-Saharan Africa where observational records have been analysed (i.e. Ethiopia, Mali, Tanzania and Uganda). Our analyses reveal substantial spatial variability among the GLDAS LSMs in subsurface runoff across Africa. Precipitation and subsurface runoff in LSMs show non-linear (i.e. reflecting bias to heavy rainfall), linear, or no bivariate associations in contrast to consistently non-linear relationships noted in in-situ observations. Our analyses will further examine- (1) two global-scale hydrological models (WaterGAP and PCR-GLOBWB) and CLM4.0 that simulate recharge explicitly+ and (2) an additional number of in-situ observational records.



**Groundwater-level response to rainfall and quantification of recharge in weathered basement aquifers in Benin**  
**Abstract n°1849**

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**KEYWORDS:** groundwater recharge, basement rocks, Benin

Weathered hard rock aquifers underline about 80% of Benin (West Africa). Despite groundwater is the primary source of water for domestic supply, the quantification of recharge and the key processes controlling it are poorly known. In this study, we monitored water-level and chemistry (including intrinsic isotopes) over several hydrological years at ten experimental sites located in different geological units of basement rocks in Benin. At six locations, water-level time-series were monitored in nested wells completed in the weathered zone (WZ) and the deeper fissured zone (FZ). We applied correlation methods to investigate groundwater level response to rainfall, and we used the Water Table Fluctuation method (WTFM) to quantify the recharge. Deuterium and oxygen 18, but also Tritium of groundwater sampled in both the WZ and the FZ indicate a current rainwater signature. Moreover, the monitoring of water conductivity in boreholes indicates a dilution of the groundwater after the rainy season in the WZ and partially in the FZ. We conclude that the recharge is direct, current and concerns the WZ and partially the FZ. Water-level variations reveal two apparent infiltration velocities, i.e. a slow flow at every location and a rapid flow at some locations. These two apparent infiltration velocities underline different recharge processes. Annual recharge rates at the ten experimental locations are ranging in-between 50 and 250mm year on average which represents 5 to 25% of the annual rainfall. Our newly quantification of recharge is lower than the previous estimates which were based on the water balance approach. Moreover, comparison of yearly groundwater balance and rainfall indicates that aquifer storage is in equilibrium with mean rainfall. Groundwater storage is then vulnerable to any change in rainfall.



# **Groundwater reserve and aquifer buffer capacity in weathered hard rocks of Africa- comparison of results obtained in Benin, Burkina Faso and Uganda Abstract n°1850**

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**KEYWORDS:** groundwater storage, magnetic resonance sounding, aquifer buffer capacity

Quantifying groundwater storage is important to estimate the capacity of aquifers to buffer changes in climatic and anthropogenic conditions (e.g. increasing pumping rate, change in rainfall and land-use, etc...). However, the buffer capacity of aquifer is poorly known notably in hard rock areas which cover about 40% of the African continent. This study aims at improving the quantification of groundwater storage and aquifer buffer capacity in three African countries- Benin, Burkina Faso and Uganda. We used the last development in the application of the Magnetic Resonance Sounding (MRS) geophysical method [1] to carry out a total number of 73 measurements in several hard rock groups (i.e. 45 in Benin, 21 in Burkina Faso and 7 in Uganda). The interpretation of the MRS measurements reveals that the storage is almost the same in the three countries, i.e. from 580 to 700mm in average. The higher storages are found in the gneisses and migmatites formations with 50% of the values ranging in-between 320 and 700mm. The storage of granitoids is lower, i.e. 70 to 140mm for 50% of the values. We also found that the storage of volcano-sedimentary rocks is almost zero even if the water content is as high as 5%, i.e. groundwater is mainly undrainable. Finally, we estimated the buffer capacity as the ratio of the storage to the aquifer annual discharge, and we found 3 to 6 years for the gneiss and migmatite aquifers. REFERENCE - [1] Vouillamoz, J.M., Lawson, F.M.A., Yalo, N., Descloitres, M., 2014. The use of magnetic resonance sounding for quantifying specific yield and transmissivity in hard rock aquifers- The example of Benin. J. Appl. Geophys. 107, 16–24.



**Improvement perspectives for borehole implementation in tropical basement rock aquifers using electrical resistivity- the example of Benin, West Africa.  
Abstract n°1853**

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**KEYWORDS:** hard rocks, borehole implementation, electrical resistivity, Benin.

40% of the wells drilled in hard rocks of Benin are negatives (yield less than 700 l per hour) although 1D geophysical techniques (Electrical Profiling – EP and Electrical sounding – ES) are routinely used for siting boreholes. Targeting a possible improvement of borehole implementation in a context of deeply weathered hard rock aquifers, our study is conducted to estimate (1) the interest and the limitations of EP and ES techniques, and (2) the advantages of the 2D resistivity techniques (Electrical resistivity tomography – ERT). First, we define the range of resistivity of the three main geological compartments (i.e. saprolite, fissured zone and fresh bedrock) based on resistivity logging carried out in six sites located in different hard rock groups of Benin. Second, we set up numerical modelling of typical tropical weathered hard rock aquifers and we compare the model responses of EP, ES and ERT. We found that (1) resistivity can discriminate the different hydrogeological compartments in about 80% of the cases, (2) several geophysical implementation points selected from typical anomaly in EP are clearly uninteresting because they correspond to shallow clayey structures, (3) ES is subject to strong equivalences and suppression phenomena which makes the interpretation results highly uncertain, and (4) interesting targets (large deepening resistive saprolite zones) are clearly identified by ERT interpretation (with the notable exception of deep isolated fracture systems) and uninteresting structures are clearly evidenced and thus can be discarded for drilling. Our numerical modelling approach is then confirmed on several field test sites in Benin, all displaying interesting and uninteresting implementation points. At last, we conclude that the use of ERT should be highly encouraged by hydrogeologists in Africa, while current use of EP and ES should be abandoned to avoid unappropriated borehole implementation failure and increase success rate.



**Seasonality of recharge fluxes in southern Quebec from subsurface monitoring-  
processes controlling recharge in seasonally frozen permeable soils  
Abstract n°1854**

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KEYWORDS: recharge, frozen soil, snow

In cold environments such as that of Quebec (Canada), groundwater recharge mainly occurs during the spring from snowmelt and as a result of the fall rain. Smaller recharge events also occur during the winter due to snow melting at the soil surface and infiltration into frozen or partly-thawed soil. However, soil water dynamics and water infiltration before the onset of spring snowmelt and even during snowmelt are neither well studied nor constrained. Furthermore, they are not fully considered by the models currently used to estimate groundwater recharge. The objective of this work was to quantify the seasonality of recharge fluxes, as well as the sensitivity of winter and snowmelt recharge to meteorological forcing, and especially to soil freeze thaw events. Recharge fluxes were monitored at an instrumented site located on sandy deposits on the top of a fluvio-glacial landform (esker) located west of Montreal (Quebec, Canada). Water content and temperature were measured in the first meters of soil and in the snowpack during two hydrological years. One dimensional numerical modelling was used to quantify surface water and energy budgets and recharge fluxes. This quantification of recharge is compared to results obtained from water table fluctuations. The results are used to discuss the influence of changing climate conditions on the intensity and the seasonality of recharge.



**Specific yield estimation using resistivity and chargeability in tropical basement rock aquifers- experimental relations in Benin, West Africa.  
Abstract n°1856**

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**KEYWORDS:** hard rocks aquifer, electrical resistivity, chargeability, specific yield, clay content, Benin.

Groundwater in hard rocks is the only water source for many human communities in Africa. 80% of Benin surface area is underlined by hard rocks which are deeply weathered as in many tropical climate areas. 40% of the wells drilled in hard rocks of Benin are negatives (yield less than 700 l per hour) although implemented with the use of electrical geophysical method. In this study, we explore the usefulness of an additional geophysical parameter, i.e. the chargeability, that can be measured jointly with resistivity (using the same device). Particularly, we look for a possible link between geophysical parameters (electrical resistivity and chargeability) and hydrogeological parameter (specific yield). We focus on weathered zone (saprolite) that constitutes the main reservoir of groundwater. Electrical resistivity, chargeability and specific yield are obtained by interpretation of boreholes logging and pumping tests carried out at six experimental sites. The resistivity values are corrected from borehole diameter effect, and the IP time-domain relaxation curves are analyzed using a Cole-Cole dispersion model. The clay content of saprolite is estimated by the use of the “bleu of methylene” test carried out on borehole cuttings. First, we observe that mean chargeability and mean resistivity values tend to increase with specific yield at the 6 experimental sites. This observation is confirmed on 7 other sites where specific yield is derived from magnetic resonance soundings. Second, we find that higher the clay content, less the chargeability and resistivity values. We conclude that the measurement of electrical chargeability in addition to resistivity may improve the knowledge of weathered hard rock aquifers, and we recommend confirming our observations with new experiments carried out in new locations.



**Groundwater recharge and trends in seasonally humid tropics- comparative analysis  
of sedimentary and basement aquifers in Benin  
Abstract n°1857**

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**KEYWORDS:** water-level trend, groundwater recharge, Benin

Groundwater is the primary source of water for domestic and agricultural water supplies throughout the tropics and much of Sub-Saharan Africa. The sustainability of current and projected groundwater withdrawals depends on groundwater recharge. In the seasonally humid area of Benin, we present new estimates of recharge using long-term (1991-2015) groundwater-level records in three aquifers that are found across Sub-Saharan Africa- quaternary unconsolidated sediments, Mio-Pliocene sediments, and weathered basement rocks. We compute annual recharge using the water-table fluctuation method in which specific yield values are constrained by Magnetic Resonance Sounding. Strong seasonality is observed each year in groundwater levels in all three geological contexts. Recharge correlates well to rainfall (mean = 1200 mm year) but varies substantially in magnitude from 460 mm year in shallow Quaternary sediments, to 260mm year in older sediments and 70 mm year in weathered crystalline basement rocks. High rainfall intensities between 10 and 60 mm day primarily contribute recharge in basement rocks, but no threshold in rainfall intensity is associated with recharge in sedimentary rocks. Rising trends in groundwater levels in Quaternary (8 cm year) and Mio-Pliocene (11 cm year) sediments are well explained by increases in rain-fed recharge. Since trend in recharge is mainly controlled by trend in rainfall, groundwater is very sensitive to any change in rainfall in all three geological contexts. However, substantial differences in recharge magnitude between geological contexts still have to be discussed.



**Efficiency of Magnetic Resonance Sounding to characterize hydrogeological properties of weathered hard rock aquifers**  
**Abstract n°1858**

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**KEYWORDS:** weathered hard rock aquifers, magnetic resonance sounding

As compared to other non invasive geophysical methods, Magnetic Resonance Sounding (MRS) is selective to groundwater and has the potential for quantifying aquifer properties. We developed a MRS measurement methodology adapted to African hard rock context, i.e. low specific yield, daily fluctuation of the earth magnetic field [1] and electromagnetic noise. Weathering process of hard rocks results in a typical two-layers groundwater reservoir where an unconsolidated saprolite layer is located just above a fissured layer [2]. We carried out numerous MRS in hard rock aquifers in Benin (West Africa), and we compared MRS and pumping test results. We found that parameters integrated over the saturated thickness, i.e. transmissivity and aquifer storage, can be estimated from MRS with an acceptable accuracy when weathered layers are thick enough. When the saprolite layer is stripped, transmissivity and storage are mainly controlled by the fissured layer and are poorly estimated from MRS. We conducted numerical modeling to assess the conditions when the properties of each layer can be defined separately. We found that specific yield and hydraulic conductivity of each layer cannot be accurately estimated yet. Finally, we conclude that MRS is nowadays efficient to quantify transmissivity and storage in deeply weathered bed rock aquifers. However, development in MRS methods is still needed to improve the estimate of the distribution of specific yield and hydraulic conductivity with depth. REFERENCE- [1] Legchenko, A., Vouillamoz, J.M., Lawson, F.M.A., Allé, C., Descloitres, M., Boucher, M., in press. Magnetic resonance measurements in varying Earth's magnetic field. GEOPHISICS. [2] Lachassagne, P., Wyns, R., Dewandel, B., 2011. The fracture permeability of Hard Rock Aquifers is due neither to tectonics, nor to unloading, but to weathering processes. Terra Nova 23, 145–161.



**Dependence of low-cost urban water and sanitation in Sub-Saharan Africa on conjunctive use of groundwater and shallow subsurface- a town city mega-city inter-comparison**  
**Abstract n°1859**

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KEYWORDS: urban, water and sanitation, Africa

Reducing poverty in many African cities by expanding access to safe water and sanitation depends, in part, upon conjunctive use of the shallow subsurface as both a source of freshwater and receptacle of faecal wastes. We report on situation analyses conducted in a town (Lukhaya, Uganda), city (Kisumu, Kenya), and mega-city (Dakar, Sénégal) under a new 5-year (2015-2020) research and capacity-strengthening consortium (AfriWatSan), that characterise the current physical and policy contexts in which efforts to improve urban access to safe water and sanitation in Sub-Saharan Africa are taking place. In low-income neighbourhoods within each conurbation, access to piped water and sewerage is minimal and the provision of safe water and sanitation is considerably lower than mean statistics reported nationally for urban areas. Further, these neighbourhoods depend upon a range of water sources including unprotected sources for their year-round water supply. Use of on-site sanitation facilities including pit latrines and septic tanks is often constrained by poor drainage and or poor siting in flood-prone areas. A key central finding of these surveys is the continued dependence upon on-site, "closed-loop" water and sanitation systems. Such development pathways are increasingly being recognised formally at a policy level (e.g. Life Cycle Cost Approach) as governments in Sub-Saharan Africa seek to develop sustainable pathways for increasing provision of safe water and sanitation to all.



**Groundwater flow numerical modeling based on estimates of rainfall infiltration and groundwater abstraction for irrigation of cropland**  
**Abstract n°1860**

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**KEYWORDS:** agriculture impact, scenario, unconfined aquifer, water budget, imperviousness

Integrated hydrodynamic modeling is recognized as an efficient approach for quantitative scenario making and a reliable method for groundwater management, provided that the numerical simulations are from a validated model. The model set-up, however, involves many inputs due to the hydrology of a complex system. Rainfall infiltration and groundwater abstraction are important inputs of the groundwater flow model since they control recharge and depletion of the unconfined aquifer. The accuracy of the model output is influenced by the estimates of these two inputs. Agricultural activities are among the main land uses in the lower Var river valley on the French Riviera and almost 1/3 of the valley is of concerned. While private pumping wells in the unconfined aquifer are authorized for irrigation in this area, the abstracted volumes are not documented. Due to disconnection between the river and groundwater table, the rainfall infiltration is the most direct water feeding process of the unconfined aquifer. In this paper, monthly cumulative precipitation and monthly potential evapotranspiration are used through a water-balance method so as to estimate first the monthly actual evapotranspiration and rainfall infiltration terms. Secondly, the groundwater abstraction by farmers is estimated by using recorded data of groundwater levels underneath cropland areas. These inputs are used by the groundwater flow model of the lower Var river valley on a 1266 days finite element simulation. This method gives good results of predicted groundwater levels for both the rainy season and the dry season- the Nash coefficients calculated at two wells in cropland areas are respectively 0.747 and 0.751. It is concluded that this method requires detailed information on land-use in order to obtain a precise estimate of the imperviousness of the study area to validate the model.



## **When is remediation required for groundwater contamination by chlorinated solvents? Abstract n°1862**

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**KEYWORDS:** chlorinated solvents, remediation, economics

Groundwater contamination by chlorinated solvents has been documented since the 1950s, with treatment required for drinking water and potential health impacts from vapour. The most common solvents, trichloroethene (TCE), tetrachloroethene (PCE) and 1,1,1 trichloroethane (TCA), are persistent in groundwater and natural biodegradation is slow. Although implementation of European Union legislation has resulted in a sustained drop in the number of pollution incidents in the UK since 2000, solvents and their daughter products are still frequently found in groundwater at concentrations exceeding the drinking water limit. The contaminants include 1,1,1 TCA, banned in 2000, and TCE, which has only been permitted in closed systems since 2010 and requires authorization for continued use after 21 April 2016. This implies that existing contamination is likely to be historical and not due to on-going sources. In the UK, remediation of contamination is required only if the results of risk assessment demonstrate a significant risk to human health, groundwater or the wider environment. For volatile organic contaminants where vapour transport is important, future human health risks may be the limiting factor if residential land use is proposed. However, it is well known that groundwater remediation costs can be excessive and thus restrict brownfield development. If it can be shown that the costs of remedial works outweigh the productivity and value of the groundwater resource, remediation may not be warranted. This decision is facilitated by a new method for quantifying the loss of available groundwater resource associated with a point source contamination event, when no impact on existing uses has occurred (Bartlett et al, 2014). Avoidance of groundwater remediation will significantly reduce development costs and may allow future development of otherwise unsuitable sites. The issues are illustrated with examples from three recent investigations in the UK, where the groundwater is not used for abstraction and of marginal value, despite its designation as an aquifer.



# Unlocking the Potential of Interdisciplinary Research on Groundwater Abstract n°1865

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**KEYWORDS:** interdisciplinary, research methods, stakeholder engagement

'Unlocking the Potential of Groundwater for the Poor' (UPGro), is a seven-year international research programme (2013-2020) jointly funded by UK's Department for International Development (DFID), Natural Environment Research Council (NERC) and the Economic and Social Research Council (ESRC). It focuses on improving the evidence base around groundwater availability and management in Sub-Saharan Africa. In 2015, UPGro awarded large grants to five international research consortia to conduct interdisciplinary research combining cutting-edge natural and social science with innovative stakeholder engagement processes to address this challenge. UPGro contends that the programme's success will be measured by the way that its research fills important evidence gaps and generates new knowledge which can be used to benefit poor people in a sustainable manner. This paper presents the results of a comparative analysis of how interdisciplinary research efforts are unfolding in the initial phase of the five consortium projects. Drawing on insights from development studies and science and technology studies on multi-, inter- and transdisciplinary research, and informed by an extensive review of key project documents and a series of qualitative interviews with the social and physical scientists involved, we examine the efforts of the consortium projects to operationalise integrated and policy relevant research in diverse, risk-prone, groundwater environments in Africa across a range of scales. The research was initiated to fulfill a perceived need for in-depth empirically grounded research on the philosophy and practicalities of knowledge-making in interdisciplinary groundwater projects. Our study seeks to provide insights to the groundwater research community by highlighting novel methodological innovations, thorny epistemological challenges, and details of how the projects have sought to meet the challenge of generating academically rigorous analysis while producing usable results to address complex, real-world problems.



**New developments in exploring the saturated zone of karst aquifers- Applications to the Quercy region (Southern France)  
Abstract n°1867**

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KEYWORDS: karst, saturated zone, geophysics

Laboratory and field work show that we can estimate water storage and residence time in the epikarst from seasonal seismic velocity variations. It is however necessary to take into account the rock weakening during dissolution to estimate correctly the water saturation from seismic velocities. We postulate that variations of calcite saturation in the water recharge could lead to the same chemo-mechanical effect in the saturated zone of the karst. Several authors reported significant variations of seismic velocities and amplitudes on cores saturated with different waters. We want to verify in this work if this observation is still valid at the field scale, and helpful in locating karst conduits, a task generally impossible to achieve with traditional methods. We use here seismic amplitudes because they provide better resolution than velocities for deep targets. Le Ressel test site is located in the Quercy region (Southwest of France). The location of the 100-meter deep conduit is known and piezometers reaching the drain are available. Time-lapse seismic surveys found a signal dimming with seasonal variations above the conduit+ the conduit signature is easier to detect during the dry season. Downhole measurements indicate that the variations could be linked to changing water mixing conditions in the volume surrounding the conduit. Following this result, the Conseil Général du Lot decided to apply the methodology to the Font Vincent case. This karstic spring supplies drinking water to several communities but does not comply with protection regulations. It is necessary to relocate the water intake upstream to a less vulnerable position by putting in a well to intercept the conduit. The seismic amplitudes map of the area shows that the initial model of a large connection between the spring and a nearby known conduit flow is unlikely. New targets are identified and being evaluated to reduce uncertainty.



## 40 years of rising nitrates and future concentrations in UK groundwater Abstract n°1868

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KEYWORDS: nitrates, catchment management, modelling

In response to the European directive on drinking water quality, the UK government commissioned a review of groundwater quality in the 1980s, which identified a growing problem of contamination by agricultural chemicals and industrial hydrocarbons. In the popular scientific press, the results were reported as 'The hills are alive with nitrates', but rising nitrate concentrations had already been highlighted by Foster and Crease in 1974. Despite this awareness, long term monitoring shows a rising trend in most of the UK's major aquifers, with widespread exceedance of the drinking water standard of 50 mg l (as nitrate). This prevents compliance with Water Framework Directive 'good status' and requires treatment or blending for water supply. Modelling of nitrate fate and transport in the soil, unsaturated zone and saturated aquifers allows prediction of future concentrations, often continuing to rise. Since 2010, most water companies have investigated catchment management, changing land use and farm management, as a potential environmentally and economically sustainable solution to improve groundwater quality. Working collaboratively with farmers and landowners, the pilot projects produced some significant reductions in nitrate concentrations, which then rose in two successive wet winters. Although modelling indicates that catchment management can be effective more widely in the long term, many groundwater sources show little or no response to catchment management in the short-medium term, due to the aquifer properties and unsaturated zone thickness. As practical considerations and cost limit the extent of catchment management measures, identification of the most favourable areas is a priority. A GIS based approach was developed, combined with a sensitivity matrix to allow selection of priority areas. This was combined with modelling to estimate the rate and amount of changes in concentrations. The approach, results and predicted future nitrate concentrations are illustrated for a range of hydrogeological settings, highlighting where catchment management could be most effective.



**Episodic groundwater recharge in a semi-arid environment- assessing the impact of the 2015 16 El Niño in Central Tanzania  
Abstract n°1869**

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**KEYWORDS:** Groundwater recharge, climate change, recharge process, El Niño, rainfall intensity

Groundwater recharge in semi-arid environments occurs directly by rainfall infiltrating in-situ, and indirectly via focused pathways that involve leakage from ephemeral or perennial surface water bodies. Very few detailed monitoring networks observing groundwater recharge exist in semi-arid regions hindering resolution of recharge processes and the relative contributions of direct and indirect recharge pathways. Previous research in a semi-arid basin of central Tanzania (Makutapora) compiled a near-continuous 60-year record of groundwater-level observations and showed that recharge occurs episodically, depending primarily on heavy seasonal rainfall associated with El Niño Southern Oscillation (ENSO). The top decile of recharge events coincide with El Niño years and account for >50% of recharge by volume. Here we report on new observational evidence derived from the deployment, prior to the onset of the 2015-16 ENSO event, of new instrumentation in the Makutapora Wellfield (59 km<sup>2</sup>). This enables hourly monitoring of groundwater levels in 6 monitoring wells, and river stage at both the inlet and outlet of the wellfield, which is the primary source of water for the capital of Tanzania, Dodoma. Unprecedented rates of groundwater-level decline (~6 m year) observed in 2015, coinciding with increased abstraction, now exceeding 1.5 million m<sup>3</sup> per month, have heightened concerns over the long term viability of groundwater abstraction and the need to identify potential adaptive strategies (e.g. Managed Aquifer Recharge) to amplify recharge and enhance sustainability. Preliminary results reveal that recharge derived from anomalously heavy rainfall during the 2015 16 El Niño, has arrested the water-level decline. Further analyses of high-frequency observations will examine (1) recharge process by exploring the presence (focused) or absence (diffuse) of the development and decay of groundwater 'mounds' near stream channels or ponded areas+ and (2) recharge thresholds resulting from intense rainfall exceeding a runoff threshold (focused) or cumulative rainfall overcoming a soil moisture deficit (diffuse).



**Monitoring fluorescence of groundwater, mineral and thermal water at distinct wavelengths as potential tool for earthquake precursor research**  
**Abstract n°1873**

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**KEYWORDS:** groundwater fluorescence spectra, seismic risks, tectonic activity, seismic hazards, precursor research

On-line measurements with an on line flow-through fluorometer, that was developed for the monitoring of tracer tests in karst areas using fluorescence substances as e.g. uranin, sulforhodamin or naphthionate is used for long term monitoring of fluorescence variations of groundwater and thermal water springs in Switzerland. The presented measurements originate from an undisturbed spring within small old coal mine (Käpfnach, Horgen ZH) situated in an area of low seismicity) and secondly of a thermal spring at Baden AG (Northern Switzerland) The comparison shows fluctuations related to natural variations of a) undisturbed spring (but influenced by infiltration events) and b) of a thermal spring, with possible influences of seismicity, but also of use of the spring water for a thermal spa. As newly developed on line spectrometric instruments for fluorescence analysis are applied as quality monitoring tool for drinking water supply in municipal water works, encouraging new possibilities arise for the on-line fluorescence monitoring too. First results of such a new instrumental approach are shown for the Tamina Spa (Eastern Switzerland). These data are compared with the previous fluorometer results. As conclusion the insights towards earthquake precursor research are discussed with reference to the actual literature.



**Bedrock aquifer characterization based on underground mine site investigation-  
Results and opportunities  
Abstract n°1874**

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KEYWORDS: bedrock aquifers+ hydrogeology and geomechanics+ mine drainage

Underground mine operation requires groundwater pumping to dewater the excavations, and discharging that water in surface water bodies. This drainage often generates environmental and economic impacts, but it also provides unique data set for characterizing bedrock aquifers and it presents interesting research opportunities on fundamental hydrogeological processes. Besides direct hydrogeological effects, mining also generates significant perturbations of the geomechanical stress field in the rock mass surrounding the excavations. All of these perturbations produce hydrogeological (H), geomechanical (M) and geochemical (C) phenomena occurring simultaneously, and interacting with each other. Important phenomena include- 1) the geomechanical stress perturbations resulting from the excavations+ 2) the effects of these perturbations on rock mass permeability+ 3) the important decrease in groundwater pressure at depth+ 4) the variety of types and ages of the groundwater extracted at operating mine sites+ 5) the generation of an important volume of desaturated rock mass due to pumping+ 6) the percolation of infiltrating groundwater through acid-generating backfill material placed in upper level excavations in operating mines. All of these factors are acting simultaneously at operating mine sites, creating real field laboratories to conduct research on the coupling of H-M-C processes. At mine closure, existing mine excavations may affect adversely ground stability up to the surface, as well as the quantity and the quality of groundwater flowing through the system. A number of analytical models developed to predict inflow into underground workings are used with input data collected at underground mines in order to estimate the hydraulic conductivity of the regional bedrock aquifer. Mine excavations also provide unique opportunities to characterize the fracture networks and to collect water samples at various locations and depths, allowing for a better structural and hydrogeochemical characterization of the regional aquifer. Many of these factors will be illustrated with data from a number of mine sites in Canada and elsewhere, calling for more hydrogeological research taking advantage of increasing mineral resource extraction.



**Hydrogeologic and hydrochemical framework of the shallow groundwater in fractured shale of Ukelle area, Lower Benue trough, SE Nigeria**  
**Abstract n°1875**

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**KEYWORDS:** Fractured shale, lineament, resistivity

Ukelle area (SE Nigeria) is characterized by acute water shortage. This is partly due to the underlying low permeability fractured shale rock and existence of salt ponds. As a result of this, the daily water needs of the communities are being met mainly from polluted surface ponds especially during the dry season. This has resulted in many water-related illnesses, the most endemic being guinea worm infection. In order to alleviate this problem, government decided to provide clean water through the provision of shallow hand-pump fitted boreholes. The present study is therefore aimed at using surface electrical resistivity method supported by geologic data to delineate fractured water bearing layers for the siting of productive boreholes. The study also includes the determination of aquifer parameters from resistivity and pump test data as well as different water types. Lineament mapping indicate trends in NE-SW and NW-SE directions. Forty four percent of these lineaments vary between < 2 and > 10 km in length. The lineaments in the area are linked to tectonic activity and associated magmatism which resulted in the injection of intrusive rocks. This gave rise to baking and fracturing of the shales in the area as observed in the field and borehole lithologic logs. Aquifer resistivities range between 4.8 and 180.0 ohm m, while thicknesses vary from 2.3 to 209.5 m. Aquifer parameters were evaluated from geoelectrical and pumping test data. Transmissivity values range from 1.97 to 13.44 m<sup>2</sup> day and are greater than transmissivity estimated from surface resistivity data. Chemical data show that the water types are Na-HCO<sub>3</sub> (43%), Ca-HCO<sub>3</sub> (30%) and Mg-HCO<sub>3</sub> (27%). The groundwater chemistry is controlled by silicate and carbonate weathering and reverse ion exchange. The water quality meets national and international standards for drinking and domestic use. However, the use for agriculture is highly variable based on some indices.



**Spatial and seasonal evaluation of groundwater quality- implications for drinking and irrigation use in parts of southeastern Nigeria**  
**Abstract n°1876**

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KEYWORDS: Groundwater, Evaluation, Seasonal

Groundwater is often the cheapest source of water to exploit for domestic, irrigation and industrial use. Therefore it contributes significant percentage to meeting water demands of the population. Changes in climatic variables, such as temperature and rainfall, have significant impacts on water resources. Hence climate change will influence and affect the demand for water. In addition, climate change would degrade water quality through higher water temperatures and increased pollutant load from runoff and overflow of waste facilities. With the expanding nature of the study area thus it is bound to face the problem of groundwater depletion and quality deterioration due to increase in human activities and inadequate management of water resources. In the present study, chemical analyses of groundwater samples were carried out. The groundwater samples were collected between 2009 and 2013 from open wells to cover seasonal variations. The analyzed data are utilized to characterize the hydrochemical processes dominant in the area. Besides, various criteria are employed to assess the suitability of groundwater in the area for drinking and irrigation purposes. Results showed that considering the different scenarios, substantial proportions of the groundwater showed good potentials for drinking, domestic and irrigation use and should be better managed for sustainable development.



# **Tracing Recent Water Level Changes in a Saudi Arabian Cave by Mining YouTube Videos**

## **Abstract n°1877**

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**KEYWORDS:** participatory research, social media mining, crowdsourcing

Traditional participatory data collection methods are increasingly complemented by social media mining – the harvesting of pre-existing, crowd-generated data from Twitter, Flickr, etc.. Although this approach is participatory in a broader sense, the social media users are mostly not aware of their participation in research. Inspired by this emerging trend, we watched YouTube videos taken in Dahl Hith, a Saudi Arabian cave. The latter has recently experienced a rapid (but undocumented) water level rise. By identifying reference points in multiple videos (e.g., cave graffiti) and visually estimating the decreasing distances between these points and the water level, we were able to reconstruct the groundwater rise for 2013 and 2014 (approx. 9.5 m at an average rate of 0.4 m month). To the best of our knowledge, we thereby establish a precedent of using YouTube to study water level changes over an extended time period. Despite the sacrifice in precision, we believe that analyzing YouTube footage may represent a viable option in data-scarce settings and that the approach could be adapted to other environments (e.g., reconstruction of stream discharge, flood extents, etc.). Moreover, we see a significant outreach potential in such novel approaches. Although hydrogeology plays a pivotal role in the future of society, its importance is mostly not reflected in its public visibility. One reason could be that some of our sophisticated methods in hydrogeology might seem rather abstract to non-scientists. The present study, by contrast, utilizes one of the most popular social media websites as water level archive and applies an easily comprehensible estimation technique to reconstruct piezometric changes. We can imagine that such simple, creative approaches hold a certain potential to spark greater interest for hydrogeology among the general public.



**From boreholes structural and hydraulic conductivity data to fracture system modelling**  
**Abstract n°1878**

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**KEYWORDS:** peridotites, discrete fracture, weathered zone

Ultramafic rocks of New Caledonia are actively mined for Ni and Co. They present extensive fractures at all scales, resulting from several pre- to post-obduction tectonic event. Four 200 m deep boreholes have been drilled on the Koniambo Massif which is one of the major Peridotite klippe of the New Caledonia West coast. Detailed study of 4 x 200 m of fractured peridotites and hydraulic conductivity tests performed at several depths during drilling allowed characterizing the fracture system, conceptualizing and modelling its hydrodynamic behavior. A methodology of fracture description has been established including dip, macroscopic mineralogy of coating or infilling, and stage of weathering grade of the peridotite. Two types of fractures are observed- discrete fractures and highly fractured and or weathered zones. Both discontinuity types are considered when defining fractures frequency as they may impact the groundwater flow. From these observations, discrete fractures spacing is estimated around 30 cm. Snow model is applied to define discrete fracture aperture which is validated with hydraulic tests. The value of 0.1 mm gives a hydraulic conductivity around  $10^{-6}$  m s which is consistent with field measurements. Highly fractured zones and weathered zones have been considered individually to extract an equivalent hydraulic conductivity from field test results. These parameters are then used to build a fracture system model of peridotites including (i) discrete fractures, (ii) porous matrix corresponding to non-fractured and non-weathered peridotites, and (iii) variable conductive zones corresponding to weathered and or highly fractured zones. Percolation and equivalent hydraulic conductivity of the system are calculated and compared to field data.



**NH<sub>4</sub><sup>+</sup> occurrence in subsurface aquifer- an assessment to binding mechanism of ammonium with OM in aquifers of Jianhan Plain, China**  
**Abstract n°1879**

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**KEYWORDS:** NH<sub>4</sub><sup>+</sup> contamination, dissolved organic matter, binding, PARAFAC-EEM, mitigation considerations

NH<sub>4</sub>-N contamination in subsurface aquifers has been increasingly reported and for many cases, assumed to be associated with sediment organic matter (SOM). Thus, the specific mechanism of natural occurrence of ammonium is necessary to be assessed. We investigated NH<sub>4</sub>-N concentration, its spatial distribution and assessed the binding mechanism of ammonium with organic matter (OM) for groundwater of Jianhan Plain by combing areal investigation with experimental studies. A widespread and accompanying occurrence of ammonium with organic matter (OM) was observed in the groundwater. NH<sub>4</sub>-N concentrations of most of groundwater were 1-8 mg L while those of DOC were 3-7mg L. Our experiment study firstly revealed the close relationships of NH<sub>4</sub><sup>+</sup> with specific OM components both on sediment and also in groundwater. High significant correlation relationships ( $p < 0.001$ ) at different levels were observed between NH<sub>4</sub><sup>+</sup> and various fluorescent DOM components for sediments extracted DOM solutions and groundwater samples. We then designed complexation experiments to investigate affinity of NH<sub>4</sub><sup>+</sup> with aqueous DOM (i.e., groundwater DOM) by employing techniques of advanced spectroscopies (differential adsorption spectroscopy and PARAFAC-EEM) and model predication of thermodynamics equilibrium. The results demonstrated consistent variations in spectrum signals with the binding levels of NH<sub>4</sub><sup>+</sup> to DOM. Based on the results presented, we believe the close relationships of NH<sub>4</sub><sup>+</sup> with OM on solid phase of sediments could be related with both effects of electrostatic sorption and physical assemblage, while the affinity relationship in aqueous solution is mainly caused by the binding of NH<sub>4</sub><sup>+</sup> to OM functional groups ligands. Our investigation revealed widespread and accompanying occurrence of NH<sub>4</sub><sup>+</sup> with OM in aquifers. The assessment to binding mechanism of NH<sub>4</sub><sup>+</sup> with OM demonstrated the significant binding ability of OM components to NH<sub>4</sub><sup>+</sup> both on sediments and in groundwater. Thus the considerations of potential mitigation measures for naturally occurred NH<sub>4</sub><sup>+</sup> should include the associations of ammonium with OM.



**After 20 years of implementing new regulations (1997-2016), which impacts of on-site wastewater treatment in Australia  
Abstract n°1881**

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KEYWORDS: wastewater, groundwater, soil pollution, wastewater treatment, septic devices

This paper will focus on On-Site Wastewater Treatment system (OSWT, i.e. septic system) in Australia and in particular in New South Wales (NSW). In a country where the soil, the climate and the rain pattern are different within the country itself and compared to European countries, are the challenges linked to OSWT and effluents so different to the one known in Europe? The literature states that the Australian stakeholders (politicians, scientists, users) have argued since the need to dispose of the effluents arose. This led to compromising rather than agreeing on the most beneficial solution. Insufficient regulation was in place until a major Hepatitis A contamination event occurred fairly recently in 1997, in NSW- the "Wallis Lake" case. This raised concerns among the above mentioned stakeholders and maybe awareness on the need to appropriately monitor both the installations and the effluents released in the Australian soil. This paper will explain the load of regulations that has emerged in Australia since 1997, the lacks and inadequacy with regards to the effluent monitoring and evaluation, and the message conveyed by the government and received by the public. How much does the Australian user know about his OSWT system? Data, extracted from earlier studies, will explain the level of implication of the Australian users, often in remote and or rural areas. Is the future in a third pipe for grey water reuse and in composting toilets? Or should we look for an answer in what we put in our sinks and toilets rather than in what comes out?



## **Indonesian Water Law Cancellation - A Journey of Indonesian Water User Abstract n°1883**

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**KEYWORDS:** Indonesian, Water Law, Cancellation

On 18th February 2015 Indonesian Constitutional High Court of Indonesia has announced the cancellation the national water law No.7-2004 and reactivated previous water law No.11 year 1974. The Court confirms that the law No.7-2004 had encouraged privatization and commercialization of water resources at the expense of people's rights to water, in violation of article 33 of Indonesian Constitution that stipulates that water and natural resources belongs to the State and should be used to the greatest welfare of the people. The High Court also issued six Principles that should guide new water resource regulation. As a consequence of the cancellation, all permits issued based on Law. No.7-2004 was invalidated which means any industry holding water permit was no more legally allowed to withdraw water. Also, the authorities decided not to process any extension of expiring abstraction permits or issuance of new permits. In parallel in the media, allegations of water sources privatization and over exploitation were particularly targeting bottle water companies. Facing an unprecedented situation, most of Food and Beverages industries associations had to quickly organized themselves into a Forum (across association of industrial water users), to collectively lobby the government in drafting urgently a transitional law. The forum has activated different levers and methods such as fact data collection, advocacy, facilitation of seminars with water experts, involvement of KOL, political, legal and scientist experts in the preparation of an academic paper. After several months of legal drafting process, government finally issued on 28 December 2015 the Government Regulation No. 121 2015 on the Water Resources Business. The forum took advantage of this new regulatory framework to raise authorities' awareness on the necessity to draw a regulation covering all water usages, and strengthening water monitoring, control and conservation. But the journey till the new law is established is still long.



**Dating of saline groundwater from several Israeli aquifers, indication for paleo  
seawater intrusion  
Abstract n°1884**

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**KEYWORDS:** groundwater dating, seawater intrusion, radiocarbon

This study deals with dating of saline groundwater, with salinity closed to that of seawater (mostly >75% seawater), in order to estimate the timing of past events of seawater intrusion. Such dating was seldom conducted before since, in most cases, even the most saline water samples have a significant component of fresh water. Dating of saline groundwater was conducted in two of the main aquifers in Israel (the Coastal Aquifer and the Mountain Aquifer). In the Coastal Aquifer, most of the saline water was found to be young (>50 years, tritium containing, ~60 PMC) indicating recent seawater intrusion. However, in some of the deeper sub-aquifers, older saline water was found (5-10 PMC, i.e. older than ~10,000 years), implying penetration of seawater at older time. Complementary age determinations were conducted on the fresh groundwater, some of which were found to be very old. In the Mountain Aquifer, old saline water bodies were found in several locations. Estimation of the age of the different end members (fresh and saline) showed that the seawater component is older than 30,000 year, probably beyond radiocarbon dating. The isotopic values of this old seawater component is similar to that of the present seawater (e.g.  $\delta^{18}O$  of ~-1.5‰ and 1.8‰ in old and recent seawater) which implies that the intrusion took place in similar sea conditions to that of the present ones. An attempt to determine the age of this old seawater will be done with noble gases. Numerical simulations were conducted with FEFLOW in order to examine the flow regime in the different parts of the coastal aquifer. Due to the limitation of the radiocarbon methods, samples were taken for analysis of  $^{81}Kr$  and  $^{39}Ar$  in November 2005 and some results are planned to be given in this presentation.



## Management of Groundwater Resource in an Urban Area (Ljubljana, Slovenia) Abstract n°1885

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**KEYWORDS:** urban groundwater management, drinking water resource, decision support tools

Groundwater is an essential source of drinking water in many countries. Assurance of a stable and safe drinking water supply from groundwater is a complex task, especially in urban areas, where groundwater is threatened by contamination from a multitude sources. Protection of groundwater often requires restriction of human activities that could have an unfavorable impact on groundwater quality. Reduction of the risk of pollution of the groundwater by restriction can cause conflicts. Special issue in urban groundwater management are accidents or sudden spillages of hazardous substances that can pollute groundwater. To cope with these challenges decisions in groundwater management must be supported by information based on sound expert knowledge that has to be understandable for decision makers and provided on time. To assure that range of activities must be undertaken including study of hydrogeological conditions and processes of pollution transport, monitoring of groundwater, detection of potential sources of pollution, estimation of emissions and assessment of impact on groundwater quality. In this contribution integration of tools and procedures that was developed within the project INCOME to assure more efficient management of groundwater in the urban area of the city of Ljubljana is presented. An aquifer beneath the city is its main resource for the public drinking water supply. The results of the project enable simulation of the hydrogeological and pollution transport processes thus provide a basis for prompt responses and optimization of groundwater protection measures. Developed applications and tools enable easier and faster access to supporting information for groundwater management which significantly contributes to a safer and more stable drinking water supply of the city of Ljubljana.



# Assessment of brine migration along vertical pathways due to CO<sub>2</sub> injection

## Abstract n°1886

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KEYWORDS: CCS, brine migration

Brine migration into potential drinking water aquifers due to the injection of CO<sub>2</sub> into deep saline aquifers is perceived as a potential threat resulting from the Carbon Capture and Storage Technology (CCS). In this work, we focus on the large scale impacts of CO<sub>2</sub> injection into deep saline aquifers on brine migration. The methodology and the obtained results may also apply to other fields like waste water disposal, where large amounts of fluid are injected into the subsurface. We consider a realistic (but not real) on-shore site in the North German Basin with characteristic geological features such as a fault zone, a salt wall and hydrogeological windows in the Rupelian clay. These features influence brine migration rates into shallow aquifers. In contrast to modeling on the reservoir scale, the spatial scale in this work is much larger in both vertical and lateral direction, since the regional hydrogeology is considered as well by including groundwater recharge for shallow aquifers. Additionally, variable density flow due to salt transport is considered. At first different scenarios are simulated in order to identify the relevant parameters for brine migration within this setting. Simulations on this scale always require a compromise between the accuracy of the description of the relevant physical processes, data availability and computational resources. Therefore, we further test different model simplifications and discuss them with respect to the relevant physical processes and the expected data availability. The simplifications in the models are concerned with the role of salt-induced density differences on the flow, with injection of brine (into brine) instead of CO<sub>2</sub> into brine, and with simplifying the geometry of the site.



**A robust hydrochemical and isotopic method for urban and agricultural origins of nitrate in groundwater**  
**Abstract n°1887**

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**KEYWORDS:** on-site sanitation, nitrate, isotope, hydrochemistry

The ever increasing human population and the resultant increase in anthropogenic activities have led to a gradual decline in groundwater quality across many regions of the world. Amongst the many contaminants, nitrates are currently considered as one of the major causes of groundwater pollution mainly due to their high solubility in water. Frequently attributed to agricultural activities, nitrates can also come from other sources from urban and suburban areas, particularly due to the presence of on-site sanitation systems. To reclaim groundwater quality by acting on the most significant and dominant sources, it is necessary to precisely determine the origin of nitrates. A robust approach based on the combined use of multiple environmental tracers was implemented on two watersheds characterized by mixed pollution sources (on-site sanitation and agricultural activities). These two watersheds are located in Reunion Island (Indian Ocean), where on-site sanitation dominates, with a significant non-compliance rate- it is estimated that in Reunion Island the on-site sanitation is found in 60% of houses, with a non-compliance rate close to 80%. The hydrochemical analysis coupled with the spatial analysis of land use land cover helped us to characterize the different groundwater facies. Water isotope ratios ( $\delta^{18}\text{O}$  and  $\delta^2\text{H}$ ) were used to determine the average recharge altitude, while the rare earths, pharmaceutical compounds, nitrate isotopic ratios ( $\delta^{15}\text{N}$  and  $\delta^{18}\text{O}$ ), boron isotopes  $^{10}\text{B}$  and  $^{11}\text{B}$  allowed us discriminate between the agricultural and urban sources of nitrates in groundwater. The relative contribution of pollution from on-site sanitation and agricultural activities was determined. Finally, CFC's and SF6 were used to calculate the apparent ages of water and identify the temporal effectiveness of measures implemented in the watershed, characterized by mixed pollution sources.



**Using the power-law behavior of density-driven solute breakthrough curves for  
contaminant plume development reconstitution and prognosis in a large alluvial  
aquifer  
Abstract n°1888**

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KEYWORDS: Contaminant transport+ Density driven contaminant+

The upper Rhine valley alluvial aquifer is one of the largest groundwater reservoirs of Western Europe and constitutes a major water resource for the Alsace region in France. Geological formations below alluvium were exploited for potassium hydroxide (potash) extraction through underground mines. As a consequence of this exploitation, large amounts of extracted materials made of sodium chloride and mine waste have been stored at the land surface. Fifteen heaps have been created to store residuals of 568 million tons extracted during the period 1910-2002 on an area of 220 Km<sup>2</sup>. Due to rainfall and treatment activities, large quantities of chloride infiltrated to the aquifer from the waste heaps with concentration up to 40 g L leading to a widespread contamination of the alluvial aquifer by high density plumes. Contaminant plumes migrated from the heaps downgradient and, as a result, observed chloride concentrations in treatment and observation wells are similar to the shape of breakthrough curves (BTC) resulting from classical artificial tracer point injections. These BTCs recorded long tailing of more than 15 years following a power-law behavior. Despite various studies, reasons for such tailing remained partly unknown. Based on chloride BTCs from 215 treatment observation wells over the time period 1988-2015 and interpretation of the BTCs power law behavior, we were able to reconstitute the plumes historical development and behavior. Numerical density-driven contaminant transport simulations, supported BTCs interpretations and enabled to forecast plumes future evolution. Hence we developed a methodology based on power-laws as a proxy to estimate plume behavior in a context where density-driven numerical modeling is not a realistic approach at the field site scale. Such a methodology is an efficient and cost-effective tool for contaminant transport evaluation for contaminated sites impacted by long-term contamination and where long concentration time series are available from observation pumping wells.



## **An Atlas of Groundwater in Africa Abstract n°1889**

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**KEYWORDS:** Africa, groundwater, information

The availability and accessibility of robust groundwater information and data is a major constraint to developing groundwater resources in Africa, and a barrier to undertaking hydrogeological research. The online Africa Groundwater Atlas is a major initiative involving hydrogeologists across Africa, coordinated by the British Geological Survey and funded by the UK UPGro programme. The Atlas provides a systematic overview of the hydrogeology and groundwater resources of 51 African countries, and a gateway to learning more. Alongside geology and hydrogeology maps and descriptions for each country, the Atlas presents supporting datasets such as rainfall, soil type and surface waters, and information on groundwater status and management. So far, 25 country profiles have been developed in collaboration with 58 hydrogeological specialists for the relevant country, including members of IAH and AGW-Net. A further ten country profiles have been produced by BGS based on published information, without input as yet from country experts. The remaining country profiles are currently 'skeleton' pages with basic maps and information. The Atlas has been developed in parallel with an online Africa Groundwater Literature Archive, which to date indexes nearly 7000 references related to African groundwater. These can be searched spatially or by thematic keyword, and as many as possible are freely available as digital downloads. This initiative grew out of the publication of continental groundwater maps for Africa in 2012, which renewed interest amongst donors in the key role that groundwater resources can have in shaping Africa's future, and highlighted the need for more detailed information, at a country scale, to better support the sustainable, integrated development of groundwater resources. The Atlas and Archive provide a readily updateable platform to highlight and improve access to the wealth of groundwater information and expertise that already exists in Africa.



**Karst River interactions in the Minervois (southern France)- insights from geophysical studies**  
**Abstract n°1890**

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KEYWORDS: Cabrespine, Clamoux River, geophysics

The small watersheds located on the southern slopes of the Hercynian Montagne Noire (southern France) are prone to flash floods triggered by intense Mediterranean rainstorms. It is necessary to understand the role of the carbonates rocks outcropping in this area when performing flood modeling and forecasting. In this work, we study the water exchanges occurring between the Clamoux River and the karstic network crossing underneath the valley near the village of Cabrespine. At this location, the perennial runoff flowing from the impervious axial zone is swallowed nearly all the year round by Quaternary deposits and routed to another watershed through the karst. The main goal of this work is to describe with geophysical methods the geometry and the hydrodynamic state of this alluvial infilling. Seismic methods, SP measurements and GPR have been the most efficient tools for this geological setting. The alluviums are 25 meters thick, overlying a well-developed epikarst in the area of the river losses. The valley incision almost reaches (or perhaps intersects) the karstic network, consequently the transit time of the water between the surface and the underground stream should be much shorter than previously estimated. New water temperature and electrical conductivity measurements carried out inside the cave at several outlets confirm this hypothesis. The SP interpretation and the petrophysical modeling of seismic velocities indicate that the alluviums are not yet saturated during the late fall, the period of the year most affected by intense rains. It is therefore possible that a sizeable retention capacity during a flood exists in the Cabrespine area. A secondary outcome of the resistivity survey using TDEM soundings is that a significant amount of mining waste seems to be present in the alluviums, which may raise some concern about a possible arsenic contamination during infiltration.



## **A 4D ERT tool to characterize heat transfer and storage in aquifers Abstract n°1891**

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**KEYWORDS:** EDSM, ERT, ATEs, monitoring, geophysics, heat storage, geothermics, electrical resistivity

Combining energy demand side management (DSM) and aquifer thermal energy storage (ATES) systems could lead to an improvement of seasonal performance factor (SPF) of such geothermal systems and to more flexibility. Before storing heat (efficiently converted from electricity) in aquifers, we must insure that a sufficient yield is possible with the help of predictive models of the subsurface. The design and functioning of ATES systems have strong interconnections with the geology of the site which may be complex and heterogeneous, making predictions difficult. Today, most of models rely on local measurements made in wells. Due to budget constraints, it is impossible to collect a sufficient amount of data to capture aquifers heterogeneity. In this context, we developed a non-invasive and less expensive subsurface monitoring methodology to better characterize heat transfer and storage in the subsurface with the help of 4D electrical resistivity tomography (ERT), multiple hydrological measurements, and a short-term heat storage experiment conducted for the purpose in a confined alluvial aquifer. Results clearly show the ability of 4D ERT to delimit the thermal plume growth during injection, the diffusion and decrease of temperature during storage, and the decrease in size after heat recovery. Moreover, thanks to 4D ERT and hydrological measurements, we imaged semi-quantitatively the temperature distribution of the heat plume. By integrating these spatialized, permanent, and transient data in predictive models, we account for the local aquifer heterogeneity and therefore, improve the reliability of model predictions. On the DSM side, energy balance shows that up to 70% of the stored energy can be easily recovered with an adapted strategy. By better designing storage recovery cycles with the help of reliable predictive models of the subsurface and by targeting specific aquifer characteristics, there is even a potentiality to reach better yields. This proves that short-term heat storage in alluvial aquifer during hours, days, or even a week is efficient enough to be used in the context of DSM and ATES systems.



**Karst Aquifer Vulnerability Assessment (KAVA) Method on the example of two catchments in Croatia**  
**Abstract n°1893**

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KEYWORDS: karst aquifer, vulnerability assessment KAVA method, Croatia

During 2013-2016, within the GEF UNEP MAP and UNESCO-IHP's MedPartnership Project, a new method for assessing the intrinsic vulnerability of catchments and springs in karst terrains was developed. The Karst Aquifer Vulnerability Assessment (KAVA) method was developed based on the analysis of parameters and experience from the fieldwork and protection system of karst areas in Croatia. For assessing of the intrinsic vulnerability of karst aquifers are used four basic factors- Overlay, Precipitation, Infiltration and Aquifer conditions. The overall result of the analysis is presented with two indices of vulnerability- SV index (source vulnerability index) – for karst springs vulnerability, and RV index (resource vulnerability index) – for karst aquifers vulnerability. Within this paper will be presented results of using this method at two very complex karst sites in Croatia, one large and one small catchment. Both catchments belong to the Adriatic Sea catchment and have discharge at the northern coastal area of the Adriatic Sea. The first site is the Novljanska Žrnovnica catchment, which is one of the largest karst catchment in Croatia. Part of this springing zone is fed from the Gorski kotar sinking zone, part from the mountain area in the hinterland of the main spring, and part from the Lika sinking area. The main spring Novljanska Žrnovnica is captured for the public water-supply. The second site is the Bakar Bay catchment area that occupies area of about 156 km<sup>2</sup>. This catchment area spreads from the discharge zone towards the mountain region of the Gorski kotar. However, in this discharge zone are captured even three springs for the public water supply. These four springs water quality and quantity are very important for the very wide coastal touristic area especially during the tourist season. Sanitary protection zones of these springs were defined, and the use of the intrinsic vulnerability mapping as the KAVA method can contribute to the groundwater protection as an additional data which should be used for updating of the protection zones.



## Abstract n°1894

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KEYWORDS: <p>Sessions 2.01, Kisumu, groundwater, wells, water pollution and sanitation

<p>Shallow wells provide fresh water to billions of people worldwide who are either not connected to the piped water or have intermittent supplies. These shallow wells are hand dug and, therefore, are mostly less than 20 meters in depth. This same sub-surface environment is also used as a repository of human waste. This study, which sets a basis for further investigation of the conjunctive use of the subsurface for water and sanitation in Kisumu City under the AfriWatSan project, aimed at appraising the groundwater and sanitation challenges based on a rapid survey, sampling, interviews, existing literature review and historical borehole data in Kisumu city, Kenya. Previous studies in the area have shown that the number of shallow wells, city buildings, the density of unimproved pit latrines and sanitary risks have increased tremendously between 1999 and 2015. Most of the wells are shallow and, therefore, prone to contamination by pollutants. Fluoride and chloride content in most boreholes are above the recommended WHO maximum values and the local KEBS standards. The study confirmed that the main water and sanitation challenges in Kisumu are poor and deteriorating water quality, poor waste disposal management systems and poor sanitation services. There is need for the introduction of new and sustainable groundwater approaches supported by scientific models and involving all stakeholders. Current deficiencies in the provision of adequate water and dignified sanitation to the poor in Kisumu can be remedied through improved knowledge on shallow aquifer dynamics and innovative research. It was noted that apart from the donor agencies and multi-national NGOs, the private investors are unwilling to invest in water projects in Kisumu due in part to government legislation that constrains the cost that may be levied on water.



**Hydrogeological conceptual model of a crystalline thermo-mineral carbo-gaseous aquifer driven by a weathering profile and tectonic fractures**  
**Abstract n°1895**

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**KEYWORDS:** Crystalline aquifer, weathering profile, hydraulic properties

Thermo-mineral and carbo-gaseous systems are associated to specific geological structures, such as faulted and fractured bedrock, allowing the upward circulation of deep hot mineral fluids and or gases. Although conceptual models based on groundwater flow through faults and tectonic fractures can be relevant, the 3-D extension and hydraulic properties of such aquifers exploited either for bottling or spas are rarely considered. Moreover, faults are not always conductive structures and in many cases, they can constitute impervious boundaries due to compressive tectonic activity, clogging or recrystallization, etc. Here we develop a comprehensive research based on various approaches (i.e. geological, geophysical, hydrodynamic, geochemical and modelling). The converging results allow conceptualizing the functioning of the carbo-gaseous aquifer system of the Saint-Galmier (France) natural mineral water, located along major border faults of an Oligocene graben. Based on seismic profiles, geological observation (outcrops) and more than 200 boreholes, a 3-D geological and structural model has been build up. Conceptual and numerical modeling of the system was based on 36 pumping tests data, piezometric and chemical surveys, and more than 80 punctual samples for groundwater and surface water chemistry and isotopy. Such a density of information is rarely equaled in complex context. Several approaches highlight the significant role of the fissured layer of an ancient weathering profile on the hydrogeological properties, spatial extension and compartmentation of this typical mineral carbo-gaseous aquifer system. Numerical hydrodynamic modeling has been performed on one aquifer compartment because of high density data. It notably allowed estimating the location of the deep fracture feeding the granitic aquifer with deep fluids and allowed a good assessment of mixing rates between deep waters and water from the fissured layer.



## Groundwater recharge in Africa- identifying critical thresholds Abstract n°1896

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KEYWORDS: RECHARGE+ thresholds, field studies Africa

Increasing access to groundwater is fundamental for improving health, reducing poverty and increasing food security for the rapidly growing African population. Recent assessments of groundwater storage and expected borehole yields highlight the potential of groundwater storage to meeting domestic needs and also in some areas supporting extensive irrigation [1]. However, groundwater recharge remains one of the most difficult parameters to estimate, particularly on a regional scale [3], and there are key uncertainties around the magnitude and nature of groundwater recharge, and the relationship between rainfall and diffuse or focused recharge across different climate and hydrogeological zones. There is emerging evidence that the relationships are non linear, controlled by critical recharge thresholds based on rainfall intensity [4]. This observation is of particular importance given climate change projections which suggest a move towards increasingly intense rainfall events in Africa [5]. In this study we analyse data from 200 groundwater recharge field studies published from across Africa. Estimated values from these studies vary from 0–940 mm yr with an interquartile range of 6–82 mm. We find a direct relationship between long term total annual average rainfall and estimated recharge from the field studies, which describes approximately 50% of the variance. Further analysis of the individual field studies demonstrate that much of the remaining variance can be explained by the patterns of rainfall (such as intensity) and also land use. Long term average recharge is rarely >10 mm yr where annual rainfall is <250 mm, or <10 mm when rainfall is >500 mm. Reliable long term recharge of >50 mm yr is observed for nearly all field studies where long term annual rainfall is >1000 mm. [1] MacDonald AM et al. (2012) Environ. Res. Lett. 7, 024009 [2] Edmunds WM (2012) Environ. Res. Lett. 7, 021003 [3] Healy RW and Scanlon BR (2010). Estimating groundwater recharge. Cambridge Univ Press. [4] Jasechko S and Taylor RG (2015) Environ.Res.Lett. 10, 124015 [5] Allan RP and Soden BJ (2008) Science 321, 1481 1484



## **Examples of the possible artificial recharge in the Zagreb aquifer, Croatia Abstract n°1897**

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**KEYWORDS:** Zagreb aquifer, artificial recharge, FeFlow

The water supply of the city of Zagreb, Croatian capital, is organized by capturing groundwater from the alluvial aquifer, which is mainly fed by the Sava River. For the water supply are used numerous dug and drilled wells. One of the biggest water supply site is a "Mala Mlaka" where the first wells were operational in 1964. The capacity of wells was about 1.7 m<sup>3</sup> s, at that time more than enough. However, from the 1980s to the present day there has been continuous decrease of the groundwater level due to erosion of the Sava riverbed and overexploitation of the aquifer due to increase water demand. This paper deals with results of the research that was aimed to examine the possibilities of artificial recharges of groundwater in the area of "Mala Mlaka" by using infiltration of the surface water from the nearby flood relief canal Sava-Odra that was built in 1970 for the flood protection of Zagreb. A mathematical model and the simulation of the groundwater flow for the period 2006-2010 was conducted. Due to the complexity of the natural conditions the software package FEFLOW was used. This was the basis for different models of artificial recharge of the aquifer. The initial simulation was performed with the assumption of maintaining constant potential of surface water in the flood relief canal. The obtained result was satisfactory, but required constantly large amounts of water in the flood relief canal. Therefore, additional artificial recharge scenarios were tested. The most promising solution was simulated by construction of a smaller dam building in the flood relief canal nearby the well site, and using the infiltration of surface water from obtained water retention. The other promising solution was simulation of a several infiltration wells along the edge of the water supply site by using of water from different surface water retentions. The final demonstrations of achieved results, as well as other spatial representation were prepared by using the software package ArcGIS ArcMap.



## Complexity of the Indo-Gangetic aquifer system revealed by in situ observations Abstract n°1899

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KEYWORDS: GRACE+ groundwater storage, water-level observations

Groundwater abstraction from the transboundary Indo-Gangetic alluvial aquifer comprises 25% of global groundwater withdrawals and sustains agricultural productivity in Pakistan, India, Nepal and Bangladesh. Recent interpretations of satellite gravity data indicate that current abstraction is unsustainable, yet these large-scale interpretations lack the spatio-temporal resolution required to govern groundwater effectively and often lack ground truthed data. Here we synthesize available in situ information from across the basin to provide high-resolution maps of groundwater-levels, groundwater storage trends, abstraction and groundwater-quality. The data reveal that poor groundwater quality is likely to be a greater problem than depletion. We estimate the volume of groundwater to 200m depth to be >20 times the annual flow of the Indus, Brahmaputra and Ganges and show the water-table has been stable or rising across 67% of the aquifer between 2000-2012. Groundwater-levels are falling in the remaining 33% amounting to a net annual depletion of 6.8 A2.6 km<sup>3</sup>. These results are consistent with the regional evaluations from GRACE but give much greater resolution. Much of the of the regional depletion for Northern India observed from GRACE occurs outside the main IGB aquifer, in the desert of Rajasthan, which should be considered a separate aquifer system. In situ observations also provide evidence of the strong link between groundwater and surface water within the basin. Given the high volume of abstraction in parts of the basin, the measured rate of water-table decline is too small to derive from direct rain-fed recharge alone. Field studies show that abstraction can markedly increase recharge, reduce natural discharge, and induce younger water deeper into the aquifer. Recent depletion in northern India and Pakistan measured by GRACE has occurred within a longer history of groundwater accumulation through canal leakage. We conclude that in-situ groundwater observations are essential to supplement GRACE and provide the spatial detail essential for policy development and the multi-decadal context for short term evaluations based on satellite data.



## Abstract n°1900

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KEYWORDS: <p>Session 7.02, Kisumu, groundwater, hydrostratigraphy, hydrodynamics

<p>The paper presents a diagnostic assessment of groundwater hydrodynamics and hydrostratigraphy of Kisumu aquifer in Kenya as a precursor to further studies that are being undertaken to characterize the Kisumu City aquifer in the context of the new five-year AfriWatSan project. The aquifer is located in the Kavirondo rift and underlain by lithologies ranging from Recent alluvium to Archean crystalline basement rocks. The hydrogeological characteristics of these lithologies that influence well yields and water quality vary as a function of rock type, age, post-depositional alteration, and weathering. Regoliths primarily comprising saprolite and alluvium are often clay-rich and range in thickness from 5 to 50 m. Most hand dug wells are located in this unconsolidated zone. The base of the saprolite including the saprolite-saprock interface has a higher porosity and permeability, and the thickness ranges from 80 to 150 m in lowlands but is comparatively thin in upland environments. Beyond 200 m, aquifers are quite productive. We conclude that the groundwater dynamics in the study area are controlled by geological history and structural deformation. Structural deformation has resulted in a density of faulting and fracturing that is associated with high-yielding boreholes. Chemical analyses of water samples confirm that the water is generally suitable for human and animal consumption, domestic and industrial use, and for irrigation purposes. However, deep (>150 m below ground level) boreholes contain fluoride higher than the WHO maximum limit and the local KEBS recommended limits and, shallow wells are often contaminated by faecal microorganisms.



**Examining functionality and sustainability of groundwater supplies equipped with hand pumps**  
**Abstract n°1901**

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**KEYWORDS:** SUSTAINABILITY GROUNDWATER SUPPLY, functionality, handpumps, Africa, UPGro research programme

Improving access to water, and helping to achieve new Sustainable Development Goals of universal access to safe water, will depend to a large extent on accelerated development of groundwater resources, usually through drilling boreholes and equipping them with handpumps. However, emphasis on new infrastructure has obscured a hidden crisis of failure, with an estimated 30% of new sources non-functional within 5 years. This problem has remained stubbornly persistent over the last four decades, with little sign of sustained progress despite various interventions. The accumulated costs to governments, donors and above all rural people are enormous. The lack of systematic investigation and understanding into the complex multifaceted reasons for failure has given limited opportunity to learn. Preliminary results of a collaborative research programme across Ethiopia, Uganda and Malawi are presented where we - (1) bring clarity to the definition of the functionality of hand pump equipped boreholes, and the functionality and performance of water governance arrangements - essential for developing shared data and knowledge base+ and (2) develop a survey methodology for measuring functionality and performance. We have found it useful to divide objective measures of functionality (based on meeting design criteria) from user experience and demands put on the system. Here we present result from the initial surveys in the project, in Uganda, Ethiopia and Malawi. The results show the utility of detailed survey design and undertaking an interdisciplinary survey. The primary reasons for poor performance and failure are low yield, poor quality or mechanical failure. However, behind these initial symptoms of failure are many secondary reasons and underlying conditions. By examining these deeper factors to poor performance using an interdisciplinary approach the underlying causes of the rapid failure of approximately 30% of Africa's hand pump equipped boreholes can be understood, diagnosed and ultimately mitigated.



**Radioactive tracers in groundwater of the European North of Russia ALEXANDER I. MALOV Institute of Environmental Problems of the North at the Ural Branch of the Russian Academy of Sciences, Arkhangelsk, Russia malovai@yandex.ru  
Abstract n°1904**

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KEYWORDS: radiocarbon, uranium, dating

Isotopic tracers are known to be tools to refine groundwater conceptual models and their management strategies, including protection actions. Using of isotopic tracers may provide a support for identifying flow paths and transit time distributions in aquifers. At the same time, the using of them individually does not always allow to carry out a full account of all the factors necessary for the task. We used the information on the joint distribution of isotopes of carbon, tritium and uranium in 50 groundwater samples taken in 2011-2014 from the thermal springs draining carbonate deposits at the junction of the East European Platform and the Pre-Urals Foredeep and wells in the sand and carbonate sediments at the junction of the Mezen syncline with Baltic shield. The researches allowed to identify the most vulnerable areas of the surface contamination of fresh groundwater in Quaternary and Carboniferous sediments, as well as in the least mineralized groundwater in sediments of the Padun suite of Vendian. Radiocarbon age of these waters is defined as modern. It was found that all the fresh waters was formed in the Holocene. U concentration in them correlate with age, reaching 14 ppb with total alpha activity of 0.8 Bq l. The maximum concentrations of up to 16-20 ppb with total alpha activity 1.7 Bq l was found in the salt waters with TDS of 8-13 g l at the redox barrier in the aquifer. These waters were formed in the Late Pleistocene, and their radiocarbon and uranium-isotope age is 27-57 ka. Behind barrier U concentration sharply drops to 0.1-0.2 ppb. Here is the most ancient water with total dissolved solids of up to 22 g l and uranium isotopic age of 130-580 ka, corresponding to Middle Pleistocene. In general, the studies have contributed to clarify of conceptual models of groundwater in the investigated hydrogeological systems and a deeper understanding of the evolution of uranium isotopes in groundwater systems.



# Climate change impacts on Irish fractured-bedrock aquifers- A sensitivity analysis Abstract n°1905

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KEYWORDS: groundwater recharge, Ireland, climate change

Groundwater recharge calculations in Ireland have been typically based on a combination of soil water-budget techniques and river base-flow analysis. The water-budget techniques are based on estimate effective rainfall (which is defined as the difference between rainfall and actual evapotranspiration) using a soil moisture deficit approach. Afterwards, recharge coefficients are applied in order to represent the percentage of water that reaches the water table and becomes actual recharge. These coefficients depend on a number of variables such as, the aquifer type, soil drainage, but especially subsoil permeability and thickness. The reason for using this approach is that a large portion of Ireland is overlain by low glacial deposits, which frequently have a low permeability, and are an important controlling factor of groundwater recharge. Another determining factor is the capacity of the underlying aquifer to accept the potential recharge. This is especially relevant in Ireland, where two thirds of the country is covered by bedrock aquifers with low sotrativity and throughput capacities. This restricted acceptance is represented by setting a limit of the amount of recharge that these aquifers can accept. A recharge characterisation and sensitivity analysis has been carried out for some Irish catchments with different hydrogeological settings. Recharge estimations and sensitivity analysis have been approached by combining a GIS tool and water budgeting methods. The sensitivity test include the analysis of the main variables controlling potential recharge such as rainfall amounts, its intensity and seasonality, and temperature. It also comprehend the variables constraining actual recharge such as the cited recharge coefficients and aquifer caps. Climate change is expected to alter groundwater resources as a consequence of increasing temperature and variations in rainfall distribution and intensities. However, it is also known that the magnitude of these variations are strongly dependent on specific catchment characteristics. In fact, the results show that the areas affected by constraining hydrogeological settings are more sensitive to these variables than to the possible changes induced by climate change.



# Numerical simulation of groundwater residence time distributions in karst aquifers

## Abstract n°1906

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KEYWORDS: karst, distributed numerical modeling, residence time

Groundwater residence time data provide important information for the management of groundwater resources. Together with the time the water needs to pass through the protective overburden, it determines the vulnerability of groundwater resources towards pollution. Hereby, the spatial distribution of the groundwater residence time in the aquifer and the respective ages of the different water components are essential. Deriving these parameters in karst aquifers is especially challenging. They are highly heterogeneous and many of them act as triple porosity systems. Therefore, residence times range between hours and decades within a single aquifer. In this study, distributed numerical modeling is employed for understanding the interaction between the three karst aquifer compartments, i.e. conduits, fractures and rock matrix. The major aims are assessing the kind of field investigations necessary for simulating the groundwater residence time distribution in karst aquifers and deducing whether such a simulation can give additional information on the hydraulic and geometric parameters of the aquifer. A hybrid and a double continuum approach are combined for simulating all three compartments. Results show that hydraulic conductivities are of minor importance and lose influence for larger conduits with few intersections. The highest influence on the observed residence times can be attributed to the ratio between direct and diffuse recharge, with the total recharge, the porosities of the fissured and porous systems and the aquifer thickness as secondary factors. Since the measurement of porosities at different scales is possible in the field and in laboratories and recharge can usually be derived in the field, the method shows a good potential for reproducing the groundwater residence time distribution of karst aquifers. Detailed knowledge on the parameters of the conduit system is not necessary due to their relatively low influence. This is promising, since these parameters are poorly known for most aquifers. Further, this shows that the groundwater age largely depends on different parameters than the spring discharge, which makes it valuable for characterizing those parameters, which cannot be deduced by discharge measurements.



**Carbon isotopic signature of CO<sub>2</sub>-rich hydro-systems in varied geodynamic contexts of Europe (French Massif Central, Italy and Peri-alpine grabens)  
Abstract n°1908**

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**KEYWORDS:** geogenic CO<sub>2</sub>, delta13C signature, CO<sub>2</sub>-rich hydrosystems

The isotopic signature of carbon ( $\delta^{13}\text{C}$ ) of carbo-gaseous and thermo-mineral hydro systems has been largely used to determine the origin and processes associated with deep CO<sub>2</sub> degassing. An overview of the isotopic signature of free gas phase and TDIC in several European carbo-gaseous systems from contrasted geodynamic contexts (French Massif Central, the Tyrrhenian subduction area and peri-alpine extensional areas) shows a range of  $\delta^{13}\text{C}$  between -10‰ and 0‰ vs. PDB. This range is larger than that admitted for mantle carbon -6‰. Thereby it is considered that carbon ascending from the lithosphere undergoes fractionation related to partial melting and degassing of magmas. It could also be interpreted as a mixing of mantle CO<sub>2</sub>, soil CO<sub>2</sub> ( $\delta^{13}\text{C}$  of -20‰) and carbonate deposits ( $\delta^{13}\text{C}$  0‰). Here we propose to quantify mixing of different sources of carbon (e.g. Carbonate deposits, organic matter) and to identify additional processes (e.g. degassing) based on the carbon signature. Finally, the sampling bias induced by isotopic fractionation between gas phase and TDIC in the hydro-systems will be further described and assessed.



# Optimizing Dewatering and Depressurization of a Coal Mine in North China Based on Numerical Simulation

## Abstract n°1909

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KEYWORDS: coal mining, water inrush, groundwater management, optimization

China produced 3.75 billion tons of raw coal in 2015. Many water inrush accidents occurred during coal underground mining. Dewatering and depressurization (Dw–Dp) are commonly used for preventing the occurrence of water inrush. In a long period, people focused on safely mining and conducted Dw–Dp without reasonable control, which led to large depression cones in many areas where the groundwater serves as a water supply. To avoid excessive drainage, Dw–Dp should be optimized with safe, economic and environmental benefits. In this study, Dw–Dp conducted by a coal mine in north China were optimized based on numerical simulation. Water from the Cambrian limestone aquifer rushed into the coal mine for six times. Dw–Dp were conducted through underground boreholes and the water table declined significantly. The optimization goal was to minimize the Dw–Dp rate under the safe conditions. Firstly, the water inrush coefficient was applied to evaluate the inrush risk for each workface to identify the excessive drainage. Using the empirical threshold value of the coefficient, the maximum water level approved by each workface was computed as the safe condition. Secondly, a two-dimensional numerical model for heterogeneous, anisotropic, non-steady flow was established by FEFLOW. At last, the optimal Dw–Dp rates were determined through iterative simulations based on the numerical model. The results show that the recharge of that aquifer is weak and the excessive drainage exists in three workfaces. For safely mining the three workfaces within one year, the optimal rate could be reduced by 15 m<sup>3</sup> h, which could decrease drainage by 131,400m<sup>3</sup> a and save cost amount to 130,000 RMB a. According to the results, excessive drainage caused by Dw–Dp exists in coal mines and significantly increases the cost of power and treatment. In future, more efficient methods, such as surrogate based optimization algorithms, should be applied on solving the Dw–Dp optimization problems. This work was supported by National Natural Science Foundation of China(NSFC) (41302203).



**Groundwater-related environmental phenomena in complex geologic setting of Tihany Peninsula, Hungary  
Abstract n°1910**

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**KEYWORDS:** environmental agency of groundwater, 3D groundwater flow simulation, wetlands

Gravity-driven groundwater flow, controlled and determined by topography, geology and climate, is responsible for several natural surface manifestations and affected by anthropogenic processes. Therefore, flowing groundwater can be regarded as an environmental agent. Numerical simulation of groundwater flow could reveal the flow pattern and explain the observed features. However, in complex geologic framework, the geologic–hydrogeologic knowledge is limited to build reliable numerical models. The aim of the study was understanding the background and occurrence of groundwater-related environmental phenomena, such as wetlands, surface water-groundwater interaction, slope instability in the Tihany Peninsula with complex geologic setting based on electromagnetic geophysical, hydrogeological survey and numerical simulation. The hydrogeologic model was prepared on the basis of the compiled archive geophysical database and the results of recently performed geophysical measurements complemented with geologic-hydrogeologic data. Derivation of different electrostratigraphic units, revealing fracturing and detecting tectonic elements was achieved by systematically combined electromagnetic geophysical methods. The deduced information can be used as model input for groundwater flow simulation concerning hydrostratigraphy, geometry and boundary conditions. The 3D model clarified the hydraulic behaviour of the formations, revealed the subsurface hydraulic connection between groundwater and wetlands and displayed the groundwater discharge pattern, as well. The position of wetlands, their vegetation type, discharge features and induced landslides were explained as environmental imprints of groundwater. The highly vulnerable wetlands have to be in the focus of water management and natural conservation policy.



**Poroelastic response to terrestrial water loading of the Bengal Aquifer System provides high-resolution, in-situ measurements for comparison with GRACE  
Abstract n°1912**

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**KEYWORDS:** terrestrial water storage, poroelasticity, geological weighing lysimetry

In the Bengal Aquifer System (BAS), low topographic relief and low vertical hydraulic conductivity constrain gravitational groundwater flow. In contrast, substantial poroelastic responses of the compressible BAS sediments to surface water loading by monsoon rainfall and flooding have been demonstrated[1] in coastal regions of the Ganges-Brahmaputra-Meghna (GBM) floodplains. The integrated change in terrestrial water mass, TWS, evident from head measurements in nested piezometers, is the same as measured by the GRACE satellite mission, albeit at dramatically different spatial and temporal scales. Therefore the BAS poroelastic response could be employed in a spatially-extensive application of 'geological weighing lysimetry'[2] to provide direct, in-situ measurements of TWS, complementary to satellite gravity data, to explore spatial variability within a single GRACE footprint. In a preliminary analysis of weekly groundwater level measurements at thirty four deep nested piezometer sites, each with a 'sensing area' of approximately 20 km<sup>2</sup>, we have investigated TWS across southern Bangladesh for the 2013 monsoon season. We applied a value of loading efficiency, the proportional change in hydraulic head relative to change in surface load, indirectly derived[1] from barometric efficiency. Values of TWS over the 2013 monsoon season are spatially variable over a range 0.53 to 3.44 m, locally consistent with the very large seasonal rise in river stage. The mean 2013 monsoon season TWS by piezometric lysimetry is 2.0 m, substantially higher than previous GRACE assessments across the full extent of the GBM floodplains[3,4] which span the lower limit of this range, 0.49 to 0.75 m per monsoon season over the period 2003-2007. 1. Burgess, W.G. et al. In review Nat Geosci. 2. van der Kamp, G. & Schmidt, R. 1997 GRL 24, 719-722. 3. Steckler, M. S. et al. 2010 JGR B08407. 4. Shamsudduha, M. et al. 2012 WRR W02508.



## **Spatially distributed modelling of pesticide leaching in Flanders**

### **Abstract n°1913**

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**KEYWORDS:** Aquifer vulnerability, Pesticides, Leaching, Flanders, GeoPEARL, Modelling

Pesticides are widely used to protect plants from harmful organisms, and to increase agricultural production. These pesticides can be beneficial for plant protection but, at the same time, can also have a damaging effect on humans, animals and the environment. In the soil system, pesticides can degrade or adsorb to soil or organic particles. Once in the groundwater, pesticides and their metabolites can persist for years. The movement of pesticides through the soil to the groundwater, also referred to as leaching, is therefore of particular concern. To assess the vulnerability of aquifers in Flanders we have set-up a physically based spatially distributed leaching model for Flanders using GeoPEARL. In this study we describe how existing national and European datasets were used to prepare the input data for the model and how the model can be used to identify areas with a high leaching risk. With these results, guidelines can be developed to reduce pesticide leaching and protect groundwater resources. The main challenge of setting-up a spatially distributed leaching model, was the generation and parameterisation of a spatial schematisation, which covers the spatial variation and heterogeneity of the Flemish agricultural landscape. Different national and European spatial databases, containing information on soil, weather, land use and the groundwater system, were collected and processed. The model results were checked by comparing long-term averages of substances and water balances with existing measurements or results from other models. The Flemish spatial leaching model gives insight in regional differences in the vulnerability of the Flemish aquifers with regard to pesticides and the sensitivity of the different variables with respect to groundwater leaching. The model can be used to guide groundwater monitoring strategies and assess the impact of for example climate changes, alternative agricultural management practices or alternative crops on the leaching of pesticides.



## Characterizing complex aquifers using flow dimension diagnostic sequences Abstract n°1915

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KEYWORDS: Aquifers models, pump test, heterogeneous flow, derivative analysis, flow dimension

In hydrogeology, pumping tests are still commonly interpreted assuming Theissian conditions, which involve gross approximations of natural aquifer heterogeneities+ the quality of water resource management is consequently reduced. The petroleum industry has long used drawdown log -derivative analyses for reservoir characterization, integrating a series of analytically derived interpretative models handling non-purely Theissian heterogeneous flow. The flow dimension theory (GRF model) further diversifies the interpretative framework to non-trivial flow conditions, which more accurately represent real aquifer responses. These approaches are integrated into a flow dimension sequence diagnostic methodology, which is suitable for interpreting successive flow regimes and interactions in natural aquifers where pumping occurs. Specific flow regimes are produced by specific heterogeneous conditions encountered by the pressure front pulse propagating outwards into the aquifer, inducing flow dimension changes. We explain how these flow dimension sequences provide powerful diagnostic tools of aquifer conditions. The case of two laterally juxtaposed aquifers is used to illustrate the methodology. The hydrodynamic properties of such heterogeneous systems are numerically constrained, and a flow dimension diagnostic sequence is formalized. It is composed of two successive  $n = 2$  radial flow regimes separated by an optional  $n = 1.5$  fractional stage if a conductive fault embodies the interface between the aquifers. Our numerical experiments illustrate how this methodology downgrades conventional interpretative approaches by identifying subtle hydrodynamic changes, and preventing erroneous aquifer diagnostics. We promote an advanced tool for refining pump test interpretations, accounting for complex aquifer conditions that are not handled in Theis-derived methods.



**A multidisciplinary hydrogeological approach to estimate a robust and meaningful  
delta 18O altitudinal gradient.  
Abstract n°1916**

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KEYWORDS: delta 18O, altitudinal gradient, recharge area

The delta 18O gradient is a well-known method in hydrogeology to characterize the aquifer's recharge area. It was parallel developed, during the 1970's , in several areas of the world. Nevertheless, the methodology implemented to characterize the altitudinal gradient shows some issues that are not frequently discussed. As rainfall delta 18O data are rarely available at various elevations to build such a straight line, data from "shallow" springs are often used, but their representativity must be assessed and discussed. A methodology, developed on the Evian catchment, is presented. It is based of the main following steps- (1) On the basis of a trial and error estimation of the specific discharge of springs, their catchment area have been estimated+ (2) the geological and hydrogeological data combined with hydrochemical profiles (regarding the known soil coverage and land use) allowed the delineation of each catchment+ (3) then the mean elevation of each recharge area can be estimated rather accurately. This average elevation can then be used to plot the altitudinal gradient. On the other hand, the variability of the delta18O signal measured at the "springs" at least during 3 successive 6 months interval samplings (to capture the whole yearly cycle signal), as well as their hydrochemistry, were used to discard sampling points that revealed to be characterizing locally infiltrated surface water or specific rainfall events). Thus, some small non-permanent springs haven't been taken into account. The analysis of the delta18O variability also allows a better precision to estimate the mean value for each spring. Such a methodology is of particular interest for recharge areas with quite gentle slopes and variations in elevation where no accurate result would be obtained without a high accuracy on the 18O gradient. It has been successfully used in the Evian (French Alps, France) hydrogeological system.



**The contribution of a multidisciplinary approach to conceptualize the structure and functioning of a complex Natural Mineral Water Glacial aquifer**  
**Abstract n°1917**

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**KEYWORDS:** multidisciplinary approach, complex aquifer, glacial sediments deposited

The Evian (French Alps, France) Natural Mineral Water emerges at the bottom of a thick sedimentary pile of glacial sediments deposited, during the last glacial cycles, below and at the edge of the Rhône glacier. A multidisciplinary approach was implemented to more precisely define the geological structure and the hydrogeological functioning of this complex system. It is based on- (1) the detailed study and synthesis of existing boreholes geological logs, completed with field geological and geomorphological observations in order to reconstruct the local geological history and, from that, the main lithological facies. One of the main results is that the North-South growth of the glacier during the lemanic stage (-30 -27ky BP) infers a North-South sedimentary polarity with a pile of impervious basal tills on the northern proximal edge of the Plateau, and less impervious sediments in its the southern distal part, (2) the precise location and interpretation of the functioning of shallow aquifers' springs and the plateau's streams (discharge – time series data, and spatial variations -, hydrochemistry and isotopy, etc.), as well as deep piezometers, confirmed and clarifiprecised this scheme, and provided indications on the water transit time within the pervious layers of the sedimentary pile. In the Evian case study, these results prove to be of high interest to delineate the aquifer's recharge area in order to implement efficient protection policies. Similar complex deposits are known in several places in the world (Alpine englaciation from the Alps to the Hymalaya, North and South Americas, New Zealand, etc.), where similar structure and functioning can be expected. The usefulness of a such a multidisciplinary approach is demonstrated. In fact, each method provides some clues that can only be considered as proofs when different methods provide convergent clues.



**Geochemical and isotopic characterization of surface river-alluvial groundwater relationships in a high altitude semi-arid basin, Elqui (Chile)**  
**Abstract n°1918**

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**KEYWORDS:** Surface water groundwater interactions, Hydrogeochemistry, Andes

Geochemical and isotopic tools are used to trace surface water groundwater interactions, which are major recharge processes for alluvial aquifers, especially in arid zones. In this context, geochemical characteristics of surface and ground waters should be strongly linked. Nevertheless, geochemical signatures can be very complex in valleys, especially in volcanic contexts where different processes are involved such as rock weathering, mixing with geothermal fluids or dissolution of particular minerals producing specific geochemical facies. The study area (upper Elqui valley and tributaries) is located in Chilean Andes (800 - 5500 m). The upper zone (> 3000 m) comprises various volcanic rocks including locally mineral-rich areas (El Indio Gold Belt) and is supplied by several glaciers including the Tapado (HCO<sub>3</sub>-Ca hydrochemical facies) and rock glaciers (SO<sub>4</sub>-Ca hydrochemical facies), with increasing mineralization from upper to lower parts of the basin (EC from 150 to 630 IS.cm<sup>-1</sup>). In zones including mining activities (El Indio mining) or mineral-rich terrains, increases in mineralization (up to 4000 IS cm), acidification (pH <4) and high concentrations of metallic elements are observed in surface waters. The lower part of the basin is composed of plutonic rocks and detrital terrains in which alluvial aquifers are developed. The hydrochemical facies of tributaries is HCO<sub>3</sub>-Ca, but the major river retains the SO<sub>4</sub>-Ca signature acquired in the upper part of the basin. All through the alluvial aquifer, hydrochemical and isotopic characteristics of surface waters and ground waters generally show good relationship, highlighting a good connectivity between these two compartments. Nevertheless, isotopic values of some tributaries can be different and contrasted compared to others as a function of the origin of water (from glaciers, rain and or snow). Radon measurements have shown some possible contributions from plutonic rocks. This mutitracer approach coupled with hydrodynamic information allow to better characterize surface water groundwater interactions, which are complex to identify but are fundamental to optimize the integrated water resources management in arid contexts at middle to high altitudes.



## **Inferring groundwater ages in complex aquifers using gas tracers and tritium. Abstract n°1919**

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**KEYWORDS:** environmental tracers, unsaturated zone, cosmogenic production

The determination of transit time distributions in complex aquifers with environmental tracers might be affected by a series of processes. We compare results from a 50-years' time series of a water-bound tracer ( $^3\text{H}$ ) and a complete set of gaseous environmental tracers ( $^{85}\text{Kr}$ ,  $^{39}\text{Ar}$ , CFCs,  $\text{SF}_6$ ) sampled at a single date. Study area is the complex aquifer system of Evian (French Alps). The interpretation using lumped parameter models and  $^3\text{H}$  data is not sensitive to distinguish between residence times in the unsaturated (USZ) and saturated zone. Since gas tracers behave differently in the USZ they provide a differenced view on the water flow path including some estimates about the recharge area and process. The comparison of  $^{85}\text{Kr}$  data with CFCs allow for a quantification of degradation processes of the latter. Due to the prolonged gas residence time in the USZ the initial  $^{39}\text{Ar}$  activity is possibly affected by cosmogenic production by the  $^{39}\text{K}(n,p)^{39}\text{Ar}$  reaction. It is concluded that the combination of time series measurements and a multi tracer snapshot in time complete each other and provide also an assessment of the transient behavior of a groundwater flow system. Furthermore, hydrogeological conceptualization in order to pre-design the possible schemes for the lumped parameter models (e.g. models in series or in parallel), highly helps to converge towards more realistic sets of parameters.



**Storing CO<sub>2</sub> in deep saline aquifers as part of integrated territorial energy and climate plans**  
**Abstract n°1921**

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KEYWORDS: CCS technology, groundwaters, climate mitigation

CO<sub>2</sub> Capture and Storage (CCS) is a key climate change mitigation technology, as highlighted by IPCC, UNFCCC and IEA. Geological storage of the CO<sub>2</sub> captured at industrial facilities such as power, cement and steel plants can massively reduce CO<sub>2</sub> atmospheric emissions and can even generate negative emissions when combined with CO<sub>2</sub> capture i) at biomass plants (BECCS - BioEnergy with CCS) or ii) directly from the atmosphere. Deep saline aquifers (DSA) constitute suitable widespread targets with sufficient CO<sub>2</sub> storage capacity to enable worldwide CCS deployment. Globally there are several commercial CO<sub>2</sub> storage projects in DSA injecting each about 1Mtpa CO<sub>2</sub> (Norway, Canada, and soon Australia and USA). Pilots (e.g. Hontomin in Spain) and demonstration projects in other settings are currently running or planned to accelerate 'learning by doing' and push worldwide deployment. The efficient and wise use of these DSA requires robust methodologies and tools for appropriate characterization and safe CO<sub>2</sub> storage, with no harm to the local environment including the overlying potable groundwater. Extensive research since the 1990s has enabled the development of best practices, such as the FP7 ULTimateCO<sub>2</sub> guidance report (2016). Legislation and regulations have evolved, such as the EU Directive on the geological storage of CO<sub>2</sub> (2009) and the upcoming ISO standards for CCS. Interestingly, CO<sub>2</sub> storage in DSA could be combined with geothermal heat recovery, as investigated by France in the ANR CO<sub>2</sub>-DISSOLVED project, or with enhanced water recovery for producing fresh water as investigated in China and USA. The ambition of the Paris Climate Agreement to try to limit global warming to 1.5°C calls for even stronger consideration of CCS in countries' Intended Nationally Determined Contributions (INDCs) and in regions' integrated territorial energy and climate plans. The H2020 ENOS project "ENabling Onshore CO<sub>2</sub> Storage in Europe" (2016-2020), an initiative of the CO<sub>2</sub>GeoNet European Network of Excellence, will contribute to facilitating this. Indeed, CO<sub>2</sub> storage offers more flexibility to territories for managing their CO<sub>2</sub> emissions while contributing to local economic development.



**COMETE project Valensole- lavender and water quality - spatiotemporal  
characterization of impacts to waters of agricultural pollution  
Abstract n°1922**

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**KEYWORDS:** groundwater 2,6-dichlorobenzamide lavender

The Valensole plateau (Alpes de Haute-Provence, France) is formed of heterogeneous alluvial deposits in which numerous but relatively small aquifers are found. About a third of the drinking water wells supplying the surrounding area have been shut down due to a large contamination of groundwater by 2,6-dichlorobenzamide (BAM), a metabolite of 2 active substances (dichlobenil, chlothiamid) previously used on the area. This molecule is related to the lavender production, which is the main agricultural practice on the plateau. Most of these wells were defined in local management action plan as priority groundwater well. In this context, the COMETE project aims at better understanding the hydrogeology of the area and by the way to assess pesticide transfer to groundwater. This project includes also the identification of measures involving farmers with a common objective of groundwater quality recovery. A continuous hydrodynamic and physicochemical monitoring network has been set up for 9 priority wells and springs. Groundwater dating campaigns using CFC SF6 on 10 selected points have been carried out, as well as a large spatial analysis of groundwater chemistry and pesticides and some metabolites content on 70 wells and springs all over the plateau during the sampling campaign (June 2014). Permeability tests were also conducted on soils in order to establish a vulnerability map of the groundwater resource. Besides, investigations were conducted with farmers to trace the history of agricultural practices. All these results were brought together to build up a hydrodeological conceptual model of the aquifer and to delineate the impluvium of the priority drinking groundwater well. Analyses of pesticides showed that 12 molecules (active substance or metabolite) were found among the 50 molecules that were looked for, some of them related to products that are now prohibited from sale (Bromacil, deethylatrazine, BAM), and others still authorized (Isoproturon, Fluazifop-p-butyl...). Finally, recommendations and priority actions to reduce the anthropogenic pressure leading to the pesticides contamination of groundwater were proposed for each catchment of the priority groundwater wells.



**Sustaining urban groundwater-fed water supplies and sanitation systems in Africa-  
case study of Lukaya, Uganda  
Abstract n°1923**

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KEYWORDS: groundwater, sanitation, health

Increasing and sustaining access to low-cost urban water supplies and sanitation systems in towns and cities of low-income countries depends upon the conjunctive use of the shallow subsurface for both the supply of safe water and receptacle of faecal wastes (e.g. pit latrines, septic tanks). As part of a three-country, town-city-megacity study under the AfriWatSan consortium, we present a situational analysis of the water and sanitation conditions for Lukaya, a town in Uganda with a population of 25000 that is dependent upon shallow groundwater for its water supply. Lukaya experiences a seasonally humid climate with bimodal rainfall and is drained by a regional wetland that overlies a buried river channel. Metasedimentary and cratonic rocks are overlain by unconsolidated weathered rock (saprolite) and shallow alluvial and lacustrine sediments. Groundwater levels are shallow (up to 0.5 mbgl) and well yields are typically low (0.5-1.5 m<sup>3</sup>h<sup>-1</sup>) with the exception of a production borehole installed in an area with shallow alluvial, lacustrine and possibly fluvial sediments. Yields in distributed handpump wells are highly variable leading to both inconsistent performance and intermittency in supply despite rising water demand. Sanitation facilities comprise pit latrines that are often flooded due to shallow water tables with coverage unassessed but expected to be low. These facilities are proximate to water sources and often emptied into surrounding wetlands increasing associated health risks. Access to water sources is limited and demand is high, with most households being separated from these sources by distances >3km and having to wait for >30 minutes for their turn to replenish supplies. Background groundwater quality is largely fresh of Ca-Mg and HCO<sub>3</sub>-SO<sub>4</sub> types but in some cases it may have undesirably high total iron concentrations. Key issues needing attention include- (1) water sources (e.g. insufficient sources and storage)+ (2) water quality (e.g. chemical treatment costs)+ and (3) water and sanitation management (e.g. sanitary waste discharge to surrounding wetlands).



# **Groundwater recharge assessment of Takelsa multilayer aquifer (Northeastern Tunisia)**

## **Abstract n°1926**

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**KEYWORDS:** Groundwater recharge, WetSpass, Takelsa multilayer aquifer

Facing to the risk of the imbalance between demand and water supply, the Tunisian water authorities are called to prospect new groundwater resources and enhance aquifer recharge. The Takelsa multilayer aquifer is among the important aquifers in the Northeastern Tunisia. This region is characterized by semi-arid climate and water resources scarcity with groundwater resources largely used in the agriculture sector especially for irrigation. The groundwater recharge of this aquifer is mainly based in the infiltration of the precipitation through the permeable outcrops of sandstone formations of the region. The aim of the present research work is to evaluate the distribution of the groundwater recharge in order to better assess the groundwater resources of the studied area and improve their management. For this purpose WetSpass model, acronym for Water and Energy Transfer between Soil, Plants and Atmosphere under quasi-Steady State, has been used. It is a physically based model for the estimation of the groundwater recharge, surface runoff and evapotranspiration employing physical and empirical relationships. The model is integrated in GIS ArcView as a raster model. The inputs include grids of land use, groundwater depth, climatic data (precipitation, potential evapotranspiration, wind-speed and temperature), soil, and slope. The resulting recharge map shows values ranging between 0 and 168 mm year with a mean of 22 mm year and a standard deviation of 32 mm year. The average annual groundwater recharge represents a mean infiltration rate of 4 % of the annual rainfall. The calculated recharge distribution is introduced in the groundwater flow model developed with Processing Modflow, in order to simulate the hydraulic head distribution. The calculated hydraulic heads matches well with the observed values. The groundwater resources of Takelsa multilayer aquifer estimated by the model, are about 15 Mm<sup>3</sup> year+ this value is less than the current pumping volume measured to 18 Mm<sup>3</sup> year. The sustainable management of the Takelsa multilayer aquifer is recommended.



**Impact of a future high-capacity ship canal on the nearby wetlands of the Seine estuary nature reserve - An on-site pilot to demonstrate the efficiency of a water supplied ditch to preserve wetland integrity**  
**Abstract n°1929**

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**KEYWORDS:** impact assessment, modeling, public debate, on-site pilot, decision tool

To improve inland waterway transport from the Port of Le Havre (north-western France) to the River Seine, the Grand Port Maritime du Havre (GPMH) plans to connect two existing ship canals- the Tancarville Canal and the Le Havre Grand Canal. The planned connecting canal is located near the Seine estuary nature reserve and could impact the surrounding wetlands by lowering the water table level in the area. In a preliminary study, a modeling approach was used to assess the possible impacts of this project. It appeared then that the extent of the drawdown zone could locally span over a distance of several hundred meters from the envisaged connecting canal layout. However, it was also found that a water supplied ditch running along the connecting canal could maintain the water table at a high level within the wetland area thus reducing or possibly eliminating the initial impact of the project. These results were presented at public debate meetings. In view of the skepticism of some participants and in order to fine-tune the potential implementation of this innovative solution, GPMH decided to launch an on-site pilot project. A one hundred meter long prototype ditch was then implemented in a zone close to the Tancarville Canal. An automated pumping system was installed to regulate the water level in the ditch and a piezometric network was developed to monitor the impact of the ditch on the water table. Tests made during a complete hydrological cycle demonstrated the ability of this innovative solution to preserve wetland integrity. The combination of a modeling approach and on site pilot project not only enables the technical development of the envisaged solution but also make it easier for non-specialists to gain more insight on hydrogeological issues and provide communication support to decision makers.



## Methodology to design a permeable reactive barrier for soil aquifer treatment Abstract n°1931

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**KEYWORDS:** Permeable Reactive Barrier, Artificial Recharge of Aquifers, Wastewater Reuse and Groundwater

As anthropogenic pressures on fresh water resources are expected to intensify in the future, managed aquifer recharge (MAR) could play a crucial role in sustaining water availability for various uses. Among the numerous MAR schemes that can be designed and implemented to meet local needs, interest is rising for Soil Aquifer Treatment (SAT), a technical solution based on infiltration and purification of treated wastewaters through the unsaturated zone. One of the main challenges of SAT is how to design and build an effective Permeable Reactive Barrier (PRB) to protect receiving groundwater. To address this challenge a methodology was developed, within the scope of a collaborative project entitled ACTISOL, to assess the feasibility of a pond equipped with PRB for infiltration of treated municipal wastewater. This methodology breaks up into 4 steps- 1) analysis of the regulatory, environmental and socio economic context of the site, 2) design of the PRB - selection of reactive materials (local soil, sand and other reactive materials), reactive transfer numerical modelling and column trials for improving process efficiency, 3) design of the MAR scheme (shape and size of infiltration ponds with PRB) and 4) cost-benefit analysis of the MAR scheme including operation and monitoring. This methodology was developed from the following work items- reactive transfer numerical modelling (BRGM), identification and characterisation of geo-materials (GRS Valtech), column trials (BRGM), monitoring (Solexperts), construction and operation of an experimental 150 m<sup>3</sup> PRB (VeRI), health risk assessment (Lorraine University) and engineering (Artelia). The ACTISOL project was supported by the French Ministry of Industry under the Eco Industries Program.



**Paleo-modelling the formation and development of the freshwater lens on Langeoog  
Island, Germany  
Abstract n°1932**

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KEYWORDS: freshwater lens, modeling, islands

Langeoog is a barrier island located in the North Sea, Germany. It extends approximately 12 km east-west and 1.5 km north-south. Dune areas of up to 20 m a.s.l. can be found predominantly along the northern part and eastern ridge of the island, protecting it from flooding. Three distinct freshwater lenses are present+ the westernmost one is tapped for local water supply. Langeoog consists mainly of medium to coarse sands, containing randomly-occurring clay deposits up to several metres thick. In general, hydraulic conductivity increases with depth. Paleo-reconstructions of the geomorphologic development of the island showed that Langeoog formed around 2500 years BP. Because dunes started to form by sand accumulation and prevented certain areas from flooding, a freshwater lens started developing. This original sand island of Langeoog, however, formed at a location several hundreds of metres northwest of its current location. By successive sand accumulation, redistribution and removal by the wind and sea, the island migrated over time. In this study, we model the formation and development of the freshwater lens under Langeoog, including the geomorphologic changes over time. As large areas were flooded in the past, the freshwater lens was partly destroyed. Anthropogenic groundwater abstraction during the last century is also acknowledged, as well as dam constructions leading to hydrological changes on the island. To our knowledge, this is the first study that simulates the paleo-evolution of a freshwater lens up to its current state, showing that steady-state may hardly be assumed for the present situation.



**Salinization of coastal groundwaters in multi-layered sedimentary aquifers- multi-isotope constraints illustrated by examples in North East of Brazil and South of France**  
**Abstract n°1933**

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**KEYWORDS:** Isotope, Salinization, Coastal aquifer

Coastal aquifers constitute vulnerable water resources threatened by the increasing concentration of population density on the coast worldwide and thus the related water demand. Freshwater stored in coastal aquifers is particularly susceptible to degradation because of seawater proximity. Seawater intrusion, e.g. saline water intrusion into freshwater aquifers, especially threatens groundwater resources because of enhanced pumping for water supply, change of land-use, irrigation and industrial activities, in addition to climate variations or sea-level fluctuations. Here we present a multi-isotope approach (stable isotopes of the water molecule, strontium isotopes, boron isotopes and sulfur and oxygen of sulfates) to constrain salinization sources and processes in two coastal multilayer aquifers. The first one is located in Brazil, in the city of Recife where groundwater is overexploited in some areas as complementary resource for water supply. Results highlight that the saline component in deep strategic aquifers is partly inherited from the Pleistocene marine transgression with very low groundwater renewal. Present day marine intrusion only occurs in very limited areas on the seashore where overpumping leads to reverse the natural groundwater flux, inducing seepage from saline groundwater from the surficial aquifer. The second one is located in South of France in the coastal part of the Roussillon sedimentary basin seasonally facing increase of water abstraction for tourism. Salinization sources and processes were investigated in detail along a 120 m vertical profile using a Westbay monitoring system located a few hundred meters from the coast (sea and lagoon). Groundwater sampling in both high and low productive layers allows pointing out the high diversity of geochemical processes involved+ there is no evidence of present day seawater intrusion neither of present day (>1950) recharge within the system containing paleo-groundwater with a remaining paleo-seawater.



**Global methodology for climate change impacts on groundwater resources assessing-  
Morocco's case study  
Abstract n°1936**

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**KEYWORDS:** aquifer, climate change, IPCC, modeling, groundwater, and methodology.

Morocco is an arid country where the hydraulic potential is limited and most aquifers are overexploited involving a continuous decrease of their piezometric levels. The annual total deficit is approximated to 1 billion m<sup>3</sup>. This situation is due to an increase in water demand to respond to the various objectives fixed by the national development projects, correlated to the effect of the climate changes negative impacts. Several national research papers related to the impacts of the climate changes on the groundwater resources, was published during the last decade. However the majority of them focused in one or few aspects but rarely with a global approach. This communication based on Berrechid aquifer case study and on the international state of art, proposes a global methodology to better analyze this phenomenon. The paper is organized in different steps- - Defining climate change scenarios in the future based on Global climatic models (GCM) and on regional climate models using "downscaling" methods. - Aquifer's recharge modeling using climatic parameters (rain, temperature and solar radiation) and their evolution inside the hydrological cycle. - Salt intrusion modeling under the effect of sea water level increase - Aquifer's hydrodynamic modeling in both steady and unsteady regimes and calibration process - Impact of climate change on groundwater resources modeling analyzing the effect of different issues especially- recharge, saline intrusion, and pumping rates. A global flow chart will be proposed and a panel of tools will be recommended, to help to improve this phenomenon analysis in Morocco.



**Think Before You Drill- Role of Hydrogeologists in Long-Term Changes Affecting Groundwater Sustainability in all Aspects of their Professional Practice  
Abstract n°1937**

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**KEYWORDS:** Groundwater sustainability, Long-term effects of pumping wells, Changes in hydrogeology parameters

When hydrogeologists work to directly exploit groundwater or mineral resources with a direct or indirect impact on groundwater, the long-term effects of these actions are often ignored. The reasons are many and complex. Hydrogeologist practitioners may not have the tools, time, mandate or power to properly assess the long-term impacts of their actions, or may simply not consider these effects. For example, when planning to tap into an aquifer, recommended practice should be to anticipate short-term and long-term impacts on groundwater conditions, quantity and quality. Factors to consider include- 1- studying natural groundwater flux before drilling+ 2- considering effects of drilling single or multiple wells+ and 3- considering cumulative factors that can affect groundwater sustainability, such as changes in groundwater use, demand, climate, recharge and ecosystems. This presentation discusses the different issues that should be considered by the hydrogeological community, from policymakers and researchers to field practitioners, to avoid compromising the water resource. Also discussed are the impacts of other activities that may affect groundwater resources- shale gas extraction, underground waste disposition, CO2 sequestration, geothermal exploitation, etc. Some ideas, possible solutions and practice changes are presented that may help to limit the impacts of our actions on groundwater. For example, contamination and overuse may be prevented by means of practices such as well-pooling, critical design of wellhead protection areas, protection of surface water to ensure groundwater replenishment, limiting impermeable pavements that diminish groundwater recharge, etc. Hydrogeologists are positioned to play a major role in educating the many stakeholders and decision-makers who invest in and plan industrial and territorial development projects that impact resource sustainability.



**Prediction of artificial surface reservoir and shallow aquifer connectivity using diver data loggers and water balance model approach in data scarce developing country  
Abstract n°1938**

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**KEYWORDS:** automatic water level data, groundwater recharge, hydrology, reservoir leakage, Ethiopia, Tigray, Ethiopia

Climatic and hydrological conditions result in vulnerability of many developing African countries like Ethiopia. In this study runoff production, groundwater recharge and response and connectivity of a shallow aquifer to Arato micro-dam reservoir (MDR) leakage were assessed using Soil Conservation Service Curve Number (SCS-CN), soil moisture balance (SMB) and diver (automatic data loggers) measurements for 2014 and 2015 hydrological years. Groundwater recharge was also estimated using chloride mass balance (CMB) and water table fluctuation (WTF) techniques. Results show that the runoff for 2014 and 2015 from the catchment was estimated at about 48.8 mm and 4.54 mm (7.7% and 1.88% of the rainfall) respectively, while yearly groundwater recharge was estimated at about 104 mm, 92.8 mm and 100 mm for 2014 and nil, 37.5 mm and 30.5 mm for 2015 using SMB (on daily basis), CMB and WTF techniques respectively. In addition, based on the water balance model of Arato MDR, the leakage amount from the reservoir was estimated at 13.2 mm day for 2014 and 1.9 mm day for 2015. The estimated leakage is much higher than the seepage foreseen during the initial design of the project (9965 m<sup>3</sup> year). This study will be helpful for hydrologists and engineers engaged in flood forecasting, looking for suitable sites for MDRs, and for soil and water conservationists as baseline information and alternative technique for similar regions. It also highlights the importance of using actually measured climatic and physical characteristics of a watershed rather than using data from literature, and proved reservoir and aquifer connectivity supporting the conventional geological, geophysical, hydrogeological and engineering geological studies at the site. The result of the study provides a scientific basis for reservoir leakage understanding and control.



**Investigating groundwater flow pattern at a bank filtration site in Québec province  
(Canada).  
Abstract n°1942**

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KEYWORDS: bank filtration,  $^{222}\text{Rn}$ -radon, temperature

In Québec province, Canada, many tubewells are implemented in the vicinity of surface water masses. Pumped groundwater therefore potentially features a proportion of bank-filtrated water. Nonetheless, little is known about the reactivity of such systems to environmental and anthropogenic forcing and the subsequent consequences on contaminant attenuation capacity. This is mostly due to the transient regime of bank filtration sites. The purpose of this study is to characterize the spatio-temporal evolution of mixing rates and residence times of infiltrated surface water inside a bank filtration site located at a sandbar between two lakes with different hydrodynamic regimes. To this end, monthly campaigns for water heads, physico-chemical parameters (temperature, EC, pH, dissolved oxygen content, redox-potential), geochemistry and isotopic tracers ( $^{222}\text{Rn}$ ,  $^2\text{H}$ ,  $^{18}\text{O}$ ,  $^{13}\text{C}$ ) are carried out at the 2 lakes and at 8 tubewells located at different locations along the sandbar. Results of the preliminary campaigns provide a better understanding of groundwater flow pattern in this complex system, particularly regarding mixing rates and residence time of groundwater. They also offer an insight on the transient regime of the system and on the possibility of preferential flow paths inside the sandbar.



**Transfert of pollutants from an on-site waste water treatment to the ground water- a case study**  
**Abstract n°1944**

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KEYWORDS: sand filter, transfer, organic micro pollutant, vadose zone,

On site waste water treatment (OWWT) is implemented where the population density is too low to make a collective disposal affordable. In France the OWWT concerns 20% of the population and is submitted to a recent regulation in terms of means. Usually household water is settled and digested in a septic tank, followed by an aerobic sand filter. If the filter is not drained, the soil is acting as post treatment. As the effluent will reach the ground water it's necessary to evaluate how the OWWT and the underlying soil mitigate the pollution. In order to study the impact of an OWWT, a real scale system of one family in a small rural community south-east of Paris, was followed during one and half year. The system, composed of a septic tank and a 25 mC non-drained sand-filter, was equipped during the construction for quantitative and qualitative hydrological monitoring. Volumetric water content, water tension and quality of interstitial liquid were followed at several depths, ranging from 70 to 160 cm, inside the filter and the underlying soil. In parallel the household water consumption was recorded, as well local precipitation, evapotranspiration and ground water level. Hydrological data were collected at 10-min interval from March 2012 to June 2013, together with monthly water samples. The water quality parameters followed were nutrients, carbon, parabens and triclosan. The hydrological parameters made it possible to follow specific hydric fluxes like morning shower across the treatment system towards the groundwater. The analysis of specific household tracers nitrogen and parabens allowed to estimate their elimination rate and the residual flux towards groundwater. The presentation will detail the impact of precipitation, groundwater level etc. on the elimination rate and the pollutant transfer, as well the limits of the experimental set-up used. The results show that domestic health care products, frequently considered as risk for the surface water quality, should also be considered as threat for areas with OWWT and vulnerable ground water resources.



**Measurement and characterization of hydraulic conductivity of peridotites in New Caledonia**  
**Abstract n°1948**

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**KEYWORDS:** peridotites, weathering profile, hydraulic conductivity

The Peridotite Nappe obducted on New Caledonia in Late Eocene. Since its emersion in Oligocene, a deep weathering profile has developed and now covers the fractured and serpentized peridotites. From top to bottom, the weathering profile consists in one hard layer of ferricrete, a semi-imperious layer of laterites (also termed 'red laterites') and saprolites ('yellow saprolites' or 'fine saprolites'), and a coarse saprolites and fissured highly fractured peridotites layer. In the study area which is the southern part of the Massif du Sud of New Caledonia, ferricrete is around 5 m thick, laterites around 40 m and coarse saprolites around 10 m. Thickness of fissured peridotites is an ongoing research topic. This complex aquifer has been characterized through the study of hydraulic conductivity of the laterite–fine saprolites and coarse saprolites-fissured peridotites layers. Slug tests have been performed on nearly 40 piezometers of the Massif du Sud. Additionally, 11 short duration pumping tests have been analyzed and the hydraulic conductivity estimated. Distribution of this parameter is established for the two main layers of the weathering. Hydraulic head data and the statistical distribution of field hydraulic conductivity data are used to regionalize hydraulic conductivity over a 30 kmC area. This map allows highlighting structural heterogeneities from hydrodynamic data only. Finally, hydraulic conductivity data estimated from various nesting-scales, i.e. slug tests, pumping tests and regionalized hydraulic conductivity, are used to analyze scale effects.



## **Modelling spatio-temporal variability of water table depths monitoring data Abstract n°1953**

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**KEYWORDS:** geostatistics, covariance models, ST variogram, ST interpolation

Groundwater monitoring data are particularly interesting when analysing aquifer characteristics because can reveal not only temporal patterns but also spatial distributions and variation over time if collected in a geospatial network. From spatial and temporal correlations, it is possible to predict values at points from neighbouring observations and make predictions in between observation times. Spatio-temporal interpolation can potentially provide more accurate predictions than spatial interpolation because observations taken at other times can be included. Recent advances in the implementation of spatial statistics methods allowed the join modelling of spatial and temporal structures into the geostatistical scope. However, adding the temporal domain implies that variability in space and time must be modelled. This procedure requires covariance models capable to join spatial, temporal and spatiotemporal dependence structures, for instance represented as variograms. This work presents a spatio-temporal modelling of water table depths monitoring data collected in a conservation area in Águas de Santa Barbara SP-Brazil. The Santa Barbara Ecological Station (EEcSB) is a 15 km<sup>2</sup> area with natural Cerrado vegetation and some reforest with pine and eucalyptus trees, under the domains of Bauru Aquifer, a cenozoic sandstone sedimentary rock 60-m thick limited in the bottom with basaltic volcanic rock and in the top with more recent geological covers. This aquifer is one of the major groundwater sources of Médio Paranapanema hydrographical region (UGRHI-17), an important region for hydroelectricity generation and biofuel production in Sao Paulo state. The water table is monitored semi-monthly from September 2014 to March 2016 at 65 piezometers near the main drainage channels. Three covariance models were tested- separable, product sum and metric. The fitted variograms revealed information about spatial and temporal dependence, based on groundwater oscillation process in space and time. These results are important information for groundwater management and planning, monitoring strategies, managed aquifer recharge and remediation plans.



**Site C Dam - Inadequate Hydrogeological Assessment and Lack of Assessment of Cumulative Effects  
Abstract n°1954**

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KEYWORDS: Key words- Large hydroelectric project, cumulative effects on water, First Nations rights

Key words- Large hydroelectric project, cumulative effects on water, First Nations rights  
First Nations of Northeast British Columbia (Canada) are opposed to the construction of a large hydroelectric dam (Site C Dam) on the Peace River. When reviewing the hydrogeological studies completed by the provincial energy corporation (BC Hydro) in preparation of the permitting process, the First Nations discovered that the groundwater regime had not been properly defined, pre and post construction. For example, the basic definition of the aquifers, aquitards, and piezometric conditions near the dam has not been carried out. In addition, the proposed dam is located in a region already highly affected by industrial activities, in particular oil and gas and the recently developed shale gas industry and associated hydraulic fracturing. What is particularly lacking is an adequate understanding of the cumulative effects of the various activities (including drilling for oil and gas, the deep disposal of liquid waste, the induced seismic activities due to disposal of liquid waste and hydraulic fracturing) on water and ecosystems. The hydrogeological team working on behalf of the First Nations has the very important role of reviewing and critiquing BC Hydro's information and providing technical guidance to the First Nations leaders. This having to be done facing the challenge of compiling a large set of information, presenting it in a simple and illustrated way, with very limited time and resources. The presentation will describe the complex setting of the dam and how the completed hydrogeological studies are inadequate to describe the basic hydrogeological conditions, for such a large dam, in 2016. It will also describe other activities conducted in the area of the dam, for which the cumulative effects have not been taken into account.



**Coupling groundwater models in integrated socio-economic and biophysical models  
for assessment of conjunctive use options  
Abstract n°1958**

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**KEYWORDS:** Groundwater, surface water, model emulation, conjunctive use

Assessment of conjunctive use options requires the development of integrated models that adequately capture the behaviour of both surface and groundwater systems. Groundwater flow processes are often modelled using complex numerical models that precludes their use in higher level integrated socio-economic and biophysical models. This preclusion results from the large computational expense associated with solving the non-linear partial differential equations representing groundwater flow processes. The computational expense can be reduced while keeping the key model outputs required by the integrated model by either employing a lumped model+ or by developing a surrogate model. The simplest form of a groundwater model is one which treats the aquifer as a single unit, and focuses on the inputs to, outputs from, and the storage in that unit. Such spatially lumped models are very computationally efficient. The limitation of this approach is that spatial information is lost, and there is also a question of how to manage the different scales between surface and groundwater systems. Surrogate models can be separated into three classes- multi-fidelity models, data-based and projection-based approaches. Here we will focus on multi-fidelity models and data-based approaches. Multi-fidelity models attempt to reproduce the complexity of the full model through use of a hierarchy of models, with fewer runs of the more complex model. Data-based approaches use techniques for analysing the response of selected outputs from the complex model to build a simpler version of the model (e.g. using Polynomial Chaos Expansion). The resulting model is computationally efficient, but does not capture all the behaviour of the complex model. This paper will present research on adapting a complex groundwater model for inclusion in an integrated model of the Campaspe Basin in northern Victoria focused on assessment of conjunctive water use options.



## Abstract n°1960

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**KEYWORDS:** Weathered hard rock aquifers, productivity, Yaounde-Cameroon

Surface water nowadays constitutes the main potable water supply for the Yaounde city and its suburbs (2.10 million inhabitants). This resource is not sufficient to satisfy the population needs of this large city built on a weathered Precambrian basement, cut by N-S, NW-SE and NE-SW fractures. This basement is constituted from metasedimentary and metaplutonic rocks which hydrogeological knowledge can contribute to partly answer a growing water demand. The present research, based on a statistical analysis of the data from 86 borewells covering an about 300 km<sup>2</sup> area, shows a similar range of weathering cover (saprolite) both for the paragneisses (7 to 47 m) and the orthogneisses (2 to 40 m). For these two types of geological formations, the blowing discharges are also similar (respectively between 0.1 and 10 m<sup>3</sup> h and between 0.2 and 12 m<sup>3</sup> h). The most represented discharge class, whatever the lithology, is the one between 1 and 5 m<sup>3</sup> h. From the hard rock aquifers literature, such a productivity is well representative of aquifers with open and connected fissures networks. Statistically, the pervious fissured zone extends from 10 to 60 m below the base of the soft weathered rocks (saprolite), with a higher density between 10 and 25 m and a second zone, more represented, between 30 and 50 m. The ratio discharge depth measured from the saprolite's base (Q B), a representative indicator in such a context, ranges from 0.003 to 0.36 m<sup>3</sup> h m, and was mapped over the whole study area. On this basis, the links between morphology, weathering and Q B, as well as with the location of the borewells was investigated.



**A particle-tracking method for discrete fracture network modeling considering the spatial correlation of fracture distribution**  
**Abstract n°1962**

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KEYWORDS: Particle-tracking, Spatial correlation, DFN

Solute transport issues in fractured media have caused widespread concerns. A dissolved contaminant can migrate rapidly along preferential pathways represented by fractures. Numerical simulation of particle-tracking is gradually being employed to address these issues. The main numerical models of fractured media currently in use include the equivalent continuum model, dual-continuum model, and discrete fracture network (DFN) model. However, the first two of these models do not adequately represent the anisotropic and discontinuity features of fractured media as does a DFN model. Moreover, the fractures in a DFN model are generally generated by a random method relied on limited field data. DFN model is highly dependent on the distribution of fractures. In the actually fractured rock, fracture density may vary from the different spatial position, which can hardly be neglectful in numerical models. However, the traditional random generating method ignores the spatial correlation of the fracture density. Based on the random walk particle-tracking method in DFN model, a simulation method taking into account the spatial correlation of fracture density was proposed in this study. DFN models can be randomly generated according to any spatial correlation function with this method. Thereafter, several numerical cases were set up to test the new method. The flow fields and solute migration ranges have been calculated in each model. The DFN models considering the spatial correlation and those ignoring the spatial correlation were compared. This method was further applied to study the influence of the different spatial correlation function on simulated results, and these models were generated with the same total fracture density. The results demonstrate that the spatial correlation brings significant difference compared to the traditional method. Different spatial correlation function affects the results obviously. The spatial correlation of fracture density in DFN model is therefore of considerable practical importance in terms of fractured aquifer modeling.



**IMPACT ON GROUNDWATER DUE TO SOLID WASTE DUMP IN JATINANGOR  
DISTRICT WEST JAVA PROVINCE INDONESIA  
Abstract n°1964**

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**KEYWORDS:** groundwater, jatinangor district, permeability, solid waste dump

Jatinangor is one of the largest educational areas in Indonesia with over 50,000 students and 98,035 local residents living in this district. The number of people in the Jatinangor region increase the amount of waste generated (12 ton day). Unmanaged and uncontrolled solid wastes openly dumped in Jatinangor district have potential for causing serious adverse impact on the environment. Ground water & Surface water Contamination, Land Pollution, and Air Quality Deterioration. Leachate is a toxic liquid that seeps through solid waste in a land fill. This process extracts soluble dissolved and suspended materials from the waste. It contains bacteria, toxic substances, heavy metals, etc. The impact assessment of the open dumping was assessed by collecting and analyzing ground water (within 3 km of the site) around the jatinangor waste dump area. In this various parameters analyzed pH, EC (Electrical Conductivity), TDS (Total Dissolved Solids), calcium, magnesium, sodium, potassium, bicarbonate, sulfate and chloride. Hardness, Mg, Na and K Concentration of pollutants in groundwater samples were of a high order due to the leachate from the solid waste, but groundwater quality still in under minimum level allowed according to the regulation of Indonesian Governments No.82 2001 and Minister of Health No. 907 MENKES SK VII 2002. This condition occurs because the study area is located in a volcanic area with low permeability ( $k=10^{-6}$ ).



**On the efficiency of ELLAM for mass transport in fractured porous media- Application to Qatar's aquifer storage project  
Abstract n°1965**

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**KEYWORDS:** fractured porous media, modeling, ELLAM

Water security is one of the main Grand Challenges aligned with Qatar's 2030 National Vision, which highlights the urgent need to have access to safe, high quality and sustainable water supply. The Aquifer Storage and Recovery (ASR) project aims at artificially storing water in the aquifer for future use. This study contributes to the ASR by developing an efficient and accurate numerical model for flow and transport in fractured porous media. The developed model is based on the discrete-fracture approach. A variety of numerical methods have been used and developed for the modeling of flow and transport in fractured porous media using the discrete-fracture approach. This approach is known to be accurate but its computation expense is high when applied to field scale problems. Despite the progresses in this field, scientific community is still interested in the development of new numerical methods and techniques to improve the accuracy and the efficiency of the existing numerical codes. The flow in the fracture system is known to be advection-dominated. Classical numerical schemes, such as Finite Element or Finite Volume, may introduce unphysical oscillations and or numerical dispersion. The Eulerian Lagrangian Localized Adjoint Method (ELLAM) is a successful technique for dealing with such advection-dominated problems as it has widely been used to simulate transport in simple porous media. In this work, the ELLAM is used for the first time to simulate transport in fractured porous media. Our objective is to adapt and to evaluate the efficiency of ELLAM for modeling transport in fractured porous media. The first results show that ELLAM is well adapted to handle the high contrast of velocity between the fracture and the porous matrix. It provides accurate results with less computational and memory requirements than advanced Eulerian methods.



**Non Isothermal Groundwater Flow in Geothermal Area a Case Study of Mt.Rajabasa,  
Lampung  
Abstract n°1966**

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**KEYWORDS:** Non-isothermal, Geothermal system, Groundwater flow

This study aims to clarify non isothermal groundwater flow in geothermal area in the southern flank of Mount Rajabasa and understanding thermal effect to groundwater flow in the area. Sub surface hydrogeological condition of the study area was re-constructed based on, geological mapping, geophysical data and water chemistry data. Based on the reconstruction the study area is comprised by four geological units those are andesite lava, volcanic breccia, tuff and andesite boulder. Geothermal manifestation e.g. hot springs and fumaroles are controlled by fault that was exist in Pangkul Area. Quantitative analysis of non isothermal model groundwater flow was built using SEAWAT MODFLOW 2010.1. Based on this study it can be clarified that the recharge water from western part of the study area infiltrate to the fault zone to a depth 650 meters below ground surface. It can be seen that depth groundwater flux are flowing toward to the surface as effect of thermal convection flow. It can be concluded that the thermal effect in the fault zone result change the patterns of groundwater flux to the upward at 450 m depth, in other words meteoric recharge water can not reach more than the 200 depth



**Agricultural water quality and quantity management in an evolving legal context- the case of France**  
**Abstract n°1969**

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KEYWORDS: agriculture, water quality, water quantity, irrigation management, legislation, cooperatives

Three major topics involve agriculture in water management in France- • Quality- Water quality is a national priority in France since the European water framework of 2000 (Parlement européen 2000+ European commission 2013) and its translation in the french law (Parlement 2004). The quality of the raw water is problematic, largely polluted by nitrates and pesticides (Mueller and Helsel 1996+ European Environment Agency 2012). This type of pollution, even though not always due to agriculture, is has been largely related to the agricultural practices (Lassaletta et al. 2009). • Quantity- Water quantity management is becoming an issue in some regions of France where irrigation is well represented and where there's recurring droughts (Martin 2013+ ERDLENBRUCH 2013). The use of appropriate and calibrated equipment becomes more and more relevant (Portier 2013), along with a better organization of the withdrawals through the creation of specialized organisms (2007a+ 2007b) • Legislation- Moreover, the legal context narrows over the years and does not allow much flexibility to the farmers where quality or quantity problems often emerge. Taking note of these observations, and instead of letting them paralyze their actions, the French agricultural cooperatives decided with their Union (InVivo) to act directly on the field with their subscribers to change the impact of their profession on the water and the environment. A few examples can be emphasized.



## **Domestic water purification equipment market vis-à-vis the role of hydrogeologist Abstract n°1970**

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### KEYWORDS:

The global market of water desalination equipment is growing 9.1 per cent CAGR in recent times. This is against the all short of odds and volatile market conditions prevailing worldwide. Thanks to the growing awareness about drinking untreated water and health consciousness, particularly in the developing nations. This is the basic reason behind the phenomenal growth of water purification industry. However, it also generated a blind race particularly among the urban middle class society for showoff. People without knowing the requirements and implications are going for advance water purifiers with UV and or RO technology. In India alone, the market of water purifiers is worth of Rs. 6100 core and is growing annually by 23 per cent. The water purifiers market is largely urban based in India. Presently, India is having 30 per cent urban population which shall increase to 50 % by 2050. 62 per cent population of Indian cities having tap water through treated source. Irrespective of this, urban dwellings are invariably having water purifier at their use, especially RO. Ground water is still a safer source of drinking water in India. As per the ground water resource estimates, out of the 5842 assessment units, 4277 units(73%) are still have been identified safe units quantitatively .The quality of ground water is also under permissible limit for drinking in general. Why water treatment is necessary? It is to remove contaminants- inorganic, organic and biological, to achieve maximum permissible contaminant level, to remove suspended particles to improve taste, colour ,odor and for softening of water. Groundwater of large parts of India does not required treatment on the above account and treated tap water supply takes care of these factors. Then why a citizen of developing nation requires buying costly domestic water purifier, on the cost of other essential needs. Is it not the failure ,educate the society adequately? The role of hydrogeologist is to spread water literacy among the citizen to protect their interest from market driven economy.



**Time series analysis of groundwater levels and recharge estimation in Seoul, South Korea**  
**Abstract n°1971**

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**KEYWORDS:** groundwater level, time series analysis, Seoul

Seoul, the capital of the republic of Korea and one of the megacities in Asia, has complex groundwater flow system because of various and large underground structures. Recently, lake water level decline and road depressions have been frequently occurred due to extensive excavation works for construction of buildings and subways, and citizen's concerns about groundwater management have been raised. For the systematic management of groundwater it is necessary to analyze the patterns of groundwater level fluctuations. In the present study, time series analysis was conducted for groundwater depth data of 212 groundwater stations in Seoul and groundwater recharge rate estimated. The average value of the groundwater depth for all stations ranges between -8.4 m and -7.5 m with no significant trend during last 14 years, however, fluctuation patterns are different by land use. The results of Sen's tests for the groundwater depth data of each station show that upward trend is more frequent than downward at green or residence areas, whereas downward trend is more frequent at areas adjacent to river or subway. The range of fluctuation in groundwater depth is from 0.72 m to 15.66 m and the median value is 3.23 m. Median values of maximum daily rise and descent rate of groundwater depth are 0.42 m day and -0.49 m day, respectively. To estimate the groundwater recharge rate the water table fluctuation method was applied to time series data of groundwater level at 12 monitoring stations. The result that the groundwater recharge rate varies between 1.5% to 15.1%, and the median value is 5.4%. It is expected that the overall results of time series analyses for the groundwater depth data can be a good guide for making a standard of groundwater level control at excavation work site and estimating a safe yield of groundwater for its sustainable use.



## Volatile degassing during the 2011 Van earthquake, eastern Turkey Abstract n°1973

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KEYWORDS: He isotopes, earthquake anomaly, volatile degassing

The 23 October 2011 Van earthquake (Mw= 7.2) and aftershocks are the latest manifestations of active tectonics in the eastern Anatolian region, Turkey, that has been prevailing since the Miocene. In this study, we examine the relationship between the 2011 Van earthquake and temporal changes in CO<sub>2</sub> <sup>3</sup>He and R<sub>RA</sub> ( $R = ({}^3\text{He}/{}^4\text{He})_{\text{sample}}$  and  $R_{\text{RA}} = ({}^3\text{He}/{}^4\text{He})_{\text{atmosphere}}$ ) values of geothermal waters in eastern Anatolia for the period of 2009-2011. For all samples, the difference between measured and air-corrected <sup>3</sup>He/<sup>4</sup>He ratios is only minor ( $\Delta 0.1 R_{\text{RA}}$ ). Air-corrected R<sub>RA</sub> values of waters selected for the comparison are in the range of 0.93-6.36 for 2009 and 0.84-6.37 for 2011. Waters with high R<sub>RA</sub> values are mostly discharged from geothermal springs around historically active dormant volcanoes and major tectonic lines. Based on three-component mixing model for mantle, atmosphere and crust end-members, mantle-helium contributions to waters from the vicinity of Nemrut crater, Çaldıran fault zone and Diyarin region are 46-81%, 6-53% and 2-23%, respectively. Post-earthquake R<sub>RA</sub> values and the proportion of mantle-He remained unchanged for samples around the Nemrut crater whilst those for Çaldıran springs increased and Diyarin waters decreased. CO<sub>2</sub> <sup>3</sup>He ratios of the most samples (ranging from  $4.9 \times 10^{10}$  to  $6.8 \times 10^{13}$ ) behaved in a more ambiguous manner possibly due to hydrothermal-related fractionation processes. Our findings show that the 2011 Van earthquake resulted in a change in the hydrogeologic system of the region along the Çaldıran fault zone at a distance of 58–60 km from the epicenter. The energy released by the 2011 earthquake facilitated reopening of fracture systems and formation of new fractures in the region which gave rise to volatile transfer from asthenospheric melts to the surface.



**Impacts of intensive exploitation of the Jurassic-Cretaceous aquifer system on the organisation of the subsurface water flows (Syria)  
Abstract n°1974**

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**KEYWORDS:** karstified aquifer, intensive groundwater exploitation, piezometric change, Orontes basin, Syria

The Orontes river basin, shared between Lebanon, Syria and Turkey, has the largest irrigated area around the Mediterranean. The first irrigated systems, set up on a large scale in the 1960s, were supplied directly from the river Orontes or from small dams built on it. In the 80s, the irrigated area has been greatly expanded through groundwater extracted from the vast karstified Jurassic and Cretaceous aquifer located upstream and central part of the basin. Intensive exploitation of water resources of the basin has led to summer drying of the Orontes river and numerous springs in the 1990s. Multiple studies and several hydrogeological models were devoted to this situation, but many questions remain on how it came to be. As part of a recent program of the Swiss Cooperation, the authors established a new hydrogeological map and several cross-sections of the basin. Referring to that map and to historical and recent flow rate data of springs and of the Orontes river, a piezometric map of the Jurassic and Cretaceous reservoir was created for the period prior to the development of irrigated areas, while in parallel, another piezometric map of the same reservoir showing two large groundwater drawdowns was drawn up, based on 2005-2006 data issued from a publication related to regional groundwater recharge. The comparative study of these two maps provides a valuable basis for understanding the 1980s dramatic decrease in the flow of springs and of the river and the recent surprising increase in the flow of the same springs and of the river, result of the Syrian conflict. In the future, that study should significantly, as peace returns to the region, facilitate the necessary implementation of sustainable management of groundwater in the whole basin when the irrigation systems will be rebuilt.



**Groundwater-surface water interaction and related groundwater dependant ecosystems - case study of the Natura 2000 wetlands of the Crau plain (SE France)  
Abstract n°1977**

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**KEYWORDS:** Groundwater-surface water interaction, groundwater dependant ecosystems, global change, stable isotopes

According to the European Water Framework Directive (2000 60 EC) and groundwater directive (2006 18 EC), groundwater and surface water dependent ecosystems have to be protected. Thus, management protocols need to be implemented at the watershed scale in order to reduce water uptakes, e.g. for agriculture, and to restore the required volumes toward ecosystems. In the Crau plain (SE France), grassland production depends essentially on traditional flooded irrigation practices, with water derived from the Durance river. The large amount of irrigation return flow represents nearly 70% of the Crau aquifer recharge. This large-scale artificial recharge thus becomes essential for some directly connected wetlands. In the present global change context, pressure on the Durance River resource is rising. Therefore, it is imperative to quantify water requirements of wetlands directly or



indirectly supplied by Durance River and to find the optimal balance between water saving and ecosystem demand. The present study constitutes a preliminary diagnosis about groundwater resurgences of the Crau aquifer, named laurons . Outflows of these poorly known springs provide water to a remarkable wetland ecosystem, maintaining numerous habitats for biological species including glacial relics. These wetlands are classified as Special Protection Area (Natura 2000). The overall objective of the study is to estimate the importance of these laurons in maintaining the ecosystem of the Crau wetlands and to model their evolution according to the hydrodynamic changes in groundwater flows especially in response to irrigation. The proposed multi-criteria analysis aims to determine the hydrodynamics and hydrochemical characteristics of these laurons (water budget, flow-rates and directions, physicochemical parameters and major ions), and their connections with the aquifer using geochemical tracers (stable isotopes in water and radon). This analysis will provide new insights on the surface water - groundwater interactions necessary for the preservation of these fragile ecosystems.



## Abstract n°1978

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KEYWORDS: Nitrate, Atrazine, Catchment, Grenelle, Vulnerability

In the Val d'Oise department, in the heart of the regional natural park of Vexin Français, twelve catchments supply now 42 000 inhabitants in drinking water. Wells abstract water from shallow aquifers in rough limestone of Lutetian age or sand of Ypresian. They provide flow rates superior to the needs. However, abstracted water contains nitrate concentrations exceeding the admitted maximum of 50 mg l and about 0.2 lg l of Atrazine or its metabolites. Over the past few years, treatments with ion exchange resins (nitrates) and active coals filters (pesticides) have been implemented by local authorities. Nevertheless, these curative treatments do not constitute a lasting solution as shown by the constant increase in nitrate observed in raw waters and confirmed by the emergence of new molecules used as crop protection agents that are authorised in conventional agriculture. In this context, these twelve catchments were included in the list of priority catchments under the Order of the 30 May 2008 (Grenelle I), then under the environmental Convention of the 22 September 2015 (Grenelle II). Aware of the resource protection issue, in February 2016, the ten local authorities concerned organized a public order grouping. Local elected officials, supported by technical assistance of the Val d'Oise department and the Seine Normandie water agency, gave themselves 2 years for delineating catchment feeding areas, assessing intrinsic vulnerability of the aquifers, making a diagnosis of hazardous practices and elaborating action programmes. This grouping is the first stage of a strategy which aims at driving a dynamic to promote the resource protection by the construction of a common territory. These authorities, by pooling financial resources, will be able to coordinate projects to help the emergence of new technical channels based on low level of farm inputs, to promote products from organic farming and adopt new land policies.



**Groundwater resource management facing global changes- from the European Directive to the local action plan for the Crau aquifer (SE France)  
Abstract n°1979**

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**KEYWORDS:** local water policy, action plan, global change, stakeholders, Crau aquifer

Global changes have to be taken into account to reach the objective of good water status, laid down by the European Water Framework Directive (2000/60/CE). The 2016-2021 master plan for water development and management of the Rhone-Mediterranean basin (SDAGE Rhône-Méditerranée) set the climate change adaptation as a new basic orientation of the water policy. For the local managers of water resources, this policy is difficult to implement because of a deficit of knowledge and methods. The Crau aquifer (550 km<sup>2</sup>) supplies water for 300,000 inhabitants, for major economic sectors and for agriculture. 70% of the aquifer recharge depend on irrigated grasslands (14,000 ha) with water derived from the Durance River. Located in coastal area, the south part of aquifer is sensitive to saltwater intrusions, which are mainly controlled by recharge conditions. But at medium term these recharge conditions could be affected by global changes, e.g. the decrease of water availability from the Durance River and the decrease of irrigated grassland surfaces due to urban sprawl. The local public manager of the Crau aquifer (SYMCRAU) has defined with the stakeholders an action plan (contrat de nappe de la Crau) to anticipate global changes and propose adaptation solutions. Collaborations with research institutes have been developed to study global changes processes and better forecast their local impacts. A numerical model of surface drainages and groundwater flows allows quantifying the sensitivity of the resource to global changes. Special protection areas were identified to protect future of drinking water supply. Additional studies are scheduled to assess the impact of recharge decrease on saltwater intrusions and on wetland ecosystems. A project is planned to define the conditions for a sustainable adaption of irrigation practices to global changes. This program provides knowledge and methods to adjust policy to local challenges and to support stakeholders in its implementation.



**Towards an EQS assessment in groundwater bodies- ammonium contamination and response of groundwater copepods**  
**Abstract n°1980**

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KEYWORDS: groundwater, stygofauna, ammonia

As a result of agricultural practices and underpowered wastewater treatments, groundwater bodies frequently show ammonium (NH<sub>4</sub><sup>+</sup>) concentrations exceeding EU and National Quality Standards. We investigated NH<sub>4</sub><sup>+</sup> contamination in 17 alluvial and 9 rocky aquifers of the Abruzzo region (central Italy) to highlight the associated biological risk for the groundwater copepods (Crustacea Copepoda) selected as the target group. We used 10,000 groundwater samples withdrawn from 520 sites (bores and springs) from 2010 to 2014. We found that NH<sub>4</sub><sup>+</sup> contamination involved 4% of the samples collected in the alluvial aquifers, with concentrations sometimes exceeding 10-100 times the Italian QS (0.5 mg L<sup>-1</sup>). Conversely, less than 1% of samples collected in the rocky aquifers showed NH<sub>4</sub><sup>+</sup> concentrations exceeding the national QS. This is consistent with the fact that alluvial aquifer outcrops are used for farming (80%), whereas outcrops of the rocky aquifers are mainly protected areas. The level of NH<sub>4</sub><sup>+</sup> contamination detected in 4% of the investigated alluvial aquifers is such as to affect development, longevity and gene expression of the epigeal cyclopoid *Eucyclops serrulatus*, that is commonly found in groundwater habitats. Recent research in the hyporheic zone of the River Sagittario (central Italy) revealed a significantly sensitivity of copepod assemblages to 0.084 mg L<sup>-1</sup> NH<sub>4</sub><sup>+</sup>, that is to the lowest QS currently set at European level. This state of affairs suggests that the Italian QS of 0.5 mg L<sup>-1</sup> may not protect groundwater ecosystems. Since copepods are a link between primary producers and higher consumers and represent the most abundant group in groundwater bodies, the effects of the ammonia-N pollution should be taken into greater consideration for the assessment of effective criteria towards the EQS evaluation, that is so far not considered at both national and European levels.



# Hydrodynamic Parameters of Quaternary Volcanic Aquifers- A Synthesis from Indonesia

## Abstract n°1981

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**KEYWORDS:** volcanic aquifers, transmissivity, hydraulic conductivity

Hydrodynamic Parameters of Quaternary Volcanic Aquifers- A Synthesis from Indonesia Abstract  
Danone Aqua is one of the biggest bottled drinking water producers in Indonesia that utilizes mostly quaternary volcanic aquifer resources. This paper objective is to show the findings about aquifer parameters from numerous drilled wells all over Indonesia in such a hydrogeological context. A total of 40 exploitation bore-wells were drilled in various geological formations ranging from andesitic fissured lava flows to reworked volcanic breccias, including pumice flows, lahars, tuffaceous, etc. The boreholes depth ranges from 50 to 150 mbgl. The typology of aquifers spans from confined to semi confined aquifers. About 45% or 18 boreholes are self flowing confined wells with yields varying from 20 to 250 m<sup>3</sup> h measured at the end of bore-wells completion, while the remainders 55% or 22 boreholes are non flowing wells. The calculations of transmissivity and hydraulic conductivity were performed using the Cooper and Jacob solution through applying conventional step and constant rate pumping tests. As a result, the transmissivity varies between  $2 \times 10^{-4}$  to  $1.77 \times 10^{-2}$  m<sup>2</sup> s, equivalent to intermediate to very high groundwater withdrawal potential. The hydraulic conductivity values were computed on the basis of the geological and hydrogeological log of each well. They vary between  $4 \times 10^{-6}$  m s to  $6 \times 10^{-4}$  m s, the highest hydraulic conductivity value were identified from volcanoclastic sandstone, volcanic breccias and fissured lava andesitic aquifers, respectively. Most of the confined aquifers are overlaid by 30 to 50 m thick partly weathered pyroclastic sediments acting as confining layers. The conclusion from these evaluation data sets confirm that quaternary volcanic groundwater in Indonesia plays a big potential withdrawal resources for public drinking water supply and also provides opportunities in future investment for private sector to utilize the resources prudentially.



**Bio-fracturing Soil Model Using Fungus' Mycorrhiza to Anticipate The Water Shortage  
at Jatinangor Volcanic Aquifer, West Java, Indonesia  
Abstract n°1982**

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**KEYWORDS:** Artificial recharge, Aquifer, Biofracturing

Jatinangor District is located in Sumedang, West Java, at the southeast of the mount manglayang. Geologically, This area consist of only one geological unit which is young volcanic products. The products are irreducibly young sediment deposits. The region's aquifer system is a volcanic deposit aquifer that consist of matrix supported breccia and laharic breccia . The high Level of weathering resulting in thick soil covering the aquifer with the maximum depth of 10 meters. The covering soil has low permeability which is  $3.4 \times 10^{-9} \text{ m s}$  that is the lower limit of a semi-permeable soil. This condition decrease the water's ability to fill in the aquifer The massive development of the area also affects the decrease of recharge area. This study aims to assess the feasibility to create the artificial recharge area with producing biofracture. Artificial recharge area is made by growing the fungus in the roots of plants around Jatinangor to do a symbiosis with the roots of plants (mycorrhiza ) so that the plants are stimulated to extend the reach of roots that can penetrate the aquifer down below. This research was conducted with hydrogeology and geomorphology study approach to determine the suitable areas for making artificial recharge. The results obtained from this study is the zonation map Jatinangor region that contains areas that are suitable and feasible to be used as artificial recharge area. This study is expected to be used as a benchmark for researchers, especially academics in the region in order to further development of artificial recharge.



## **Semi-distributed lumped model to assess recharge of karst unsaturated zone Abstract n°1983**

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KEYWORDS: semi distributed model, unsaturated zone, recharge.

The unsaturated zone (UZ) is the poor relation of karst hydrodynamics. However, it governs spring discharge during low flow periods (e.g. Chen et al., 2016), it is a major water storage entity (Emblanch et al., 2003) and thus plays a key role in karst recharge and contaminant attenuation processes (Lastennet et al., 1995). Much more emphasis has been placed on epikarst and saturated zone characterization and hydrodynamics modelling. A qualitative assessment of the UZ dynamics have been proposed in mapping vulnerability methods (e.g. Dörflinger et Plagnes, 2009, Goldscheider, 2005) but quantitative assessment is required for groundwater management. Lumped models are usual tools for rainfall-discharge relationship modelling. They are often preferred to physically-based gridded flow models for karst hydrodynamics modelling because of the complexity and lack of detailed knowledge on the geometry of karst hydrosystems. Lumped models, although simple, can reproduce with a high quality the rainfall-discharge relationship (e.g. Marsaud, 1996+ Fleury, 2005) of karst hydrosystems. But due to their 1D construction, they can't bring insights into the spatial distribution of reserves (e.g. Tritz, 2011). This limitation is critical for resources management. The final goal of this study is to assess to the spatiotemporal distribution of the recharge of the UZ using a semi-distributed model on the Fontaine-de-Vaucluse catchment area. For that, a sensitivity analysis of the existing lumped model (Fleury et al., 2007) of the site was mandatory and highlighted the crucial hydrological role of the soil and the unsaturated compartments. Additionally, we combined a climate model with the hydrological model and suggest a non-negligible effect of rainfall distribution, which is a key point for understanding impact of climate changes on groundwater. The architecture of the semi distributed lumped model of the UZ is accordingly proposed.



## Linkage of ecological and hydrodynamic aquifer parameters Abstract n°1984

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KEYWORDS: groundwater ecology

Ecological issues represent a supplementary tool for the characterization of groundwater resources and may furthermore contribute to identify hydrodynamic processes and to act as water quality indicators. Consequently, the Swiss Water Protection Ordinance not only defines microbiological and chemical water quality standards but also ecological objectives for groundwater. The ordinance states that biocenoses in groundwater should be in a “natural state adapted to the habitat” and “characteristic of groundwater that is not or only slightly polluted”. However, today experts are still looking for approaches to carry out such assessments. In this context, two studies have recently been performed in the framework of the NAQUA National Groundwater Monitoring for testing both microbiological and faunal approaches to obtain better understanding of regional groundwater ecology in Switzerland as well as its correlation with hydrogeological information. Sampling at 50 representative monitoring sites for microbiological parameters – specifically for total cell count, measured by flow-cytometry – provided typical ranges of bacterial density between  $10^3$  and  $10^6$  cells per mL. Selected springs were sampled for faunal assemblages, resulting in up to 10 individuals per m<sup>3</sup> of discharge. Assemblages found at the sites showed a high diversity, with a total of 40 species. Results of both abundance and species composition indicate that global aquifer vulnerability and surface water influence may play a more important role than spatial or seasonal variations. Highly vulnerable karst aquifers were dominated by a high abundance of stygophilic species while less vulnerable systems which are more protected from surface water infiltration were represented by stygobiotic species. The degree of surface water influence and groundwater vulnerability could thus be directly derived from both ecological parameters and the stygophiles stygobionts-ratio. The findings are consistent with intrinsic aquifer parameters, such as spring discharge variability, and are in agreement with physico-chemical as well as other microbiological data from the sites. Both approaches seem to represent a potential for defining the ecological state of the groundwater biocenosis and indicating aquifers hydrodynamics, vulnerability and groundwater quality.



**Infiltration and potential recharge of esker aquifer in Central Finland - observation and simulation of daily soil moisture and temperature profile**  
**Abstract n°1985**

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KEYWORDS: soil moisture, infiltration, recharge

**Objectives-** In sustainable groundwater usage, prediction of recharge with a numerical models are of high importance because it will be used in optimizing groundwater pumping rates of an aquifer. In cold snow dominated regions, as in Finland, understanding the soil moisture and temperature dynamics affects the development of soil frost that controls snowmelt runoff, infiltration and recharge in winter periods. This study was initiated to investigate the performance of integrated hydrology model, ParFlow, in simulating soil moisture and temperature profile and daily recharge rate in esker aquifer in Karhinkangas in Central Finland. The goal is to represent the intra-annual and inter annual recharge rates that are the basis of sustainable pumping rates. **Desing and methodology-** Soil water content and temperature was measured hourly at several depths. The groundwater depth and temperature was measure daily from the borehole located 2 meters from the soil monitoring station and the climate data was obtained around 5 km from the soil station. The modeling domain is from the ground surface to bedrock. **Original data and results-** Soil moisture and temperature measurements from the ground surface to the depth of 2 meters are used to calibrate the numerical model. Groundwater level measurements are used to check the response of modeled groundwater level. Climate data (precipitation and temperature) are used as input data to the model. The goal is to simulate snow accumulation, snow melt, evpotranspiration and incorporate these in to this modeling study. The common land use model (CLM) that has been integrated to ParFlow wil be tested. The role of freeze and thaw cycles to hydraulic conductivity will be also discussed based on the simulation results. **Conclusions-** The implications of this study will be accurate representation of groundwater recharge rate that may change intra-annual and inter-annually. This research will give a firsthand information of groundwater recharge rates to water company management, policy makers and environmental agencies which role is to assess sustainable groundwater pumping rates in the Karhinkangas groundwater area.



# Fracture Transmissivity Development as a Response to Hydraulic Fracturing and Hydraulic Jacking at Grimsel Test Site

## Abstract n°1987

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**KEYWORDS:** Hydraulic Stimulation, Transmissivity Enhancement, EGS

Hydraulic transmissivity enhancement of natural fractures has become one of the common practices during the last two decades in various disciplines such as shale gas development in oil industry, block caving in mining and enhanced geothermal systems (EGS). The main concept is based on the pressure increment (usually less than fracture pressure) and hydraulic shearing of the existing fractures in order to enhance the fracture transmissivity permanently known as hydraulic stimulation. In order to quantify the efficiency of hydraulic stimulation, hydraulic characterization methods such as hydraulic packer testing can be conducted before and after the stimulation process. In-situ hydraulic stimulation and circulation (ISC) experiment has been initiated at the Grimsel Test Site (GTS) to study and address a wide-range of EGS related objectives in Switzerland. One of the main objectives of this multi-disciplinary experiment is to provide a high resolution pre- and post-stimulation characterization of fracture conductivity and connectivity in order to investigate patterns of preferential flow paths. A series of hydraulic fracturing (HF) and hydraulic tests in pre-existing fractures (HTPF) were conducted to characterize the in-situ local stress. The hydraulic response of the rock mass under hydro-mechanical perturbations was investigated by conducting various hydraulic packer tests (e.g. pulse, constant rate and head) in multiple hydraulically isolated borehole sections before and after the stress measurements. Detailed analysis of the transient pressure responses of the hydraulic packer tests show that HF in the packed intervals with no presence of natural fractures does not affect the hydraulic conductivity of the rock mass significantly, as the implemented pressure for hydraulic characterization was not sufficient to re-open the tensile hydraulic fractures. Contrarily, HTPF in the intervals with the presence of brittle fractures was associated with more than two orders of magnitude hydraulic transmissivity increment by two orders due to shear dilation of fractures and permanent hydraulic transmissivity enhancement. Considering the injection volume during the main stimulation phase, even more significant hydraulic transmissivity enhancement is expected.



**Hydrochemistry, isotopic ratios and origin of thermal fluids in eastern Anatolia,  
Turkey  
Abstract n°1992**

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**KEYWORDS:** geothermal spring, hydrogeochemical, geothermometer, eastern Anatolia

As a result of active volcanism and tectonism, the eastern Anatolian region in Turkey is represented by a high geothermal potential. In this study, we evaluate chemical and isotopic compositions of several geothermal springs in eastern Anatolia with emphasis on hydrochemical isotopic characteristics and reservoir temperatures. Thermal waters were sampled in areas of Miocene volcanism (northeastern Anatolia) whilst some are collected in localities near historically-active volcanoes (e.g. Agri, Tendürek and Süphan volcanoes and Nemrut caldera) around Lake Van. Waters are mostly NaHCO<sub>3</sub>-type and their temperature, pH and electrical conductivity values are 16.26-81.30°C, 5.56-9.76 and 203-10434 IS cm, respectively. Oxygen and hydrogen isotope compositions (–13.5 to –3.4 permil (VSMOW) and –92.1 to –64.5 permil (VSMOW), respectively) coincide with the Global Meteoric Water Line (GMWL)+ however, some samples plot close to the Mediterranean Meteoric Water Line (MMWL). Tritium contents are in the range of 0 to 3.2 TU. Carbon (d13C (VPDB)–17.5 to +6.9 permil) and sulfur (d34S (VCDT)–5.5 to +45.7 permil) isotope compositions imply marine carbonates and terrestrial evaporate units as the main source of dissolved carbon and sulfate in the waters. Temperatures estimated by SO<sub>4</sub>–H<sub>2</sub>O isotope geothermometry fall between 40 and 200°C and are generally not in agreement with reservoir temperatures computed from chemical geothermometers (130 °C). 14C contents of thermal waters around Lake Van fall between 0.8 to 6.0% pmC and are equivalent to corrected ages of 8.2 to 28.8 ka. Acknowledgements- This study is funded by the Scientific and Technological Research Council of Turkey (TUBITAK-CAYDAG project number- 114Y067).



**A case of natural contaminants in groundwater- High uranium concentrations in water supply wells in Burundi**  
**Abstract n°1993**

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**KEYWORDS:** Water supply, Natural contaminants, Burundi

Groundwater is often preferred over surface water as a source of potable water supply because of its favorable characteristics in terms of availability and bacteriological quality. However, the presence of natural contaminants is a risk that should be assessed. In areas with igneous or volcanic rocks, elements like fluorine and uranium often occur in groundwater at concentrations above drinking water standards. This contribution presents a case study from northern Burundi where dissolved uranium concentrations exceeding 700 µg/L have been encountered. The study area is located south of Lac Cohoha, on the border between Burundi and Rwanda. The geology is dominated by granitoids of the Kibaran belt system, which have a uranium content between 5 – 15 ppm. The original rocks have been highly weathered, and the weathered sequence forms unconsolidated aquifers that can reach a thickness of at least 91 m in the study area. The predominant land use is subsistence agriculture, with the main crops being beans, sweet potatoes, maize, cassava, banana, and sorghum. Groundwater recharge is estimated about one fifth of the mean annual rainfall, which is just over 1000 mm, and groundwater discharge occurs in valley bottoms and along the shores of Lac Cohoha. There, intense evapotranspiration occurs, and it is believed that this is the process that leads to the enrichment of dissolved uranium, which is supported by geochemical model calculations using PHREEQC. Based on a conceptual model of dissolution of feldspar minerals from the uranium-containing rock during groundwater recharge and flow, and evaporative concentration in the discharge area, the major trends of the groundwater chemistry, including uranium concentrations, can be reproduced. Whilst dissolved uranium concentrations may be influenced by other processes as well, the overriding influence of evapotranspiration highlights the need for caution when developing water supply wells near discharge zones in other regions where similar conditions exist.



# **3D hydrogeological modeling of the Turaida castle mound under changing precipitation**

## **Abstract n°1994**

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**KEYWORDS:** hydrogeological modeling, landslides, climatic parameters

In February 2002 three landslides occurred along the slopes of the Turaida castle mound, Central Latvia, causing damage to infrastructure and threatening the historical building. Several indications suggest that the landslides were caused by hydrogeological triggers - There was a lack of any elevated seismic activity and the landslides occurred at short intervals at different locations of the mound after an intensive snow melting. In the future more extreme precipitation events are expected in the study area, therefore the question arises whether this will result in elevated landslide activity. To understand the hydrogeological landslide triggers, a high resolution 3D hydrogeological model of the castle mound was elaborated. Coupled flow of saturated, unsaturated, and fractured media under changing rain and snowmelt conditions was simulated using the HydroGeoSphere software. The hydraulic conductivities of the sediments were calibrated to fit the piezometer measurements using PEST code. The hydrogeological model indicates the geological and climatic conditions, which cause the most critical groundwater heads for hillslope stability. The geology of the study site is characterized by alternating Devonian clay and sandstone layers covered by glacial and anthropogenic deposits. Perched groundwater tables and springs discharging from fractures in sandstone layers can be observed. The calibrated model confirms the geological evidence that perched groundwater tables can form in the study site. Moreover, the hydrogeological model can simulate different climatic scenarios, evaluate the influence of intensive rainfall events or snow melting on groundwater conditions and groundwater discharge from discrete fractures. This helps to determine the most critical hydrogeological scenarios for hillslope stability in the future which are useful for subsequent landslide risk mitigation in the Turaida castle mound.



## Origin and maturation of organic matter in thermal waters Abstract n°1995

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**KEYWORDS:** thermal water, organic matter, aromatic compounds

The aims of the present study were to find the origin of the possibly toxic and or carcinogen aromatic compounds (e. g. benzene, phenols, polycyclic aromatic hydrocarbons) present in high concentrations in cca. the half of the hundreds of thermal waters (TWs) studied from two sub-basins of the Pannonian Basin, elucidate their distribution and understand the interaction between kerogen, bicarbonate, carbon-dioxide and hydrocarbon gases during maturation. Water phase pyrolysis (aquathermolysis) experiments were carried out on different precursor candidates (humic and fulvic acid, bitumen, lignite) to model the generation of aromatic compounds in water. The results of the experiments were compared with the interpretation of the data (isotopic composition, major elements, dissolved aromatics and gases) of ~40 TWs. Appearance of aromatic products in the TWs requires a threshold temperature of 70-80°C. The major maturity-dependent aromatic compounds are phenol, benzene and naphthalene homologues. Maturation generates carbon dioxide, which significantly affects the major element (sodium, potassium and bicarbonate) concentrations, and hydrocarbon gases are also produced. The concentrations of benzene to alkylbenzenes produced by pyrolysis show excellent correlation, but the slope of the trend line is determined by the type of precursor material. Similarly, the concentrations of benzene to alkylbenzenes show excellent correlation in TWs, but the slope of the trend line is different in the two sub-basins considered separately. These results suggest that the major precursor of the aromatic compounds of TWs originating from a given sub-basin can be assessed. This research was supported by the European Union and the State of Hungary, co-financed by the European Social Fund in the framework of TÁMOP 4.2.4. A 2-11-1-2012-0001 'National Excellence Program'



**Hydrogeological findings in concession granting process - use of thermal water for balneology and direct use**  
**Abstract n°1996**

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**KEYWORDS:** thermal water, regional geothermal aquifer, reinjection, permit

Low temperature geothermal aquifers in loose sandstone in NE Slovenia and in dolomite basement in SE Slovenia are subjected to high risk of depletion. Several users have been producing thermal water for few tens of years there. New regional 3D geological, hydrogeothermal and hydrochemical research in NE Slovenia highlighted that the paleometeoric water was recharged in the Pleistocene. Measurements of groundwater levels imply that the regional depletion rate has been over half meter per year since 2009. In SE Slovenia, the rate of depletion is more difficult to quantify. Most thermal water users in Slovenia follow the Water Law for a concession permit as the Mining Law is valid only for doublets. Several users use thermal water for greenhouses or district heating but do not operate a reinjection well. In 2015, concessions were granted to most users in the country. Ten benchmarking indicators were suggested to be followed by project TRANSENERGY and the decrees on concessions hold several such points- need of operational monitoring, use of BAT, energy efficiency of 70%, recognition of critical groundwater level and support of reinjection in regional aquifers with identified depletion and at users of solely geothermal heat. However, the latter negotiated halved fee in comparison to spa. This resulted in several unsystematic and rather unsuccessful reinjection tests in abandoned wells in warm spring systems and sandstone aquifers. Therefore, reinjection has been given a rather negative connotation lately. Currently, no governmental support is given for transfer of good practices on reinjection from abroad, and decision and way of its implementation is left to poorly qualified users. Still, based on newest geo-scientific models, several hints can be followed by testing and operating reinjection wells in Slovenia.



**A study on the seasonal recharge patterns in the shallow groundwater area of semi-arid regions**  
**Abstract n°1997**

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**KEYWORDS:** Ordos Basin, groundwater recharge, shallow groundwater area, soil water, evaporation

Due to the higher evaporation than precipitation in arid or semiarid regions, whether rainfalls can recharge to groundwater remains controversial. Moreover, the interaction of climate, hydrology, topography, soil properties and other factors makes the recharge process complex. This research aims to investigate recharge patterns with shallow groundwater in a semi-arid region in northwestern China by observing the dynamics of soil water and water table. Our study site is situated in the low area of the Wudunao Watershed in the Ordos Cretaceous Basin. Soil moisture in two adjacent profiles and water table were monitored from May 2014 to November 2014. The groundwater depth ranged from 1.0 to 1.6 m in profile 1, and from 0.5 to 1.1 m in profile 2 near a depression. In profile 1, based on the responses of soil moisture at different depths to rainfalls, it was found that rainfall could not directly recharge to the water table from May to mid-September, but could do in late September, which lead to abrupt water table rises. It indicates that evaporation plays a major role on direct recharge because late September has the highest ratio of precipitation to evaporation. Although direct recharge did not occur in May through mid-September, rise of water table and soil moisture near the water table were associated with rainfalls. There should be other forms of groundwater recharge from precipitation. In profile 2 with shallower water table, we found precipitation could infiltrate and recharge directly to groundwater in May through mid-September. This demonstrates that rainfalls would recharge groundwater easily when the groundwater depth is shallow enough. Therefore, near-depression areas with shallow water table are ideal for precipitation recharge. Based on the field data, we simulate the effect of evaporation intensity, groundwater depth and soil properties on infiltration and direct recharge by Hydrus-1D. Numerical models demonstrate the seasonal variability of recharge patterns, as well as the control of evaporation and water table depth on precipitation recharge.



# Hydrological and data assimilation models for pseudo-forecast flash karst floods forecast-application to flood forecasting in the Lez catchment in Southern France Abstract n°1998

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KEYWORDS: karst flash floods, data assimilation, rainfall-runoff model, pseudo-forecast, Lez basin, rainfall radar

This study presents the hydrological and data assimilation models for pseudo-forecast flash karst floods forecasting developed for the Lez basin. It is the 114 km<sup>2</sup> Mediterranean catchment, subject to heavy orographic and convective rainfall and characterised by a karstic geology, leading to flash floods (19 events in the data base). The rainfall (radar and rain gauges) is particularly uncertain. The dynamics of the karst contribution during the flood is strongly heterogeneous and spatialized, features that are poorly described. This study explores 2 models-  
• The hydrological model is an event-based, distributed and parsimonious one. It uses a derived SCS method, with a Lag and Route transfer function. It is able to run in pseudo-forecast mode (Coustau et al., 2012).  
• The DA procedure is used to correct the radar rainfall inputs of the hydrological model. An extended Kalman filter was built on top of the hydrological model to assimilate discharge observations at the outlet (Harader et al., 2012). This study seeks to demonstrate that the hydrological model is robust, easy to drive in pseudo-forecast mode, coherent regarding the piezometric measurements. But it is so strongly dependant of the rainfall that the uncertainties of the rainfall lead to poor simulation performances. Furthermore a simple DA algorithm is capable of rendering radar rainfall suitable for hydrological forecasting. To test this hypothesis, the DA analysis was applied to estimate a constant hyetograph correction. The reduction of the uncertainty in the rainfall leads to a reduction of the error in the simulated discharge, but uncertainty from the model parameterisation diminishes DA efficiency. New perspectives appear from this-  
• An improvement of the hydrological model based on a better understanding of the interactions karst-hillslopes (Raynaud, 2016).  
• A more powerful DA algorithm able to correct the structure of the rainfall (submission of the iRADARTH ANR)



## **The Llobregat aquifer in the water cycle management of Barcelona (Spain) Abstract n°1999**

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**KEYWORDS:** Recharge pond, ASR, scarification, hydraulic barrier, water quality, aquifer management

The Low Llobregat and delta aquifer, close to Barcelona, is a key element for the urban and industrial water supply of Barcelona Metropolitan Area. The water demand of the area is historically very high relative to the small and highly variable water resources under the Mediterranean climate conditions. Since 1955, the joint use of surface- and groundwater has improved the guaranty of availability. In 1966 started a water transfer to Barcelona from the river Ter, to the North. Later, in 2008 a waste water reclamation plant and in 2009 a seawater desalinization plant were incorporated to the water system. In addition, the relation between the different water sources has been favoured by means of artificial recharge, which is also relevant to prevent groundwater quality degradation. Since 1950 the scarification of a stretch of the river bed to reduce siltation allows increasing water river infiltration into the aquifer. Since 1969 a storage and recovery (ASR) well system is used to recharge treated water river. Since 2007, to compensate for infiltration area loss due to new civil works, a recharge pond infiltrates river water or reclaimed water. Finally, in 2007 a hydraulic barrier was constructed to inject advanced treated reclaimed water to halt seawater penetration into the deep delta aquifer. In all cases, an additional goal is to achieve the environmental objectives derived from the European Water Framework Directive because the groundwater body in the Low Llobregat is in bad state. A protocol defines how and when these techniques of recharge are applied. Normally the decision depends on water availability and the threshold values of quality of the water source and on the piezometric level. The cooperation between different partners has been and is the key for the water cycle management.



**2D modelling of the piezometric discontinuity in a volcanic aquifer with locally non darcean flow**  
**Abstract n°2000**

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KEYWORDS: pseudo 3D modelling, volcanic aquifer, non darcean flow

The detailed study and numerical modeling of a volcanic aquifer (Volvic area, Chaîne des Puys, France) reveals piezometric discontinuities in the aquifer where the Darcy law do not apply. The aquifer system is composed of Quaternary superimposed lava flows that filled a paleovalleys network dug into impervious granite rocks. In details, the scorias (clinker) located at the top and bottom of each lava flow constitute pervious “layers” in the aquifer whereas the massive heart of each lava flow is impervious, although locally fissured (thermal shrinkage). The detailed examination of piezometric data (i) shows a high hydraulic gradient at the scale of the whole aquifer system (several %), not consistent with the high hydraulic conductivity values obtained from pumping tests in each scoria layer+ (ii) indicates that in the few places where the piezometric data are dense enough, the hydraulic gradient appears much lower and consistent with the transmissivity data and the flow through the aquifer+ (iii) shows moreover seasonal variations of the groundwater flow in the aquifer system which logically reveal changes in the hydraulic gradient, which allow to share the aquifer system into several compartments (about 14 for a about 13 kilometers long aquifer system) on the basis of the amplitude of the seasonal piezometric variations. Seasonal piezometric variations are very low at the downstream limit of each compartment whereas they are increasing towards its upstream part. This hydrogeological behavior was modelled with the finite differences MODCOU NEWSAM code in which a “waterfall” scheme was implemented. For this purpose, the downstream boundary of each compartment the piezometric level is fixed as a discharge boundary condition and groundwater is conveyed to the upstream mesh(es) as the result of a underground waterfall occurring in a very highly pervious lava flow tip composed of high granulometry scorias. In fact, the location of such “waterfalls” appears to be consistent with the geological data (location of the main lava flows extremity).



## **Pre-stimulation geothermal reservoir characterization through active thermal testing Abstract n°2001**

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**KEYWORDS:** fractured media, geothermal energy, Fiber-Optic Distributed Temperature Sensing

In order to pioneer further development of Enhanced Geothermal Systems projects in Switzerland, a decameter-scale hydraulic stimulation and circulation experiment has been launched at the Grimsel Test Site. One of the key goals of this multi-disciplinary experiment is to accurately image fracture zones hydraulic properties and connectivity before and after stimulation through the conduction of hydraulic tomography experiments. Moreover, in order to provide detailed insights into pathways for preferential fluid flow and the efficiency of the fracture-matrix heat exchange, active Fiber-Optic Distributed Temperature Sensing (FO-DTS) experiments are carried out. Here, we present active thermal test results and discuss the advantages and limitations of these methods compared to classical approaches. Hydraulic packer tests and active thermal tests, including cross-borehole heat tracer tests and thermal dilution tests in open boreholes as well as in packed-off sections of a borehole, were conducted in two boreholes intersected by a few low to moderately transmissive fault zones (fracture transmissivity of about  $10^{-9}$  -  $10^{-7}$  m<sup>2</sup> s). To obtain a data set with measurements with high resolution and distributed over the entire borehole thus providing a detailed characterization of flow and heat transport through fractures, the DTS unit with a temperature resolution of 0.01°C and a spatial resolution of 25 cm was placed in observation boreholes. Our preliminary results show that even in low-permeable environments, similar to those expected at the potential enhanced geothermal system sites in the deep basement rocks, active thermal testing may provide valuable insights into groundwater and heat transport pathways. For instance, during thermal dilution tests, different temperature responses were observed depending on the fluid flow rate across the testing interval. Thus, thermal dilution tests in open boreholes and in intervals intersected by permeable fractures are shown to be an efficient method to detect and characterize cross-flowing fractures. On the other hand, the transient thermal data recorded in impermeable intervals, may be used to estimate formation thermal conductivity in situ.



**How to measure karst contribution to a surface flood? A geochemical method applied on the Lez basin (Montpellier, France).  
Abstract n°2002**

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**KEYWORDS:** Flash Karst Floods, Geochemical Tracing, Runoff

During a flood event over a karstic watershed, the connections between surface and ground waters appear to be complex. The karst attenuates surface floods by absorbing water or contributes to the surface flood by direct contribution of karstic waters in the rivers and by diffuse resurgence along the hillslopes. If it is possible to monitor each known outlet of a karstic system, the diffuse contribution is difficult to assess. These connections vary over time according to several factors- the water content of the soil and underground, the rainfall characteristics, the runoff pathways. Therefore, the contribution of each compartment is difficult to assess, and flood dynamics are not understood. We analysed surface waters during 5 recent flood events in the Lirou watershed (a karstic tributary of the Lez river in South of France). We were able to acquire samples from the beginning, the peak and the end of the flood. Analyses consisted on chemical ones, because of the specific chemical signature of karstic waters, and on hydrogeomorphological and hydraulic ones, to supply information about water pathways and flood dynamics. A first analyse allowed us to define specific chemical signatures for runoff and karst water. Then, we used the dilution law to combine chemical results, flow data and field observations to assess the dynamics of the karstic component of the flood. We identified two distinct karst signatures, discriminated by the magnesium composition. The magnesium has a dissolution speed lower than the calcium, so these two signatures represents two different karst dynamic- a slow dynamic karst (with a high rate of magnesium) and a faster one. The separation between runoff and karst water is obvious with all parameters ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{HCO}_3^-$  and conductivity). By using the dilution law, we evaluated the contribution of karst water to surface flood. To end, we discussed the origin of the waters responsible for the apparent runoff coefficient rise during flash karst flood. This study was funded by the French Flood Forecasting Service (SPC Med Ouest).



**Temporal variations observed in near-surface seismic data at the Ploemeur hydrogeological observatory  
Abstract n°2003**

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**KEYWORDS:** hydrogeophysics, near-surface seismic, hydrosystem monitoring

Near-surface seismic methods are mainly used to determine the geometrical characteristics of hydrosystems. However, they have been recently suggested to investigate the mechanical properties of the Critical Zone (CZ) influenced by water content, thanks to the combined estimation of P- and S-wave velocities. We propose here a time-lapse application of this approach. Two seismic acquisitions were carried out under distinct hydrogeological conditions along the same line at the Ploemeur hydrogeological observatory (France). Vertical component seismic data were recorded to extract- (i) P-wave first arrival times and (ii) Rayleigh-wave phase velocities. The significant variations with time and space, of both datasets, indicate marked changes in mechanical properties of the CZ to be compared with hydrological data.



**Geochemical characterization of the Venice Lagoon and its coastal plain- a general overview**  
**Abstract n°2004**

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**KEYWORDS:** coastal aquifer, salinization, Venice Lagoon

In the near future the population living in coastal areas is expected to increase, leading to a growing demand for groundwater supply, both for human well-being and agricultural and industrial activities. The increasing water withdrawal to support drinking, industrial and agricultural uses may result in the overexploitation of aquifers, drawing salt water from the sea and leading to salt-water encroachment and soil salinization. In addition the reduced groundwater recharge and the lower availability of fresh water, linked to climate change, can favor salinization processes of soil and groundwater. This will strongly affects the management and protection of coastal plain areas, such as the Venice Lagoon and its inland, mainly devoted to agricultural and touristic activities. In the Venetian coastal plains several elements contribute to the extent of the salt-water contamination- the close vicinity of both sea and lagoon+ the complex geological structures characterized by reclaimed land, low lying areas, paleorivers and paleochannels, rivers suspended above the surrounding land+ the disappearance of coastal dunes+ the hydraulic gradient+ the land use. Aim of this research is understanding the main origin (meteoric, deep or sea water) of groundwater hosted in the Venetian coastal aquifers by geochemical, isotopic and geophysical analyses. An overview of the major achievements obtained from hydrogeological studies promoted mainly between 2000-2010 by the University Ca' Foscari of Venice is here presented. The results obtained led to improvements of the local knowledge of this phenomenon, allowing a more comprehensive identification and circumscription of salt contamination and a better understanding of the process dynamics.



**Time-lapse electrical resistivity monitoring (surface and downhole) of subsurface CO<sub>2</sub> storage at the Maguelone shallow experimental site (Languedoc, France)  
Abstract n°2005**

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KEYWORDS: CO<sub>2</sub> geological storage, electrical resistivity monitoring, saline reservoirs

CO<sub>2</sub> geological storage, electrical resistivity monitoring, saline reservoirs CO<sub>2</sub> geological storage remains a recent research field and many questions are still open, particularly for saline formations, which are expected to provide over time a larger storage capacity than depleted hydrocarbon reservoirs. At the shallow Maguelone experimental site for subsurface gas storage (Languedoc, France), an integrated monitoring concept has been developed for reservoir characterization before and during N<sub>2</sub> and CO<sub>2</sub> injections. The presence of small saline coastal reservoirs (R1- 13-16 m and R2- 8-9 m) bounded above and below by clay-rich layers provides an opportunity to study a saline formation for geological storage in the field at 10 to 100 meter scale. The objective is to improve monitoring of subsurface gas transport and to study the sensitivity of monitoring systems for leakage detection. Series of injection experiments were run in 2012-2015 offering flexibility for testing different monitoring configurations, performing repeated injection releases with variable injection parameters and type of gas (e.g., N<sub>2</sub>, CO<sub>2</sub>), and cross-calibrating the monitoring methods. To image the spatial extent of the gas plume, surface and downhole resistivity monitoring play a key role in this multidisciplinary approach. Besides some limitations, electrical methods are shown to be sensitive to the gas propagation within a saline reservoir, with clear changes immediately after the beginning of injections. During each experiment, the gas plumes were successfully detected from time-lapse induction logging, downhole resistivity monitoring with dipole–dipole array and surface electrical resistivity tomography (ERT). The resistivity increase is attributed to the presence of free gas. Dissolution and desorption exchange following CO<sub>2</sub> injection are attributed to geochemical processes responsible for the observed decrease in resistivity. Chemical analyses confirm this hypothesis with a decrease in pH and an increase in the concentration of dissolved species in the latter case.



**Small scale gas injection experiments at the Maguelone shallow experimental site  
(Languedoc, France)  
Abstract n°2006**

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**KEYWORDS:** CO2 geological storage, hydrogeophysical monitoring, saline reservoirs

The Maguelone shallow experimental site for shallow CO<sub>2</sub> injection (Mediterranean coastline, Gulf of Lions, France) has been developed to compare and integrate surface and in-situ (downhole) hydrogeophysical monitoring methods providing data on the safety and reliability of CO<sub>2</sub> geological storage. The presence of two small reservoirs with impermeable boundaries provides an opportunity to develop gas storage experiments at small scale in a saline formation. More in details, the shallow depth of the porous and permeable reservoirs (R1- 13-16 m and R2- 8-9 m) provides an opportunity (i) to test at a reasonable cost a set of geophysical (resistivity, temperature, pressure, SP, seismic and gas measurements), hydrological and geochemical (pH, minor and major cation concentrations) methods, both downhole and at surface with a range of monitoring configurations and in a coordinated manner, (ii) to perform a series of injection under variable conditions (volume duration pressure), (iii) to inject different gases (either neutral such as N<sub>2</sub> or reactive such as CO<sub>2</sub>) to measure and characterize the site response to gas storage, and (iv) to cross-calibrate the different monitoring methods. Three N<sub>2</sub> and three CO<sub>2</sub> injection experiments were performed in 2012-2015 as part of the MUSTANG, PANACEA and TRUST FP7 EC projects. During each experiment, the gas plumes were successfully detected by all monitoring techniques. A number of limitations (e.g., subsurface gas leakage, identification of an appropriate baseline in order to exclude the impact of natural phenomena) should be taken into account. Integrating the lesson learned from these experiments, the next stage is to propose guidelines for CO<sub>2</sub> injection, post-injection monitoring and, in perspective, not only to detect and follow the CO<sub>2</sub> plume but to quantify the CO<sub>2</sub> migration.



**ROLE OF GROUND AND SURFACE WATER IN TRIGGERING LANDSLIDES IN GREAT  
KABYLIA (TIZI-OUZOU, ALGERIA)  
Abstract n°2007**

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**KEYWORDS:** Seepage, modeling, instability, risk, landslides, Kabylia.

Landslides in unconsolidated formations are widespread in Algeria, particularly in great Kabylia. Indeed the morphology of the North of Algeria, essentially characterized by mountains and steep slopes, often gives rise to landslide of variable intensity. Water play a central role in the landslides processes in this region+ it exerts on these soils a special influence which translates into several instabilities. This communication aims to the study of the impact of ground and surface water on the triggering of landslides in great Kabylia and numerical modeling of these instabilities caused by water in its various forms. The increase of the water content of ground is usually closely linked to the weather conditions- It is due mostly to seepage or groundwater lifts following the heavy or prolonged rainfall, at which can be added the snowmelt. Landslides in great Kabylia (Ain el Hammam, Azazga, Tizirt, Illilten, Tala Tgana, Azeffoune ... etc.) occurred or reactivated following the heavy rains and melting snowpack especially in winter 2012. If one must more often attributed the increase in water content of ground to natural causes, it also happens to be anthropogenic due to the presence of man and his activities (leakages, the rupture of underground pipes, concentration of water discharges after a waterproofing surfaces, abandonment of water sources, unplanned urbanization). The results of this study show the need to the realization of ground and surface runoff water management system (drainage systems blanked, bad raccordment in systems supply of potable water, the return to the use of water sources in mountains to reduce the pressure exerted by the ground water).



**Hydrogeological and geochemical dynamics of the Western Haouz Aquifers. Tensift Basin (Western Morocco)  
Abstract n°2008**

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**KEYWORDS:** Haouz, Mejjate, High Atlas aquifers, turonian, Abainou spring, geochemical

The compilation of geological, hydrogeological and geophysical data reveal that the Western Haouz plain, located near Marrakech, is divided into two morphostructural synclinal units separated by the horsts of Marmouta. In the southern part, the Mejjate Syncline is very subsiding including a number of geological formations ranging from Paleozoic to Quaternary. However, in the northern part, the syncline is less developed and is constituted only by Mio-Pliocene and Quaternary. From the hydrogeological map, the geometry of the aquifers and groundwater circulation are well controlled by subsurface geology. Two aquifers can be recognized in the southern part of the plain between the Marmouta Anticline and the foothills of the High Atlas Range- a thick Quaternary and Mio-Pliocene phreatic aquifer and a deep confined aquifer located in Turonian limestone. This latter is recharged at the level of the High Atlas Range, showing a karstic morphology and great cliff of the Turonian limestone slab. The relationship between Oxygen-18 and deuterium shows a good correlation ( $R^2 = 0,901$ ) and all samples are close to Global Meteoric Water Line. The isotopic signatures indicate that the aquifers are recharged from elevated altitudes ranging from 980 to 2200 m a.s.l. which correspond to the High Atlas Mountains. Age dating of groundwater using C14 show significant differences among waters from Western Haouz aquifers+ The oldest waters (about 5000 years old) appear at the almost forty Khettaras (underground water galleries) distributed along the Assoufid Fault, the Abainou Spring and the well 397 52 exploiting the deep Turonian aquifer. This can indicate that the recharge came from distant area (e.g. High Atlas Mountains) with a relatively long residence time. In opposite way, groundwater from phreatic aquifers is much younger indicating the dominance of the recent recharge. These results can help the decision makers to more improve the water resources management in this region showing serious shortage water.



**The impact of urbanization on groundwater quantity and quality – model predictions  
for urban planning of the city of Lille  
Abstract n°2009**

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**KEYWORDS:** drinking water resource, impact of urbanization, hydrogeological model

At less than 10km south of the urban core of the city of Lille (North of France), the chalk aquifer is a shallow and productive groundwater resource. Around 40% of the water supply of the city of Lille comes from wellfields located in this area. Due to its location, this area is becoming more attractive for economic and residential development. Urbanization inevitably causes soil sealing and runoff collecting, leading to the decrease of groundwater recharge, and then to the risk of a non-sustainable drinking water resource. In this study, the impacts of urbanization on groundwater systems are analyzed using a previously developed hydrogeological model [1]. Predictive simulations over the next 30 years are built taking into account surface sealing of soil due to future urban development projects. The modeling results suggest that urbanization in south of Lille should increase the supply by rivers and waterways and should decrease the groundwater level in the chalk aquifer. No modification of the size of the feeding area could have been identified. These changes of amount and origin of water should likely impact the water resource quality because (1) the water and sediments of rivers and waterways are of poor quality, (2) the decrease of groundwater levels can alter the wetland purification system, and (3) the decrease of groundwater levels near a Chalk-Clay interface can modify the geochemical behavior of undesirable substances (see [2] for details). The impacts of urbanization on groundwater systems can be predictable and should be considered in urban planning. The impacts of soil sealing have been analyzed in the area around the city of Lille. Urbanization also leads to a more intense anthropic activity that increases the risk of accidental pollution. With the aim of defining a territorial development consistent with the sustainability of water resource, hydrogeological study should be associated with economic and or social studies. References- [1] Bessiere et al. (2015) BRGM RP-63689-FR. [2] Cary et al. (2014) Applied Geochemistry 48-70-82.



**Groundwater flux estimation from point dilution and active distributed temperature sensing methods in a fractured bedrock aquifer**  
**Abstract n°2010**

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**KEYWORDS:** groundwater flux, point dilution method, distributed temperature sensing, fractured rock.

Determining the location and magnitude of volumetric groundwater fluxes in depth discrete intervals along open rock boreholes in a fractured aquifer is important for the management of contaminated sites and efficiency assessment of geothermal heat exchange systems. Measurements made under natural gradient conditions provide insight into the ambient flow system and determine long term plume behavior that drastically improve decision making capabilities. A recent study demonstrates an active distributed temperature sensing method (active DTS) applied in sealed boreholes can locate and differentiate zones with variable groundwater flow in fractured bedrock aquifers (Coleman et al., 2015). This presentation highlights an advancement of the field deployment and mathematical approach to provide quantitative estimates of groundwater fluxes along the full borehole length using active DTS. Validation of this technique requires a second, independent method such as the point dilution method (PDM). This method is well-established and provides flux estimates derived from the dilution of a tracer within intervals isolated by straddle packers. A new PDM system was developed by G360 at the University of Guelph, Canada by modifying a straddle packer system to allow both the application of the PDM, and to perform multiple, high resolution hydraulic tests such as rising and falling head, and constant head step tests in the same 1.07 m long interval without removing the packers. Hydraulic tests, especially constant head step tests, are conducted to avoid non-linear flow to improve estimation of apparent hydraulic. The active DTS and PDM techniques were applied in the same 12.50 cm diameter borehole at the Bedrock Aquifer Research Station on the University of Guelph campus. Seven intervals, accounting for 80% of the entire borehole transmissivity, presented volumetric fluxes ranging from 2 to 3000 m day, demonstrating large variability in local fractured zone flux. These same intervals have noticeable heat dissipation in the active DTS temperature profiles yielding corroboration of methods.



## **Assessing the impact of climate variability in large aquifers Abstract n°2012**

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**KEYWORDS:** climate change, satellite observations, GRACE, groundwater levels, water management policies

NASA's Gravity Recovery and Climate Experiment (GRACE) - first satellite mission able to monitor total water storage changes (including groundwater) remotely – has provided new insights of the dynamics of large aquifers (>100 000km<sup>2</sup>) since 2002. However, given that the dynamics of groundwater are not solely a function of temporal patterns in pumping but also a function of interannual to multidecadal climate variability, a longer observation time than the one GRACE analyses currently permit is required to separate the respective impacts of anthropogenic activities (land use changes, abstraction) and climate on water resources. Thus, there is a need to extend storage information provided by GRACE to the “past” to better evaluate the current and future evolution of groundwater resources. This study aims at paving the way to better water management decisions and policies in large aquifers by “reconstructing” past groundwater storage changes as a cornerstone to provide a first quantitative evaluation of the potential effects of anthropogenic activities and climatic oscillations cycles such as the El Niño Southern Oscillation (ENSO) (2–7 year cycle), Pacific Decadal Oscillation (PDO) (10–25 year cycle), and Atlantic Multidecadal Oscillation (AMO) (50–70 year cycle) on large aquifers (area > 100 000 km<sup>2</sup>) located in arid semi-arid and temperate regions. Validation is carried out by comparing obtained modeled results with GRACE groundwater storage changes, and ground-based measurements. This study is part of the UNESCO International Hydrological Programme (IHP) research project on groundwater and climate change (GRAPHIC).



# **Development of organic compounds transport model for the sustainable management of groundwater in a deep aquifer**

## **Abstract n°2013**

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**KEYWORDS:** Integrated Water Resources Management, Numerical Modelling, Organic Compounds

Water resources management in aquifers involving participation of stakeholders with different interests is not an easy task. Management strategies should be designed to ensure long-term sustainable development of the water resource. An integrated approach using a numerical model and the simulation of future scenarios that take into account the needs and interests of each stakeholder is recognized as a useful management tool that supports the decision-making process. This integrated approach was used to analyze the vulnerability and sustainability of a deep aquifer in an area where a conflict of interest exists between different stakeholders. These conflicts are related to limitations on water use for industrial, agricultural and potable purposes from- 1) a quantitative point of view, due to decreased groundwater levels during recent dry years+ and 2) a qualitative point of view, due to impacts on groundwater by organic compound resulting from localized spills in an industrial facility. Numerical flow and transport models, in conjunction with a Quantitative Risk Assessment and evaluation of water disposal alternatives, were used as a conflict management tool through the simulation of future scenarios that incorporated climate change and socioeconomic drivers. Behavior of the organic compound plume was modelled allowing key management factors to be identified and communicated to stakeholders. These included- 1) potential future resource limitations for existing and new groundwater users+ 2) selection of a hydraulic barrier as the best way to limit further down-gradient migration of the plume+ and 3) optimization of the barrier design including location of boreholes and treatment plant, use or disposal of the treated water, minimum barrier operation time to meet water quality threshold values for irrigation and potable uses.



## **Managing groundwater extraction for irrigation in Tarn-et-Garonne (France)- Abstract n°2014**

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**KEYWORDS:** alluvial aquifers, management tool, use conflicts

In France, in one of the watershed districts from the European Water Framework Directive, the Adour-Garonne basin, alluvial aquifers make for strategic water resources thanks to their high productivity, their accessibility and their low providing costs. Therefore, they are highly exploited for agricultural irrigation. These aquifers are closely linked to the rivers and support their low flows. Since several decades, lower rainfall has led to more severe low flows, which created conflicts of use. The need for a groundwater extraction management tool arose for local water authorities (DDT). As an example, in 1995, the BRGM was asked to build a hydrodynamic model of the alluvial aquifer in Tarn-et-Garonne. 940 km<sup>2</sup> divided in 5 alluvial terraces crossed by 3 main rivers (Garonne, Tarn and Aveyron) were modeled with MARTHE (BRGM software). The first model ran in steady state on a 1x1 km grid. The study area was divided in several spatial units and a simplified groundwater extraction management tool with EXCEL was developed. From 1997, DDT has used this tool to manage groundwater extraction for irrigation in each spatial unit. In 2007, the model has been updated to run in transient state with a refined mesh (250x250 m). In 2016, a second update has been launched - the model now has two layers and 36,500 cells+ it simulates the water level and flow of 41 rivers in a 20-year span and takes into account 750 agricultural pumping wells. The updated management tool integrates the Allowed Pumping Volume and Unique Authorization Over Several Years notions and the new French legislation with water management driven by "Organismes Uniques" based on watersheds rather than administrative breakdown. A participative forecasting study, combining the scientific approach with the farmers' and the territorial actors' point of view, was also carried out to model the quantitative management of groundwater resources in France around 2020-2035.



**Modeling the thermodynamic properties of CO<sub>2</sub> aqueous solution following the HKF formalism**  
**Abstract n°2017**

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KEYWORDS: thermodynamic properties, HKF formalism, CO<sub>2</sub> aqueous solution

Although the CO<sub>2</sub>-H<sub>2</sub>O geochemical system has been extensively studied, a thermodynamically-consistent model able to explain all experimental data (molar volume, heat capacity, reciprocal solubility) is still lacking. The HKF (Helgeson, Kirkham, Flowers) equation of state [1] has been developed to model the standard thermodynamic properties of aqueous solutions taking account the ions and neutral solutes up to 5kbar and 1000°C. Following this formalism, Shock et al [2] proposed a set of HKF parameters for describing the thermodynamic behavior of dissolved inorganic gases like CO<sub>2</sub>. Since this original work, Shulte et al [3] modified some parameters to account for new experimental heat capacity data [4]. More recently, new measurements of the partial molar volume of aqueous CO<sub>2</sub> have been published [5] which cannot be described with the existing set of HKF parameter. Therefore, there is a need to re-adjust them. First, this work critically reviews the experimental data, including density and heat capacity of CO<sub>2</sub> aqueous solution, and reciprocal solubility of CO<sub>2</sub> in water. Then new HKF parameters are proposed to obtain agreement both with density and heat capacity of CO<sub>2</sub> aqueous solution. To explain the reciprocal solubility data, two types of non-ideality are analyzed- the activity model in the aqueous phase and the fugacity correction in the CO<sub>2</sub>-rich phase. The aim of this work is a unique model, thermodynamically consistent, able to calculate with an equal accuracy the reciprocal solubility, the density and the heat capacity of the CO<sub>2</sub>-H<sub>2</sub>O system in the T and P ranges relevant for CO<sub>2</sub> storage. The same methodology should be applied with others gases (O<sub>2</sub>, N<sub>2</sub>, Ar, SO<sub>2</sub> ...) to take into account the CO<sub>2</sub> impurities. References- [1] Tanger (1988) [2] Shock (1989) [3] Shulte (2001) [4] Hnedkovski (1997) [5] McBride-Wright (2015)



**Groundwater model of single well tracer test coupling Fiber-Optic Distributed Temperature Sensing and Electrical Resistivity Tomography. The Villaverla case study (Italy)**  
**Abstract n°2018**

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**KEYWORDS:** DTS, Groundwater heat transfer, ERT

Environmental studies are becoming more relevant over time, due to an increasing awareness both on the ecosystem vulnerability and on its sustainable exploitation. Groundwater traces tests lead to the definition of the aquifer parameter that are indispensable in order to properly understand and exploit drinkable water and control its possible pollution. Typically traditional hydrogeological tracer methods often show several disadvantages, such (1) the need of pouring pollutants to the groundwater system (fluorescein, radioactive elements, etc.)+ or (2) the modifications to the physical groundwater properties (ionized substances like sodium chlorite, or potassium chlorite). Ground Response Tests in a shallow piezometer provided the thermal footprint pattern to the groundwater system+ Distribute Optical Sensing methods allowed the recording of the temperature profile, modified by the heat transfer. Finally Electrical Resistivity Tomography from the surface detected the changes of electrical conductivity due to the increasing of groundwater temperature. The combination of these methodologies allowed the definition of several aquifer parameters. A numerical model simulated more in detail all the involved hydrogeological and heat transfer parameters in order to improve the aquifer modelling for fresh groundwater management and environmental protection purposes.



**Evaluation of groundwater resources in the Tana and Beles sub-basins (Ethiopia)  
within a framework of River Basin Authorities development and Water Resources  
Master Plan build-up  
Abstract n°2019**

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**KEYWORDS:** groundwater potential map, river basin authorities, Master Plan, stakeholder

The catchment basins of Lake Tana and the Beles River in Ethiopia have been identified as a priority area for development, especially in terms of improving access to water. The Ethiopian government has thus decided, through specific public investments, firstly, to create two River Basin Authorities (TaSBO and BeSBO) based on the French model of basin authorities and, secondly, to increase the knowledge on water resources within these areas with a special focus on groundwater. In this complex context of multiple surface, lake and groundwater interactions and of increasing pressure on water resources, groundwater could represent an attractive alternative to surface water. The aim of the study performed by Artelia along with its Ethiopian partners Yerer and Geomatrix (2010-2015) was to assess groundwater potential within these catchment basins (covering a total surface area of 30,000 km<sup>2</sup>). Using a combination of geological and hydrogeological approaches, test boreholes drilled at depths up to 500 m and isotopic analyses, a series of geological, hydrogeological and groundwater potential maps were produced at scales of 1-250,000 and, locally, 1-50,000. The approach adopted highlighted sectors with high potential that had been hitherto not known. The initial assessment of groundwater potential was confirmed through the setting up of a pilot well field in a target area. This qualitative leap in knowledge of groundwater will enable the new basin authorities to fully take into account groundwater resources within the water resources master plan that is currently being drawn up. More particularly recently highlighted groundwater resources could be used beneficially for local water supply schemes and small to medium-scale agricultural irrigation schemes. This study also addresses the redistribution of stakeholder role in relation with the creation of the new basin authorities.



## **Irrigation with treated domestic waste water- a future? Abstract n°2020**

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**KEYWORDS:** Agriculture, Recreation areas, Infiltration, Pollution, Reuse

The reuse of wastewater has experienced considerable world growth during the last few years. It is a political and socio-economic challenge for the future development of sanitation services, the main interest being to lower the pressure on natural resources such as groundwater. The provision of an alternative low-cost resource in order to limit water shortage will allow for better preserving natural resources and will contribute to integrated water management. This approach is especially relevant when applied to irrigation in both rural and urban contexts, both with on-site sanitation and treatment plant management (52% of treated waste waters are used in the irrigation of croplands and recreation areas – Global Water Intelligence 2009). In spite of advanced technologies for the water treatment (membrane bioreactor, microfiltration, UV treatment...), France falls behind other countries in this field. The conditions for reuse must be guided by the regulations to prevent the sanitary risks bound to this practice. Indeed, residual waters, even handled by a water-treatment plant, contain diverse pathogenic micro-organisms, organic molecules and mineral elements that are potentially toxic. The French regulations as well as other National and International bodies bring recommendations adapted to urban and agricultural practices, and set the objectives in terms of quality when handling wastewater and ways to reach them. Necessary precautions on the key stages of the primary secondary treatment will be described as well as tertiary treatment and storage which can be the source of contamination. This paper makes a state of the art of techniques for the reuse of treated wastewater for agricultural irrigation at regulatory, environmental, and social levels. Bottlenecks linked to the user's standpoint are highlighted. Solutions to answer all these constraints are considered in order to promote irrigation by wastewater.



## Optimization of hydraulic parameters – The industrial way Abstract n°2021

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KEYWORDS: inverse modelling, calibration, parameter, estimation, unique, pumping test, analysis, time series

With the integrated combination of MODFLOW and parameter estimation models like PEST, in most pre- postprocessors, it has become more easy to calibrate local and or regional models. Mostly this is been done by means of inverse modelling, based on the results of sensitivity analysis. By simultaneously recording time series of groundwater levels and times flowrates of the pumped wells, it is very well possible to estimate the classic hydraulic parameters like conductivity, storage coefficients by inverse modelling. The advantages of this way of deriving hydraulic parameters this way are obvious-

- Easy, non-disturbing way of performing aquifer testing in high activity areas like industrial sites.
- Pumping rates of multiple level-wells on various locations and time series of groundwater levels are mostly readily available.
- All necessary logistical preparations, which are normally pretty hard to obtain prior to a classic pumping test can be readily skipped.
- Possibility of determination or parameters in complex hydrogeological situations (classic pumping test analysis requires horizontal, infinite stratigraphy).
- Erratic and rapidly changing pumping regimes and boundary conditions do not create interpretation problems.
- Compared to a classic pumping test analysis, one gets more than one chance.
- Chances on non-unique results are significant lower compared to classic test pumping analysis.

The greatest advantage of this way of practice is the use of one integrated model for pumping test analysis and site simulation of events like convective transport, dewatering, ... Moreover, inverse modelling with codes like PEST, in combination with MODFLOW, do result in unique results. Design and conceptualization of remediation measures, dewatering, risk analysis on fate of contaminants, will be less prone to inaccuracies towards estimation of environmental results, time schedules and budget controls.



# **Groundwater Quality and its Sustainability in Ojo Local Government Area of Lagos, Nigeria**

## **Abstract n°2022**

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**KEYWORDS:** Water quality, exploitation of groundwater, sustainability of groundwater

With the absence of pipe borne water supply, residents of Ojo Local Government Area of Lagos, Nigeria depend solely on groundwater for all their water needs. Characterizing the dense network of houses in the newly urbanized area are shallow hand-dug wells built without the supervision of any regulatory agency. Such wells are of concern to the quality of water consumed by the residents and the sustainability of groundwater resources. The study was designed to assess the quality of groundwater and the interaction of residents with the resource which have implications for future use. Samples collected from 30 hand-dug wells were tested to determine the concentration levels of eleven parameters. Five hundred questionnaires were administered using the simple random sampling technique. Descriptive and inferential statistics were adopted in the analysis. Results showed that escherichia coli, silica and lead were not detectable in samples. Compared with the Nigerian Standard for Drinking Water, zinc exceeded the 3mg L limits in 13 wells while magnesium exceeded the set limit in all samples. Wells were observed to be vulnerable to further contamination if necessary precautions were not taken. The average depth of wells was 4.43m. The stipulated minimum distance between wells and a potential source of contamination (15m) was adhered to by 25% of the respondents. Domestic activities were carried out around the wells. The required sanitary inspections were not done. The study shows that urgent steps need to be taken by policy makers so as to preserve groundwater resources for future generations.



**A multi-layer transient groundwater flow and transport model of the Crau aquifer  
using stable isotope tracers  
Abstract n°2024**

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**KEYWORDS:** Hydrogeology, Transient model, Stable isotopes, Geostatistics

In the last decades, the Crau aquifer (Southern France) became an example of the complexity of anthropogenic aquifer management. To supply a high consuming irrigation practice, water is diverted from the Durance River, and the large amount of irrigation return flows constitutes the main recharge of the Crau aquifer (70%), which is in turn largely exploited for domestic, industrial and agricultural water use. A possible reduction of irrigation fluxes due to a need of water saving or to a future land-use change could endanger the groundwater resource. Available hydrogeological models of the Crau aquifer only consider the well-known superficial reservoir made of puddingstone. However, the underlying heterogeneous layer considered the basement shows groundwater flows evidences (springs and water table levels within this layer). An updated transient groundwater flow and transport model considering this new multi-layer geometry is built, integrating the simulation of conservative tracers. The database used to validate the simulation is based on an extensive groundwater sampling covering time variations and spatial distribution of  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$  signals over the whole aquifer. Essential to model groundwater flows, some aquifer properties are estimated by independent methods. The permeability fields of the two reservoirs are stochastically calibrated by looping steady-state simulations. The poorly known specific yield distribution is estimated using the water table fluctuation method on extreme rainfall events. These properties implemented in a transient hydrogeological model allow simulating the seasonal behavior of this aquifer, and thus, establishing a sustainable management of this resource.



**Spreading hydrogeology to the masses - demystification of science and integration of disciplines**  
**Abstract n°2025**

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KEYWORDS: Hydrogeology, aquifer, interdisciplinary, demystification, participative

The crisis of groundwater depletion and contamination in India is becoming more serious by the day. Groundwater depletion and contamination requires a clear resource management approach that is based on a strategy requiring multidisciplinary skills. Current mainstream responses attempt simply to copy and adapt exploratory, resource-development methodologies from twenty years ago. These methodologies fall short on many counts when dealing with the complexity of hydrogeological and socio-economic conditions that are inherent to groundwater occurrence and usage, particularly as part of a resource (aquifer) management approach. Mainstream institutions, including academia and research bodies in India, struggle to bridge the gap between 'skills-on-offer' and 'desired resource-management proficiencies'. This gap is leading to increased skepticism regarding the efficacy of hydrogeology in solving groundwater management and governance challenges in India. ACWADAM's training approach, of taking the subject of hydrogeology from classrooms into nature's own laboratories of watersheds and aquifers, is a promising mechanism of bridging many such gaps. These trainings are pitched within the space of extra-curricular education and sometimes within the framework of co-curricular education. More significantly, it is also a stand-alone training that does not compromise the basic tenets of hydrogeology, bringing in interdisciplinary aspects of groundwater resources into aquifer management approaches at the same time. Foundation trainings, specialized workshops and location-specific modules combine perspective building, conceptualization and skill development, all of which include social, economic and environmental aspects of groundwater resource management, without compromising on hydrogeology as the foundation. Demystified versions of training content and delivery in local languages have provided training to a spectrum of stakeholders ranging from policy makers to village-level volunteers, creating two sets of impact. Firstly, a large-scale acceptance of the concept of aquifers as the unit of understanding (and sometimes managing) groundwater resources and secondly, stimulating attempts on a people participative management of aquifers as common pool resources. It has also led to creating a pool of more than 2000 scientific practitioners.



**Massively parallel free-surface SPH simulations and laboratory experiments of gravity-driven flow and partitioning dynamics in unsaturated fractured media**  
**Abstract n°2027**

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**KEYWORDS:** unsaturated flow, fractured media, gravity-driven flow, SPH, high-performance simulations

In this work we present low-Capillary number free-surface fracture-scale flow simulations obtained with a parallelized smoothed particle hydrodynamics (SPH) model. In the model, surface tension and fluid-solid interactions are modeled with pairwise forces added into the SPH equation. The model is used to simulate free-surface flow dynamics including the effect of surface tension for a wide range of wetting conditions in smooth and rough fractures. The code employs an adaptive MPI domain decomposition to increase the computational efficiency in the presence of a sparsely populated domain. Due to the highly efficient generation of surface tension via particle-particle interaction forces, the dynamic wetting of surfaces can readily be obtained. We used the model to simulate unsaturated flow observed in a fractured system. Flow velocities of water in porous geological media generally do not exceed a few millimeters per day. However, tectonic stresses commonly induce the formation of discontinuities, i.e. fractures, which allow much higher flow velocities. In the case of vertical, gravity-driven flows, this leads to a pronounced deviation from classical volume-effective descriptions and complicates the prediction of water movement for example in the context of nuclear waste repository sites, mining industry and in general water resources management. On fracture-scales the spatial and temporal distribution of flow modes and its influence on travel time distributions is still not very well understood. The complex interplay of flow modes such as droplets, rivulets, turbulent and adsorbed films and its relation to the geometrical properties of the system is difficult to model and requires efficient numerical methods. We validated the model via empirical and semi-analytical solutions and conducted laboratory-scale percolation experiments of multiphase flow through synthetic fracture systems. The setup allows us to obtain travel time distributions and identify characteristic flow mode distributions on wide aperture fractures intercepted by horizontal fracture elements. The effect of flow mode formation on fracture partitioning dynamics is demonstrated.



**Comprehensive Exploitation Strategy and management for Nandong Underground River System in Yunnan Province, Southwest China  
Abstract n°2028**

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**KEYWORDS:** Nandong Underground River, Groundwater Exploitation, Environmental Treatment

The Nandong Underground River System is located in a typical karst area in the southeast Yunnan Province, China. It is a major feeding source of Lujiang River, a tributary of Zhujiang River, with a drainage area of 1684 km<sup>2</sup>, which is the second ultra-large underground water system in China with annual average runoff amount 3.542 billion cubic meters and has a great potential exploitation water resource. However, with the rapid increase in population and expansion of land use, groundwater quality has degraded. Meanwhile, ecological environment problems such as rocky desertification, soil erosion and so on are also very prominent in Nandong Underground Water basin. In order to rational exploit the groundwater resource and treat the environment problems in Nandong underground water system, Chinese Government has devoted huge manpower and material resources. A geological survey and research project was started up by China Geological Survey to find hydrogeological characteristics and comprehensive exploitation strategy for Nandong underground river system from 2014 to 2015. Included used controlled source audio-frequency magnetotelluric and large power mise-à-la-masse methods to find underground river main ducts, used fluorescein sodium tracer test methods to research the medium property of groundwater etc. Mainly results up to date show that the system has three main underground river ducts in the lower reach and has an annual average of 433.5 thousand tons sediment discharge from the total drain outlet. Karst rocky desertification area was up to 642 Km<sup>2</sup>, which is over 38% of the total watershed land area. It is therefore necessary to take a scientific and reasonable measure to management the basin. Furthermore, the most rational exploitation policy of the ground water is to build an underground dam in Moshi Valley in the lower reach.



**Management of litter from dry toilets- comparison of the environmental impact onto the soil between three composting practices  
Abstract n°2029**

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**KEYWORDS:** Keywords- on-site sanitation, outhouse provider, private owner, indicators of contamination, soil, composting

French regulations sanitation relies on the health and environmental impacts. Regarding dry toilets (which is an accepted disposal), any possible environmental impacts can be generated when the products or litter containing excreta are managed (soil or river contamination). As part of two scientific studies funded by the Environment and Energy Management Agency (ADEME) in France, the association o Toilettes Du Monde - TDM O has been working since 2012 on three composting practices of dry toilets litter (i) composting at plot level of dry matter in litter toilets in on-site sanitation context + (ii) composting on private property of the litter collected in event-delivery by an outhouse provider+ and (iii) composting on an approved composting platform of litter collected on events . This is to present a comparison of the 3 practices and their potential environmental impacts to the soil. As part of these studies, TDM has produced analyzes of flow and concentration in leachate and residual solid matter, which are based on indicators regularly monitored in sanitation context- nitrate, nitrite, biological (BOD), and chemical (COD) oxygen demand, pH, total suspended solids (TSS), microbiology, etc. Initial results show that the generated leachate flows are low and composters have a role of biodegradation of these leachates. The materials can be recovered as an organic soil amendment.



# Multicriteria Decision Analysis of Freshwater Resource Management in Southwestern Bangladesh

## Abstract n°2030

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**KEYWORDS:** Bangladesh, decision, freshwater, managed aquifer recharge, multicriteria decision analysis

Freshwater resources in coastal Bangladesh fluctuate with extreme periods of shortage and abundance. Bangladeshis have adapted to these alternating periods but are still plagued with scarce drinking water resources due to pond water pathogens, salinity of groundwater, and arsenic contamination. The success of attempts to correct the problem of unsafe drinking water have varied across the southern Bangladesh as a result of physical and social factors. We use a multicriteria decision analysis (MCDA) to explore the various physical and social factors that influence decisions about freshwater technologies and management schemes in southern Bangladesh. MCDA is a holistic, analytical tool for evaluation of alternatives. MCDA is used to support public participation and provide structured, rational, and transparent solutions to complex management problems. To determine the best freshwater technologies and management schemes, we examine four alternatives, including managed aquifer recharge (MAR), pond sand filter (PSF), rain water harvesting (RWH), and tubewells. Criteria are grouped into four categories- environmental, technical, social, and economic. Weighting of social factors will be determined by community surveys, non-governmental organizations (NGO) opinions, and academic interviews. Current data include regional water quality perceptions, perceptions of management technology success, MAR community surveys, and interviews with NGO partners. Environmental and technical feasibility factors are determined from regional water quality data, geospatial information, land use land change, and regional stratigraphy. Survey data suggest a wide range of criteria based on location and stakeholder perception. MAR and PSF technologies likely have the greatest environmental and technical potential for success but are highly influenced by community dynamics, individual perspective, and NGO involvement. RWH solutions are used less frequently due to quantity limitations but are successful at reducing the water security threats of contamination by pathogens, arsenic, and salts. This MCDA informs us of community and stakeholder water resource decision processes.



**81Kr Dating of Groundwater in the Baltic Artesian Basin on the One-Million-Year Timescale**  
**Abstract n°2032**

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**KEYWORDS:** 81Kr, groundwater dating, mixing

With the recent improvements in analytical techniques, 81Kr dating is becoming a viable and powerful alternative to tracers such as 36Cl and 4He for estimating groundwater ages and flow patterns on time scales of hundred thousands of years. Here we present a case study of the multi-layered sedimentary Baltic Artesian Basin (BAB), which is a source of drinking water for Estonia, but also considered for storage of CO<sub>2</sub> or radioactive waste. We focus on the Cambrian Aquifer System (CAS), which covers the whole BAB and is sandwiched between the bedrock and a thick aquitard. Samples from seven



deep wells (up to 1800 m) were analyzed for a suite of dating tracers ( $^{85}\text{Kr}$ ,  $^{39}\text{Ar}$ ,  $^{81}\text{Kr}$ ,  $^4\text{He}$ , and  $^{40}\text{Ar}$ ), noble gas concentrations, chemistry, and stable isotopes of the water. The results are consistent with a mixing of three water types, as proposed in earlier studies - (i) fresh meteoric water, (ii) glacial meltwater, and (iii) a brine end member. These end members are expected to also have different residence times, which need to be deconvoluted. We find that the three end members also have very distinct noble gas concentrations varying over one order of magnitude. As a consequence of this, end-member proportions calculated based on chemistry and stable isotopes are different from end-member proportions of Kr, which are relevant for interpreting the  $^{81}\text{Kr}$  measurements. For the brine component,  $^{81}\text{Kr}$  ages exceed the dating range of the ATTA 3 instrument of 1.3 Ma. Ages of  $> 1$  Ma for the brine component are also supported by  $^4\text{He}$  and  $^{40}\text{Ar}$ . In turn,  $^{81}\text{Kr}$  ages of the fresh meteoric and glacial meltwater components range from 300 ka to 1.3 Ma. The spatial pattern of these ages implies that in the past, flow directions in the CAS must have been different from those inferred from today's hydraulic heads. A conceptual model shows that it is plausible that the flow direction reversed during the advances of the Scandinavian Ice Sheet.



**Development of a Knowledge Based Platform for Data Preparation for Groundwater Models- Part 2-Knowledge Acquisition  
Abstract n°2033**

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KEYWORDS: Groundwater Modeling, Data Preparation, Knowledge Acquisition

One of the major problems of hydrogeology modeling is the basic data preparation namely those related to the geology, hydrogeology, hydrometeorology, and the appropriate choice of model parameters. The experienced user or a newcomer of various existing powerful models such as MODFLOW, FEFLOW, etc ..., is often lost during the data preparation phase highly required for running a model. Hence one of the main motivations of this work to develop an intelligent system able to reproduce heuristics mechanisms of hydrogeologists experts to assist any engineer researcher in all stages prior to any hydrogeological modeling of the groundwater system studied. However, the knowledge acquisition for the expert system development is a complex process that must be addressed rigorously. Indeed, the transcript of expert reasoning requires going through phases of extraction, modeling and knowledge formalization. Each of these steps involves specific work methods. The acquisition of knowledge is certainly the task more complex, the less formal, but also the most interesting in the development of the knowledge base of the expert system. The interest which is dealt with in this work is important because it determines the quality and relevance of the realized expert system and its effectiveness for decision support in the field of hydrogeological modeling. During this acquisition phase of heuristics, many experts in multiple fields interacting in hydrogeological modeling have been consulted. Also, the acquisition method by structured interviews, accomplished by a knowledge engineer (ourselves), was highly effective. This approach helped to understand the knowledge basics and performances of the experts. What helped in the development of a specific methodology for hydrogeological modeling. These heuristics have also contributed to the development of a second-level conception, based on structured objects, of the Knowledge Based Platform for Data Preparation for Groundwater Models "ALAE".



**Evidences and characterization of groundwater circulation in dryland piedmonts+ impacts on aquifer recharge. Example of the Andean Piedmont between 19.5°S and 20°S (Northern Chile).  
Abstract n°2034**

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**KEYWORDS:** hyperarid climate, TDEM, piedmont cover, Pampa del Tamarugal

A piedmont acts as a transition zone, shaped by an alluvial cover overlying the bedrock, between i) a mountain range area and its lowland+ ii) a high and low precipitation area which generally correlated with the relief in drylands. These transition zones can be associated to significant groundwater circulation, from the mountain front recharge zones towards a downstream aquifer, generally located in the lowlands. Nevertheless, due to several constraints (rugged terrains, significant vadose zone) the density of observation points (e.g. well) in the piedmont is very restricted, whereas a large number of wells (groundwater exploitation) are usually available in the lowlands. Consequently, both groundwater circulation and aquifer recharge in the piedmont cover are poorly addressed and thus often neglected. The Andean Piedmont (between 19,5°S and 20°S - Northern Chile) is located in the Pampa del Tamarugal (PdT) Central Depression. The piedmont cover and the lowlands are composed of late-Cenozoic alluvial deposits (hundreds of meters thick) which contain the Pampa del Tamarugal Aquifer (PTA). In this arid and hyperarid climatic context, the PTA is one of the main strategic groundwater resources in Northern Chile. In order to determine both groundwater circulation and aquifer recharge within the piedmont, we used various approaches such as (i) Time Domain Electromagnetic (TDEM) method to assess resistivity variations with depth+ (ii) stream flow measurements+ (iii) analysis of current springs location and paleogeomorphic features of the piedmont cover and (iv) hydrogeological modelling. This allowed to better constrain the aquifer boundaries with the geological structures+ to identify preferential recharge areas and to highlight a regional groundwater flow pattern in the alluvial cover. This methodology, transposable to other dryland piedmonts, allowed providing a new conceptual model of the PTA.



**Heat dissipation test to estimate groundwater fluxes- test case at an unconsolidated coastal aquifer  
Abstract n°2035**

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**KEYWORDS:** Groundwater flow, thermal dissipation test, Fiber-Optic Distributed Temperature Sensing

Estimation of groundwater flow is a key element for the quantitative and qualitative monitoring of groundwater resources. Continued monitoring of groundwater flux should help to manage unconsolidated coastal aquifers, which is our motivation. We propose using Fiber-Optic Distributed Temperature Sensing (FODTS) as a new approach to measure groundwater flux with a high temporal and spatial resolution, so as to characterize seawater intrusion and processes occurring at the fresh-salt water interface. FODTS has already proved to be a useful cost-effective tool to get detail monitoring of environmental processes. Armoured fiber-optic cable was installed outside the casing of several piezometers located close to the coast. Heat dissipation tests were carried out by heating the cableEs armouring alternatively at the pumping and observation piezometers, under different pumping rates and heating powers. The same cable was used to monitor the heating and dissipation phases in both piezometers. Heat dissipation rate at the buried cable is governed by thermal advection and diffusion. Thermal advection is proportional to groundwater flux, which varies in space and time. Thermal diffusion is essentially proportional to thermal conductivity, which is constant in time and varies little in space. Therefore, the latter can be used to for quality assurance, whereas the observed change in temperature at different pumping rates allows us to validate the mathematical model. The resulting empiric relationship between flux and heat dissipation will be used to estimate groundwater flux under natural conditions.



**Multi-corehole thermal tracer tests using DTS to identify flow pathways in a fractured dolostone aquifer**  
**Abstract n°2036**

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KEYWORDS: DTS, Fractured Rock, Aquifer, Thermal Tracer

Modern fibre optic distributed temperature sensors (DTS) with improved spatial and temperature resolutions have allowed for the development of novel borehole applications in many different geoscience fields. We present recent advances in the application of DTS for identifying hydraulically significant fractures and karst features within a regionally important fractured dolostone aquifer. Several thermal tracer tests were conducted at the Bedrock Aquifer Research Station on the University of Guelph campus in Guelph, Ontario, Canada. The site was designed to study the Silurian dolostone aquifer used by the City of Guelph (population 125,000) for its municipal water supply and includes a cluster of 9 bedrock coreholes (6 vertical and 3 inclined), closely spaced from 7.5 to 70 m apart in a 75 x 75 m area. A network of custom designed composite fibre optic cable was installed in 8 of the coreholes and spliced together on the surface to form a continuous loop of approximately 1750 m. The coreholes were then sealed with flexible borehole liners to prevent vertical flow and hydraulic cross-connection between hydrogeologic units. Two different thermal tracer tests were conducted to assess the hydraulic properties of the aquifer sequence including- (1) multi-corehole active-DTS tests to identify and quantify ambient groundwater flow and flow features+ and (2) forced gradient hot water injections to identify hydraulic connections between coreholes. Results are repeatable and identify several discrete hydraulically active flow zones throughout the aquifer sequence and provide critical information as to which porosity features are laterally continuous and hydraulically significant. Thermal tracer tests using the multi-corehole fibre optic network and high performance DTS delivers an efficient way to test a large number of boreholes and provides insights in three dimensions often not achieved through single corehole tests.



# Origin of groundwater and CO<sub>2</sub> in the crystalline environment of Saint Galmier, France

## Abstract n°2037

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**KEYWORDS:** groundwater age, isotope tracers, noble gases, CO<sub>2</sub>-rich hydrosystems

The Badoity natural mineral water in Saint Galmier, France was investigated in order to determine the origin of the water, the carbonic gas and the residence time of groundwater in the fractured granite aquifer. Two distinct populations of sparkling natural mineral water were identified based on groundwater geochemistry (major ions,  $\delta^{18}\text{O}$ -2H,  $\delta^{13}\text{C}$ ,  $^3\text{He}$   $^4\text{He}$ , noble gases)- i) a relatively low-mineralized and young (below 30 years) groundwater and (ii) highly mineralized, CO<sub>2</sub>-rich, deeper and older groundwater. The residence time of groundwater was estimated using radio-chronometers ( $^{14}\text{C}$ ,  $^3\text{H}$ ,  $\text{SF}_6$ ,  $^{39}\text{Ar}$  and  $^{85}\text{Kr}$ ). However, in our study area the use of such tracers is complicated by a series of factors- (i) degassing of upwelling water due to high pCO<sub>2</sub> pressures may lead to a decoupling of the gas (age) and water (age) and makes  $^{14}\text{C}$  dating very difficult+ (ii) the fractured crystalline basement with various degree of weathering causes very heterogeneous hydraulic and geochemical conditions+ (iii) high water temperatures at greater depth and elevated U contents in the rocks facilitate the release of radiogenic isotopes. Most of these factors were overcome by the completing combination of suitable methods e.g is the  $^{85}\text{Kr}$  dating method much less sensitive to degassing compared to other gas based tracers.



**A new efficient implementation of the Fourier-Galerkin method for solving Dispersive Henry problem with contaminant transport**  
**Abstract n°2038**

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KEYWORDS: Density driven flow - Saturated Porous media - Fourier Galerkin method

Density driven flow in saturated porous media is encountered in a board spectrum of environmental and engineering applications including CO<sub>2</sub> sequestration, seawater intrusion and geothermal systems. The Fourier-Galerkin (FG) method has been mainly used to obtain exact solutions for density driven flow problems as it doesn't suffer from any numerical errors, except for the error associated with truncating the infinite Fourier series. However, it is known that for high truncation orders the FG method becomes impractical. This is why the use of this method has been limited to simple synthetic cases as the highly diffusive Henry problem. Moreover, by virtue of the nonlinear dependence of the dispersion tensor on the velocity components, the use of the FG method is only limited to purely diffusive cases. In this work we develop a new sound implementation of the FG method to obtain an exact solution for the dispersive Henry problem which is known to be more appropriate for benchmarking codes than the purely diffusive problem. With this implementation, the velocity dependent dispersion terms are managed by numerical integration via an adaptive order technique that controls the integration numerical errors. The efficacy of the new implementation is reinforced by developing a specific algorithm to reduce the number of evaluation of the Fourier series and simplify the evaluation of the nested summations terms. It is also underpinned taking advantage of parallel computing on shared memory architecture. Furthermore, several recent studies used the Henry problem to investigate contaminate transport in coastal aquifers. Yet, there is no exact solution for such problem. Here the new FG implementation is extended to include contaminant transport in the dispersive Henry problem. The new implementation is used to develop exact solutions for several cases by considering differences in molecular diffusion, longitudinal and transversal dispersion coefficients and contaminant occurrence. The accuracy of the developed solutions is investigated in terms of the truncation orders of the Fourier series and by comparison against advanced finite element code.



**Groundwater recharge and vulnerability of shallow aquifers under a Sahelian metropole- N'Djamena (Chad Republic)  
Abstract n°2040**

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**KEYWORDS:** N'Djamena, Environmental tracers, Groundwater vulnerability

In the Lake Chad basin, N'Djamena, the capital of Chad, lies in the north western part of the Chari Baguirmi region, on the Chari floodplain and the right bank of the Chari River. In detrital Quaternary sediments, the groundwater system globally consists of two main layers between 6 and 13 m, and 30 and 46 m deep respectively. These two aquifer layers might locally be hydraulically connected. Only about 23% of the urban population, which is steadily increasing, is connected to a network of drinking water supply originating from the deeper layer. The city has no functional sewage system. An open canal, which collects domestic sewage, crosses the city from the north to the south. Moreover, many old mines in the outskirts of the city form depression where water remains stagnant almost permanently. As in most African cities, groundwater pollution occurs firstly from direct infiltration of rainfall after leaching the soil, and in a second time when the water table reaches the bottom of the latrines. In such a context deciphering recharge processes is of major concern. The data obtained from different sampling campaigns and analyses (major ions, traces,  $^{18}\text{O}$ ,  $2\text{H}$ ,  $^{13}\text{C}$ ,  $3\text{H}$ ,  $^{14}\text{C}$ ), conducted between 2002 and 2003 (Kadjangaba thesis), and 2010 (IAEA TC project) underlined the major role of the Chari River, and allowed to characterize and localize the recharge of urban runoff. The results also reveal that the deeper part of the Quaternary water body is still relatively well preserved despite anthropogenic pollution on the surface. Nevertheless, this aquifer layer stays vulnerable in case of over exploitation that might drain polluted surface water to deeper levels.



## **Diversity and functionality of groundwater viral communities**

### **Abstract n°2041**

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**KEYWORDS:** Groundwater, Viruses, Horizontal gene transfer

Viruses are the most abundant and diverse biological entity on the planet and their impact is global. They affect microbial hosts through mortality, re-mineralization of nutrients, and horizontal gene transfer. While viral communities in surface freshwaters and marine systems received considerable attention in the recent past, our knowledge about viruses in groundwater is almost zero. Sampling pristine as well as organically contaminated groundwater from different sites in Germany, we started to shed light into the viral diversity and functionality. Viral communities were concentrated by nanofiltration and then analyzed by means of viral tagging, metagenomic pyrosequencing, and protein cluster (PC) analysis. Viruses in groundwater were dominated by dsDNA bacteriophages of the families of Myoviridae, Podoviridae and Siphoviridae. The dominance of tailed-morphology Myoviridae in our groundwater sample was confirmed by Transmission Electron Microscopy (TEM). Comparison of the groundwater viral metagenomes with different metagenomes from a variety of other aquatic environments (marine and freshwater) revealed that the freshwater viral consortia were more close to each other than to marine consortia. However, no significant difference between freshwater (including groundwater) and marine viral assemblies could be found, which is likely due to the insufficient sample size of the current database. The cluster richness of each virome, deduced from PCs, was significantly different between the groundwater environments from others, with the highest diversity being observed in groundwater. Mapping metabolic pathways from viral metagenome data obtained from groundwater of an organically polluted site revealed that viruses in this system carry bacterial functional genes related to biodegradation of the site-specific contaminants. Current research is directed to the functional role of viral communities in groundwater ecosystems.



**Electrical Resistivity Tomography (ERT) as a tool for the assessment of karst features  
in carbonate aquifers.  
Abstract n°2042**

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**KEYWORDS:** electrical resistivity tomography, fault zone, groundwater flows, karst

In the Mediterranean Basin, most of the groundwater resources are located in carbonate aquifers. In the Montpellier area, southern France, several regional faults affecting these carbonate reservoirs control the location of the main flow paths and thus the groundwater flow. These faults zones are characterized by a strong anisotropy of permeability, sometimes induced by an offset between compartments on both sides of the fault. Fluid flow generally occurs preferentially in the fault-parallel direction. Fractures located in the damaged zone of these faults, partly responsible for this anisotropy, are also at the origin of karst features development. Thus, to identify the main permeability components of such fault zones, it is essential to identify - (i) the structure of the damaged zone+ - (ii) the fault offset and, - (iii) the presence of karst features and their geometry. A methodology based on Electrical Resistivity Tomography (ERT) was thus proposed with this purpose. It allowed - (i) to highlight en-echelon fracturing in the studied fault-zones+ - (ii) to identify the presence of karst feature and - (iii) to precise their geometry. Though the fault was a priori considered as a conduit-barrier, we demonstrated that groundwater flow across the fault probably occurs due to the en echelon offset of the fractures and that karst features preferentially located along bedding planes control most of the flow.



**Assessments of groundwater recharge in the hyperarid Tarapaca alluvial fan  
(Northern Chile) at various scales of time and space.  
Abstract n°2044**

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**KEYWORDS:** aquifer recharge, environmental tracers, groundwater modelling, Pampa del Tamarugal

In drylands, the scarcity of streams and their temporal variability have led to a particular interest for groundwater. The alluvial fans describe complex sedimentary patterns. In order to understand the current and future behavior of groundwater resources, especially under climate change, the recharge processes need to be properly characterized. The study focus on Northern Chile, where high seasonal precipitation events occur between December and March in the Precoyuntura (4500 m a.s.l.) associated with ENSO variations. These events lead to local flooding above the alluvial fans in the downstream hyperarid Central Depression (1000 m a.s.l.)+ where the regional size Pampa del Tamarugal Aquifer is located. This strategic resource is one of the main issues in Northern Chile. Groundwater recharge through the Tarapaca Alluvial Fan (TAF) - around 150 kmC - is assessed by combining environmental tracers, piezometric records, geomorphic surveys and flow modelling at



different scales of space and time. Vertical flows in the vadose zone were assessed by sensitivity analysis, computed with Hydrus-1D software, at the flood events scale. The saturated flows, at the TAF scale, were assessed by 2D flow modeling (Feflow software). These results are in line with the piezometric records analysis and highlight contrasted recharge areas, correlated with geomorphic patterns, implying various recharge rates between few mm.d-1 and mm.yr-1. In some areas, at distance from the TAF, the recharge can be considered as nil. Groundwater age inferred from <sup>14</sup>C (between 14 and 107 pMC) and dating tools (<sup>3</sup>H He, SF<sub>6</sub>, CFCs) sampled at the water table depth, are compared with groundwater ages estimated from flows modeling. The assessment of groundwater recharge in dryland alluvial fans, need to be quantified by multidisciplinary approaches (environmental tracers, piezometric records, geomorphic surveys, flow modelling) at different scales of space and time.



## **Transient flow in alluvial aquifer and detention basin design, River Po (Italy) Abstract n°2047**

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KEYWORDS: KEYWORDS- transient, flow, saturation

KEYWORDS- transient, flow, saturation The aim of the study is an hydrogeological quantitative analysis of the interaction between the Po River (Piedmont, Italy) and the shallow unconfined aquifer, oriented to support the planning of a detention basin system, through the implementation of groundwater flow transient simulation model (FE-FLOW). The simulation model evaluates the piezometric trend and the saturation time of the aquifer, until groundwater spread on the topographic surface. The aquifer-river system is long about 9 km and wide 1.5 km, is located 33 km east of Turin+ the flooding-control system offers a significant reduction degree of the hydraulic risk into the town of Casale Monferrato. The simulation model includes a finite-difference mesh with 523.086 cells referred to 3 slices and 2 layers+ the 3-D vertical discretization is controlled by a geological and geophysical survey. The calibration has been made on the hydrologic year 2015, using a network of piezometers measured with monthly frequency, with daily-recording in a river gauge and a thermo-pluviometric station into the study area. The interaction between river boundary conditions (1st order, Dirichlet) in the flooding area and the aquifer has been setup by a dedicated plug-in (IFM-Basin), assigning 22538 spatially distributed time-series of flood level on the ground. The response to flooding events with a return-time of 5 years shows significant differences in the groundwater flow, depending on the seasonal initial conditions (wet-dry). The response to extreme flood event (200 years return-time) shows the areal progression of the aquifer saturation starting from the artificially depressed zones (drainage channel, artificially lowered surfaces). The effect due to the shallow impermeable bedrock causes groundwater growth to the ground before the water flows from the control levee. Groundwater can be considered an important factor in the evaluation of the efficiency degree of the flood-risk mitigation structure.



**Hydrodynamic parameterization in 2D fractured heterogeneous porous media-  
example of the Damour (Lebanon)  
Abstract n°2048**

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**KEYWORDS:** Fractured porous media - Hydrodynamic parameterization- refinement indicators

Fluids flow through fractured porous media is a process encountered in many areas of the geosciences ranging from groundwater hydrology to oil production. This work contributes on the development of a robust and efficient numerical model for the parameterization of the hydrodynamic in fractured heterogenous porous media. The developed model allows for determining the hydrodynamics parameters of the porous media as well as the geometrical distribution of the zones of heterogeneity using local measurement data. It is based upon specific technique for each step of its algorithm. The refinement indicators algorithm is used for adaptive multi-scale parameterization. At each step, this algorithm ranks new possible parameterizations in the domain by using the global refinement indicators and selects from the remaining nominated parameterizations, the one which gives the best actual decrease in the objective function. For each level of refinement, the Levenberg–Marquardt method is used to minimize the difference between the measured and predicted data that are obtained by solving the direct problem with the mixed finite element method. Sensitivities of state variables with respect to the parameters are calculated by the sensitivity method. The adjoint-state method is used to calculate the local gradients of the objective function necessary for the computation of the refinement indicators. The algorithm is tested on synthetic cases. It is also applied to the Damour coastal aquifer system, south of Beirut (Lebanon). In ideal cases (“enough”) measurements, spread over a wide range of values), the suggested algorithm allows to identify the proper parameterization and the hydraulic parameters for each zone. The measurement errors do not seriously affect the algorithm behavior. The algorithm provides a good parameterization even in case of lack of data.



**Managed Aquifer Recharge in Barcelona with reclaimed and pre-potable water-  
towards a practical application in urban water supply  
Abstract n°2049**

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KEYWORDS: Aquifer recharge, injection well, non-potable water

Barcelona metropolitan area is already well-known by hydrogeologists working in Managed Aquifer Recharge (MAR). Four different techniques co-exist in a relatively small area, including- infiltration ponds, river bed scarification, hydraulic barrier against sea water intrusion and Aquifer Storage and Recovery (ASR) wells. Despite the amount of existing publications and projects demonstrating its feasibility, MAR is still perceived by operators and administration as an uncertain technology and difficult full-scale solution for the water supply in Barcelona area. The EU funded project DESSIN (2014-2017), aims at demonstrating the technical feasibility of injecting and recovering pre-potable water. The demonstration phase takes place in one of the reversible wells of Sant Joan Despí Drinking Water Treatment Plant (Barcelona, Spain), equipped with injection and recovery system (36 and 220 L s respectively). The demo site is located in one of the most transmissive aquifers registered (there are records of hydraulic transmissivity up to 15.000 m<sup>2</sup> d). The injection water comes from an intermediate stage of the drinking water treatment plant, after sand filtration. First results are already available, including a comprehensive analysis of international guidelines and recommendations for ASR using non-potable water, evaluation of risks of sand filtered water as injection water and pilot experiment simulating ASR. An innovative method to simulate the well screen has been developed and tested, allowing the quantification of extracellular polysaccharides along the injection period. The project will open the discussion about the practical implementation of MAR systems, and specially ASR in Barcelona area. These techniques could be considered as an alternative in the renovation of drinking water production schemes.



**Recharge conditions of Mediterranean mountain karst aquifers. Consequences for resource protection and proactive management**  
**Abstract n°2050**

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**KEYWORDS:** Karst, groundwater resource, management, Mediterranean, engineering, Lebanon

Mediterranean mountains are commonly made of carbonate rocks where karst processes acted for long time since the Miocene. Large, well developed, often multi-storey conduit systems are known everywhere, originating large karstic springs. These aquifers are recharged by direct infiltration of rain and snow melting above 1200-1500 m asl. The pluriannual hydrographs of some Lebanese springs, typical of Mediterranean mountain karst, were studied by means of correlation and spectrum analysis. Despite their location in the upstream part of main valleys, these aquifers, feeding karst springs, do not function as true karstic aquifers, showing a typical slow infiltration and a residence time longer a few months. For a start snow melting was suspected to delay the infiltration, because it is a recharge process long of some months, as shown when deciphering the signal. However field works showed that at its surface the karst is coated with a continuous cover of screes and slope debris resulting from the weathering of the epikarst especially by freezing, particularly during the cold phases of Quaternary. The consequence is a partial plugging of conduits in the infiltration and in the phreatic zones which delays the flow in a long infiltration phase, followed by a relatively long and slow baseflow phase. Among several consequences, two must be considered- i) the Mediterranean mountain karst aquifers may be generally well protected from fast infiltration and thus relatively resistant toward pollutions+ ii) any important work at the surface, scrapping the debris mantle, may change the infiltration conditions, then favouring fast infiltration and creating risks of pollution. Mediterranean mountain karst aquifers are interesting examples for proposing some engineering solutions for exploiting karst groundwater resources.



# CONTRIBUTION OF MANAGEMENT OF THE GROUNDWATER AT THE DAKHLA BAY

## Abstract n°2051

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KEYWORDS: Dakhla, Geophysics, Geometry, mathematical model.

The aquifer of Paleogene-Cretaceous is the most important water resources, by its size and its capacity, in the Sahara Hydrologic Basin, southern Morocco. Its extension is about 110,000 km<sup>2</sup>. The deep aquifer is fossil with a very low rechargeable. This is confirmed by groundwater depletion in heavy isotopes. The reservoir reaches 10 bar in artesianism and 82 °C. In the area of Dakhla (southern Morocco), the deep aquifer of The Paleogene is the only source used for all sectors. It's encountered at depths ranging from 150 to 400 m. It is generally artesian. This is a groundwater considered as fossil, which water is practically non-renewable because of the low rainfall (30mm). Drilling has high productivity, operating flow vary from 5 to 40 l/s. The water quality is about (2 to 3 g/l). The geophysical data have resulted a good property of the geometry of the Aquifer. Geostatistics, especially kriging, led to a better interpolation electric surveys, the top varies between the altitudes 44 and -525, and the bottom between 50 and -740. The established numerical model is consistent with the observations made in the field and it has been used in conditions of permanent and transient. The correlation is quite satisfactory with a margin of 0.5bar, simulations have provided a better understanding of the local water supply. Future scenarios were used to determine the impact of flow levied on the piezometric evolution of the web. The increase in irrigated area up to 150 ha years the scenario that will have the greatest impact, the groundwater level can reach 10m in 2025, But the use of unconventional resources can remedy this situation.



## Which funding for Research and Innovation for Water in Europe and Beyond Europe? Abstract n°2052

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KEYWORDS: Research funding, Water challenges, European and national levels

Research and Innovation are funded through different mechanisms- single funder (FP7, National Programmes) or bilateral funding, and since 2008, an increased role of the multilateral mechanism via the Joint Programming Initiatives (JPIs). The overall aim of the Joint Programming process is to pool national research efforts in order to make better use of Europe's precious public R&D resources and to tackle common European challenges more effectively. With the switch of H2020 to Innovation actions, JPIs will play a major role for European academic and applied research. Since 2012, the Water JPI has assembled a cohesive group of European RDI Programmes from 20 partner countries plus the European Commission. The Water JPI has developed a joint vision on water challenges, a shared Strategic Research and Innovation Agenda and an operative management structure, which has reached a critical mass of 88% of the public annual RDI expenditures (around 500M€ per year). Progress towards alignment of national research agendas is a crucial priority enabling the optimal use of national research funds. The Water JPI is launching annual Joint Transnational Calls- 2013 call on emerging contaminants (9 M€, 7 projects funded), 2015 call on wastewater treatment and water reuse (15.2 M€, 16 projects funded) and 2016 call on water and agriculture challenges (25.5M€ - call deadline- 19 April 2016). The Water JPI has encouraged and stimulated the opening of the JPI to several international partner countries (5 involved in the 2016 call) to become privileged partners in international cooperation, and increasing the leverage effect and expected impacts. The presentation highlights the major achievements, the objectives (JPI activities budget amounting to at least 20% of the publically funded RDI expenditures in 2020) and the future activities such as the development of a water knowledge hub and progressing an online platform on infrastructure & mobility, in cooperation with the research communities.



**An integrated hydrogeophysical approach for karst water assessment and management in humanitarian context - Mahafaly Plateau in Madagascar  
Abstract n°2053**

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**KEYWORDS:** Water management, karst, hydrogeophysics, humanitarian project.

This research study has been applied to a humanitarian project implemented in the Mahafaly plateau (3600km<sup>2</sup>), in southern Madagascar. Its objective was to allow a strategy for safe and sustainable water access for the most vulnerable population. This operational research combined several prospecting tools and technologies (geology, hydrogeology, hydrogeophysics and hydrochemistry) to better understand the hydrogeology of this poorly documented area. The first phase consisted in a comprehensive characterization of the groundwater resource, including stock assessment, vulnerability to pollution and over-exploitation appraisal. The second phase consisted in the determination of the most favorable locations for the implementation of groundwater drawing infrastructures mainly through geophysics due to constant sand cover (2m). The third on-going phase is to achieve an automatic piezometric and meteorological monitoring to ensure the sustainable management of the groundwater resources. The study identified two main groundwater resources- a deep one (below 160m) located in karst conduits and a shallow one located in the near surface within recent sediment overlying the karst formations. Hydrochemical results highlighted the vulnerability of the deeper aquifer to saline water intrusion. Hence, the second phase focused on the shallow hydrogeological target. A piezometric survey (217 measurements) reveals a general flow in the west direction. A combination of geophysical measurements at moderate cost (262 TEMfast soundings, 2588 Slingram measurements, 35 electrical soundings) was used to investigate the complex and discontinuous geology of the recent sediments. Nine positive boreholes and wells were positioned. Despite numerous measurements, the study area remains insufficiently known to ensure a sustainable water management. In the global change context, it is primordial to prevent any over-exploitation. Therefore the project installed piezometric and meteorologic sensors and setup a team with local institutions to ensure data collection during ten years. This part of Mahafaly plateau is now a unique observatory for drought warning in one of the largest karst system of the southern hemisphere.



## Hydrogeology of volcanic debris avalanche deposits Abstract n°2055

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KEYWORDS: Breccia avalanche deposits, groundwater, volcanic island

The hydrogeology of volcanic islands is deeply studied and precisely described, with the major goal of providing and managing water resources for populations. Modern hydrogeological conceptual models of basaltic volcanic islands are essentially based on studies concerning lava flows aquifers, yet breccia deposited by debris avalanches represent a significant volume at the scale of a volcanic edifice. These breccias have so far been neglected in conceptual models because these deposits are considered as low permeability aquitards, and because their origin has only been recently understood. In this research, a multidisciplinary approach combining geology, geophysics, hydrology, hydrodynamics, and hydrochemistry has been conducted to characterize the geological structure and hydrogeological properties of large debris avalanche breccias from the basaltic Island of La Réunion (France). The results allow identifying a continuous saturated zone inside the breccia deposits. The breccia's permeability is mostly a function of the induration state+ "young" deconsolidated breccia ( $K \sim 4 \cdot 10^{-4}$  m s) are more permeable than "old" indurated breccia ( $K \sim 4 \cdot 10^{-6}$  m s). Moreover, it appears that the actual deformation in unstable slope areas contributes to the development of another type of aquifer ( $K \sim 1 \cdot 10^{-4}$  m s) inside the old indurated breccia aquitard. Spring recession curve analysis and modeling allow describing the hydrodynamics of these deposits. On the basis of these results, a new type of aquifer is identified in basaltic volcanic context. A genetic classification of this kind of aquifer is proposed, as a function of the history of breccia deposits (mostly diagenetic processes and gravitational deformation).



**A methodology to reduce the intake of nitrate to rivers and coastal regions in fissured and altered hard-rocks**  
**Abstract n°2056**

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KEYWORDS: Natural denitrification, Interfluve, Brittany.

The hydrodynamic and hydrochemical natural functioning of fissured and altered igneous or metamorphic basement, in areas of low slope gradient as the Armorican massif (France), results in redox groundwater organization, which is specific to such geomorphic conditions. Indeed, beyond a 30-50 m depth, a reductive layer in relation to nitrates always exists, depending on the type of rock, structure of the aquifers and hydrodynamic. In areas of priority protection (catchments with the stream for drinking water supply, coastal watersheds, etc.), a change in the distribution of nitrogen inputs into the aquifers could provide a solution to the nitrate pollution of surface waters by taking into account, in addition to the model of groundwater flow, both the flow conditions of nitrate transport and the redox stability domain of nitrates. The solution would be implemented as the following guideline. Application of chemical and organic fertilizers in the vicinity of streams, where the flow lines reaching the rivers are entirely included within the shallow oxidizing zone and natural denitrification of groundwater cannot occur, would be prohibited or strictly controlled. Fertilizer or manure would be allowed only around interfluves, where hydraulic flow lines go through deep denitrifying level, thus giving a better approach to the delimitation of preferential manuring areas. Numerical simulations show that significant improvement is possible in less than 2-5 years, mainly because the stocks of nitrates are located in the most renewed parts of the aquifer. Management measures would be applied to facilitate deep infiltration and prevent shallow nitrate transfer, such as ploughing lines perpendicular to slopes of hillsides, or removal of drains in nitrogen spreading areas. Finally, the stresses generated by this approach would be minimal and with no significant impact on agricultural production, which should facilitate its application.



**Consequences of mine depressurisation on a regional carbonate aquifer, Tata,  
Hungary  
Abstract n°2058**

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**KEYWORDS:** mine dewatering, groundwater depression, recovery, spring, karst, Tata

Mine dewatering operations in the Transdanubian Mountains, Hungary between 1960 and 1990 caused significant groundwater depressurisation and the vanishing of significant karst springs in the regional carbonate aquifer. Following the termination of mining operations, the flow system started to recover and karst springs are reappearing. The reactivating springs cause environmental and engineering problems. The aim of the present study was to characterise the recovering flow system, to delineate affected areas and to provide predictions on the location and timing of spring reactivation. In order to investigate future hydrogeological conditions, geological assessment, piezometric and spring discharge measurements, hydrograph analysis and hydrochemical analysis were undertaken. Spring locations are aligned with deep tectonic structures both in uncovered and confined aquifer zones. The analysis of well hydrographs indicates that there is no hydraulic connection between shallow and deep groundwater bodies. The analysis of recovery curves suggests that equilibrium groundwater level will be reached within a few years from the time of the analysis. The chemical composition of most reactivating springs indicates karst water origin. Some springs discharge shallow groundwater and show signs of local pollution. Geochemical data indicates significant changes in karst water chemistry in response to groundwater depressurisation and the following recovery. While bicarbonate concentration decreased, sulphate concentration increased during mine dewatering operations. Recent hydrochemical data indicates the delayed rebound of main water component concentrations, suggesting the geochemical recovery of the groundwater system. A further increase of piezometric levels and reappearance of karst springs along tectonic features are expected to impact on built-up areas. Reactivating karst springs will facilitate the reconstruction of parklands and baths and will positively influence the revival of groundwater dependent ecosystems.



## Hard-rock aquifers in african intertropical zone (Côte d'Ivoire) Abstract n°2059

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KEYWORDS: Fissure, Groundwater ressources, Positioning of drillings

The management of the water resources which metamorphic or magmatic hard-rocks contain, because of their strong heterogeneity and anisotropy, supposes a knowledge and a conceptual modelling of the reservoir as exact as possible. The complexity of these hydrogeosystems implies a plurimethodologic approach carrying on the observation and of measurements on the outcrops, in the careers, the water-points, the use of maps and various types of aerial photographies, geophysics, hydrochemistry, etc.... Information obtained from the work carried out on metric scales to kilometric in many areas, often using experimental sites, results in proposing a scheme of the fissured hydrogeosystems. In this scheme, various surface formations, mainly of the alterites with particularly varied characteristics, top on hard rocks basement comprising of the networks of fissures hydraulically active, more or less regularly distributed, mainly of tectonic origins (fractures), resulting from the superposition of the effects of phenomena generating discontinuities. Alterites and hard rocks constitute a unit compared to a double-layered aquifer of the drain (fissured hard rock) - capacity (surface incemented rock) model. The drain allows significant but located flows and transmits quickly and far the influence from pumpings, following certain preferential directions. The capacity provides the main part of exploitable volumes of water, coming from interstices, but slowly. It is the complementarity of the components of this model which makes its hydrodynamic effectiveness. This organization and the availability of suitable technics (rotary-percussion drilling), involved, since the middle of the Seventies, the exploitation of the water resources of the basement by the intermediary of the fissures hydraulically active networks. The hydraulic characteristics of the fissured medium conditioning the possibilities of management are mainly forced by the interactions between the alterites and fissured hard rocks and the distribution of the fissures, in particular in-depth or following certain privileged directions.



**Granitic hard rock aquifers deep geometry from a 3D geological model based on an exceptionally high density geophysical survey  
Abstract n°2060**

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**KEYWORDS:** Hard rock aquifers, weathering profile, deep discontinuities, electrical tomography, well siting

Survey of groundwater resources, especially in hard rock context, requires the use of geophysical methods. In this context, electrical resistivity tomography (ERT) is commonly used to image the structures associated to the weathering- the saprolite and the stratiform fissured layer, and deeper discontinuities. However, the geological and hydrogeological interpretation of the results is often complex, and boreholes siting has often a uncertainly success rate. We present the results of a high-resolution geophysical survey performed in France (50 km of ERT profiles, dipole-dipole and pole-dipole arrays, on 10 sq km area) and the results of 4 deep vertical and inclined boreholes. The results show significant vertical resistivity contrasts (superficial subhorizontal layers with variable resistivity, and deep resistants related to the weathering profile) confirmed by the boreholes. The base of the conductor corresponds to the base of the connected fissured layer. Moreover, deep subvertical conductive structures are highlighted, and interpreted from boreholes as the deepening of the weathering along fault zones related to a regional graben. These low permeability ( $<10^{-6}$  m s) structures have an exceptional extension- depth  $> 200$  m and width  $> 400$  m, kilometeric length. On the basis of these data, we map the base of the fissured layer all over the studied area, the extension of deep weathered zones, and the one of some faults that offset the weathering profile. The resulting model provides a precise description of the weathering profile geometry. Especially, it highlights the absence of correlation between the orientation of the main tectonic structures and topography (valleys) but often a topographic control on the depth of the weathering profile. For groundwater surveys in such a context, we recommend an optimum profiles mesh of 300 x 400 m for a precise location of the main weathered structures edges, and the identification of artefacts induced by lateral 3D effects.



**Comparison of temperature from DTS and ERT with direct measurements during heat tracer experiments in heterogeneous aquifers**  
**Abstract n°2062**

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KEYWORDS: DTS, ERT, heat tracer

Geothermal field characterization and heat tracer experiments often rely on scarce temperature data collected in boreholes. Electrical resistivity tomography (ERT) and distributed temperature sensing (DTS) have the potential to provide spatial information on temperature changes in the subsurface. In this contribution, we show how DTS and ERT have been jointly used to investigate the heterogeneity of an alluvial aquifer during a heat tracing experiment under forced gradient conditions. Optic fibers were installed in the heat injection well and in two piezometers intersecting the main flow directions at 8 m from the injection well. These piezometers were also equipped with ERT. The DTS measurements in the injection well clearly show the two-layer nature of the aquifer. After the end of injection, the temperature in the bottom part of the well decreases faster than in the upper part due to the higher water flux. Those results are confirmed by DTS measurements in natural flow conditions during a heating wire test. DTS and ERT in the cross-panel both show the vertical and lateral heterogeneity of the aquifer. Temperatures only increase significantly in the bottom part of the aquifer where advection is predominant. However, strong differences are observed laterally. ERT additionally shows that the hot plume is divided in two main flow paths, which is confirmed by direct temperature measurements. The comparison of DTS and ERT shows that one of the well is suffering from water mixing. Indeed, temperatures from DTS are homogeneous over the whole thickness of the aquifer, whereas ERT temperatures, less affected by local conditions, are varying. Our study demonstrates the value of spatially distributed measurements for the monitoring of heat tracer experiments and highlights the issue of multilevel sampling. The detailed temperature measurements can be subsequently used in hydrogeological modeling to better estimate heat flow and transport parameters.



**Interest and limits of electrical tomography for groundwater survey in metamorphic hard rock aquifer context**  
**Abstract n°2063**

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**KEYWORDS:** Hard rock aquifers, metamorphic rocks, weathering profile, electrical tomography, well siting

In hard rocks, and particularly in the metamorphic context, borewell siting for groundwater abstraction is complex. Consequently the failure rate is currently higher than in other hard rock contexts. In this study, we valorize the experience of more than 10 years of surveys aiming at prospecting for new natural mineral water resources in the Southern part of France, on the basis of a multidisciplinary approach (geology, hydrogeology, 39 km of ERT profiles, 70 drillings). The calibration of pole-dipole electrical profiles on exploratory boreholes highlights several important results. First, electrical profiling is not accurate to identify the lithology. Second, the weathering profile (saprolite and the underlying fissured layer) is clearly identified by the electrical geophysics in most cases. In contrast to granites, and in accordance with lithological contrasts and folding, in such metamorphic rocks the depth of the interface between the weathering profile and the underlying fresh rocks is strongly varying spatially. The majority of the water inflows is located at the transition area between the upper conductive and the lower resistant bodies, attributed to the top of the fissured layer. Third, vertical conductive anomalies, intersecting the resistant substratum at depth (>50 m), are observed. These anomalies are generated by two main types of structures- (i) a saturated fractured medium (of variable permeability) (ii) a strongly weathered low permeability medium. Saturation by highly mineralized also generates conductive anomalies. This case study defines more precisely the capacity of hydrogeophysical interpretation for surveys in the context of metamorphic rocks. The fissured layer is well imaged by geoelectrical methods. More than 90% of exploration wells show there an interesting productivity ( $Q > 2 \text{ m}^3 \text{ h}$ ). As regards the deep conductive anomalies, the success rate is lower ( 70% of wells with a  $Q < 1 \text{ m}^3 \text{ h}$ ), due to the equivalent geophysical signatures of high and low permeability zones.



# Can Rainwater Harvesting in india Save Groundwater from Disastrous Situation? Abstract n°2065

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KEYWORDS: Rainwater Harvesting, Groundwater, Disastrous, Situation

India's water supply comes mostly from rivers lakes, which are mostly polluted. Inadequate supply of good quality water resulted in increasing dependence on groundwater and its indiscriminate abstraction, causing water levels decline in many parts. Due to this, augmentation of groundwater resources through recharge is practiced in semiarid rural areas by simple rainwater harvesting structures for conserving local surface run-off. Despite over decades of much glorified publicized activities, debates have been ongoing for or against the large-scale acceptance of these technologies. The evaluation studies reported so far are highly qualitative with limited sketchy knowledge on hydrogeological situation and recharge structures' actual performance in specific locations, mostly reporting change in water availability, increased ground water table, revival of flow of rivulets, yields of crops, etc., based on secondary information collected from local farmers beneficiaries. No scientific quantitative analysis is done based on baseline chronological data. In this context, taking examples of rainwater harvesting structures for groundwater recharge in villages, based on the groundwater recharge and pollution assessment studies in different river basins, this paper highlights the evolution of the artificial groundwater recharge in India, achievements so far, local benefits and gaps in knowledge, possible negative impacts, the governance problems, and the extent to which these technologies have succeeded in finding solution in the arena of water conservation, and proved useful to solve water scarcity problems in any meaningful sense. The analyses indicate that water quantity that can be actually harvested depends on rainfall amount, catchment characteristics, runoff amount, water pollution, topsoil properties, and water infiltration and percolation rates to recharge the aquifers. Local users are not aware that surface runoff usually carrying pollutants along with can cause groundwater degradation. For successful implementation and revival of these approaches, creating public awareness and stakeholders' ethical values for water use and efficient management of groundwater use conflicts have significant roles to play.



**Soil erosion difference in different geomorphologic positions and land uses in karst peak-cluster depression**  
**Abstract n°2066**

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**KEYWORDS:** Soil Erosion+ Soil leakage erosion+ Karst peak-cluster depression+ Land use+ <sup>137</sup>Cs tracing+ Longhe karst ecological experimental site

With the combination methods of water flow monitoring, rock scratching, buried piles in soil and radionuclide <sup>137</sup>Cs tracing in a case study in Longhe karst ecological experimental site, Pingguo County, Guangxi, the soil erosion differences in different geomorphologic positions and different land uses in the karst peak-cluster depressions are showed clearly. There are four geomorphologic positions in the karst peak-cluster depression, peaks, strip between peaks, slopes and depression. On the slope, no much surface flow, the soil is eroded mainly by underground water, and underground soil leakage accounted for more than 75%. Only in the bottom of depression, soil was eroded mainly by surface water, and most soil lost into underground river from the sinkhole. From peak slope to depression, the total soil erosion modulus and the relative surface soil erosion contribution rates are increased gradually. There are also five kinds of main land uses in the karst peak-cluster depression, farmland, Kudingcha tea land, young Lignum Sappan land, shrub-grassland and pasture land. The soil erosion modulus of farmland has the biggest value, and with an annual increasing trend. The other four kinds of lands made the soil erosion modulus decreased with time, and the pasture land had the best soil protection effects. The human activities of the lands are the key causes to aggravate the soil erosion, especially to exacerbate the soil leakage erosion of the lands on the slope. With the treatment of rocky desertification and the ecological rehabilitation in Longhe karst ecological experimental site, the mean soil erosion modulus of the karst peak cluster depression decreases about 65% from 2003 to 2010.



## Groundwater dating and tracing by CFC in fissured medium (< 100 years) Abstract n°2067

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KEYWORDS: Dating, Pollution, Brittany

Chlorofluorocarbons (CFC) are anthropic organic compounds of origin, used since the Forties. Their concentrations there are uniform and increase more or less regularly. They are very employed in oceanography and also to estimate the age of groundwaters. In Brittany, it is the CFC11, associated with the tritium, which was tested in the Nineties to estimate the age of water of a fissured and weathered basement. Two experimental perimeters were employed, one on schist, in Finistere, the other on granite, in Côtes d'Armor. Special precautions were taken to avoid the pollution of the samples by the air or used equipment. The sampling were made using a set of two pumps. One of them (pump of guard) made it possible to establish a directed flow compared to a fissure. The other (pump of sampling), with a flow lower that of the fissure and to pump of guard, made it possible to carry out the sampling. The sample was collected in closed circuit under pressure in a sampler of glass closed by Teflon taps. The samplers were preserved in PVC cases completely filled of sampled water. Titrations were made by the Marine Chemistry Laboratory (pr. Le Corre, IUEM, UBO), in gas chromatography, with a circuit of introduction of the sample, extraction and trapping. The limit of detection of the CFC11 was of 0.02 ng l and the accuracy of 6%. The CFC11 varied from 0.11 to 3.90 picomoles l and the tritium from 0.8 to 4.9 UT. In the experimental perimeter of Finistere, if it was estimated that the apparent age of water increased downward one year every 1 to 2 m, that was not possible in the perimeter of Côtes d'Armor. Indeed, garbage dump buried involved pollution which was perceptible only by the CFC11, which, although that is not the expected result, does not miss interest for the identification of sites of old waste, nonlocatable by the usual indicators of pollution.



**STABLE ISOTOPES MIXING MODELS FOR GROUNDWATER RECHARGE  
CONTRIBUTION ESTIMATION- CASE OF PRECIPITATION (RAIN AND SNOW)  
CONTRIBUTION IN THE MOROCCAN HIGH ATLAS MOUNTAINOUS.  
Abstract n°2068**

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**KEYWORDS:** Stable isotopes, Water resources, High Atlas Mountains

Effective management of groundwater requires good control upstream of different supply sources and their contribution. In the southern watersheds of Morocco, the High Atlas Mountains represent the most important water supply of aquifers. Precipitation in these mountains fall as both rain and snow, but the snow cover is non-permanent and varies during winter. A common global practice in arid zones is upstream water storage in dammed reservoirs that captures mountainous snowmelt, and downstream agriculture irrigation. However, future climate scenarios announced that climate change may exacerbate the water problems of the region, which is already under high water stress. To better understand the hydrological relation between the High Atlas Mountains and the adjacent plains, several studies have been carried out in recent years using multiple isotope investigations. Previous studies have shown that the contribution of precipitation on the plains is negligible and the major recharge of the aquifers beneath the plains is provided by High Atlas stream flows, but the contribution rate of snow cover has not been quantified. Under the CRP 16166 project, a study is conducted on the contribution of the component snow recharge of surface water and groundwater in the High Atlas. Herein, we conducted a study on the contribution of the component snow recharge of surface water and groundwater in the High Atlas. The isotopic results from the 2 sites upstream catchments (Souss and Tensift) highlight the importance of spatial and temporal variabilities for isotopic signal. Using the stable isotope mixing model, the contribution of runoff derived from snowmelt ranges between 42 and 71% in the headwaters of the studied catchments, while the component of rainfall is 29 to 58%. The snowmelt contribution varies within similar range depending snow cover area during the year which is very sensitive to climate change. The results allowed us to have a clear quantification of the contribution of rain and snow from High Atlas and will be used to help refine hydrological conceptual models at a variety of scales.



**Regional assessment of contamination dynamics of a Eastern Mediterranean karst aquifer system**  
**Abstract n°2069**

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**KEYWORDS:** karst groundwater, wastewater contamination, groundwater monitoring

In the Eastern Mediterranean (Levant) drinking water supply is heavily dependent on springs fed by karst aquifers since prehistoric times. Those springs are often located within growing built-up areas and therefore spring water quality is frequently affected by contamination, e.g. from wastewater disposal or livestock farming. The aim of this study is to enhance the understanding of pollution dynamics of spring water resources in order to optimise raw water management and treatment. The analysis focuses on multiple parameters of 35 springs located in a study area of approx. 700 km<sup>2</sup> – the central West Bank north of Jerusalem and Jericho- (1) repeated sampling of E.coli, nitrate and chloride to quantify microbiological and chemical contamination and (2) continuous high-resolution monitoring of electrical conductivity plus partly spring discharge and nitrate concentration for 13 individual springs in order to assess hydrological system variability and contamination dynamics. The sampling was conducted during (1) stable low flow conditions (after > 5 months without any significant precipitation), (2) stable high flow conditions (after the rainy season) and (3) dynamic conditions during single precipitation events. Even adjacent springs with similar hydrogeological and land use settings display entirely different behaviour in terms of hydrological characteristics and dynamics of contaminants. Furthermore, on regional scale, there is no correlation between microbiological and chemical contamination. For example, some springs located in urban areas with a high wastewater borne flow fraction (nitrate concentration frequently ranges around or above 50 mg L) still display low quantities of faecal indicator bacteria, indicating a sufficient long residence time in the aquifer. Vice versa, several springs with a low chemical contamination load (low chloride and nitrate concentration) but high E.coli counts were detected. Because of the observed spatial and temporal heterogeneity, each individual water source needs to be specifically investigated and characterised, preferentially by high-resolution monitoring, to ensure an appropriate assessment. Special attention should be drawn to small springs which are frequently used for local water supply without any purification measures.



**Hydrothermal system important for local touristic development in North centre  
Algeria province  
Abstract n°2070**

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KEYWORDS: hydrothermal systems, tourism, balneology, hydrochemistry, Algeria

North Algeria center provinces is the seat of several thermal manifestation, known by them geological and structural complexity. This region is one of the significant geothermal areas in the country. Characterized by an arid climate, with intense dryness and a medium rainfall. The hydrothermal systems in the study area are reliant with huge geological fault at regional scale with following direction NE-SW. The combined chemical campaign and geological field works of the geothermal system, to evaluate the geothermal resource management and deep reservoir temperatures vary between 110 to 125 ° C estimated by chemical geothermometry. Thirty thermals outlet in the region were investigated. Field works and sampling were carried out in September 2015+ thermal waters samples were analyzed for major and minor dissolved chemical constituents. Samples collected from geothermal springs characterized by high temperatures varying from 40°C to 70 °C and conductivities between 1000 to 3500 IS cm. The total dissolved solids (TDS) of the thermal waters range from 1600 to 5800 mg l. the main thermal waters in study area are sodium-chlorinated types. The mineral equilibrium modeling indicates that the thermal waters in the region are under saturated. After chemical results for main hot springs, we find that these thermal waters are very important for balneology and cure of disease.



**Modelling the connection between groundwater abstraction and recharge to quantify baseflow for a RAMSAR listed wetland in Western Cape, South Africa  
Abstract n°2071**

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KEYWORDS: Groundwater modelling, salinity

With the increased scarcity of surface water across the south-west of South Africa, abstraction of groundwater has become a more common practice. This study aims to investigate the interactions between groundwater and surface water in the Krom Antonies River, an important tributary of the Verlorenvlei estuarine lake (RAMSAR #525). The most important issue facing the long-term health of the lake is the reliability of freshwater inflow, which mitigates elevated salinity levels. Recharge estimations for regional primary aquifers in the Sandveld region are between 0.2-3.4% of rainfall, where 20% of this recharge is abstracted for potato production. The majority of recharge occurs in the higher lying mountainous regions, inland of the Sandveld, where the Table Mountain Group (TMG) occurs. The TMG is mostly characterised by mature sandstones that provide a fractured rock aquifer system. These units also form the Piketberg Mountains that surround the Moutonshoek catchment through which the Krom Antonies River drains. In this study, a conceptual model will be constructed to depict how geology and topography impact on groundwater levels in the Moutonshoek catchment. Drilling suggests that in the lower lying areas the regolith is about 25 m thick, below which metapelites of the Malmesbury Group are found and which act as an impermeable basement. The delineation of the modelling domain is important so as to include all water that might flow into the Moutonshoek catchment. A digital elevation model, ArcHydro and cross sections will be used to refine the modelling boundaries, based on a cross-section through the study area, and this will form the boundaries of the MODFLOW model. The MODFLOW model is being developed to determine the sustainability of groundwater abstraction, taking into account possible changes in recharge due to changes in regional precipitation patterns. We predict that during low flows, groundwater abstraction will exceed total recharge and therefore have an impact on freshwater flows into the Verlorenvlei River and consequently salinity levels in the lake system.



**Hydrogeological functioning and groundwater contamination of two contrasted tropical volcanic basins belonging to the Observatory of Agricultural Pollution in the West Indies (OPALE)  
Abstract n°2073**

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**KEYWORDS:** Environmental Observatory, Experimental sites, Volcanic aquifer, Hydrogeological functioning, Groundwater, Contamination, West Indies

The Observatory of Agricultural Pollution in the West Indies (OPALE) focuses on the agronomical and hydrological processes that fit the strength of tropical volcanic settings. Two basins were instrumented in 2015 in Martinique and Guadeloupe, both set up under the “Plan Chlordécone 2”. They are run by a consortium of research teams from CIRAD, INRA, IRD and BRGM. The aim of OPALE is characterizing and monitoring of the pollution caused by agricultural practices on volcanic media under a tropical climate. The major challenge is to report the complexity of the water contamination in such heterogeneous context. The basins are Galion and Pérou on weathered (10-15 Myr) and un-weathered (<1 Myr) formations, respectively. Before setting-up the observatory, it was first required to have some insights on the contrasted hydrogeological functioning of the basins in order to optimize the groundwater monitoring. A multi-disciplinary approach was used to give a first hydrogeological scheme as well as a first groundwater contamination representation of the two hydrosystems. Firstly, geological surveys coupled to the interpretation of the resistivity models from heliborne electromagnetic surveys had shown a high spatial variability of volcanic deposits. Geological boundaries and the associated aquifers were identified. Secondly, a differentiation of hydrodynamic properties of the aquifers was achieved from the modelling of long duration pumping tests accounting for vertical and lateral compartmentalization. Thirdly, a hydrochemical and isotopic approach ( $^{18}\text{O}$   $^{2}\text{D}$ ,  $^{87}\text{Sr}$   $^{86}\text{Sr}$ ), coupled with water age dating tools (CFC,  $\text{SF}_6$ ) has allowed better characterize the nature of aquifers, the groundwater residence time and the mixing between groundwater bodies and the surface water. Finally, the compilation of all results helped to defined two contrasted hydrogeological conceptual schemes of andesitic volcanic environments according to the weathered level of the geological formations- predominant subsurface processes in weathered aquifers vs. predominant deep processes in un-weathered aquifers. This hydrogeological scheme was used to support the representation of the groundwater contamination, and finally to better understand the pesticide fate in groundwater.



**Investigation of possible surface contamination from a deep waste disposal well in  
Northeastern British Columbia, Canada.  
Abstract n°2075**

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**KEYWORDS:** deep waste disposal, injection wells, oil and gas

In British Columbia, Canada, deep injection wells are the only option for disposing of brines and other produced waters (including fluids used in hydraulic fracturing) generated as a by-product of oil and gas operations. Unfortunately, nothing is required by law to monitor the fate of the injected liquids. The purpose of this study is to investigate whether or not these injected fluids remain at depth as intended or rather, return to the surface along undefined hydraulic pathways. In order to address this question, a study is being conducted focusing on one disposal well in particular. This well is almost 50 years old and has been used to inject over 41 billion litres of liquids into a 2km deep formation. This same formation is also simultaneously exploited for natural gas. Measurements of water and gas chemistry at the surface will be used to detect the potential uncontrolled discharge of the injected liquids back to the surface. Measured parameters include salinity, pH, dissolved oxygen content and redox-potential of water as well as the concentration and composition of soil gases. Concentration contour maps of measured parameters will be used to evaluate the presence of anomalously high zones, whose source will be further investigated through isotopic and geochemical fingerprinting. In addition to the preliminary results of the geochemical survey, an examination of reservoir volumes, pressures, and piezometric conditions from the disposal formation and surrounding hydrogeological units will be presented.



**A simple method of waste waters biomonitoring for the risk assessment – a case study from mining area (Zlatna, Gold quadrilateral, Romania)  
Abstract n°2078**

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**KEYWORDS:** biomonitoring, mining pollution, waters

Zlatna is a mining area included in the Gold Quadrilateral of the Apuseni Mountains (Romania), known since preroman times. The extraction and processing of the Au, Ag, and Cu deposits caused continuous pollution. Although the mining activities are stopped, the pollution continues because water contacts the polymetalsulphurous reserves, opened on the large surfaces. The finding of a simple method to survey the pollution effect of the mine waste waters was the goal of our study. Biomonitoring based on water sampling, identification and quantitative determination of living organisms is a method of assessing the quality of water sources. These organisms are extremely important in maintaining the health of aquatic ecosystems and also represent a very useful instrument for rapidly assessing of the pollutants risk. The water samples for biological monitoring were seasonally collected from ground waters (wells and springs) and running surface waters. The count of total aerobic bacteria, yeast and molds were performed using the specific RIDAyCOUNT dry compact medium. The water invertebrates were sampled by qualitative filtration of water, counted and sorted to different taxonomic levels. Our results showed that acid mine waters (pH < 5.5) characterized by extremely high SO<sub>4</sub><sup>2-</sup> (>1000 mg l), Fe (>1000 mg l), and elevated Cu, Cr, Ni, Pb and Zn concentrations were inadequate for life support or proved a low concentration of mesophilic aerobic bacteria, yeast and molds, and aquatic invertebrates. The running waters had the highest concentration of microorganisms and invertebrates, the unaffected upstream areas being richer in aquatic organisms than the downstream of the mines. The ground waters showed an intermediate pattern of microorganisms content, but were richest in aquatic invertebrates. In conclusion, our researches suggests that the microorganisms and invertebrates water monitoring can be a useful method that allows the assessment of the capacity of water ecosystems to maintain life and it can also be a method in assessing the risks of the mining pollution.



**Thermal waters in the Villány region (Hungary) – hydraulic and geochemical interplay  
of karst and sedimentary basin  
Abstract n°2079**

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**KEYWORDS:** thermal water, hypogenic karst, hydraulics, N°8.06

In the Villány thermal karst area (Hungary) the outcropping Mesozoic carbonates and their subsurface continuation covered by young sediments in the adjacent basin basement form a thick (up to 1500 m) karst reservoir. Majority of the natural springs is characterized by lukewarm waters (20-26°C) with 712-930 mg l TDS in the area. Natural thermal water discharge (52-62°C, 1100 mg l TDS) occurred only in Harkány, as a marshland. According to previous studies, in the Villány Hills on the surface of bare carbonates infiltrating meteoric waters can maintain only the lukewarm springs' discharge, i.e. there might be other water components (especially in case of the sulphuric thermal waters in Harkány). Previous studies suggested e.g. active tectonics-induced mantle fluid contribution or the role of the sedimentary basin. Some caves in the area, discovered by human activity (quarrying), are characterized by phenomena related to thermal waters- tectonically controlled maze-like pattern, morphological features such as spherical niches, and typical minerals such as huntite, aragonite, and calcite as cave popcorn. Some of the caves are connected to thermal waters even today. Different theories exist to explain the formation of these caves and their mineral association, such as hydrothermal activity induced by Neogene basaltic volcanism, sulphuric speleogenesis, or the "classical" mixing corrosion. The thermal waters and the caves were hitherto investigated separately. However, all these phenomena belong to one single system, a hypogenic karst system and they can be evaluated only if their context is understood, i.e. if their common cause is revealed- the pattern of groundwater flow and its thermal and geochemical characteristics. The aims of the present study are i) to evaluate the groundwater flow system based on measured hydraulic data, ii) to characterize the geochemical composition of the waters, using natural tracers to identify different fluid components, and iii) to evaluate the cave forming processes. The research was supported by the National Research, Development and Innovation Office – NKFIH, PD116227 project.



## Mapping Ground Water Potential in hard rock formations. Case study of Burundi Abstract n°2081

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KEYWORDS: Hydrogeology, map, Burundi, Hard-rock, aquifer, spring, drilling

The improvement of Burundi safe water supply has long been slowed down by successive conflicts and crises. The proportion of the population supplied with drinking water is about 60% nationwide (2012). However, Burundi rural population is still facing problems associated with unsafe water and long distance walks to collect water, as most of its provision is through springs and rivers. Around 25 000 springs are tapped in the country. Springs come from hard-rock layers and are of three types (typology based on a statistical approach regarding 3000 springs in the Ngozi region)- - alterite springs- at the head of catchment area, they are sources of low flow. - piedmont springs- at the foot of the hill they drain the fissured zone which flanks the hill. - alluvial springs- near the river beds, they mainly drain the alluvium deposit. Most of the springs have a very low discharge (in Ngozi province, 85% have a discharge below 1 l s) they are vulnerable to contamination and many run dry in the hot season. Tapping water in deeper and less vulnerable areas using borehole constitutes a valuable alternative to spring water supply. Surprisingly, the interest to groundwater is very recent. Prior to 2010, there were less than 30 boreholes in the whole country (apart from shallow wells in the north). Within a programme supporting water sector reforms financed by the German cooperation (GIZ), a Groundwater mapping was carried out in 2011. It involved an innovative use of DEM treatment and geological maps in an iterative approach using field work and computer processing. The map identifies productive areas with good potential (probable yield over 10 l s) in the Imbo Region (along and north to Tanganyika Lake) and the Moso graben (next to Tanzania). Smaller valleys may present some interests inside the country. Particular attention should be paid to fault zones and filonian areas, whose presence is linked to the African rift. Their fracturation constitutes permeable features which can give considerable discharge when intercepted by drillings.



**Characterization of groundwater dynamics in an heterogeneous karstic aquifer  
through active and passive Fiber Optic DTS methods  
Abstract n°2083**

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**KEYWORDS:** Fiber-Optic DTS, Temperature, groundwater flows, karstic aquifers, fractured media, flow velocity

Temperature has been proposed as an excellent tracer for monitoring groundwater flows, especially in karstic aquifers which are characterized by fast and localized flows. Here, we present innovative experiments that demonstrate the interest of passive and active Fiber-Optic Distributed Temperature Sensing (FO-DTS) for characterizing heterogeneities and groundwater dynamics in a karstic aquifer. The experimental tests were achieved at the Poitiers Experimental Hydrogeological Site where groundwater flows are associated with sub-horizontal karstic structures and sub-vertical fractures. The site consists in 35 boreholes drilled within a regular 210 x 210 m grid, and having an average depth of about 125 meters (<http://hplus.ore.fr>). The simplest experiments consist in monitoring temperature changes simultaneously in 3 to 4 boreholes during a pumping test. The duration of each pumping test was about 3 to 4 h, a duration that allowed obtaining a clear hydraulic response on most boreholes. Temperature was monitored every 30 seconds with a temperature resolution about 0.05°C for a spatial resolution equal either to 29 cm or 50 centimeters depending on the DTS unit. As expected, the changes in temperature are highly variable from well to well. In most boreholes, one clearly observes some changes of borehole temperature that may be used to locate precisely the main permeable levels and to estimate borehole flow rates through the borehole temperature evolution. When no temperature changes are observed, active DTS methods may still allow monitoring of groundwater flows. Active-DTS methods are considered when the cable or borehole fluid is heated. For instance, it is possible to use a thermal resistance within a borehole and monitor fluid movement through temperature evolution with time. Thus, passive and active DTS methods are found very complementary for providing spatial and temporal monitoring of groundwater dynamics in heterogeneous aquifers.



**THERMAL DISTURBANCE CAUSED BY ALTERATION OF CRYSTALLINE ROCKS GUY  
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Abstract n°2084

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KEYWORDS: Stratified Fissured Layer, Heat Generation, Temperature

As proposed by Lachassagne (2008), a typical weathering profile in crystalline rocks is composed of stratiform layers following the paleotopography. Below the upper unconsolidated layer (saprolite), the permeable layer is a fissured zone where horizontal fractures are generated by tensile stress induced through by hydration by swelling of some minerals. Since the chemical reaction is exothermic with heat  $E$  released per unit volume on the order of  $0.5 \text{ GJm}^{-3}$  so that temperature increases. The purpose of the present 1D thermal model is precisely to discuss the conditions under which a substantial temperature increase can develop. Since the enthalpy of the weathering reaction  $E$  (in  $\text{Jm}^{-3}$ ) is finite, the heat is generated only during a limited time ( $Dt$ ) at an average rate  $A$  (in  $\text{Wm}^{-3}$ ) =  $E \text{ Dt}$  as imposed by the kinetics of the chemical reaction. The continuing nature of the reaction requires that the chemical front propagates downward with a velocity  $V$  into intact rock, furnishing new fuel. The thickness  $a$  of the active zone is  $a=VDt$  so that the volumic heat generation rate becomes  $A=EV a$ . With the conductive 1D heat equation, the relevant parameter is the "integrated heat"  $Aa=EV$  which has the dimension of a heat flow and where  $Dt$  is absent. Only when  $EV$  is comparable with the natural geothermal heat flow  $q$  (about  $.1\text{Wm}^{-2}$ ), does its thermal effect become significant. According to the  $V$  value, two cases are considered- the value of  $V$  is low and consistent with the erosion rate. A steady state is maintained. For  $V=10\text{m My}=3.10^{-13} \text{ ms}^{-1}$ ,  $EV=1.5 \cdot 10^{-4} \text{ Wm}^{-2}$  ( $\sim 0.0001q$ ) which induces negligible thermal effects.



**Understanding of a coupled groundwater - surface water system as a framework for mitigation of nitrate pollution in an agricultural catchment**  
**Abstract n°2085**

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**KEYWORDS:** nitrate, groundwater, catchment

A karstic-fissured Czesochowa aquifer in Southern Poland is an important groundwater body threatened by pollution. The aquifer is a sole source of potable water for Czesochowa agglomeration and neighboring municipalities (ca. 300 000 inhabitants). High concentrations of nitrates are found in large parts of the aquifer, which shows a low denitrification potential. Moreover, nitrate-polluted groundwater discharging to the Kocinka river and its tributaries affects their ecological status. The main source of nitrates in the aquifer is agriculture, whereas the shallow groundwaters and streams are additionally affected by the improperly managed domestic sewage. The measures undertaken by the Czesochowa Water and Sewage Company to reduce threats to the groundwater quality are limited to the exploitation schemes aimed at reducing concentrations of nitrate at groundwater intakes and application of the costly biological denitrification system. A sustainable management of this coupled groundwater – surface water system relies, however, on identification and quantification of nitrate sources and on understanding of their pathways and removal processes in soils, groundwater and streams. The ongoing research project BONUS-Soils2Sea combines numerical modeling of groundwater flow and transport, observations of water chemistry and use of the environmental tracers to provide an integrated view of nitrate behavior in the system. This scientifically based knowledge is a prerequisite for the catchment scale mitigation of nitrate pollution and particularly for the involvement of all relevant players, such as farmers, municipalities, governmental institutions, NGOs, anglers association and others.



## What to do with all your hydrogeological data- some ideas for data management Abstract n°2086

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KEYWORDS: web-based tools, data management, data interpretation

In hydrogeology water quantity and quality data are important to monitor the status of the water bodies, for model calibration and validation, and for (statistical) evaluation of trends. Apart from grab sample data, advances in sensor technology continuously improve the possibility for detailed monitoring of the groundwater system. When large amounts of data become available proper data management is important. To facilitate the pathway from data to information and solutions we developed two data management tools- WaterProtect and Sensorview. WaterProtect is a web-based tool allowing to access, explore and evaluate surface water and groundwater monitoring data. The application offers geo-referenced visualisation of monitoring results on different background maps as well as graphical and tabular representation of selected data. The tool contains tailor made reporting features as well as functionalities to facilitate the interpretation of the data such as land use maps, catchment areas, comparison with user-defined environmental quality standards. The tool is currently used for the evaluation of groundwater and surface water quality data collected in Belgium. Sensorview, is a web application for geographical representation, visualization, analysis, evaluation, and management of monitoring data. The application can handle data from grab samples or manual measurements, sensor data recorded at a fixed location and sensor data recorded by mobile platforms (the latter relates only to surface water). The SensorView user can assemble all monitoring data from a considered area of interest in a single system and exploit these data for various purposes- water quality management, status evaluation, risk management and early warning. The tool has mainly been applied for collecting and interpretation of mobile sensor data, but can as well serve for storing and interpretation of groundwater data. Both tools will be presented including cases from Belgium.



**Combined use of physico-chemical parameters and isotopic composition to characterize groundwater flow systems and their response to intensive extraction  
Abstract n°2087**

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**KEYWORDS:** chemical age, isotopes, extraction, SLP, Mexico

The objective of this study is to develop a methodology which emphasizes the combined use of isotopes, geochemical analyses, geological features, soil and vegetation characteristics in assessing the effect of intensive groundwater extraction in San Luis Potosi Catchment, Mexico. The study area is located at the eastern boundary of the Central Alluvial Basins+ it has been subject to intensive groundwater extraction since late 1980's. Reported drawdown values under current extraction ( 4.0 m<sup>3</sup> s) range from 0.5 to 4.0 m year. During the last two decades, studies proved Cl, Li, F and temperature to be used as potential residence time indicators+ increase in temperature accompanied by increase in Cl, Li and F was found indicative of long residence time. However, during a recent investigation Li and F contents registered a slight decrease with Cl and temperature increase in some sampled wells. Adapting appropriate sampling techniques+ the challenge lies in understanding how the change in chemical age proxies relates to stable and radioactive isotopes dating tools and how their combined use with regional parameters could identify different groundwater flow systems and their vulnerability to intensive extraction. This study proved effective, regarding the use of chemical and isotope dating tools to determine groundwater origin+ thus, groundwater is represented by an intermediate flow characterized by relatively cold water (22-25°C), with low Li (0.01 mg l) and F (0.3 mg l) contents. The +18O shows depleted values (-10.09 to -11.09 ‰)+ and the corrected groundwater age ranges from 1,000 to 3,300 years BP. Comparatively, induced regional groundwater flow system following intensive extraction, shows high temperature (30-34°C), high Li (0.18 mg l) and F (3.9 mg l) contents+ and more enriched +18O values (-9.2 to -10.4 ‰). The corrected regional groundwater age ranges from 1,300 to 6,500 years BP, suggesting longer residence time and deeper travelling conditions.



**Groundwater Futures in Sub-Saharan Africa- an integrated approach to assessing sustainable groundwater use for poverty alleviation  
Abstract n°2089**

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KEYWORDS: poverty alleviation, integrated social and physical science, Africa

Sub-Saharan Africa is characterised by endemic poverty, food insecurity, and some of the most variable hydrological environments on the planet. Groundwater, Africa's largest distributed and natural store of freshwater, can play a vital role in alleviating poverty and food insecurity through expanding access to safe water and irrigated agriculture as well as enabling adaptation to freshwater variability amplified by climate change. Research under the Groundwater Futures in Sub-Saharan Africa (GroFutures) consortium project seeks to make advances not only in the physical understanding of groundwater systems which can inform and constrain decision-making as well as prompt innovation but also critically through advances in social science as the latter address non-physical constraints that fundamentally restrict access to, and use of, groundwater for poverty alleviation. We present a rationale and methodology for integrated social and physical research and modelling that recognises the vital but ultimately subordinate role of physical science in determining resources availability. We report on preliminary observations highlighting the range of political, socio-economic, and biophysical conditions that exist within a representative Network of African Groundwater Observatories and how these shape groundwater demand, renewability and use in Sub-Saharan Africa. Developed models are used to constrain the range of physically viable development pathways+ a Pathways Approach is applied to link our interdisciplinary, multi-scale research with a deliberative, multi-stakeholder engagement process. This Pathways Approach is designed to inform and influence groundwater governance and planning processes at nested scales opening up new pathways towards more sustainable and socially just groundwater futures in Sub-Saharan Africa.



**Groundwater Quality Monitoring and Testing- A Key Necessity for Identifying  
Groundwater pathogens and preventing Endemic and Epidemic Infection due to  
Borehole Proliferation in Nigeria.  
Abstract n°2091**

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KEYWORDS: Groundwater Monitoring, Testing, Pathogens, Endemic, Epidemic

In Nigeria, urban access to piped water has declined sharply since 1990. Despite the MDGs, use of unimproved water sources has increased, especially in informal peri-urban settlements with the fastest rates of population growth. In Lagos, approximately 74% of the population rely on water from informal sources, particularly from private boreholes which are drilled indiscriminately across most cities and rural areas. The quality of most or all of these boreholes are not monitored or tested. There is great need to begin to monitor and test groundwater emanating from boreholes so as to identify pathogens and prevent endemic and epidemic infections.



**Hydrochemical and isotopic assessment of the Bölmekeya Geothermal Field (Denizli Basin, Southwestern Turkey)  
Abstract n°2092**

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**KEYWORDS:** Hydrogeochemistry, Geothermometry, Fluid-mineral equilibria

The results of study on the chemical and isotopic properties of thermal and cold waters from the Bölmekeya Geothermal Field (BGF, Southwestern Turkey) are described in order to a better understanding of the hydrological circulation. These thermal waters originate from Menderes Metamorphic rocks and emerge along northern normal faults. Thermal waters are mostly of Ca-Mg-HCO<sub>3</sub>-SO<sub>4</sub>, whereas cold waters are Mg-Ca-SO<sub>4</sub>-HCO<sub>3</sub> types. Discharge temperatures of the thermal waters are mean of 36°C, whereas the cold waters are mean of 14°C. In the reservoir of the geothermal system, dissolution of host rock and ion-exchange reactions changes thermal water types. Thermal waters with high correlation in some ionic ratios (e.g., B vs. Cl, Na vs. Cl, HCO<sub>3</sub> vs. Cl, SO<sub>4</sub> vs. Cl) and high contents of some minor elements (e.g., As, B, Cl, F, Sr) likely indicate enhanced water-rock interaction. Thermal and cold waters from the BGF have not reached complete chemical re-equilibrium, possibly as a result of mixing with shallow freshwater during upward flow. Reservoir temperatures of the BGF was calculated as 111°C for the quartz and 82°C for the chalcedony geothermometry. Slightly positive C-13 ratios (mean of +0.5‰) of the thermal waters imply a metamorphic origin of thermal waters. Negative carbon isotope ratios (mean of -8‰) of the cold waters are related to exchange in freshwater carbonates of the Neogene formations. Very negative O-18 (mean of -8‰) and H-2 (mean of -48‰) isotopic ratios and low tritium values (<1TU) of the BGF thermal waters reflect their recharge from pre-thermonuclear (>50 yr old) meteoric water and relatively long subsurface circulation. During the long subsurface circulation along faults and fractures in the metamorphic rocks, prolonged water-rock interaction causes enrichment of some dissolved ions and silica in the thermal waters. This research is supported by bilateral cooperation of TUBITAK-CNR with grant number 113Y551.



# Origin and evolution of the thermal waters from the Gölemezli and Yenice Geothermal Fields (Denizli Basin, Southwestern Turkey)- Hydrochemical and isotopic evidence Abstract n°2093

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**KEYWORDS:** Hydrogeochemistry, Geothermometry, Fluid-mineral equilibria

Thermal water chemistry from the Gölemezli and Yenice Geothermal Fields (Southwestern Anatolia, Turkey) are investigated in order to determine hydrochemical facies and major geochemical processes that effect water composition. These thermal waters derive from metamorphics of Menderes Massif and emerge along northern normal faults in the Denizli Basin+ they are commonly used for heating of greenhouses and bathing facilities. Mean discharge temperatures of the thermal waters are ~55°C for Gölemezli and ~48°C for Yenice thermal waters. Gölemezli thermal waters are mostly of Na-Ca-SO<sub>4</sub>-HCO<sub>3</sub> type, whereas Yenice thermal waters are mainly of Na-Ca-HCO<sub>3</sub>-SO<sub>4</sub> type. Dissolution of host rock and ion-exchange reactions modifies thermal water types in the reservoir of the Gölemezli and Yenice geothermal systems. High correlation in some ionic ratios (e.g., Mg vs. Cl, HCO<sub>3</sub> vs. Cl) and high concentrations of some minor elements (e.g., As, Sr, B, Cl, F) in thermal waters likely originate from enhanced water-rock interaction. All thermal waters have not reached complete chemical re-equilibrium, possibly as a result mixing with groundwater during ascent. Gölemezli and Yenice thermal waters are oversaturated at discharge temperatures for carbonate and silica minerals allowing increase to a carbonate- and silica-rich scale and correspond to travertine tufa precipitation in the discharge area. Very negative oxygen-18 and deuterium-2 isotopic ratios of the thermal waters are mean of -8‰ and -59‰ (respectively) for Gölemezli and mean of ~8‰ and -55‰ (respectively) for Yenice. Low tritium values (<1TU) values reflect a deep circulation and a meteoric origin. Positive carbon-13 ratios (mean of +6‰ for Gölemezli and mean of +9‰ for Yenice) of the thermal waters reflect a metamorphic origin of thermal waters. These waters likely derived from the infiltration of rainwater through fractures and faults to the deep thermal reservoirs. This research is supported by bilateral cooperation of TUBITAK-CNR with grant number 113Y551.



**GroundCare - Concept for the integrative ecological assessment of groundwater ecosystems status and services**  
**Abstract n°2094**

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**KEYWORDS:** bioindication, ecological assessment, microbial communities, monitoring

Targeted provisional session No. 8.09 Today, the ecological assessment of surface waters is routine and made its way into national and international (e.g. European Water Framework Directive) regulations. For groundwater and aquifers a comparable approach, considering ecological aspects, is still missing. In contrast, groundwater monitoring and management schemes follow almost exclusively physical-chemical and quantitative criteria. However, groundwater systems are ecosystems harboring diverse communities of microorganisms and invertebrates. Directly linked to these biological components, groundwater systems provide important ecosystem services of societal relevance, such as the natural production of clean drinking water, biodegradation of pollutants and elimination of pathogens, to name a few. The application of suitable biological indicators for groundwater systems potentially allows the detection of changes in ecosystem services associated to natural or anthropogenic effects, thereby sustaining groundwater quality assessment. In the recent past, we contributed to the development of a first concept of an ecologically sound groundwater assessment scheme. Work included (1) the identification of biological ecological criteria, (2) set-up of a groundwater ecosystem typology, (3) deduction of natural biological groundwater background values and definition of reference conditions for selected sites, and (4) a first evaluation model. In the framework of the project consortium GroundCare, recently funded by the German Federal Ministry of Education and Research, ten partners from science, authorities and the private sector challenge and further develop the early concept extending the focus to a qualitative and quantitative assessment and monitoring of groundwater ecosystem services. The talk will inform about first results and developments in GroundCare, and further activities related to groundwater ecosystem status and services assessment.



**A geomorphometric characterization of Northern basins of Algeria through Arc-Hydro toolbox in ArcGIS environment**  
**Abstract n°2095**

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**KEYWORDS:** Geomorphometry, Algerian Northern basins, DEM, GIS, Digital Terrain Analysis.

DEM analysis is now used to characterize and to extract relevant geomorphology characteristics in Algerian Northern basins, which are required for various studies namely surface hydrology, Hydrogeology, watershed management, land management. A software tool is described for the extraction of geomorphometric land surface variables and features from Digital Elevation Models (DEMs). The Arc-Hydro-toolbox consists of a series of Python Numpy processing functions, presented through an easy-to-use graphical menu for the widely used ArcGIS package. Although many GIS provide some operations for analyzing DEMs, the methods are often only partially implemented and can be difficult to find and used effectively. Users can control the threshold values for land surface classifications. The size of the processing kernel can be used to identify land surface features across a range of landscape scales. The pattern of land surface units from each attempt at classification is displayed immediately and can then be processed in the GIS alongside additional data that can assist with a visual assessment and comparison of a series of results. The functionality of the Arc-Hydro toolbox is described using an example DEM.



**Impact of climate change and human activities on groundwater resources in Kenya-  
current knowledge and initial findings in Nairobi aquifer system, a strategic aquifer  
under high pressure  
Abstract n°2096**

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KEYWORDS: Hydrogeological, Anthropogenic, Climate Change, Groundwater

Eastern Africa has been identified as one of the regions at greatest risk globally with regards to the impacts of climate change while also having one of the highest demographic growth rates, e.g. more than 2% currently in Kenya. These combined factors put water resources under very high pressure. One of the most important and strategic groundwater resources in East Africa is the Nairobi volcanic-suite aquifer, which supports the development of the greater Nairobi region. Nairobi metropolitan area has over 6.5 million people and is a major economic centre in East and Central Africa. Currently, the impacts of climate change and human development on the groundwater resources remain uncertain and no conclusive quantitative studies have been carried out so far. The present research is synthesizing the available hydrogeological data relating to the impact of climate change and human activities on groundwater resources. Preliminary data indicate that groundwater demand and borehole drilling is dramatically increasing with population growth and infrastructure development (5 new borehole applications for registration per day). Land use changes are dominated by a reduction of forest cover and open lands and an expansion of urban and built lands estimated to 255 km<sup>2</sup> within a span of 50 years. Groundwater levels have generally been decreasing in borehole hot spot areas by 10 – 30 m, following an increase in abstraction together with a possible decrease in recharge resulting from surface sealing. All hydrogeological data, including abstraction, aquifer structure and properties, recharge discharge and groundwater time-series (heads and quality) are being compiled into updated conceptual and numerical groundwater models for the Nairobi aquifer system. Model results will enable a quantitative understanding of the groundwater response to external climate and anthropogenic drivers, as well as their relative importance with regards to groundwater sustainability. This quantitative understanding is key to improving the long-term management of groundwater resources.



**Saturated-Unsaturated Groundwater Flow model to assess the design of Sustainable Urban Drainage Systems  
Abstract n°2097**

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KEYWORDS: infiltration, groundwater model, SuDS

The accelerated cities expansion in recent decades, have had various environmental impacts+ one of them has been the replacement of permeable and semi-permeable natural soils by impervious surfaces+ this fact and the climate change have produced an alteration of water cycle in urban areas. The rain water management concept in cities, have changed from the typical perspective known as end of pipe solution, to a more integral concept of sustainable approach to mitigate the externalities of urbanization. Sustainable Urban Drainage Systems (SuDS) aim to look for alternatives to improve the runoff management, and Infiltration is one of the mechanisms that could be implemented to restore the water cycle, mainly in permeable soils due to its condition to recharge a quifers. The objective of this study is to assess the design of ground and underground infiltration tanks, build up from modular geocells, for different types of soils, taking into account the infiltration rates through the unsaturated zone up to the water table. A numerical saturated-unsaturated ground water flow model was implemented in Feflow to evaluate the different alternatives proposed. The Feflow infiltration rates outputs were used to optimize the design process of tanks based on the variation on water level inside the infiltration structure.



**Short and long term coastal aquifer comprehensive vulnerability mapping. The ACVM method a valuable tool for groundwater managing plan.  
Abstract n°2098**

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**KEYWORDS:** Coastal aquifer vulnerability mapping, Sea water intrusion vulnerability map, Impact of sea level rise on groundwater

Coastal aquifers are subject to contamination from both land-based pollution sources due to human activities and sea salt water intrusion if an hydraulic connection with the sea is present. So coastal aquifers may be vulnerable to the threat of contamination from human land-based activities (vertical vulnerability) and salt water intrusion from the sea (horizontal vulnerability). Furthermore, coastal aquifers are vulnerable to climate change, and in fact a modest increase in sea levels can result in significant negative impact on groundwater quality. Therefore, the goal of this study was to create a method able in describing all aspects of aquifer vulnerability using a single parameter. This new method called ACVM (Aquifer Comprehensive Vulnerability Mapping) was invented, developed and applied in the Ghar El Melh coastal aquifer in Tunisia, in the context of the GEF UNEP-MAP Strategic Partnership for the Mediterranean Sea Large Marine Ecosystem (UNESCO-IHP Sub-component 1.1 on "Management of Coastal Aquifers and Groundwater"). The Ghar El Melh coastal aquifer is a multilayer aquifer in hydraulic connection with the sea, making it susceptible to the phenomenon of salt water intrusion. In this area a short and a long term vulnerability map were carried out applying the ACVM method. The short term vulnerability map considers the land-based activities (vertical vulnerability) and salt water intrusion from the sea (horizontal vulnerability) like external threats that can induce degradation of groundwater quality. While the long term vulnerability map also considers the 'groundwater vulnerability to sea level rise'. These two maps show the combination of the considered components of aquifer vulnerability using only one parameter called comprehensive vulnerability. Consequently they can be a valuable resource for land use management, since it is possible to translate this parameter into management recommendations for the short and long term. The ACVM method establishes a new conceptual approach to evaluating aquifer vulnerability and could be replicated at other coastal aquifers to demonstrate its potential for widespread use.



# **Sensitivity of rainfall recharge estimates to global precipitation datasets, rootzone depth and runoff**

## **Abstract n°2101**

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**KEYWORDS:** Global recharge estimates+ Global precipitation data sets+ Soil water balance+ Root zone depth+ Runoff curve number method

The quantification of recharge is fundamental to determine the degree to which current groundwater extraction rates are sustainable or whether these exceed the naturally renewable resource in an area. To estimate groundwater recharge to large aquifers, there is significant potential in the use of globally available datasets, which are therefore increasingly used. In the current study we explore the sensitivities and uncertainties of rainfall-derived global recharge estimates using a simplified daily soil water balance model. We evaluate four global precipitation datasets, namely TRMM-3B42, CMORPH, CHIRPS and PERSIANN, and two sedimentary transboundary aquifers with different climate conditions- the Indus River Basin Aquifer (arid climate) and the Cambodia Mekong Aquifer (tropical climate), for a temporal scale of 10 years (2000 – 2009). Three key inputs parameters are varied to explore their influence on the recharge assessment, namely- i) variation in precipitation dataset input+ ii) variation in root zone depth, and iii) variation in runoff characteristics as defined using the curve number method. Results for the Indus River Plain aquifer show that rainfall intensity, both in the way it is simulated in global rainfall products, as the predicted increase under climate change, largely contributes to the uncertainty of recharge estimates. The variation and uncertainties in root zone depth (or other soil parameters defining water holding capacity) also show a significant impact on recharge results. For the Cambodia Mekong River Delta aquifer, recharge estimates show that the high rainfall rates throughout the year provide a much larger recharge as fraction of rainfall. Runoff as predicted by the curve number method shows a lower range of uncertainty, but seems to be underestimated, thereby overestimating recharge when compared to existing data such as the IGRAC-WHYMAP database and the PCR-GLOBWB global hydrological model. These results demonstrate that due care needs to be taken when using global rainfall products for recharge simulation, and that the uncertainty due to precipitation, soil and runoff characteristics should always be explicitly considered in global recharge assessments.



## **Seepage water. A new resource? Abstract n°2103**

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**KEYWORDS:** underground infrastructure, seepage water, ground water, Paris

The city of Paris was constructed on the banks of the river Seine approximately in the center of its river basin, made of marine sedimentary rocks like limestone and gypsum. The presence of rivers, combined with precipitation and permeable underground has as consequence that numerous underground infrastructures like subway, parkings or basements of modern building complexes are submerged in ground water and have to deal with seepage water. Paris is therefore pumping about 20 000 cubic meters daily to keep its underground infrastructure dry. This water is discard principally into the combined sewers of the city and charged for collection and treatment. Paris is also using a huge amount of river water for urban uses like sewer flushing, street cleaning and watering. The seepage water could potentially be used for these city needs preserving rivers for other needs. Though the elevated hardness and conductivity of seepage water together with long residence times in the secondary supply network and the quality needs for lane watering, make the equation less simple. To evaluate adequately the potential of seepage water utilization, better knowledge of existing resources and application risks is needed. The proposition will give a quantitative and qualitative estimation of seepage water at present and sketch the limits of its application. A GIS is used to link existing seepage water data with geological and hydrological information to test the relation with the underground composition and the presence of urban rivers. The presentation will complete this picture with case studies where partial use is practiced and their simplified cost – benefit balance. Preliminary results indicate that seepage water might contribute to the reduction of the environmental impact of the existing city water cycle if appropriate changes are made to the actual water practices.



**Clay sealed canal- Water supply and irrigation cohabitation managed in an arid delta having sea water contaminated water table. Communities' villagers water management and facilities maintenances.  
Abstract n°2105**

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KEYWORDS: Senegal, infiltration test, coastal aquifer, clay liner, earthwork, agriculture

This agricultural area between the delta of Dagana and Podor Middle Valley in Senegal is an semi desert zone with fragile ecosystem at almost under sea level. The coast is within 10 km such as groundwater has a high salinity. A structuring water development was built to improve agricultural productivity through irrigation with water from Senegal River. In parallel, water uptake from Senegal River is also used for drinking water supply needs of St-Louis City. Major work is earthworks in the adductors rehabilitation- weed cutting and cleaning, setting to dimensions and containment dikes, raises or reinforcement of existing dikes. Then there was construction and rehabilitation of hydraulic structures as bridges, valves, water flow controlling facilities and culverts to cross over Gandiol Channel. Conditions are not simple- exchanges between surface water and groundwater to be avoided to preserve water within irrigation and drinkable water supply system from salt contamination. Works to be carried out while water supply should not be interrupted and environmental impact due to civil works could be damageable if strong protective measures were not taken. Earthen canals and reservoirs with clay seal coating were to be constructed. Clays are located mainly in crops areas+ their extraction causes alteration of the quality of soil and affects its further productivity. A geomembrane liner would have been a perfect seal for canals and reservoirs to prevent infiltration from water table into irrigation water, and would have saved local resources in clays. This solution would have been more eco-friendly but it was not adopted due to economic considerations.



**Use of the Conduit Flow Process for the simulation of passive mitigation measures against the piezometric damming effect at the new underground High Speed railway station of Florence**  
**Abstract n°2106**

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**KEYWORDS:** "Conduit Flow Process", Florence, piezometric damming

The new High Speed railway station of the city of Florence (Italy) will be located below ground level inside a huge excavation, 25 m b.g.s deep, 450 m long and 50 m wide+ the pit, already built, is surrounded by concrete cut-off walls causing a piezometric damming effect against the main aquifer of the Arno River. As permanent mitigation measure against the piezometric mounding, the design of the station considers a series of drain pipes drilled horizontally on up and down gradient sides of the pit and connected by blind wall tubes. A numerical finite differences model has been implemented with the Modflow code, in order to quantify the expected damming effect and to verify the design hypothesis of the drain-based mitigation measures (i.e. frequency and length of the drains). One of the major challenges of the numeric approach was the coupling between the groundwater flow in the porous medium and the water flow towards and through the drains and the blind wall tubes connecting the sides of the excavation. Thus, the drains were simulated using a recently published Modflow Process originally developed for karst conduits (Conduit Flow Process – CFP), which allows combining the groundwater flow in the porous medium with laminar or turbulent flow into pipes. In order to guarantee an acceptable head differential between both sides of the excavation, the results showed that the system should permit a discharge flow rate of about 0.026 m<sup>3</sup> s, considering a hydraulic gradient equal to 0.5% (i.e. hydraulic gradient from the averaged piezometric distribution before pit excavation). The drain Conductance turned out to be the most influent parameter towards the effectiveness of the drainage system.



## Geodetic tools for hydrology- potentials and future prospects Abstract n°2108

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**KEYWORDS:** gravity, deformation, water cycle, human pressure, fractured rock large-scale aquifers, tiltmeter,

Sustainable management of water resources requires knowledge of water flow and storage in the subsurface, and their response to anthropic and climatic destabilizations. This challenging question is complex given the multiscale heterogeneity of geological layers, their deformable nature and the wide range of spatio-temporal scales covered by boundary conditions- spatially from focused recharge and pumping to continental-scale flow+ temporally from intense rainfall events to interannual stresses. The recent technological and methodological developments in geodesy (ground and space gravimetry, deformation from InSAR, tiltmeters, ...) have opened a new window on the dynamics of GW systems on a wide range of spatial scales, based on the interpretation of highly sensitive and stable instruments. Two main processes are of interest- (i) a volume of water is equivalent to a mass, and affects the Earth's gravity field according to the Newtonian attraction and (ii) Pressure changes, powering fluid flow, generate poro-elastic deformations that can be observed remotely. In this case, the surface over which pressure is applied – i.e. the reservoir geometry, is also an important parameter of the deformation. Geodesy provides tools to capture the internal state of groundwater systems on a wide range of spatio-temporal scales. We will focus on recent results obtained with tiltmeters in a fractured aquifer system to infer (i) permeable structure geometry and storativity during a pumping test and (ii) monitor water cycle and investigate recharge processes with a 7-year tilt observation. We will finally underline the value of geodetic methods and their application to GW systems, highlighting their potentials, limitations and complementarity with more classical observations.



# Visual Presentation of Uncertainty in Groundwater Age and Transit Time, Wairarapa Valley, New Zealand

## Abstract n°2109

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KEYWORDS: groundwater, transit time, uncertainty

New Zealand's National Policy Statement for Freshwater Management (NPS-FM), enacted in 2014, requires community engagement in setting limits for land and water management. Limit setting requires understanding of groundwater transit time, i.e. the time lag between contaminant release on land and the arrival of that contamination in a receiving water body after transport through the aquifer system. Involvement of the community in limit setting therefore requires water managers to explain this process and its associated spatiotemporal uncertainties. A transient finite element groundwater flow model for the Middle Wairarapa Valley, New Zealand, was calibrated to match time series measurements of groundwater level, stream spring flows and tritium concentration. The time-marching Laplace transform Galerkin (TMLTG) technique was then used to evaluate the full spectrum of age (i.e. age distribution) and transit time at each model node and at each time step. Results showed that the transit time through the aquifer system varies from a few months to a few decades and is strongly dependent on location and time. Results also demonstrated important differences between the transient age distributions derived from the TMLTG technique compared to the much simpler steady-state lumped parameter models that are frequently applied to interpret age tracer data. Uncertainty in the modeled age and transit time distributions was depicted in map form. A workshop with water managers was used to evaluate the strengths and weaknesses of different paired, intrinsic and extrinsic approaches for mapping model uncertainty alongside the model output. The importance of using multiple methods for communicating uncertainty was shown, for example for identification of land areas where age distributions vary seasonally and the associated model uncertainty is high. The results from this study will assist land and water managers to engage with communities when discussing options for implementation of the NPS-FM.



**Loosely coupled modeling of a regional groundwater-surface water system,  
Southland, New Zealand  
Abstract n°2110**

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KEYWORDS: groundwater, surface water, model coupling

There is a global trend towards increasingly conjunctive management of groundwater and surface water. Fully coupled groundwater-surface water modeling tools are available and suit certain applications. However, fully coupled models can be slow to run and cumbersome to calibrate. In comparison, loosely coupled models may run more quickly because their groundwater and surface water components are independent and exchange input-output datasets only to the minimum extent necessary for adequate process representation (e.g. data exchange may be between but not within individual model time steps). This study involves the construction of a finite element groundwater model covering 8,400 km<sup>2</sup> of the Southland region of New Zealand, including 2,300 km of streams. Conceptualization was informed by a recently developed 3D geological model for the study area and rich data set of hydrochemistry, radon (for identifying locations of groundwater inflow to rivers) and age tracers (tritium, chlorofluorocarbons, sulphur hexafluoride, halon 1301). The groundwater model was loosely coupled to the TopNet surface water flow model. TopNet was used to route precipitation inputs into infiltration excess, saturation excess, soil water content or recharge to groundwater. The groundwater recharge was applied as input to the groundwater model. The groundwater flow solution was used to determine discharge of groundwater into the stream network, which was then added to TopNet's infiltration excess and saturation excess to derive stream flow for each stream reach. The loose coupling involved a limited number of iterations of data exchange between the two models, aiming to achieve a good match to measured stream flows and groundwater levels. Overall, this study has shown that a loosely coupled, regional scale groundwater-surface water model can be developed for New Zealand conditions.



# **Monitoring Groundwater Abstraction Effects in Sensitive Wetlands Using a Statistical Approach**

## **Abstract n°2111**

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**KEYWORDS:** Monitoring, Wetlands, Groundwater levels

Groundwater abstraction may significantly affect water levels in groundwater dependant wetlands. In these wetlands even small changes in surface and groundwater level outside normal seasonal variations may have a deleterious effect on wetland health. The Mackays to Peka Peka Expressway is identified as a road of National Significance for New Zealand and runs in close proximity to several wetlands of significant ecological and cultural value and unique fauna and flora. Resource consent conditions for Expressway construction require groundwater monitoring and management to avoid, remedy or mitigate water level changes in existing wetlands caused by the construction and operation of the project. Although a rigorous groundwater monitoring programme was established prior to construction commencing, with some 110 piezometers to record natural variations in groundwater levels, there was a limited number of measurements available for the understanding of “normal” wetland levels especially during extreme periods like the very warm and dry summer of 2014 and the very wet winter of 2015. In order to differentiate construction related effects from normal seasonal variations, a statistical approach was developed for calculating the drawdown, and both high and low trigger levels for the 22 telemetered piezometers located in and around five sensitive wetlands. Using data from telemetered piezometers monitored by the Regional Council and screened in the same shallow aquifers outside the project area, the naturally “expected” water level and appropriate trigger levels were calculated for each project piezometer based on a multivariate linear regression model for each daily reading. Exceedance of the calculated triggers, activates appropriate mitigation measures. The monitoring data demonstrate that the statistically calculated triggers take into consideration district-wide changes in groundwater levels and more clearly distinguish natural effects such as weather patterns from those resulting from construction activities than triggers set as a standard difference.



# Wavelet analysis of groundwater variability of the Tensift watershed (Morocco) Abstract n°2112

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**KEYWORDS:** wavelet, groundwater variability, Tensift, Morocco

The Tensift watershed located near Marrakech, in Morocco, present a water production in the mountainous area of the High Atlas and a downstream consumption in the Haouz plain, mainly driven by agriculture. The Haouz plain contains a groundwater which the recharge is provided by four processes- (1) direct rain infiltration+ (2) river water, considering runoff regime+ (3) flux from headwater catchments and (4) loss of irrigation. Therefore the impacts of climate variability, combined with population growth, urban expansion, tourism development and intensification of agricultural activities, should increase the Haouz groundwater deficit. In order to assess the Haouz groundwater levels variability, due to climate change and anthropogenic impact, wavelet analysis is used on long time-series records of rainfall, groundwater levels and rivers discharge monitored for 30 to 45 years. We used data from 6 stations for rainfall and rivers discharge and from 11 piezometers for groundwater levels. In order to correlate this variability to the global climate variability we also used the North Atlantic Oscillation indices (NAO). The results of analysis indicate common modes of variability between rainfall, rivers discharge and groundwater levels. The groundwater levels variability presents several modes of variability from annual to interannual scales. The annual variability is the result of local climate variability and the interannual is due to global climate variability (NAO). The groundwater depletion due to the overexploitation is much greater to than that of the climate variability effect.



**Interpreting hydraulic and hydrochemical data in an Australian alluvial aquifer-aquitard system using multivariate statistics  
Abstract n°2114**

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KEYWORDS: multivariate, statistics, connectivity

Groundwater in the Mooki River alluvium (New South Wales, Australia) supports a valuable agricultural industry and is important for town water and environmental flows. Irrigation extraction has caused widespread groundwater level decline and local salinity increases are becoming evident. However, despite the high economic and ecological value of the groundwater resource, considerable uncertainty remains in system conceptualisation which translates into uncertainty in appropriate management solutions. We aimed to reduce this uncertainty and improve understanding of system behaviour by (i) undertaking a statistical assessment of temporal groundwater level and chemistry data to identify chemical and hydraulic trends since the 1960's+ and (ii) relating these trends to hydraulic connectivity and anthropogenic environmental stresses. Historic groundwater chemistry records were quality-checked and supplemented with additional targeted sampling. Manual water level readings were historically recorded bimonthly in government monitoring bores. We recorded water levels with dataloggers at 15-minute intervals in representative boreholes for comparison. The hydraulic and hydrochemical time series data were analysed using multivariate statistics and interpreted in the context of lithological setting, groundwater extraction and climatic variability. The 15-minute interval groundwater level data enabled estimation of loading efficiency to distinguish loading response from recharge and an assessment of how monitoring frequency influences interpretation. Our analysis provided insight into catchment processes and showed how long-term groundwater chemistry trends are related to hydraulic changes in the system. We demonstrated how spatial variations in chemistry and hydraulic response can be related to variations in hydraulic connectivity. We recommend that to adequately characterise the response of this complex aquifer-aquitard system, routine hydraulic and chemistry observations should be supplemented with higher frequency data at targeted sites. Our improved system understanding can contribute to effective groundwater management and enable improved predictions of future stress effects.



**An artificial groundwater recharge system for water supply using mine discharged water in Sangju, Korea**  
**Abstract n°2116**

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**KEYWORDS:** Artificial groundwater recharge, mine discharge water, water supply

Artificial groundwater recharge will be a promising technology in the future to resolve the local seasonal imbalance of water resources, water security by climate change. The study site, which is in Imgok-ri Sangju Korea, was selected based on 10 year drought occurrences, water supply ratio, hydrogeological condition, groundwater development demand, and particularly, local governmental cooperation. The geology of the area is mainly composed of sedimentary rocks such as limestone, shale containing coal bed, conglomerate and sandstone are distributed, and they were metamorphosed severely. Mine discharged water is a potential recharge water source in both consistent quantity and water quality except for arsenic content. The arsenic content of the water is 12~13 L, which exceeds a little bit high to drinking water standard, 10 L. And then, the waters from the mine have to be properly treated before they are used for the source of recharge water or water supplies. The conceptual artificial recharge system consists of mine discharged water and a pumping well. The mine discharged water is transported to a storing tank in the upstream area through pipelines, and the water has to be treated before supplied to the public. No-power pumping system (hydraulic ram pump) under development or electric pumps can be considered for transporting the water to the upstream area. Economic evaluation for the efficiency of the artificial recharge system was conducted. The system was compared with regional water supply system based on surface water, and expense of establishment, replacement and maintenance costs were estimated for 50 years. Since the expense of the artificial recharge system is only 9.3% of that of regional water supply system, the system which we are developing is favorable in economic sense. In addition, because the regional water supply system does not cover the water demand during the drought, the artificial recharge system for consistent water supply will be more economic and powerful.



# Online Functional Composition of Hydrogeological Models through OGC Standards and Distributed Geoprocessing

## Abstract n°2118

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**KEYWORDS:** hydrogeology, model composition, MODFLOW, GWML2, OGC WPS

The characterisation and modelling of a hydrogeological setting is a multi-faceted complex task. Unobstructed availability, access and quality of relevant data are major challenges. Environmental assessments naturally depend on field observations and technological advancements, which allow the automated collection, transmission and processing of these measurements, such as live telemetry for natural phenomena, such as river flows, rainfall or soil moisture as well as consented abstractions from water wells. Analysis and visual exploration of the datasets demand practical support by computer applications. Modelling of natural processes involves applying expertise of scientists as well as a host of data preparation steps. Although a variety of software for this purpose is freely available nowadays, they require a good understanding of the technology or programming language for a useful application in complex hydrogeological settings. Thus, integrated proprietary software products are often used to analyse, model and particularly provide high-quality visualisation of the system. However, these software tools are typically desktop programs with a strict licensing scheme, limited extensibility and lack of interoperability with other applications. We present an open standards and web-based (platform independent) framework to enable retrieval, exploration and visualisation of hydro-climate time series data as well as three-dimensional hydrogeological information via a web browser. We describe, how distributed data and processing services can be linked to prepare an on-demand analysis and exploration of hydrogeological data. Case studies are geological and water budget assessments for the Horowhenua area in southern Manawatu-Wanganui, New Zealand, and a rainfall recharge model in the Upper Rangitaiki catchment, Bay of Plenty, New Zealand. We show a new approach towards a functional composition of internet-enabled groundwater models with MODFLOW that integrates field observations and internet-based environmental data with a rainfall recharge model to calculate water budgets.



# Changing recharge dynamics from urbanisation in southeast Melbourne, Victoria Abstract n°2119

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KEYWORDS: Recharge, urbanisation, age dating

Melbourne's urban growth boundary was extended in June 2012 by 6,000 ha which will push residential development into a Water Supply Protection Area. This area has been used for irrigated horticulture for the past century, and is considered to be a regionally important recharge area. Changes in land use associated with urbanisation have the potential to significantly alter the hydrological cycle and recharge in particular. In this study, a combination of nested groundwater monitoring bores, spatial groundwater sampling data (including natural and radioactive isotopes), surface water monitoring and time series monitoring data provide evidence of a changing regime of groundwater recharge due to urbanisation. Drilling and installation of nested monitoring bores has shown that the water table aquifer locally consists of a basalt aquifer which overlies a sandy confined aquifer. Groundwater head measurements indicate an upward vertical gradient. Groundwater sampling results show that shallow groundwater contains 2,300 mg L total dissolved solids, minor amounts of tritium (0.023 Tritium units), and a radiocarbon age of 2,255 years before present (76 percent Modern Carbon). Deeper groundwater, on the other hand, is fresher (660 mg L TDS), contains no detectable tritium and has a radio carbon age of 9,840 years BP (29 pMC). This data suggest that over the longer-term that groundwater system is locally confined with limited opportunity rainfall recharge with recharge to the deeper sand aquifer likely to be coming from further upstream in the catchment. However times series data shows a strong correlation between water levels, groundwater salinity and rainfall events. This suggests that rainfall recharge is currently locally active at the water table. The two most likely explanations for the apparent change in recharge regime in this area are- (1) leakage from the constructed wetland adjacent to the monitoring site and or (2) increased permeability of soils due to mechanical disturbance during site earthworks. This has implications for the future development of land in this region and management of water resources.



**Numerical investigations of the spherical flow regimes induced by constant-rate pumping tests**  
**Abstract n°2120**

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**KEYWORDS:** Pumping well test, flow dimension, diagnostic plots, 3D modelling

The discrepancy between the complexity of real flow behavior and the simplicity of analytical flow models makes the interpretation of transient well tests an ambiguous and imprecise task. Hydrogeology practitioners commonly use conventional Theis-like models for aquifer diagnostics, making the implicit postulate of a radial flow regime, leading to a significant degree of error when the real flow behavior is in fact non-radial. Derivative analysis combined with a flow dimension interpretation provides detailed knowledge of real flow behavior. A bilog plot of  $ds/d\log(t)$  time series emphasizes typical stable slopes that are interpreted as successive flow regimes with specific flow dimension values. This parameter reflects the transient shape of the cross-flow area as the pressure front-pulse is diffused through the aquifer. The hydrodynamic understanding of flow regimes successively occurring during a pumping test is thus a very promising avenue for the analysis of complex aquifer behavior. The statistical significance of the non-radial flow regime ( $n + 2$ ) in nature is emphasized by the analysis of  $n$  occurrences from numerous pumping tests in various geological settings. Specifically, it is shown that spherical or pseudo-spherical regimes ( $n = 3$  or  $2 < n < 3$ ) are frequently produced by weathered crystalline aquifers, thick alluvial deposits and leaky aquifers. Based on a numerical approach, the aquifer features that induce such  $2 < n < 3$  flow regimes are investigated. Simulations are performed using a 3D finite elements code (HydroGeoSphere) to track the transient shape of the pressure front pulse during the test. It is shown that the spherical regime may result from a partial screening completion or an inclination of the aquifer's substratum, under certain conditions. Its sequential association with other flow regimes makes it possible to discriminate between these models, providing more unequivocal diagnostics. Finally, the aquifer models are confronted to real field data.



## **A new technique for perforating steel casing to seal and protect aquifers Abstract n°2121**

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KEYWORDS: perforation, annular seal, aquifer protection

A new technique for perforating steel bore casing has been designed and trialed in Victoria, Australia. The technique uses a high pressure hydraulic packer system to expand and stress steel bore casing to a point beyond its ductile strength limit to yield and perforate the casing. This allows retrospective sealing of bore annuli to protect aquifers from cross flow and contamination. The Victorian State Observation Bore Network (SOBN) provides critical groundwater information to enable effective groundwater management. Many of the bores are very deep (131 are from 300m to 1,200 m deep), and transect multiple aquifers. Typically the deep bores are more than 30 years old, constructed with steel casing were often not fully cemented. This poses a risk to groundwater resources due to vertical leakage across aquifers. Perforation of steel bore casing is traditionally completed by either small explosive charges or mechanical cutting. Use of explosives has a number of safety risks and potential to excessively damage casing while mechanical cutting requires the mobilisation of a drilling rig and produces perforations of limited aperture. The hydraulic packer perforating system, on the other hand, has the following advantages+ (1) it is intrinsically safe (2) it can be deployed from a small truck and (3) produces large aperture perforations which can be readily verified by caliper log or camera survey. The hydraulic packer assembly consists of a multi-layer high yield rubber packer rated to 10,000 psi lowered into the bore to the specified depth. The packer is inflated to a pressure of 8,000 psi or until the steel casing yields. Field testing showed that the steel casing yields with longitudinal ruptures approximately 1m long and up to 0.02m wide. This perforation allows cement grout to be injected beyond the bore casing to retrospectively seal the bore annulus at specific depths, typically adjacent to aquitards. This innovative technique has allowed the completion of large scale programs of decommissioning and refurbishment in an efficient and cost effective way.



**Comparing Fiber-Optic Distributed Temperature Sensing to Hydrochemistry for understanding groundwater inflows to streams  
Abstract n°2122**

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**KEYWORDS:** fiber-optic distributed temperature sensing, hydrochemistry, groundwater-surface water interaction

Fiber-optic distributed temperature sensing (FODTS) is an established technique for identifying locations and quantifying fluxes of groundwater inflows into rivers and streams. FODTS has the advantage of being able to provide very high spatio-temporal resolution of groundwater inflows relative to conventional methods such as differential stream flow gauging. However, in the traditional longitudinal configuration in which the FODTS cable is deployed along the stream bed, the method may not provide detail on hyporehic exchange. Even where FODTS is used to examine longitudinal and vertical temperature profiles, it provides relatively little information on the flow paths along which inflowing groundwater has travelled. In this study we employ hydrochemical methods to complement FODTS surveys in New Zealand settings, including Ngongotaha Stream, situated in ignimbrites and related volcanic sediments+ and the Hutt River in a greywacke gravel setting. Longitudinal FODTS surveys were carried out in both rivers under baseflow conditions. In the Ngongotaha Stream study, water samples were collected for analysis of major dissolved constituents at the reach scale and also across the wider catchment. Interpretation using multivariate statistics indicated that the hydrochemical data, particularly silica concentration, clearly identified the aquifer of origin for the water inflows – information not provided by FODTS alone. In the Hutt River study, samples were collected for radon analysis at a spacing of ca. 250 m. The pattern of groundwater inflows inferred from FODTS and stream gauging did not always align with the radon concentrations, likely because the techniques capture hyporheic exchange to different extent. This study has illustrated the strengths of FODTS in two different hydrological and geological settings, and also demonstrated the utility of collecting complementary hydrochemical data to aid FODTS interpretation.



**Groundwater Evolution and Flow Pattern Determination using Hydrogeochemical and Stable Isotopic Data of The Volcanic and Lacustrine Deposit in Bandung-Soreang Groundwater Basin, West Java, Indonesia**  
**Abstract n°2123**

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**KEYWORDS:** Bandung, Groundwater Evolution, Hydrogeochemical, Isotop

The study of the groundwater evolution and recharge area determination has been carried out in the Bandung-Soreang Groundwater Basin using hydrogeochemical data and stable isotopes. This study is required as part of the groundwater management consideration in order to conserve groundwater in the Bandung City and its surroundings. Bandung-Soreang Groundwater Basin has geomorphological characteristics that form a basin surrounded by volcanic mountains which once inundated by water that formed the lake. The research area has lithology which are consisting of a Volcanic Rocks and Lacustrine Deposit. Hydrogeochemical Data was taken from 95 springs, 138 wells, and 84 wells drilled (maximum depth 200 meters) and stable isotopes deuterium, tritium and oxygen conducted at 172 locations across the upstream of Bandung-Soreang Groundwater Basin. Hydrogeochemical Analysis has been conducted in order to determine the pattern of groundwater evolution using major chemical elements plotting method in the piper diagram has obtained distribution of hydrogeochemical facies in the shallow aquifer are CaHCO<sub>3</sub>, NaHCO<sub>3</sub>, MgHCO<sub>3</sub>, CaSO<sub>4</sub>, and CaMgCl with facies CaHCO<sub>3</sub> spreading 60% of the study area. Then, in the deep aquifer, hydrogeochemical facies are dominated with CaHCO<sub>3</sub>, NaHCO<sub>3</sub>, and MgHCO<sub>3</sub>. Stable isotope analysis <sup>+2H</sup> Deuterium and <sup>+18O</sup> Oxygen to determine groundwater flow patterns has been done with plotting the correlation between these two elements that generate the flow pattern of shallow aquifer which has trending from north to south (Dago – downtown Bandung), while the deep aquifer is trending from northeast to southwest (northern part of the Bandung district – Cimahi) Analysis of stable isotope Tritium (<sup>3H</sup>) is used to determine the age of groundwater that shows the distribution of age at the shallow and deep aquifer. The age pattern which has been obtained are the groundwater older relative to the northwest and getting older from the southeast toward center.



**CHARACTERIZATION OF AQUIFER SYSTEM OF THE HIGH BASIN OF CHAMBO RIVER  
THROUGH GEOHYDRODYNAMICS AND GEOCHEMISTRY- CHARGING PROCESSES  
AND SUSTAINABLE RESOURCE MANAGEMENT.  
Abstract n°2124**

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**KEYWORDS:** Integrated Water Resources Management, hydrodynamics, hydrogeochemistry.

The water resources management is crucial and implies the knowledge of dynamics, hydrochemistry and the interaction between the surface water and groundwater, as well as the relations among the urbanization, weather changes and environment impacts in cities where the main drinkable water supply comes from the subsoil. This is the case of Riobamba and Guano (Ecuador), cities whose surface and underground water resources have been monitored for decades, but without planning. Such planning is essential for a better exploitation of the hydrological cycle, taking into account the influence of the recharge and water quality on the aquifers that underlay the populations. The aim of this project is to evaluate the water resource interrelations, their complementarity, hydrodynamics, hydrochemistry and the benefits in order to create strategies for exploitation of water in these cities.



## Reviving Himalayan Springs as Climate Change Adaptation Action Abstract n°2125

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**KEYWORDS:** Climate Change, Water Security, Groundwater, Hindu Kush Himalayas, Springs, Hydrogeology, Sustainable Water Management

The Hindu Kush Himalayas (HKH) is called the water towers of Asia as it is the source of ten major rivers and has the largest snow and ice deposit outside of the two Poles. Much of the recent literature looks at long term climate change impacts on snow, glacier and on rivers, but ignores the localized springs, which is the main supplier of fresh water in the mid hills of the Himalayas. These spring systems are the source of domestic and irrigation water and also provide very important ecosystem and cultural services. Recent assessment from various pilot areas have estimated that there are over 4 million springs and 90% of the population living in the region are directly dependent on these resources. However, there is very little current scientific understanding about the hydrogeology of springs and the way they are managed by local communities. Anecdotal evidence is emerging from around the HKH area that springs are increasingly drying up, leaving the women, the poorest and the most vulnerable at risk of water and food insecurity. Reviving drying springs through a thorough understanding of hydrogeology and through involvement of local communities can be an important climate change adaptation policy. This paper will present findings from three springsheds in Nepal and focus on the links between spring discharge and long term rainfall trends, and categorize springs based on patterns of annual and seasonal discharge and the underlying geology. It will also correlate spring hydrogeology with social rules that are in place for managing those springs – for example, springs where discharge has reduced drastically over the years, local rules and regulations has been formulated to maintain equitable distribution of water.



# Characterising status and changes of regional scale groundwater systems using similarity

## Abstract n°2126

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**KEYWORDS:** Regional scale, classification, similarity, time series analysis

Regional hydrogeology is becoming increasingly important, but at the same time, scientifically sound, universal solutions for typical groundwater problems encountered on the regional scale are hard to find (Barthel, 2014+ Barthel and Banzhaf, 2015). One of the main challenges encountered on the regional scale in hydrogeology is the extreme heterogeneity that generally increases with the size of the studied area - paired with relative data scarcity. Assessing the status and predicting the behavior of groundwater systems under conditions of global change is typically done by using rather coarsely discretized and or poorly parameterized numerical models, or by using very simplistic conceptual hydrological models that do not take into account the complex three-dimensional geological setup. Numerical models heavily rely on local data and are resource-demanding. Conceptual hydrological models only deliver reliable information on groundwater if the geology is extremely simple. In this contribution, we present an approach to derive statistically relevant information for un-monitored areas, making use of existing information from similar localities that are or have been monitored. The approach combines site specific knowledge with conceptual assumptions on the behavior of groundwater systems. It is based on the hypothesis that similar groundwater systems respond similarly to similar impacts. At its core is the classification of (i) static hydrogeological characteristics (such as aquifer geometry and hydraulic properties), (ii) dynamic changes of the boundary conditions (such as recharge, water levels in surface waters), and (iii) dynamic groundwater system responses (groundwater head and chemical parameters). The dependencies of system responses on explanatory variables are used to map knowledge from observed locations to areas without measurements. This contribution focusses on the main hydrogeological concepts underlying the approach. References- Barthel, R., 2014. A call for more fundamental science in regional hydrogeology. *Hydrogeol J*, 22(3)-507-510. Barthel, R., Banzhaf, S., 2016. Groundwater and Surface Water Interaction at the Regional-scale – A Review with Focus on Regional Integrated Models. *Water Resour Manag*, 30(1), 1-32.



## Demystifying hydrogeology training barefoot hydrogeologists in the Himalayas Abstract n°2127

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**KEYWORDS:** Spring Hydrogeology, Hindu Kush Himalayas, Community Water Management, Demystify Science

Springs dot the middle hills in the Hindu Kush Himalayas and play a very important role in ensuring water security for millions of people living here. Springs also contribute to base flow of Himalayan rivers and support irrigation systems. There is growing anecdotal evidence that these springs are drying up, due to a combination of climate and other socio-economic changes. Given this background, there is widespread demand from the local communities to revive these dying springs. What role can hydrogeologists play in this? We contend that the role of hydrogeologists is enormously important for at least two reasons- for demystifying the science and for training the local communities to understand their local groundwater fed spring systems and then carry out interventions to revive springs. In this paper, we will present an eight step methodology for mapping, monitoring and reviving springs in the mid hills of the Himalayas and also present preliminary results from the field where we have implemented this methodology. There are two basic pillars of this methodology – understanding the hydrogeology and delineating recharge areas and understanding the social and governance systems in place for managing these springs. Hydrogeological investigations and results from socio-economic studies are used to train the local communities to monitor their springs regularly and ensure that spring water is used in a sustainable and equitable manner. Physical interventions such as construction of recharge ponds and troughs, afforestation of recharge areas are also undertaken in consultation with the communities and spring discharge and rainfall is regularly monitored to capture the impact of spring revival activities on spring discharge.



**Global change impacts on water resources on a regional scale- A study of participatory modeling  
Abstract n°2128**

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KEYWORDS: Participatory modelling, Global change

Participatory modeling (PM) has become an essential concept in environmental impact assessment and planning in the field of water resources. In this contribution, we focus on the use of PM to support the development of the integrated regional modeling system DANUBIA as a scientific concept to analyze the previously unknown impacts of global change, i.e. the combined effects of climate, demographic, economic, social and ecological change, on the Upper Danube Catchment (Germany). We use this case study to examine the specific conditions for PM in the field of complex integrated models on a regional scale. We describe the stepwise PM process and discuss the respective results, focusing on (i) the stakeholder dialogue's contribution in supporting the development of new, complex modeling systems, particularly on a regional scale, (ii) conditions of stakeholder involvement in issues related to the distant future, such as climate change impacts on regional water availability, and (iii) limitations of PM and scientists' motivation to carry out participatory research at all. We conclude that the PM process was not entirely successful in improving the scientific quality and practical applicability of the developed models because the process goals were manifold and overambitious, and the definition of the problem of "global change impacts on a regional scale" was too weak and uncertain to allow for a clear common objective of modelers and stakeholders. We claim that there is a lack of incentives for scientists, particularly natural scientists, to commit to PM activities. References- Barthel, R., Seidl, R., Nickel, D., Büttner, H., (in press). Global change impacts on the Upper Danube Catchment (Central Europe)- a study of participatory modeling. Regional Environmental Change- 1-17, DOI 10.1007 s10113-015-0895-x.



## Point dilution test and numerical evaluation of the hydraulic conductivity distribution Abstract n°2130

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KEYWORDS: Point dilution test, Numerical simulation, Hydraulic conductivity field

Targeted provisional session No 8.06 Point dilution test was performed to evaluate groundwater velocity and dispersivity at the site of nitrate pollution. The test was conducted on the 50 m depth full length screen borehole. 50 g-NaCl was used as a tracer (1g m). Mulch level electrical conductivity observation was performed to obtain attenuation of tracer concentration for each depth. Groundwater actual velocity and longitudinal transverse dispersivities were evaluated with analytical solution by fitting with attenuation curve of tracer concentration. Hydraulic conductivities were also estimated with hydraulic head gradient between the borehole and adjacent river. As a results of the point dilution test, groundwater velocity is  $6.72E-3$  cm s, longitudinal dispersivity is  $5.27E-1$  cm, transversal dispersivity is  $4.63E-2$  cm and hydraulic conductivity is  $4.81E-2$  cm s (all parameter values are depth averaged value). Based on the results obtained from the point dilution test, three dimensional numerical simulations were carried out and attenuation curve of tracer concentration in each depth were reproduced. In the numerical simulations, three dimensional artificial heterogeneous hydraulic conductivity fields generated by the stochastic fractal model was used. The numerical simulation mimicked and visualized the real flow field and the distribution of tracer concentration. As a results of the simulation, the relationship between statistical properties of hydraulic conductivity field and macroscopic dispersivity of the site was evaluated.



**The use of particle tracking-based groundwater age distributions in assessments of contamination risk from coal seam gas development**  
**Abstract n°2133**

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**KEYWORDS:** particle tracking+ groundwater age modelling+ stochastic modelling

Observations of environmental tracer concentrations in groundwater can provide valuable information to constrain conceptualizations of groundwater flow systems. These data may be particularly valuable in contexts where historical groundwater monitoring data are unavailable+ for example, in deep groundwater flow systems. Various modelling approaches may be used to produce outputs that can be compared to tracer data, ranging from semi-analytical advective particle tracking methods to models of reactive tracer transport or theoretical groundwater age. This study explored the efficacy of two computationally efficient particle tracking methods. The methods were used to constrain conceptualizations of groundwater flow in two separate geological basins in Eastern Australia. In the first application, a range of particle travel paths were generated stochastically in order to simulate groundwater age distributions at a number of bore locations in the Surat Basin, Queensland. Using the Null Space Monte Carlo approach, stochastic particle simulation was undertaken by generating an ensemble of model parameter sets that each calibrated the model equally well to a given set of hydraulic head observations. In turn, this ensemble produced a set of equally-likely flow paths that were used to simulate a groundwater age distribution at each bore of interest. Environmental tracer concentrations previously observed at these bores (and subsequently interpreted as ages) were compared to modelled age distributions. In the second application, advective particle tracking analyses were used to evaluate the potential for water supply bore contamination resulting from the subsurface transport of chemicals used in coal seam gas production in the Gunnedah Basin, New South Wales. Forward particle tracking was used to estimate the destinations of flowlines originating from the locations of coal seam gas production wells. The statistical distribution of simulated particle travel times was then used to estimate potential for chemical attenuation for different exposure pathways.



## Vertical characteristics of groundwater chemistry at the nitrate polluted site Abstract n°2134

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**KEYWORDS:** Nitrate concentration, Multi-depth sampling, Principal component analysis

Targeted provisional session No 7.03 Groundwater samples were collected from several depths down to 50 m below soil surface to investigate vertical profiles of nitrate and hydrochemical characteristics of the experimental site. The experimental site is located in the Shimabara City, Nagasaki, Japan, where nitrate contamination in groundwater has occurred due to intensive agricultural activities. The transition zone between dissolved ions was found between specific depths caused by differences in the permeability of soil layers. Though nitrate concentration decreased significantly in the transition zone groundwater, the entire soil depth exceeded permissible level (50 mg L<sup>-1</sup>) for drinking purposes. Comparing the temporal fluctuation of nitrate concentration above the transition zone with that of the below, distinct fluctuations were observed depending on sampling campaign. High rainfall amounts typically lead to initial decrease in nitrate concentration for the shallow groundwater. After some time, however, increase in nitrate concentration occurred due to leaching of accumulated nitrate in the soil matrix. This indicated that temporal fluctuation of nitrate concentration is mainly controlled by natural impact and occurring crop system. Results of principal component analysis suggested that application of chemical fertilizers (ammonium sulfate, ammonium nitrate, and potassium chloride), dissolution of minerals (feldspar, calcite and dolomite), and ion exchange are the predominant factors resulting in the observed vertical groundwater chemistry. The relative magnitude between these three principal component scores changed across the transition zone. Below the transition zone, groundwater chemistry reflected application of ammonium nitrate and potassium chloride fertilizer and dissolution of albite and orthoclase.



## Predicting groundwater level of Korea in relation to climate change Abstract n°2135

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KEYWORDS: KEYWORDS- groundwater level, GRACE, climate change

Changes in the amount, intensity, frequency and type of precipitation in conjunction with global warming and climate change critically affect groundwater recharge and subsequently groundwater level fluctuation. South Korea has an area of ~100,000 km<sup>2</sup> with mountains over 70% of the total territory and four river basins – the Han River, Nakdong River, Geum River, and Yeongsan-Sumjin River basins – that are divided by mountain ridges. Precipitation in Korea is greatly affected by the complex topography and drainage systems. The mean annual precipitation over the period 2000–2012 was 1416 mm with different amounts for the river basins- 1472 mm in the Yeongsan-Sumjin River basin, 1457 mm in the Han River basin, 1373 mm in the Nakdong River basin, and 1364 mm in the Geum River basin. This study estimated and predicted groundwater level fluctuation with regarding Korea's regional climate change scenarios as well as The Gravity Recovery and Climate Experiment (GRACE) that is a joint satellite mission of NASA and the DLR for measuring changes in total, column-integrated terrestrial water storage (TWS) from space. Hourly groundwater level data from 334 national groundwater monitoring stations (NGMSs) operated by the Water Resources Management Information System (WAMIS) of the Korea Water Corporation (<http://www.wamis.go.kr/eng/main.aspx>) were used for the analysis of long-term variation in relation to climate change. For the study, groundwater level change of from 2002 to 2014 was compared with precipitation amount as well as with GRACE data. At the scale of the river basins, a good relationship was found between groundwater level fluctuation and precipitation amount change as well as between groundwater level fluctuation and TWS data from GRACE. Afterwards, the relationships among groundwater level fluctuation and precipitation trend of the RCM scenarios and TWS data were extended to predict groundwater level change until 2100.



## **Active management of groundwater during Australia's Millennium Drought Abstract n°2136**

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**KEYWORDS:** Australia's Millennium Drought

From the late 1990s through to 2009, parts of Australia experienced severe drought conditions, in many cases the worst on record. This is now called the Millennium Drought. The impact of the Millennium Drought on agriculture, the environment, and urban residents was enormous. As many countries and regions across the world confront the potential for longer period and more severe droughts, what lessons can be learned from the Australian experience of groundwater management during drought? In South East Australia the Victorian State Government prepared and responded to the extreme drought conditions with policy initiatives that changed its water entitlement system, supported liberalising water markets, and provided water for the environment. Reforms in groundwater management focused on prioritising high use areas, capping resources, addressing uncertainty and adaptive management. Reforms were taken to improve accessibility to both surface water and groundwater systems. These included provisions such as carryover which enabled licence entitlement holders to manage their own risk and water trading which enabled water to move to its highest value use. Augmentation of supply from groundwater was part of these reforms. Tools were provided for prospective groundwater users on groundwater availability, which is now online and allows prospective users to find aquifer information for any location in Victoria. Measures were introduced to address potential adverse impacts while fast tracking access to groundwater licence entitlements particularly for urban water supplies. These provided new groundwater resources for regional cities and townships such as Geelong, Ballarat and Wangaratta while ensuring the protection of the environment.



# Conceptual models of risks to shallow aquifers from underground mining through geological fault structures

## Abstract n°2137

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KEYWORDS: far-field mining effects, storage changes, preferential flow

Groundwater risks associated with underground excavations through fault zones has received little attention compared to geomechanical and safety risks. Several plausible conceptual hydrogeological models for geological faults of mining operations are considered in this presentation, to inform the design of site based monitoring and adaptive management. Key lessons from several underground metal and coal mines in Australia are highlighted. Favorable conditions where faults can form barriers to groundwater include the following- partially penetrating hydrogeological facies, filled with clay gouge, tight due to favorable high stresses, lacking a fractured damage zone, vertical or horizontal fault offsets that do not connect aquifer zones, and a geologically stable. However, in other conditions, groundwater level declines may be recorded at a considerable distance along the strike of the fault zone, without affecting groundwater levels in zones with limited hydraulic connection. The likelihood of groundwater impacts increases if fault structures are reactivated by significant tensile strains that are induced by mining. For example, horizontal displacements of 65 mm have been surveyed at the ground surface over 680 m away from longwall mines. Improvements in monitoring technology and evaluation of far-field effects over at least 2 km from operations are ongoing. However, quantifying the effects of differential movement of rock masses on preferential groundwater flow and subsurface storage volume is more challenging, particularly where the rock surface does not outcrop. Monitoring and investigations of mining impacts must also account for multiple hydraulic stresses such as changing land use, water use and climatic variability. Where mining through geological faults does contribute to changes in shallow aquifers, localized loss of base flow to streams could occur and or if preferential flow occurs to mine depth, increased dewatering could be managed. In situations where the long term consequences for shallow aquifers are uncertain, further research and adaptive management is needed.



## Groundwater management under the Murray – Darling Basin Plan Abstract n°2138

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KEYWORDS: Basin Plan, planning, sustainable management

The Murray-Darling Basin extends over 1 million km<sup>2</sup> of south-eastern Australia. The Basin has large groundwater resources (estimated storage is approximately 10.13 million GL) in three main aquifer types- alluvial, porous rock and fractured rock. Although there is significant storage in these aquifers, only a small percentage is accessible and water quality is often poor. Annual recharge across the Basin averages approximately 24,300 GL. Groundwater use (mainly for agricultural irrigation) occurs across the entire Murray-Darling Basin with an annual average extraction of approximately 1,400 GL, representing on average 11% of total water use. In drought years groundwater use represents up to 25% of total water use across the Basin. The Murray-Darling Basin accounts for 70% of Australia's irrigated agricultural output. Adopted in November 2012, the development of the Murray – Darling Basin Plan was driven by the need to reduce surface water extraction and increase surface water availability for the environment. The objectives of the Basin Plan are to give effect to relevant international agreements, establish a sustainable and long-term adaptive management framework for the Basin water resources, optimise social, economic and environmental outcomes and improve water security for all uses of Basin water resources. The Basin Plan, sets a Basin wide total for groundwater use of 3,334 GL y. This total is managed through the application of limits to management areas within the Basin called sustainable diversion limits (SDLs). The SDLs represent the environmentally sustainable level of take for the area. The SDLs were determined using numeric modelling or a sustainable yield methodology. For groundwater resources, the Basin Plan represents the first time a limit on groundwater use and consistent management arrangements are implemented. The Basin Plan will be implemented by June 2019 through state prepared Water Resource Plans (WRPs). The implementation of the Basin Plan will result in better environmental outcomes and sustainable communities based on irrigated agriculture.



**Modelling the peridotites aquifer in New Caledonia massifs, the question of the saprock thickness.  
Abstract n°2139**

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**KEYWORDS:** peridotite, saprock aquifer, models

In New Caledonia, ultramafic rocks outcrop over more than one third of the territory and the associated regolith leads to Nickel and Cobalt ore deposits mined on scattered massifs all over the island. Facing growing problems of groundwater management, the mining companies are required to implement complex regional groundwater models in order to simulate their environmental impact on the water resources. For that purpose, layered models are built describing the weathered mantle overlying the hard rock peridotite. Most of these models are based on hydrodynamic character linked to the petrographic units and regolith profiles described by nickel ore prospectors. Within this framework, the hydrogeologic modeling studies are facing with the uncertainty of the lower boundaries of the saprock aquifer. The lower limit is usually considered as the bottom of the exploratory core drillings which ends a few meters deeper than unweathered peridotite occurrence. However, field observations on deep boreholes drilled up to 200m within the peridotite substratum have given evidences of potential groundwater flow path deeper in the bedrock. Thus, depending of studies, the location of the lower boundary of the saprock aquifer appears to vary from 3 meters to fifty meters within the bedrock. These thickness variations affect the configuration of models and could impact the results on flow budgets both within the saprock aquifer or the substratum aquitard. On the basis of simplified conceptual models describing the multi-layered aquifer patterns, we use a two dimensional finite element model (fellow) in order to explore the effects of various saprock geometries. The representative cross sections of three peridotite massifs with contrasted geomorphological situations have been compared. The simulations results are assessed according to the massifs hydrogeological context deduced from boreholes observations.



## Present States of Uranium and Radon in Groundwater in Chungwon, Korea Abstract n°2140

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KEYWORDS: Groundwater, Uranium, Radon, Statistical analysis

Uranium and radon concentration was assessed in groundwater samples collected from 47 private and public wells covering three hydrogeological units which is Jurassic biotite granite(Jbgr), Pre-Cambrian biotite gneiss(PCbgn) and Sedimentary rocks(Sedi). Water samples have been collected from 31 wells in Jbgr, 24 wells in PCbgn and 3 wells in Sedi. Major ion concentrations and physico-chemical parameters were also measured. These results have given the basis for an attempt to characterize the groundwaters of research area with respect to uranium and radon content. Concentration values ranged from 0.06 to 178  $\mu\text{g L}^{-1}$  for  $^{238}\text{U}$  and from 80 to 12,900  $\text{pCi L}^{-1}$  for  $^{222}\text{Rn}$ . The statistical analysis for  $^{238}\text{U}$  and  $^{222}\text{Rn}$  showed a log-normal distribution with a mean of 6.60  $\mu\text{g L}^{-1}$  and 2,006  $\text{pCi L}^{-1}$ , and a median of 0.80  $\mu\text{g L}^{-1}$  and 1,250  $\text{pCi L}^{-1}$ , respectively. Uranium concentrations were almost lower than maximum contaminant level for drinking water in U.S EPA. One of 47 groundwater samples had levels of uranium that exceeded the maximum contaminant level for drinking water. About 6% of the samples in  $^{222}\text{Rn}$  concentrations exceeded 4,000  $\text{pCi L}^{-1}$  of US EPA's Alternative MCL (AMCL) and 8,100  $\text{pCi L}^{-1}$  of Finland's guideline level, respectively. A hydrogeological study revealed correlations between the concentration of radionuclides and the aquifer material's characteristics. Higher uranium and radon concentrations in groundwater are related to the granitic rocks. The correlation analysis between uranium and radon and other variables only a weak relationship between uranium and pH value (correlation coefficient 0.37 in uranium and radon, respectively). None of major ion concentrations showed a significant statistical correlation with uranium and radon. Uranium and radon concentrations in the groundwater is relatively low compared with other countries having similar geological conditions possibly due to the inflow of shallow groundwater to the wells.



## **Groundwater allocation, community concerns and uncertainty Abstract n°2141**

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KEYWORDS: local government, groundwater allocation, community perception

Local communities experiencing land use changes may be concerned about the sustainability of their water resources and request local governments to explain their decisions on groundwater allocation. However, local governments often have to make these decisions based on limited hydrogeological information because limited funding resources prohibit extensive hydrogeological studies. Often, the only source of information on aquifers and groundwater availabilities are investigation reports submitted to support water take consent applications. These investigations may be biased or may be restricted to a relatively small area of interest, while the aquifer in question extends over a much larger area. A major challenge for local governments is therefore evaluating the reliability of this kind of information, and communicating to the community how this information is used in decision making. This paper presents a case study from the Auckland region in New Zealand, where land use is currently changing from dairy farming to avocado growing. The dairy farming community raised concerns about the increased groundwater demand and asked for clarification by the local government. Hydrogeological information was available only from investigations supporting the avocado growers' consent applications. At the example of this case study, we discuss (1) different interpretations of hydrogeological information depending on different points of view, (2) the level of understanding of hydrogeological information by the community, (3) perceptions of the community regarding uncertainty, contradiction or bias of the presented information, and (4) whether or not this kind of information is legitimate for local governments.



# **Institutional Approaches for Groundwater Management in Coastal Aquifers- An Empirical Analysis**

## **Abstract n°2142**

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**KEYWORDS:** Smart metering, monitoring, water rights, water markets, aquifer resiliency

Groundwater management is a hotly debated issue with few successful practical solutions. In coastal zones, groundwater over-pumping is the major cause of seawater intrusion and salinization of aquifers. The excuses for the absence of monitoring and management have often been explained by the high cost and lack of appropriate technology. In this paper we present a case study where smart groundwater metering is used to measure daily pumping. The results show that measuring pumping and allocating groundwater quotas are necessary but not sufficient to address the problem of a common pool resource. In our research a hydro-economic model was used+ MODFOLW-SEAWAT, and coupled to two dynamic optimization economic models with a simulation run over a period of 70 years. The first model is agent based where each farmer behaves in an uncoordinated manner with non-restricted access to groundwater. The second is an utopic model which maximizes the present value of total benefits from all farms while taking into consideration the long term effects of pumping on the aquifer's salinity. The models were developed with the aim of assessing the optimal institutional framework for groundwater regulation and management. Results show that the allocation of groundwater rights proportionally or uniformly would reduce groundwater volumes pumped but would not be sufficient to protect the aquifer from salinization. However, when groundwater rights are complemented by a reduction of irrigated land, establishment of groundwater markets among farmers, and adoption of efficient irrigation technology, the salinity of the aquifer is improved progressively. The results also show that farmers will not invest in efficient irrigation systems unless water quotas are established and monitored. This paper estimates the economic gains of monitoring groundwater and the contribution of each of the policy measures in achieving resiliency and sustainability of a coastal aquifer management.



**Managed aquifer recharge in crystalline rock aquifers- assessment, potential and dynamics. Example from south India  
Abstract n°2143**

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**KEYWORDS:** Managed aquifer recharge, Crystalline aquifers

In South India, water scarcity is a major threat due to the economic dependence on groundwater-based agriculture, to crystalline-rock aquifers lacking important groundwater resources and to the variability of the monsoon. To tackle this problem, states and federal governments develop large-scale managed aquifer recharge plans. We explored the potential and dynamic of a percolation tank in close relation to crystalline aquifer structure and hydrodynamic (i.e. decrease of the storage and transmissivity with depth, anisotropy, aquifer compartmentalization and impact of preferential flow paths). Numerous and regular field investigations (e.g. GPS, piezometric measurements, borehole logging) coupled with remote sensing over the 2000-2014 period provides a rare dataset in such context. Such assessment shows the high variability of the potential storage, the risk of inequity between farmers in water recovery and the difficulty of assessment of the tank potential. In the studied case, despite a limited potential, important works started in 2016 aiming to increase the tank depth by removing the upper saprolite layer. It may reduce evaporation through the reduction of the surface area for an equivalent volume of stored water, however, due to the low porosity of the fissured layer, underground storage will also partly decrease thus counterbalancing part of the beneficial effects. Following the modifications of tank geometry, it is very likely that water levels will rise rapid and strongly in the nearby boreholes leading to increased yield for some of them. However, rising water levels will be due to the low storage coefficient whereas the overall stored volume will remain low, so that the pluri-annual efficiency the system may be lower than expected. This detailed assessment shows 1) the need for conceptual hydrogeological models adapted to hard rock saprolite aquifers, 2) the need of developing robust decision support on tank design and potential efficiency improvements and 3) the need of developing assessment procedures for such structures upstream of infrastructures development.



## **Mapping local groundwater flow systems in the regolith of Dodowa, Ghana Abstract n°2145**

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**KEYWORDS:** regolith, local groundwater flow, waste water pollution

The objective of our research was to carry out a groundwater flow systems analysis (GFSA) in the township of Dodowa, a peri-urban area on the Accra Plains, Ghana. The GFSA will serve as input for a groundwater use management plan. Thereto, we carried out Electrical Resistivity Tomography along 7 transects of 200-1000 m, we drilled 10 boreholes with depths ranging from 15-70 m at 6 different locations and equipped the boreholes with 2 and 4 inch multi-level piezometers, we carried out pumping tests and slug tests to determine permeability, and we collected some 50 water samples from dug and drilled wells. Samples were analysed both in the field and at the UNESCO-IHE laboratories, for all major cations and anions. Finally, we determined the steady-state groundwater balance. Our first results indicated that the geology of the area is mainly composed of weathered quartz-arenites and phyllites of the Togo Structural Unit and hornblende gneiss of the Dahomeyan Structural Unit. The thickness of the weathered zone varied from a few meter to a few 10s of meter. Horizontal permeabilities in the weathered quartzite ranged from 0.01 -1.0 m d+ groundwater flow in the gneiss was mainly determined by relatively permeable (< 3 m d) and inter-connected fractures. We identified a steady-state local groundwater flow system, whereby recharge occurred on the higher northern side of Dodowa and discharge on the southern side. Groundwater quality ranged from fresh water with a low chlorinity and low alkalinity in the recharge area to brackish groundwater in the discharge area. Brackish groundwater was mainly due to evaporation, giving rise to ion concentration factors up to 20. Nested in this local system was a plume of polluted nitrate-rich groundwater originating from the infiltration of waste water from the township. Our first research results implied that groundwater dominated by local flow provides a relatively simple set of boundary conditions with which local groundwater use management strategies can be developed.



**Interaction between fresh and therapeutic groundwater in exploitation conditions based on one year H, O, and S isotope and chemical observations of selected wells (Carpathians, SW Poland)  
Abstract n°2146**

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**KEYWORDS:** Groundwater exploitation, chemical composition, sulfate, oxygen and hydrogen isotopes, Carpathians

Complicated terms of water circulation in the flysch mountain catchments make it necessary to search for effective methods of its analysis in exploitation conditions. The main goal of the study was understanding processes of interaction between medicinal (HCO<sub>3</sub>-Na type, mineral) and fresh groundwater in flysch aquifer on the basis of case in Tylicz region (Carpathians, SW Poland). Reliable approach for medicinal water protection is pivotal task which remains without answer in Polish and European regulations. One year periodic observation of chemical and isotopic composition was carried out (with parallel water table monitoring) in two neighbouring wells (with fresh and therapeutic groundwater), surface water, precipitation and infiltration water. During the study period significant differences among composition of groundwater, surface water and potential groundwater recharge sources were observed. Based on chemical (Na<sup>+</sup>, K<sup>+</sup>, Mg<sup>2+</sup>, Ca<sup>2+</sup>, HCO<sub>3</sub><sup>-</sup>, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>) and isotopic research ( <sup>18</sup>O(H<sub>2</sub>O), <sup>2</sup>H(H<sub>2</sub>O), <sup>34</sup>S(SO<sub>4</sub><sup>2-</sup>), <sup>18</sup>O(SO<sub>4</sub><sup>2-</sup>) and hydrodynamic data, it was found that studied fresh and mineral groundwater demonstrate different origins and circulation ways. Fresh groundwater resources probably integrally were formed in the catchment (modern infiltration origin) and from precipitation to drainage area was impacted only by local factors. Chemical and isotope composition of mineral groundwater indicated that its resources was formed in deeper part of aquifer as an effect of glacial infiltration origin. Additionally, during the observation period there were no evidences for mixing of these waters with fresh groundwater during their exploitation. The study demonstrated the usefulness of systematic and continuous isotopic, especially <sup>34</sup>S(SO<sub>4</sub><sup>2-</sup>) and <sup>18</sup>O(SO<sub>4</sub><sup>2-</sup>), analysis as an important complement to other chemical, isotope and hydrodynamic studies. Due to sustainable fresh groundwater resources management it is recommended not use simplified rules and limited extraction in area of fresh and mineral water coexistence without isotopic, chemical and hydrodynamical analysis.



## Membrane inlet mass spectrometer for hydrogeological studies Abstract n°2147

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**KEYWORDS:** Dissolved gases+ Membrane inlet mass spectrometer+ Groundwater ages+ Redox processes

Dissolved gases are useful tools in hydrogeology. They inform us on physical and biogeochemical processes along the flow paths of groundwater (noble gases temperature, excess air, redox processes, groundwater ages,...). The sampling and measurement of dissolved gases are often complex and require sometimes long and costly analytical methods. Recently, field membrane inlet mass spectrometer (MIMS) technologies have been developed and optimized to environmental studies. We present here our continuous flow MIMS (CF-MIMS) for field measurements of dissolved gases- H<sub>2</sub>, He, Ne, Ar, N<sub>2</sub>, Kr, Xe, CH<sub>4</sub>, N<sub>2</sub>O, O<sub>2</sub> and CO<sub>2</sub>. Calibration, optimization and limitations of the measurements are presented. The results of a gas tracer experiment and a real time dissolved gases profile in borehole are presented. This new high frequency field measurement technique offers new information for hydrogeological studies.



**Could groundwater offer a second life to the human and plant pathogens *Bacillus cereus* and *Pseudomonas syringae* ?**  
**Abstract n°2148**

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**KEYWORDS:** bacterial growth, oligotrophy, pathogens

The use of groundwater in irrigated cultures has dramatically increased in the last 50 years markedly in the Mediterranean region. Accordingly, a greater attention on the microbial quality of groundwater is now required. Studies on bacterial pathogen occurrence and survival in groundwater are common, but little is known about the growth potential of these organisms in such oligotrophic environment. Recently, the human pathogen *Bacillus cereus* (Bc) and the plant pathogen *Pseudomonas syringae* (Ps) were isolated in waters collected from a shallow unconfined aquifer (Avignon, Vaucluse, France) where intensive irrigated crop farming results in potential risks of fresh vegetable contamination. The objective of this study is to evaluate the growth potential of these pathogens in fresh groundwater water. We aim to evaluate their ability to face oligotrophic conditions and the impacts of these conditions on their metabolism and pathogenicity. Groundwater was sampled from an observation-well located in the irrigated area and characterized in terms of physico-chemical and biological features. Survival and growth behavior of Bc and Ps reference strains were studied in sterile and non-sterile water in batch cultures. The impact of nitrate and oxygen concentrations on the microbial growth, cell size and sporulation (Bc only) was also monitored. Our results indicated that (i) groundwater supported the growth of Bc and Ps and (ii) abiotic factors such as nitrate concentration and pO<sub>2</sub> are important growth parameters. The data give new information on the behavior of pathogens in the groundwater environment and contribute to risk assessment in order to prevent food-borne and plant diseases. In addition, this study provides a critical assessment of the methodology (and experimental set-up) required for deciphering the molecular mechanisms that govern pathogen growth in natural aquatic environment using a systems biology approach.



**Multilevel U-tube monitoring of shallow aquifers for CO<sub>2</sub> geological storage at the Shenhua CCS demonstration site in China**  
**Abstract n°2149**

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**KEYWORDS:** CCS, U-tube, subsurface sampling, environmental impacts, Ordos Basin, groundwater monitoring

The carbon capture (CO<sub>2</sub>) and storage (CCS) is the crucial option to mitigate the large-scale emission of anthropogenic carbon dioxide in this century. However, Understanding the potential leakage risk of CO<sub>2</sub> geological storage in the shallow aquifers is the first priority to gain the public confidence about the CCS technology before its commercial implementation around the world. As known, the Shenhua CCS demonstration project is the first full-chain CCS project in China which is capturing CO<sub>2</sub> at a coal liquefaction plant and storing CO<sub>2</sub> in an onshore deep saline aquifer in Ordos Basin, Inner Mongolia, and that around 300,000 tonnes of CO<sub>2</sub> have already been injected. In this paper, we chose the Shenhua CCS demonstration site to focus on the monitoring of shallow subsurface and to evaluate the impacts of CO<sub>2</sub> geological storage on the geoenvironment. At first, we installed novel U-tube sampling systems in eight wellbores at the demonstration site in order to periodically collect the samples of underground water and gas at fixed depths no more than 25 meters. Then, we conducted the hydrogeochemical analysis in the laboratory for the selected evaluation indexes of water and gas samples. After that, we also compared the analyzed results of the shallow surface with the ones of the deep monitoring well Zhongshenzhu #1 at more than 1000 m depth. Finally, we found some interesting results, e.g. there is no direct evidence for the possible leakage of the buried CO<sub>2</sub> at the Shenhua CCS demonstration site. This study is not only helpful for the understanding of short to long-term environmental impacts of CO<sub>2</sub> geological storage but also providing the support for the selection of reasonable evaluation indexes of underground water and gas in the coming post-closure monitoring of the Shenhua CCS demonstration project.



## **Groundwater quality in an urban alluvial aquifer, Arusha, Tanzania Abstract n°2150**

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**KEYWORDS:** basalt, alkalinity, fluoride, waste water pollution

The objective of our research was to assess groundwater quality patterns below Sombetini and Unga Limited Wards in Arusha, Tanzania. The outcome will serve as input for a groundwater use management plan. Thereto, we drilled 23 boreholes with depths ranging from 5-30 m at 15 different locations, and equipped the boreholes with 2 inch piezometers with 2 m screens at varying depths. From these boreholes and existing wells and springs, we collected some 65 samples. Besides pH, electrical conductivity, nitrate, and alkalinity, another parameter sampled in the field with a handheld ion selective electrode was fluoride. The samples were stored and analyzed for all major cations and anions. Our first results indicated that alkalinity concentrations were high to very high (up to 25 mmol L) and strongly positively correlated with sodium, suggesting the influence of magmatic carbon dioxide as a driver for the dissolution of sodium-rich silicates present in the aquifer, which was composed of basaltic pebbles, cobbles, and boulders of various size and shape. Furthermore, shallow groundwater had highest concentrations of nitrate, while concentrations in groundwater from deeper piezometers were significantly less. Fluoride concentrations ranged from 1-50 mg L, which is rather high. Fluoride concentrations were positively correlated with sodium, suggesting that high fluoride concentrations may be associated with weathering of sodium-rich silicate minerals in basalt. In addition, fluoride was negatively correlated with calcium, while saturation indices for the mineral fluorite ranged between -2 and +1. This indicated that for the higher fluoride concentrations, the saturation index of fluorite was a limiting factor. Like nitrate, also for fluoride, concentrations generally reduced with depth, implying the presence of fluoride associated with waste water infiltration. Our first research results implied that groundwater use management strategies should discard the shallowest, most contaminated, groundwater and focus on defluoridation of groundwater from depths of 20 m and more below ground surface.



## Urban groundwater management to facilitate collaboration of conflicting functions Abstract n°2151

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**KEYWORDS:** urban groundwater quality management, collaboration, governance

In the city of Hoogeveen, large pollutions of volatile chlorinated hydrocarbon (VOC)-plumes are inherited from an industrial past, exceeding remediation standards in a volume of over 4 km<sup>3</sup> of subsoil. The Province of Drenthe – as competent authority for both the remediation of pollutants and safeguarding groundwater as source for drinking water – and the municipality of Hoogeveen took the initiative to develop and operate a groundwater management plan (GMP) facilitating the use of the subsoil for spatial developments and various ambitions of the municipality while at the same time protecting the drinking water abstraction and using the Dutch governance shift allowing spreading of plumes within a well-defined area. The GMP was developed by integrating technical research and knowledge of the subsoil and the ambition and bottlenecks of the stakeholders involved. Seismic and geoelectric research provided input data for a detailed geohydrological model. In addition, comprehensive groundwater quality data was available. The ambitions and bottlenecks of the stakeholders concerned the use of the subsoil in the energy transition and the implementation of climate change measures. Further, spatial restructuring ambition of the municipality is hampered by the plumes. Finally, the drinking water abstraction is threatened since pollutants are detected in the pumped aquifer below a covering clay layer. The GMP facilitated the (re)use of groundwater abstracted to protect the drinking water abstraction by using the fire water system connecting the surface waters of the city. This discharge improves the chemical and spatial quality of these waters and contributes to a reduction of the heat stress. The use of the subsoil for heat storage is facilitated by allowing a certain spreading of the plumes within a well-defined area. The operation of the GMP is financed by offering owners of plumes the opportunity of buying off and hand over the risks of their plume to the GMP-organization.



## **Methods of streamflow depletion estimation caused by cyclic groundwater pumping Abstract n°2152**

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**KEYWORDS:** streamflow depletion, numerical modeling, analytical equation

Constantly growing water demand provides increasing scarcity of water resources. The lack of water resources is especially significant for the small river basins where the water demand is higher than the low-water flow. Cyclic groundwater pumping is used to alleviate deficiencies in streamflow discharge during dry seasons. Groundwater-surface water interaction is at the core of such use. Estimation of streamflow depletion is first-priority to evaluate the effectiveness of application of seasonal compensation pumping. It may be examined by analytical equations or numerical models. The problem of stream depletion has been extensively studied by many researchers. These solutions are limited in their applicability by their conceptual model of the river, aquifer, and pumping well. Regression dependencies between unit stream depletion and capacitance were obtained by authors for the estimation of stream reduction created by cyclic pumping. The numerical simulation approach is widespread applied to stream-aquifer investigations. Numerical modeling of cyclical compensation pumping has special features- the periodic solution, the seasonal changes through the boundaries and the importance even small drawdown of stream level. When seasonality is a modeling feature, traditional approach leads to mistaken values of streamflow depletion. Set of numerical models showed that miscalculation in some cases exceeds 70 percent and more. Simulation of cyclic pumping requires three-step procedure. The first step is usual construction steady-state model. Then steady oscillatory model is constructed in which heads and flows through boundaries vary through the seasons but repeat from year to year (from cycle to cycle). Steady oscillatory solutions are used as initial conditions for transient pumping model. The stream flow depletion is estimated by difference between the transient solution and steady oscillatory solution. The purpose of these investigations was to determine number of cycles required to reach steady oscillatory solution. Estimation of streamflow depletion created by cyclic pumping is complex and not straight-forward problem. Analytical equations, regression dependencies or numerical simulation has their assumptions and limitations



**In-situ measurements of permeability and development of a hydrogeological model that considers the permeability distribution around a fault in the Toki granite, Japan  
Abstract n°2153**

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**KEYWORDS:** Fault, Granite, Permeability, Hydrogeological model, Groundwater flow analysis, Heterogeneity

Faults have various roles in hydrology and there is concern about their influence on groundwater flow and mass transport. We used the Mizunami Underground Research Laboratory (Japan Atomic Energy Agency) in Mizunami, Gifu, Japan, as our study site. This laboratory comprises shafts and horizontal tunnels of different depths, and one of the shafts is adjacent to a vertical fault that is referred to as the “Main-shaft fault”. These research tunnels are distributed mainly in the Toki granite, and we measured the permeability of the Toki granite at 138 points in the walls of horizontal tunnels at depths of 200, 300, and 500 m with a mini-permeameter (MP-401, TEMCO Inc.). We then applied the MODFLOW hydrogeological model, developed to consider the permeability distribution, to analyze and provide an improved understanding of the groundwater flow regime around the fault. The results of the measurements showed that permeability decreased with distance from points at which local maximum values were observed, and with distance from the fault plane. There was more variability in the permeability in more deteriorated parts of the granite. There is a 40-m-wide zone of low permeability around the fault plane that resulted from alterations and infilling of fractures by clay minerals (Mikake et al, 2010+ Daimaru et al, 2012). These characteristics of permeability distribution were reflected in the hydrogeological model. The results of this study provide a unique insight into the groundwater flow regime in granite near a fault. This study was supported by a grant from the Ministry of Economy, Trade, and Industry (METI). We express our sincere appreciation to all those who contributed to this study. References Daimaru et al., JAEA-Research 2012–008, 2012. Mikake et al., JAEA-Technology 2010–026, 2010.



**An old slate mine as lower reservoir for UPSH (Underground Pumping Storage Hydroelectricity)- groundwater interactions and limitations  
Abstract n°2154**

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**KEYWORDS:** Hydropower, Energy Storage, Slate Mine, Groundwater Impacts

Renewable energy sources have an increasing role to play in the future energy framework but their intermittence cannot afford a stable production according to the demand. Pumped Storage Hydroelectricity (PSH) is an efficient technology to store and release electricity. However, the development of new PSH plants is limited by environmental and topographic constraints. An innovative alternative consists in using old underground mines as lower reservoirs of Underground Pumped Storage Hydroelectricity (UPSH) plants. In this configuration, large amount of water is pumped and injected in underground cavities and these cyclic stresses impact the groundwater system. A hybrid 3D finite element mixing cell method is used to numerically simulate the use of an UPSH facility, in the case of an abandoned slate mine. Different scenarios are computed with varying pumping injection time-sequences. In order to assess the impact on the surrounding groundwater conditions, the resulting head evolution in the cavity and at different distances is analyzed in terms of groundwater oscillation magnitude, drawdown, and seepage into the cavity. Results show clearly the influence of the pumping injection time-sequence (rates, regularity, timing and duration of no-activity periods) on the actual head evolution in the surrounding medium and consequently on the magnitude of interactions with the cavity. For a given hydraulic conductivity of the surrounding medium (i.e. slates in this case study), the main conclusion is that the resulting interaction seepage flows (in and out of the cavity) are highly dependent on the chosen pumping injection sequences. The future impact of UPSH operation must be assessed taking this fact into account.



## India's water security challenges and role of hydrogeologists Abstract n°2156

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KEYWORDS: hydrogeologist, groundwater, sustainable development, water security, India

India become a water-stressed nation with a sharp drop in per capita water availability from a surplus level to 1614 m<sup>3</sup> in 2011 and is recognized as one of the future global hot spots of food and water scarcity. To sustain the food production and drinking water needs, India started withdrawing 245 billion m<sup>3</sup> of groundwater annually and became the global leader of groundwater draft. 85 percent of rural water supply programme depends on groundwater. With the projected food production of 250 million metric ton by 2050, Indian agriculture, leading the world in total irrigated land by consuming 85 percent of the utilizable water resources, is the backbone of the country's socio-economic developments in term of its contribution to the GDP. In India, few lakh people suffer with water borne diseases chronically. All major rivers are polluted and groundwater in over 300 districts is found containing of fluoride, iron, salinity and arsenic, exceeding the tolerance levels causing acute health hazards. With increasing number of people becoming conscious of the risks of drinking contaminated water, the demand for safe water is rising rapidly. Industrial demand of water in India is still below 9 percent and is bound to take a quantum jump in near future. To meet the rising competitive demands with finite resource warrant paradigm shift in water policy of India. To address challenges faced by the nation associated with water security, through indigenous and innovative approaches and create solutions to enable, empower and embolden the nation for inclusive growth, self-reliance and societal benefit to all segments role of hydrogeologist is of paramount importance. Hydrogeologist has to come forward to assist developing and disseminate technologies, and monitor and implement national policies with the vision of scientific and sustainable development and management of India's ground water resources, including their exploration, assessment, conservation, augmentation, protection from pollution and distribution, based on principles of economic and ecological efficiency and equity.



**Characterization of non-point source pollution using a SWAT-MARTHE coupling for integrated water resource management**  
**Abstract n°2157**

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**KEYWORDS:** groundwater management, hydrodynamic model, agro-hydrological model, non point source pollution

Non-point source pollution from agricultural practices is of serious concern within the Boutonne 1,200 km<sup>2</sup> wide watershed, located in the southwestern France. National and local stakeholders are concerned and willing to get a global assessment of the water resource and a pertinent decision support for targeting appropriate measures on priority areas for restoring the water quality and complying with the European Water Framework Directive. The ETBX team of the National Research Institute of Science and Technology for Environment and Agriculture (Irstea) has developed a method for assessing the impact of agriculture on freshwater quality and aid tools for public decision, whereas the French geological survey (BRGM) of Poitiers specializes in groundwater assessment and monitoring. Thus the "Adour Garonne" basin water agency asked them for a global water assessment, through coupled modeling of the agro-hydrological Soil and Water Assessment Tool (SWAT) – GenLU2 framework and the fully distributed hydro-geological MARTHE model. The first step of the Irstea-BRGM collaboration has been to evaluate the external coupling feasibility in terms of time calculations, temporal and spatial processing scales, and to identify the correct SWAT parameters for entering lixiviated nitrate from the HRUs (calculation units) into the MARTHE meshes (km wide). The second step is to develop a specific interface for internal model coupling so as to simulate on a global SWAT - MARTHE application the hydric and nitrogen balance linked to the agricultural landuse. The ultimate step will be to widen the current modeled area up to the whole Charente watershed (10,000 km<sup>2</sup> wide) and to transfer the application to the local stakeholders.



**Development of urban shallow groundwater geothermal systems- How to promote a sustainable approach while preventing potential conflicts over underground and groundwater use? – The case of Grenoble**  
**Abstract n°2158**

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KEYWORDS: geothermal model, urban development, aquifer governance

Labelled Ecocity, Grenoble Presqu'île is a large urban development project (250 hectares) located at the confluence of the Drac and Isère rivers. The semi-public InnoVia Company, developer of this site, promotes the use of renewable energy sources and more particularly the use of shallow groundwater geothermal energy to cool the future buildings. However the implementation of geothermal doublets, made of pumping wells (abstracting groundwater) and reinjection wells (reinjecting hot water in the aquifer) could lead to detrimental impacts to underground and groundwater uses. Potential negative impacts includes notably the flooding of under-ground structures (car parks,...), extra parasite water inflow to leaky sewer pipes, lower efficiency of surrounding doublets due to recirculating waters, and at district or city level, regular groundwater temperature increase which could lead to water quality issues and limitations of geothermal use of aquifers. In order to promote a sustainable development of geothermal energy within a complex urban context while mastering potential detrimental impacts, an innovative approach has been implemented by InnoVia. Firstly, InnoVia, in collaboration with Artelia, has built a 3D groundwater and thermal model to assess the impacts of existing and future geothermal system schemes. Moreover the continuous survey of the aquifer (levels, temperature profiles) allows the monitoring of present impacts and the regular calibration of the model. Secondly, in a context where a comprehensive regulation framework related to the use of groundwater as an energy source is yet to come, working procedures have been set. Any building permit, involving shallow -groundwater geothermal use, would be submitted to InnoVia for an advisory opinion regarding the consistency of the envisaged scheme with respect to existing and future use of groundwater and underground. This twofold approach allows a mastered and sustainable development of shallow groundwater geothermal energy at a district level.



**The mechanism of groundwater fluctuations induced by sea tides in unconfined aquifers**  
**Abstract n°2159**

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**KEYWORDS:** Coastal aquifers+ Sea tide influence+ Fresh-saline water interface+ Groundwater fluctuations+ Groundwater dynamics

In this study we examine effects of tides on fluctuations of groundwater level (GWL) and of fresh-saline water interface (FSI) in unconfined coastal aquifers using a two-dimensional numerical model. The time-lags of hydraulic heads and salinities compared to sea level fluctuations are analyzed using cross-correlation analysis. The results show that both the GWL and the FSI are affected harmonically by sea tide fluctuations. However, significantly different time-lags are obtained between hydraulic head in the deeper and upper parts of the aquifer, and between head and salinity in the FSI. The hydraulic head in the deeper part of the aquifer reacts much faster to sea level fluctuations than in the upper part. Surprisingly, a similar difference was detected between the time-lag of the hydraulic head in the FSI and the time-lag of the salinity at the same location. Furthermore, the time-lag of the salinity in the FSI is similar to the time-lag of the GWL fluctuations. We suggest a mechanism in which two main processes are acting simultaneously - 1) tidal forcing at the sea floor boundary, and 2) attenuation at the GWL boundary. Sea tides cause a pressure head wave which propagates into the saturated zone of the aquifer, governed by the diffusivity of the aquifer ( $K S_s$ ). This pressure head wave is attenuated at the water table due to the unsaturated flow within the capillary fringe, which occurs during GWL oscillations. Since the tidal forcing and attenuation by the GWL act on different boundaries, two dimensional distributions of time-lag and hydraulic head amplitude are created. The unsaturated flow within the capillary fringe plays a key role in the pace of water flow and solute transport, since it controls the actual movement of the fresh water body, which results in simultaneous fluctuations of the GWL and the FSI.



**Global Groundwater Monitoring Network- the role of information technology for international cooperation and global studies**  
**Abstract n°2161**

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**KEYWORDS:** Monitoring, Information Technology, Time Series Analysis

Groundwater management decisions rely strongly on the availability and quality of monitoring data. Recognizing the need for a systematic collection of groundwater data, International Groundwater Centre (IGRAC) took the initiative to establish a Global Groundwater Monitoring Network (GGMN). GGMN is a participative, web-based network of networks, set up to improve quality and accessibility of groundwater monitoring information and subsequently our knowledge on the state of groundwater resources. In 2016, a new GGMN Portal was developed based on cloud solutions to enable processing of large data sets from both monitoring stations as well as earth observations. The GGMN portal provides an overview of the availability of groundwater monitoring data through space and time. A time series analysis tool was developed to better understand temporal changes of groundwater levels. The tool follows a step-by-step procedure to identify trends, periodic fluctuations and an autoregressive model to obtain a simulation of the time series. Both climatic and anthropic influences on the groundwater can be identified. The GGMN Portal is integrated with QGIS, an open source Geographic Information System. As such, the data in the GGMN Portal can be used to create spatially interpolated groundwater level maps or for further offline processing and modelling purposes. The GGMN operates according to the principles of the World Meteorological Organization and UNESCO with the aim of encouraging the widespread use of hydrological data for national, regional and global studies. The GGMN has been introduced to over 50 countries including the organization of five regional GGMN workshops in various parts of the world. The workshops highlighted the importance of a global network for improved cooperation and management strategies for transboundary aquifers. The new software, workshop outcomes and the role of GGMN in relation to global studies will be presented.



**Tunnels, a new potential for sensible heat storage in rock- 3D numerical modeling of a reversible exchanger within tunnel lining**  
**Abstract n°2163**

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KEYWORDS: building, heat pump, tunnel lining, absorber pipe, Grand Paris Express

The drive to reduce carbon emissions and reliance on oil and gas has led to increasing use of alternative energy heating systems. The ground source heat pumps are an example of these systems. Recently, tunnels have been considered as a way of connecting building heat pump systems to the energy stored in the subsoil. Due to the large interface area with the ground, this kind of engineering structure offers a great potential to extract heat from the surrounding rock as well as heat generated by the tunnel application (e.g. trains, passengers) for heating purpose in winter. Reciprocally, the energy extracted from buildings in summer for cooling purpose, and fatal energy from inside the tunnel, can be stored into the rock. This new-type system uses the tunnel lining as a reversible heat exchanger by means of incorporation of absorber pipes in which a heat exchange fluid is circulating. The energy can thus be applied for heating and cooling buildings by using suitable heat and distribution pumps. The study is realized in the context of the project "Grand Paris Express", more than 200 km of projected underground railway for public transport in the Île-de-France region which will be constructed from 2016. It is based on numerical modeling of the heat transfer from the tunnel air and the surrounding ground to the liquid filled pipes in the tunnel concrete segments. The transfer is being computed with the help of the finite element software COMSOL, using coupled thermo-hydro analysis in a 3-D model. To carry on a parametric study, the model is calibrated against periods with different parameters (heat extraction rates, inlet temperature of the liquid) for finding out the heat flux and the effect of this system on the temperature on concrete lining, embedded pipes and the surrounding rock. Results are generated in the form of various plots after running the analysis and show the feasibility of the concept.



## **Of groundwater flow and stock Abstract n°2164**

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**KEYWORDS:** Water resources + water management + sustainability

Several recent publications, sometimes highly publicized, aim at quantifying regional or worldwide groundwater resources for promoting their use. They are based on estimations of the phreatic aquifers recharge on one hand, and, on the other hand, on the evaluation of the volumes stored in the reservoirs without any appraisal of their exploitability while no difference is made between renewable and non-renewable resources. However, the renewable groundwater resources represent – at least in temperate climate - the acceptable reduction of the base flow of the rivers. Besides, destocking groundwater storage, which estimation relies upon the correct estimation of the storativities, offers non-renewable resources to be managed during a limited period only. Because of this confusion, important over-estimations of the actual available groundwater resource are often produced. This approach may favor the over-exploitation of the groundwater resources instead of managing their sustainability.



**Characterization of heat exchanges in fractured media using fiber-optic distributed temperature sensing**  
**Abstract n°2165**

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**KEYWORDS:** fiber-optic distributed temperature sensing, DTS, geothermal energy, fractured rock aquifer, heat, tracer, standing column well

Geothermal energy is a renewable energy source particularly attractive due to associated low greenhouse gas emission rates. Crystalline rocks are in general considered of poor interest for geothermal applications at shallow depths (< 100m), because of the low permeability of the medium. Within this framework, the purpose of this study is to test the possibility of efficient thermal energy storage in shallow fractured rocks with a single well semi open loop heat exchanger (standing column well). For doing so, several heat tracer tests monitored by fiber optic distributed temperature sensing (FO-DTS) have been achieved along a borehole between two connected fractures. The heat tracer tests have been performed at the experimental site of Ploemeur (H+ observatory network). They consist in monitoring the temperature in the upper fracture while injecting hot water in the deeper one with a field boiler. For this experimental setup, the main difficulty to interpret the data comes from the requirement for separating the temperature advective signal of the temperature recovery from the heat increase due to injection of hot water which induces heat losses all along the injection tube in the water column. For doing so, in addition to a double straddle packer used for isolating the injection chamber, FO-DTS have been implemented+ allowing spatial and temporal monitoring of the temperature all along the well. This tool allowed us to estimate heat increases coming from diffusion along the injection and to separate both effects, which would not have been feasible with local temperatures probes. We also show through signal processing how diffusive and advective effects may be differentiated. This allowed us to estimate temperature recovery for different heat tracer durations and setups. In particular we show that temperature recovery is highly dependent on hydraulic configuration such as perfect dipole or fully convergent heat tracer tests.



# Evolution of fluvial, weathered and fractured basement aquifers in Uganda

## Abstract n°2166

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KEYWORDS: Fluvial, Weathering, Stripping, Deposition, Upwarp

The evolution of aquifers in deeply weathered environments throughout the tropics is closely related to the long-term development of the landscape via tectonically controlled cycles of deep weathering and stripping. Deep weathering of the bedrock yields a thick weathered regolith and induces sub-horizontal fissures through isostatic uplift. Cycles of stripping partially erode the unconsolidated weathered overburden, producing a discontinuous regolith, and deposit coarse-grained clasts in river channels. We present evidence for the evolution of weathered regolith, fissured-bedrock and fluvial aquifers by tectonically controlled stripping and weathering based on historical observations and detailed studies in Uganda. Critically, field investigations identify, for the first time, a highly productive fluvial aquifer in addition to the primarily in situ weathered regolith and fissured bedrock aquifers that have commonly been described and exploited in deeply weathered terrain. The fluvial aquifer consists of well rounded, coarse sands and gravels with well yields of over 5 m<sup>3</sup> per hour that significantly exceed well yields of < 1 m<sup>3</sup> per hour typically experienced in weathered regolith and fissured bedrock aquifers. Fluvial aquifers are of limited extent on stripped surfaces but can feature significant thicknesses along former river channels on deeply weathered surfaces. The revised conceptual model of the evolution of aquifers in deeply weathered environments represents a key contribution to the understanding of the hydrogeology of these terrains and provides an important new target for the development of groundwater in Uganda and similar environments where groundwater resources are limited by the low permeability and storage of weathered and fissured crystalline rock aquifers.



# **Better Groundwater Governance Only can Ensure Sustained Water Supply in India**

## **Abstract n°2167**

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**KEYWORDS:** Groundwater, Governance, Water Supply, Economic Development

In India, due to increasing population and multi-sectorial demand for water+ the water supply situation is multidimensional - reliable assessment of available water, its scope for distribution, augmentation, reuse recycling+ and protection from depletion and degradation. More than 70% of surface water resources being polluted, groundwater supports >80% of water supplies and 60-90% of irrigated agriculture, although, groundwater is polluted in many parts. Since, the rules responsibilities for effective governance of water is divided between the central and state authorities, and the aggregate impact of millions of individual pumping decisions, the hydrogeological, social, economic, cultural and political factors vary greatly at local regional scales+ no single template for management can be developed. Poor management has resulted in conflicts among different sectors. In this context, this paper highlights the results of the investigations undertaken in different river basins. In much of the Northwest region, deep groundwater renewal occurred from past humid climate during 30000-12000 yr BP, and shallow groundwater renewal from limited modern recharge over the past decades and by interaction with lakes and rivers. In most places, low annual recharge (<5-11% of rainfall) to shallow groundwater suggests limited renewal potential of the groundwater dynamic component. To reduce water consumption and wasteful utilization, the practical measures could be strict regulatory enforcement to price groundwater extraction+ stop wastes discharge into hydrological system+ identify pollution sources, contain pollution spreading from known sources+ develop groundwater vulnerability maps + conserve flood water in aquifers under floodplains and delineate potential recharge and protection zones. For sustainable water supply, the development and management of resources must be based on adequate knowledge of clear aggregate situation of groundwater system, considering environmental, geographical, economic, social, and political aspects, and govern social practical actions decisions by ethical values (honesty, trust, reliability, transparency, etc.), giving more importance to citizens' welfare and economic development before private interest gain. It is desirable to recognize these inextricable linkages, and create public awareness and capacity building for a new vision for groundwater governance.



**Stakeholder engagement in groundwater management- sharing decisions, sharing opportunities**  
**Abstract n°2168**

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**KEYWORDS:** groundwater management, public engagement, Tunisia

The essential role of groundwater resources in supporting natural ecosystems and human wellbeing is more and more recognized. Undeniably increasingly attention is paid to the long-term protection and management of aquifer in developing countries, being a key element for poverty eradication and conflict reduction. However, due to the increasing water demand and the effects of climate variability groundwater resources are still threatened by overexploitation and pollution. Consequently these resources yet represent a limiting factor for the sustainable development of many poor areas worldwide. If, on the one hand the role of the hydrogeological community is fundamental to promote effective science-based management practices, public engagement of groundwater end-users and concerned stakeholders consultation is a necessary requisite for the success of such practices. This work presents the outcomes of the Bir Al-Nas research project, as the first example of the implementation of a socio-hydrogeological approach for sustainable groundwater management in rural areas that integrates social analysis into hydrological investigations. The approach is currently being tested in the rural region of Grombalia (Tunisia) affected, like many coastal aquifers in developing countries, by increasing negative pressure due to human activities. According to the new proposed approach, during in situ measurements considerable importance was given to public engagement of local households involved in the monitoring network. This was performed through the administration of structured questionnaires facilitating the creation of a momentum for dialogue about local groundwater issues while raising awareness on the role water end-users can have in groundwater protection and pollution reduction. Additionally Stakeholder Analysis was performed at the beginning of the investigation to identify the most influential stakeholders likely to support the implementation of the new management strategies based on the hydrogeological analysis. Overall, the results highlight the potential of the Bir Al-Nas socio-hydrogeological approach to pave the way for the development of participative approaches for long-term sustainable management, hence its implementation in other aquifers worldwide.



**Using stygofauna assemblages to analyze groundwater recharge effects in the  
Llobregat River Alluvial aquifer  
Abstract n°2169**

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**KEYWORDS:** groundwater recharge, stygofauna, groundwater ecosystem quality

The Barcelona Metropolitan Area is recurrently facing periods of severe water scarcity and is reliant on water transfers from nearby basins to meet demand. Local Llobregat delta groundwater resources are severally affected by seawater intrusion, limiting their use as a complementary water supply. In order to improve the aquifer resources, Managed Aquifer Recharge (MAR) solutions, such as infiltration ponds, and Aquifer Storage and Recovery (ASR) facilities, have been established near the Drinking Water Treatment Plant of Sant Joan Despí. However, this ASR system is presently inoperative due to the high water production costs and the unsustainability of the ASR scheme for producing potable water. In this context, DESSIN project aims at make flexible the existing ASR deep injection system using pre-potable water. To assess the ecological effects of groundwater recharge in the Llobregat aquifer, an analysis of stygofauna assemblages, as indicator of ecological quality, together with the aquifer hydrochemistry has been conducted. In 2015, a total of nine boreholes were sampled- four of them representative of natural conditions of the aquifer+ three were located near the infiltration pond (not operating during the sampling period)+ and two observation bores of the ASR injection well (sampled during the injection period). Preliminary results show significant differences among these three bore groups. The richness and abundances of stygofauna were higher in those bores influenced by the infiltration ponds, compared to those bores representing natural conditions of the aquifer. However, those located close to the ASR deep injection system showed the lowest values. These differences show the potential effect of MAR on stygofauna assemblages, which could modify groundwater ecosystem characteristics (e.g. temperature, pressure). Further research is presently oriented to assess temporal evolution as a criterion for the suitability of such management practices. This study has been funded by the European Project Demonstrate Ecosystem Services Enabling Innovation (DESSIN-619039), and the University of Girona project MPCUdG2016 061



# STYLOLITES CONTROL KARST FORMATION

## Abstract n°2170

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KEYWORDS: groundwater, karst, stylolites

Karst formation depends on several external and internal factors such as lithology, porosity, permeability, environmental conditions, and the couplings between fluid flow and carbonate dissolution into heterogeneous rocks. It has often been proposed that water circulation in karsts is controlled by the presence of extensional faults, assuming that they are more favorable to water circulation than other geological structures. However, the permeability of fault zones is large only in the early stages their formation because, after a short period, deposition of minerals (e.g. calcite) precipitated from underground waters. These minerals fill the empty spaces and therefore generate dramatic porosity and permeability reduction. The question arises then if other geological heterogeneities initially present in the rock, such as stylolites, do have a stronger control on karst formation. We present here a field study of karsts in the region of Fasano (South Italy) where karst features are more abundant and present along compressional features, such as tectonic stylolites, rather than faults. These field observations suggest that karst formation is controlled by several kinds of heterogeneities initially present in the formation or created during tectonic processes. The data allow characterizing which among these heterogeneities (faults, stylolites) have a larger control on karsts development. For this, the regional direction of the various tectonic structures (faults, stylolites, joints) are compared with those of the main caves. In a conclusion, it can be demonstrated that even small heterogeneities such as stylolites control partly the formation of karst.



**Groundwater nitrate pollution and water scarcity- anticipating pressures as a means to define adaptive strategies**  
**Abstract n°2171**

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**KEYWORDS:** nitrate pollution, water scarcity, sustainable management

Nitrate pollution stands as a common, widespread problem on groundwater quality around the world. European directives, for instance, deal with this issue from a perspective of water resources exploitation and agricultural practices. These are focused to prevent an increase of pollution level through a sustainable water resources management. Even though such kind of hydrological planning has a forward intention, water scarcity in the next decades will stand as a main factor that will determine the aquifer water balance and, consequently, the extent of nitrate pollution. During the last fifteen years, our research groups have characterized several aquifers in Catalonia (NE Spain) looking for the extent of nitrate pollution and the occurrence of denitrification processes from a hydrogeological and hydrogeochemical perspectives. In this contribution, we analyze the hydrogeological characteristics of the affected aquifers, the level of pollution and the occurrence of denitrification processes, the rate of present groundwater exploitation and its final use, as well as the occurrence of alternative water resources for human uses. Such analysis identifies the main present pressures on groundwater quality. Moreover, it also provides a qualitative insight for pressure evaluation under new scenarios when water scarcity related to global change will be crucial in the western Mediterranean area. This approach, which includes present circumstances and future situations, describes the vulnerability of present nitrate polluted aquifers under future hydrological conditions. It also explores potential adaptive actions that could be addressed to prevent nitrate pollution increase and spread, and to warrant water supply to fulfill human and ecological needs.



**Long-term groundwater storage changes in Haihe River Basin, China, from GRACE  
and in situ observations  
Abstract n°2173**

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**KEYWORDS:** Gravity satellite, Groundwater, natural and anthropogenic factors, Haihe River Basin

GRACE (Gravity Recovery and Climate Experiment) is widely applied in groundwater resource research as its unique ability on monitoring terrestrial water storage changes. The limited data period, however, restricts the cognition of historical evolution of the groundwater storage(GWS) change over a longer time frame. In this study, we used the GRACE data (2003-2015) and the groundwater level observations (1962-1983) to estimate the GWS changes in Haihe River Basin(HRB), with a focus on the long-term evolution of GWS as well as the hydrological implications of GRACE. The impacts of natural and anthropogenic driving factors were further analyzed through the comparing of the two periods. It is expected that this study will improve the understanding on GWS changes and GRACE measurements in this area.



## Transport and Transformation of Ammonium in the Aquitard Abstract n°2175

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KEYWORDS: aquitard, ammonium, transformation

Nitrogen in shallow groundwater may result in deep water pollution through leakage flow recharge. Therefore, the transport and transformation of the ammonium in aquitard is particularly important for the pollution prevention of the groundwater nitrogen. In this research, field survey and dynamic column experiment (combination comparison of multiple-group experiments with 15m of water head difference, 5cm and 8cm of aquitard thickness, 90mg L and 150mg L of ammonia nitrogen concentration, undisturbed soil and pure montmorillonite) were carried out to simulate the transport and transformation process of ammonium in aquitard. A field survey of Xincui River, one of typical areas in Huaihe River Basin, shows that the over-limit ratio of  $\text{NH}_4^+-\text{N}$  (45%) is much higher than that of  $\text{NO}_3--\text{N}$  (8%) (Groundwater quality standards in China GB T 14848-93) in the shallow groundwater, but the concentration of  $\text{NH}_4^+-\text{N}$  and  $\text{NO}_3--\text{N}$  in deep groundwater are not excessive. The column experiment shows that there is no form changing for  $\text{NH}_4^+$  in penetrating of  $\text{NH}_4\text{Cl}$  to column. The clay adsorption is the main reason for  $\text{NH}_4^+$  attenuation, and the transformation of  $\text{NH}_4^+$  is mainly for solid and liquid phase changes. The absorption process is mainly in cation exchanging between  $\text{NH}_4^+$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ , which mainly occurs in montmorillonite. Also, the  $\text{NH}_4^+$  has led to interlamination dehydration during the absorption and fixing process. Meanwhile, the two-region model in CXTFIT2.1 match the transport model of  $\text{NH}_4^+$  very well using the inversion of experimental parameters. And it can be concluded that the test soil has some retardant effect on the transport of  $\text{NH}_4^{++}$  for the 10m of the aquitard thickness, under the 15 m of water head difference and 150mg L of  $\text{NH}_4^+-\text{N}$  concentration, the  $\text{NH}_4^+$  can penetrate the aquitard from 360h to 2088h. Therefore, the aquitard becomes the secondary sources, and the shallow groundwater polluted by the ammonium seriously may lead to the pollution of the deep groundwater through leakage recharge.



**basement aquifer, gravity, leveling, aquifer test**  
**Abstract n°2176**

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KEYWORDS: <p>basement aquifer, gravity, leveling, aquifer test

<p>Basement aquifers are able to provide limited and localized water resources well-suited for a distributed water service in small cities and villages. Drilling for wells without precise knowledge of aquifer properties leads generally to unsuccessful flow rates. Various exploration geophysical methods have been proposed to image aquifer properties before drilling, electrical tomography or magnetic resonance sounding, for example. Combined piezometric and gravity monitoring were proved recently to allow a better definition of specific yield of sedimentary aquifers. Up to recent years, the limited precision of portable gravimeters was limiting the extension of this method. However the increasing precision and portability of gravimeters allow us to reconsider it for preliminary exploration of aquifer before drilling. We propose here a sensitivity study based on a 7 day long theoretical aquifer test experiment monitored by gravimetry and leveling. The aquifer includes a superficial saprolitic layer of known properties, and three different hypotheses were considered for the underlying medium- 1) fresh unpermeable basement, 2) a high transmissivity fissured medium typically observed on granitic basement aquifers overlying fresh basement 3) the same fissured layer overlying a vertical tectonic fracture. Subsidence is observed during pumping due to compression of clays in the saprolites. Monitoring is achieved daily during pumping thanks to a network of 6 gravity and 12 leveling stations. For the simplified medium adopted here, the present precision of 2&micro+gal for gravimetry and 2 mm for leveling allows us to retrieve the order of magnitude of both the Young modulus of clays and the transmissivity of the fissured medium. With the increased precision of 0.2 &micro+gal which can be expected for portable iGrav superconducting gravimeters, permeability heterogeneities of the fissured medium could be accessed. It is therefore suggested that simultaneous gravity and leveling monitoring should be tested on some well-known basement aquifer experimental sites.



**Numerical modeling for groundwater management and protection – The case of the Nyanzare well field in Gitega, Burundi**  
**Abstract n°2178**

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**KEYWORDS:** Water Supply – Numerical modeling – Protection zones – Burundi

The majority of the water supply for Gitega city, located in the center of Burundi, is derived from the Nyanzare well field which produces around 5000 m<sup>3</sup> day. The study area is characterised by hills of ancient formations composed of metamorphic rocks as alternating schist, quartzite, and phyllite. Due to population growth, the water demand for the second largest city of Burundi is increasing. Concurrently, progressive urbanization, clay mining, agriculture, coffee industry, and fuel depots represent a growing risk for drinking water quality. To provide for a groundwater management tool, a 3D numerical groundwater flow model of the Nyanzare catchment was developed. The model was set up using the finite element software SPRING. It contains the relevant lithological units of the highly inhomogeneous valley as well as lineaments that act as preferential flow paths leading to great efficiency in some of the pumping wells. A transient recharge calculation was carried out taking into account spatial and climate data of the area. The model was successfully calibrated using water level data from three observation wells collected during the past 3 years. The resulting flow field in the valley was applied to determine average flow velocities and to establish protection zones based on the 50 day travel time around each well. A strategy for sustainable use requires an assessment of available groundwater resources combined with changes in socio-economic and climatic conditions. Several scenarios were tested to simulate the effects of (1) increased water demand after the installation of another well and (2) the variation of pumping intervals. Furthermore, a decline in recharge caused by (3) stresses from climate change and (4) the expansion of build-up areas spreading further into the catchment area was simulated. Results show that scenarios (1) and (3) are the most hazardous.



**Real-Time Karst Groundwater Monitoring- A Case Study in Southern Latium Region,  
Central Italy  
Abstract n°2179**

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**KEYWORDS:** karst groundwater, monitoring, real-time

Pertuso Data Viewer version 1.0 is a software for the visualization, interpretation, download and web access to real time groundwater monitoring data coming from the Environmental Monitoring Plan of Pertuso Spring, in the Upper Valley of Aniene River (Central Italy). This software has been developed in the programming language Matlaby by Sapienza University of Rome for the analysis of time-series data measured by a multiparametric probe developed for the monitoring of water-bearing stratum. This groundwater multiparametric probe simultaneously measures up to 6 parameters (pH, groundwater level, temperature, electric conductivity, redox and dissolved oxygen) and collects hourly time series data. This probe directly interfaces with a datalogger for real-time visualization of instantaneous data in graphical and numerical modes and stores data in a FTP server. Pertuso Data Viewer is supported for Windows XP, Vista, Windows 7, 8 e 10 and the corresponding version of Microsoft Office (64 bit operating systems) and allows a real-time access of groundwater monitoring data and the automatic generation of data report and data chart at user specified time intervals for each parameter for a rapid interpretation of long time series data sets. Pertuso Data Viewer version 1.0 allows the visualization of concentration plots of each parameter measured which can be expanded in separate windows and saved to a variety of different formats including "jpeg", "tiff", "pdf", "metafile". Moreover, this software exports data, starting from the raw file in ASCII format, in Excel-compatible format. Pertuso Data Viewer allows to change the datalogger configuration (type of sensors, acquisition time, memorization time) and to set up thresholds on measures in manual mode or automatic. Real-time groundwater monitoring improves data availability and reduces the need for regular access to difficult mountain sites to download groundwater data.



**Geostatistical integration of logging and hydrogeological data for the characterization of the intermediate aquifer system in Sfax, Tunisia.**  
**Abstract n°2181**

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KEYWORDS: Geophysics, Geostatistics, Modeling

The Sfax basin, located in east-central Tunisia, presents a multilayered aquifer system submitted to arid and semi-arid climatic conditions. It is formed by the surface layers, the deep aquifer and by intermediate aquifer levels, recently discovered, which are characterized by heterogeneous lithology. The intermediate aquifer system covers much of the plain of Sfax and provides very important groundwater reserves. Although it is already operated since 2007, it remains little known and its geometrical and hydrogeological characteristics are poorly defined. The objectives of this work are hydrogeological characterization by geophysical methods to better reflect the heterogeneity of aquifers, geostatistical integration of geological and hydrogeological data for representing 3D spatial distribution of deposits, and the construction of a geological model for this aquifer system through the integration of geophysical and hydrogeological data. The results showed a good knowledge of the geometry of the reservoir which is of paramount importance in all work for the rational management of water resources of this aquifer system.



**EXPERIENCES ON SAT-MAR IN EARSAC PROJECT CONDUCTED FROM THE  
IRRIGATION AND RECHARGE WITH RECLAIMED WATER IN MAJORCA ISLAND  
(SPAIN)  
Abstract n°2183**

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KEYWORDS: SAT-MAR, EARSAC, Majorca

During the last five years, EARSAC project has tested the effect of the irrigation with reclaimed water on different crops, soils and aquifers in Majorca island. Four demo-sites around Majorca with an irrigation network connected to reclaimed water dams from WWTPs have been monitored. The studies conducted applying different doses of water and nutrients to plants have provided good results, not only from the agronomic point of view, but also in the interaction with soils and aquifers, due to the fact that the irrigation doses has been increased in order to obtain an intentional enhanced recharge. The effect of the hydrogeochemical interaction with soils and aquifers has been studied by means of sampling and analysis of water from wells located along the interaction circuit, and also soil profiles and probes, analyzing the water from the unsaturated and the saturated areas and the solid fraction too. The evolution of reclaimed water in the aquifer has small differences with rainwater interaction, with seasonal variations due to the higher salinization in the soils, and very low scale and intensity impacts on the aquifers, most of them related to the persisting organic compounds. In a selected case (Inca City) and after a deep advance in the knowledge of the hydrogeological behaviour of the aquifer, an interaction model has been done by means of COMSOL software. The results achieved have demonstrated the fitness of irrigation with reclaimed water on crops, with an initial affection on plants which is taken over after an irrigation period. Also an slight variation on the soils profile, registering salinization changes along the year related to rain washing with the dilution of salty compounds within the natural range. Finally a negligible effect on the aquifer, with scarce variations in most of the cases, slight accumulation of organic phases in some areas, increase of dissolved gypsum in other sites and a general induced decalcification process of the mudstone, with red clay released by effect of the enhanced interaction.



## **Implication of groundwater flow on rivers discharge in southern Benin Abstract n°2184**

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**KEYWORDS:** Surface-groundwater, Hydrochemistry, modeling

A gap in rivers discharge between gauging stations (separated by a sedimentary-crystalline rocks transition area) is being observed since the past decade in southern Benin. Integrated hydrogeological modeling is a valuable approach to investigate the reason of this observed “anomaly”. However, this requires a good knowledge of the aquifer structure, recharge and groundwater flow in the area of interest. Prior to groundwater modeling exercise, this research is conducted to get indications on the aquifers structures, groundwater flow and recharge patterns in the interested area. The methodology could be divided into three steps. First, existing drilling logs were collected for stratigraphy correlations between different geologic layers. Priority were given to drilling logs that reach the bedrock. Second, groundwater level was measured in existing wells across the area of research to draw piezometric maps. Finally, surface and groundwater samples were collected from rivers and boreholes for chemical and isotopic analysis (stable isotopes and tritium). Results show that the main cretaceous aquifer which outcrops in the North-Western sedimentary basin becomes thicker and deepens rapidly in the NW-SE direction from 260m above sea level (a.s.l) to more than 200m bellow a.s.l in the vicinity of the Oueme valley. Groundwater flows mainly in the same direction. Values above 1.5 TU (Tritium Unit) characterise area where the depth to that aquifer is less than 60m and higher nitrate concentrations (up to 66mg L) characterise the same area. This is an indication that direct recharge from rainfall, if any, is limited when the depth to the cretaceous aquifer is greater than 60m. As a result, any hypothesis of direct recharge from rainfall or from rivers contribution to the cretaceous aquifer at depth greater than 60m is less plausible. The present results are expected to contribute to sound groundwater modeling investigations with respect to the above mentioned rivers discharge anomalies in the sedimentary-crystalline rocks contact zones.



## Characterization of a High Altitude Karst Aquifer in Eastern Turkey Abstract n°2185

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**KEYWORDS:** hydrodynamic, spring recession analysis, high altitude karst, eastern Turkey

Turkish karst is mostly known by its large scale aquifers along the Mediterranean coast. However, the eastern part of the country also exhibits extensive karst with large scale karst aquifers. Gurpinar karst system, one of the best examples, is developed within Paleozoic-Mesozoic marble at the S-SE section of Lake Van basin. This study aims at hydrogeological characterization and conceptualization of the Gurpinar karst system with evaluation of physical and dynamic properties. The elevation of the watershed which extends over an area 471 km<sup>2</sup> ranges between 1648 to 3680 m asl. Groundwater from the Gurpinar karst aquifer discharges through one major and three smaller secondary springs at Gurpinar plain. The minimum, maximum and average flow rate of the largest spring known Samran were measured as 3.4, 7.3, and 5.2 m<sup>3</sup> s, respectively. The results of spring recession analysis revealed that total volume of annual storage of the aquifer is about 226×10<sup>6</sup> m<sup>3</sup> with a recession coefficient of 0.0017 day<sup>-1</sup>. The long-term temperature, pH and specific electrical conductivity values are in the range of 10.2-10.6 °C, 6.27-7.34 and 647-944 IS cm with coefficient of variation as 1.06, 2.02 and 3.3, respectively. The spring water is depleted with respect to stable isotopes (d<sup>18</sup>O= -11.5‰ and dD= -77.1‰) compared to the aquifers in the Mediterranean karst region of Turkey. The deuterium excess of the local meteoric line is found to be 16.5 which falls between the global meteoric line (d=10) and the eastern Mediterranean meteoric line (d=22). The relative deuterium excess values (16.5‰) in precipitation implies that the precipitation originating from mixing of different origin. As a result of all evaluations the conceptual model of Gurpinar karst system were obtained. Acknowledgements- This study is funded by TUBITAK-CAYDAG (project number- 106Y040).



## Perchlorates in French groundwater- Former uses and emerging concerns Abstract n°2189

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KEYWORDS: groundwater, perchlorates, emerging concern, resources management

In 2010, perchlorate contaminations have been reported in groundwater used for supplying a large city in the Southwest of France in drinking water, at concentration exceeding threshold values for children (4 lg L) and adults (15 lg L). Recent investigations show that high concentrations have been also found in groundwater used for drinking water supplies in the North and North of France. Perchlorate is not routinely analyzed in groundwater. Consequently, the extent of perchlorate contamination is not well-known. The widespread occurrence of perchlorate in drinking water leads to concerns regarding perchlorate-induced health issues. Indeed, it could disrupt the thyroid gland's use of iodine in the generation of metabolic hormones. Because of its extremely strong resistance to most treatment technologies, perchlorate has become one of the biggest challenges currently being faced by the drinking water industry. The study of literature and historical archives shows that perchlorates may come from different sources and use patterns- former and actual intentional uses in industrial and military domains+ former non-intentional uses via Chilean nitrates (that contain perchlorates) imported from 1830 to 1950 for chemical industry, explosive powders and agriculture, etc... In our work, a GIS-Database method has been developed to assess groundwater vulnerability, at French national scale, to perchlorate originating from industrial and military activities. A map showing areas considered at "high-risk" for groundwater exposure has been edited and validated. A case study has been also carried out at catchment scale in agricultural context to source perchlorates in groundwater and propose a conceptual scheme of its transfer through aquifers. Results show that perchlorate can generate diffuse pollutions when they source from former agricultural use of Chilean nitrates. The overall results led French authorities to put perchlorates in the list of priority substances to be monitored in groundwater (national decree of 7 august 2015). First results from river basin monitoring networks show that perchlorate in groundwater should become of great concern to stakeholders creating new challenges in groundwater resources management.



## How to make groundwater visible? A review of communication tools Abstract n°2191

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KEYWORDS: knowledge, information, stewardship

In the past 40 years, groundwater use has played a role in defining the development of intensive agriculture and expansion of industries, providing economic development to rural communities in both low and high income countries. Meanwhile it has been confronted with an increasing risk of depletion and pollution leading to more water scarcity and crisis. In this context, Groundwater experts strive to make groundwater issues visible. They face the challenge of shedding light on groundwater while the eyes are more easily on the surface water. Groundwater is an almost unseen resource that is easily forgotten. Its hydro-geological dynamics are complex and largely unknown. In many situations, there is no shared representation of the aquifers, especially between experts and users. Hydrologist face a dual challenge- first to develop knowledge on groundwater and secondly to share this knowledge. This second challenge requests specific equipment. This communication aims to question communication on groundwater through inventorying tools used for this purpose in France and in India. The inventory is based on web mining, literature, interviews and observation. More specifically, in France the survey focuses on the tools developed in the frame of SAGE and territorial bodies dedicated to groundwater. In India, it considers innovative tools used by Groundwater Boards. In this country, over-exploitation has led to the proliferation of warnings and thereby the development of original tools such as participatory mapping of groundwater. This study aims at developing a critical stance on the tools used and the way they frame interactions (public targeted, format, perimeter, information, indicators used, values, issues made visible, assets and limits) to improve communication on groundwater.



**Spatial and temporal evolution of antibiotics in the Baix Fluvià alluvial aquifer and its impact on groundwater resources quality**  
**Abstract n°2192**

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**KEYWORDS:** veterinary antibiotics, alluvial aquifer, agriculture.

Emerging Organic Contaminants (EOCs) occurrence and migration in groundwater has become a great environmental concern. This study looks forward describing EOCs, especially veterinary antibiotics, behavior in an alluvial aquifer (Baix Fluvià, NE Spain) in order to propose strategies for water resources quality assessment and management. A total of 56 water samples were collected (groundwater, 47+ Fluvià River, 7+ and WWTP effluents, 2) in an exploratory survey during spring 2015. Samples were analyzed for hydrochemical, isotopic and EOCs analysis. A monthly sampling campaign of 8 representative wells and 2 surface water locations was conducted during the following year to evaluate EOCs temporal evolution and its relationship with the hydrodynamics of the aquifer. Preliminary results show the dynamics of the hydrogeological system is controlled by the surface-groundwater interaction in the areas nearby the Fluvià River, whereas, marginal areas have distinct hydrochemical features. A total of 14 different antibiotics were found corresponding to six different groups- fluoroquinilones, lincosamides, macrolides, quinolones, sulfonamides and tetracyclines. No clear and continuous spatial concentration trend of EOCs has been observed in the aquifer. Even though EOCs concentrations in groundwater are not very high (order of ng L), the widespread occurrence of veterinary antibiotics detected in the Baix Fluvià aquifer is mainly attributed to diffuse



pollution from agriculture due to the use of organic fertilizers, and to the hydrological mixing between stream water and groundwater in a complex flow field during the irrigation season. Moreover, no clear relationship between nitrate pollution and presence of antibiotics has been observed. While nitrate concentrations in groundwater tend to be relatively stable over time, significant changes in EOCs concentration are observed in most of the wells. We anticipate that differences in manure EOC composition, soil adsorption and mixing due to flow field alterations caused by distinct groundwater withdrawal regimes at each well may largely influence antibiotic composition of groundwater resources. Acknowledgements- This study is funded by the EU project PERSIST-JPIW2013-118 and the Spanish project CGL2014-57215-C4-2-R.



**Investigation of the karstified carbonate aquifer of the Massif of Zaghouan  
(Northeastern Tunisia) by geochemical, isotopic and natural residence time tracers  
Abstract n°2193**

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**KEYWORDS:** karstified carbonate aquifer, geochemical investigation, isotope, residence time

The karstified Jurassic carbonate aquifer of Zaghouan, located in the northeastern part of Tunisia, is known as the best quality water resources of the region. It supplies with drinking water the local cities and the capital since the roman time through an aqueduct. This aquifer is naturally discharging by several karst springs and galleries. After a long period of drought and since the end of the Twentieth century+ an intense pumping is being directly performed, this affects the quality of water and increases the vulnerability of the system. To improve the understanding of groundwater mineralization origin and the impact of the decades of intense water exploitation, geochemical and isotopic investigations were applied. The different groundwater samples (wells, boreholes, springs, dams, galleries) have been collected during various hydrologic conditions- February, May, September 2014 and have been monitored for- physicochemical parameters, major and trace elements (Si, Sr), stable and radiogenic isotopes ( $^{18}\text{O}$ ,  $\text{D}$  and  $^3\text{H}$ ). Classic geochemical investigation, statistical and geochemical modeling were performed to understand the processes controlling groundwater geochemistry. The calcic bicarbonate facies indicate that the main source of water mineralization is carbonate minerals (limestone and dolomite) dissolution, these minerals being the main components of local Jurassic formations. This is also illustrated by different ratios such as  $\text{I}^{\text{S}}\text{Calcite}$  and  $\text{I}^{\text{S}}\text{Dolomite vs Mg}^{2+}$ ,  $\text{HCO}_3^-$ ,  $\text{Ca}^{2+}$ . The stable isotope signature of Zaghouan groundwater indicates that springs are recharged by modern rainfall that has undergone rapid infiltration through the aquifer fracturing network. Whilst, galleries and boreholes have a depleted isotopic signal compared to the modern signature. Tritium and magnesium used as residence time tracers confirm that karst springs waters spend short times to attain the discharge zone. This puts it very vulnerable to the anthropogenic pollution, as revealed by high nitrate contents recorder in some of these springs.



**Conceptual model of fractured hard rock aquifer functioning through monitoring contamination downstream a landfill (Case of Médiouna landfill, Casablanca, Morocco).  
Abstract n°2194**

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KEYWORDS: groundwater, monitoring, pollution, leachate landfill, hard rock, conceptual model.

Groundwater monitoring program around a landfill area is usually undertaken to understand the hydrogeological conditions in order to determine groundwater quality, to describe the occurrence and distribution of pollution and to delineate contaminant plume in aquifer at long term. The groundwater quality degradation represents a significant threat to public health and environment. Furthermore, the fractured aquifer presents a higher vulnerability especially toward landfill pollutants. The Mediouna landfill located 10 km SE of Casablanca is sited on fractured hard rock. This unlined landfill without any system to collect the leachate has a capacity volume of nearly three million m<sup>3</sup>. It started on 1983 in the abandoned quarries of sandstone. The present study aims to develop an understanding conceptual model to delineate pollution plume downstream the landfill. The assessment of groundwater quality is monitored through three hydro chemical monitoring campaigns carried out on 2001, 2011 and 2014. Leachate's sample and 13 wells groundwater's water have been selected from up and downstream of the landfill. Key parameters, such pH, electric conductivity and majors elements have been measured as well as chemical oxygen demand for organic pollution indication. The statistical treatment using Principal Component Analysis has identified three well water groups according to their dissolved elements. A first group characterized by high mineralization and organic matter, the second characterized by low concentration of mineralization and total absence of organic matter. The third group shows middle concentrations of both, mineralization and organic matter. As results, (i) the front of pollution is progressing toward Casablanca city, related to a structural control mainly by the lineaments. The high values are registered close to the landfill and they decrease far of it (ii) the mineral pollution is progressing downstream faster than the organic one.



**Special hydraulic tests to understand the impact on groundwater with the construction of La Linea Tunnel and the changes of hydrogeological conditions in the fractured massif of Colombian Los Andes**  
**Abstract n°2195**

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KEYWORDS: TUNNEL, HYDRAULIC TEST, HYDROGEOLOGY

Currently for the hydrogeologist, the construction of underground works (tunnels) demand a level of knowledge and expertise to the great geological and hydrogeological uncertainty in the mountainous terrain. A not understanding or adequate characterization generate conceptual and numerical models without consistency with the local or regional environment and a real estimation of the impact on surface and groundwater resources during the construction. An example is found in Colombia, with the La Línea Tunnel project. This project involves drilling two tunnels of 8.7 km each one, sections of 18-100 m<sup>2</sup> and depth of 800 m and during the construction generated a reduction of surface currents and maximum groundwater infiltration 200 L s, associated with highly fractured materials, highly conductive fault zones ~25 L s and lack of knowledge the geological and hydrogeological in the fractured massif of Colombian Los Andes. Against this background, it was proposed to do a forensic hydrogeological study to quantify the hydraulic parameters (hydraulic conductivity and storage coefficient) of some geological formations that crosses this project very influential for the country. With the infiltration points identified during the excavation, we proceeded in two phases inside the tunnel larger section- to make a drilling campaign of 30 boreholes of 480 m - PHI and a campaign of hydraulic tests (Packer, Slug Test, Pulse, pumping at a constant flow) - PHII. Once PHASE I finished, stability problems were presented in wells for the high fracturing of the rock. Given this, it was only possible to do 21 hydraulic tests that were interpreted for EPHEBO free code [UPC,2002] that use the analytical solution of general model and it was established a hydraulic characterization for 5 of 6 sectors of the tunnel, with 5 orders of magnitude for K, 10<sup>-10</sup>-10<sup>-6</sup> m s and a value for S~10<sup>-3</sup>. Later, these results helped improve local conceptual model and be analytical and numerical input for the prediction of flow and effect on surface and groundwater resources models.



**Using leading-edge research to inform freshwater management policies- example of the Southland Region, NZ  
Abstract n°2196**

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**KEYWORDS:** groundwater research, groundwater policy, freshwater management

The 2014 New Zealand National Policy Statement for Freshwater Management requires regional authorities to set objectives and policies balancing national objectives and community values for water quality. In response, the Southland region has developed a 6-year Science programme, articulated around four collaborative projects following the source, pathway, receptor model. This paper focusses on the Fluxes and Flows project, co-funded by the region and central government (contestable research fund), which provides a cutting edge framework for understanding water flux in order to inform freshwater management policy. The overarching objective of the fluxes and flow project is the development of a 3D regional, steady-state groundwater flow model, loosely-coupled to a surface water flow model, as the foundation for a series of down-scaled transient, groundwater-surface water flow and transport models (TN, TP and sediments) to be used as a policy management tool to inform catchment limit setting. A biophysical conceptual framework (physiographics), nutrient inputs and ecological sensitivity of receptors, required to inform the flow and transport models, are outputs from the other three collaborative projects. Challenges associated with this collaboration include- flexibility around scope changes+ project management and coordination (three organisations, each with inter-disciplinary teams)+ interdependencies with related projects+ managing expectations+ differences in financial schedule between funding sources+ risk to delivery associated with undertaking research (i.e., data optimisation techniques, groundwater to surface water coupling, tracer validation of the flow model). These challenges are met by shared management across each organisation+ effective communication+ adaption of project components+ stand-alone outputs delivery+ and, strategic extra-resourcing. The ability to meet these challenges stems from the shared reliance on project outputs and positive team engagement. At the end of June 2016, project outputs included- a 3D regional geological model+ a comprehensive hydrochemical review of surface water and groundwater+ and, a loosely-coupled regional flow model. Each output is available to the policy team via science and scientifically trained policy staff for community engagement and associated consultation purposes.



# **Uptake of groundwater research results by water managers – success or failure? Abstract n°2199**

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**KEYWORDS:** Aquifer characterisation, end-user uptake, satellite remote sensing, geophysics, DTS, age tracers, data visualization

New Zealand (NZ) is funding a joint NZ-EU six year research programme (SMART Aquifer Characterisation (SAC)) to assemble a suite of innovative methods within the NZ groundwater scene for characterising the nation's groundwater systems. The programme is in its fifth year. The programme emphasis is on techniques that use passive data sources that where possible rely on existing data sources, or on new measurements that can be made over large areas with reduced effort and minimal cost. This presentation illustrates the hurdles and successes of how programme outputs are being adopted by NZ water managers, which is key to the programmes measure of success. Focus of the research is on four key technical information gaps- • Refining groundwater volume estimation at both the aquifer and the national scale • Determination of aquifer hydraulic properties • Quantification of fluxes between groundwaters and surface waters • Groundwater age dating In order to address these four key information gaps, the programme has trialled and validated methodologies in geophysics, satellite remote sensing, temperature sensing and novel age tracers. In parallel, the programme developed- 1) a framework for quantifying the uncertainty in each method, and assessing which combination of traditional and SMART methods represents the best value for an investigation budget, thereby also validating the cost efficiency for knowledge gain aspect+ and 2) establishing techniques to synthesise and visualise the extensive and integrated datasets. Step gains in knowledge include the following, with varying degrees of uptake by water managers- • Satellite derived groundwater recharge • Potential for increased spatial distribution of groundwater travel time • Application of geophysical techniques for aquifer structure and hydraulic parameter characterisation • DTS and isotope techniques to characterise groundwater-surface water interaction on multiple spatial scales • Standardised data transfer and communication protocols



**Predictive uncertainty and data worth analysis to determine cost effectiveness of airborne EM data for defining hydraulic properties in a groundwater flow model used for predicting long term groundwater level drawdowns.  
Abstract n°2200**

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KEYWORDS: data worth, groundwater flow modelling, airborne electromagnetic

Traditional techniques used to define aquifer hydraulic properties combine field testing (e.g., slug tests and pumping tests) and data analysis. Although these techniques provide direct measurements of groundwater level response to a system stress, they are invasive and time cost intensive, and each test is only locally representative. In comparison, the acquisition of geophysical data is rapid and yields information at various depths and over large spatial scales. This study investigates whether airborne electromagnetic (AEM) data are a cost-effective tool for refining the spatial variability of hydraulic conductivity and vertical aquifer boundaries within a groundwater flow model when compared to more traditional techniques. The cost effectiveness assessment is made in the context of a groundwater impact assessment examining the long term pumping effects on groundwater levels and the ability of existing groundwater users to abstract at their desired yields. In this project, a linear Bayesian uncertainty analysis method is used to assess predictive uncertainty (e.g. Christensen and Doherty). The methodology has previously been successfully applied to several synthetic numerical groundwater model problems. In this example, we examine the worth of various analyses of AEM data by the extent to which they improve the reliability of groundwater level drawdown impact assessments within an 8 x 8 km groundwater flow model. For instance, constructing a spatially distributed hydraulic conductivity field, defined using estimates from pump tests in conjunction with variograms constructed using a resistivity model from AEM measurements. A cost-benefit analysis is also performed considering the added value of drilling and testing at new locations versus that of using the AEM data. This is followed by an uncertainty targeted Pareto analysis, which allows the interdependencies of cost and predictive reliability achieved for alternative data sets to be compared directly. The potential for a reduction in predictive uncertainty using AEM data in pumping effect scenarios on a small-scale groundwater flow model are currently being explored, as well as a cost-benefit comparison to traditional techniques.



**Application of self-potential method for monitoring the contamination from Olive oil mills' waste (OOMW)**  
**Abstract n°2201**

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**KEYWORDS:** olive oil mills waste, self-potential tomography, electrical resistivity tomography

The self-potential (SP) method is one of the oldest geophysical method which measures the distribution of natural electric potential at the ground surface. Integrated electrical resistivity tomography (ERT) and self-potential techniques are often used to identify groundwater flow direction and possible soil and groundwater contamination. In the present study, the results of ERT and SP measurements are analyzed to characterize a site in western Crete contaminated from olive oil mill waste (OOMW). The production of olive oil is one of the major economic importance in Mediterranean region, particularly in Greece which is the third country (worldwide) in olive-oil production with Island of Crete contributing more than 30% of the total olive oil production in Greece. The production procedure of olive oil generates large volumes of OOMW, which pose serious environmental problems due to their high organic load and rich in inorganic constituents. The OOMWs are usually disposed in poorly constructed shallow evaporation ponds, which often results into overflow or leaking of wastewaters, hence, polluting soil and groundwater. The high electrical conductivity and the high concentration of phenolic compounds are the main features that make OOMWs detectable by means of geoelectric prospecting methods. In the study area, five self-potential surveys from May to July 2014 were carried out along an ERT profile by using the fixed base configuration. The SP field data have been analyzed by using the 2D tomographic approach based on the charge occurrence probability (COP) function and spectral methods. Taking into account the electrical resistivity distribution from the ERT tomography, COP maps are interpreted to provide temporal information about self-potential sources and their possible correlations with contamination from OOMW.



## Groundwater Monitoring Network of Greece Abstract n°2202

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KEYWORDS: groundwater, monitoring, database

Institute Of Geology and Mineral Exploration (I.G.M.E.) is the Governmental Geosciences Institute of Greece. Hydrogeology Department of IGME is conducting numerous Hydrogeological studies projects and consulting, mainly for public sector (municipalities, prefectures, companies). IGME was the coordinator and the project leader of the Greek "National Groundwater Monitoring Network" which was in progress from 2013 till 2015. The objectives were the operation of an effective and representative monitoring network of main aquifers, the monitoring of the spatial-temporal groundwater changes caused by natural or and human activities and recording of field and laboratory data (hydrological, hydrochemical, physico-chemical, etc) to a Geo-database, in order to support Regional management project-plans and National water policy. The rational groundwater resources management and the achievement of a good chemical status of groundwater are essential and in line with obligation towards E.U. due to Directive 2000/60 implementation, which refers to state-members water resources protection and management. The monitoring network had included 1400 representative Hydropoints (boreholes, wells and springs) with field observation parameters and chemical analyses of the groundwater samples. All the data were imported in a geodatabase designed for the project. The outcome of the project which by the way will continue till 2022 with European funds are- Adoption of criteria for the groundwater chemical status and identification of the upward trends, classification of groundwater aquifers chemical status Identification of pollution induced by human activities, qualitative and quantitative aquifers update for reassessing all the exploitable groundwater reserves (water balance), re-designation and re-characterization of aquifers, support management plans etc., qualitative and quantitative groundwater trends assessment for adoption of protection and rehabilitation measures, rational and sustainable water resources management and the Implementation of the E.U. 60/2000 Directive.



**Application of single scavenger well for the aquifer that was contaminated by the sea water that was brought by the tsunami of the Great East Japan Earthquake  
Abstract n°2203**

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**KEYWORDS:** The Great East Japan Earthquake, Tsunami, Scavenger well, Single location doublet well

**Objectives-** In coastal areas, which were damaged by the tsunami caused by the Great East Japan Earthquake in 2011, the salinity of the groundwater rose by infiltration of seawater. Currently, freshwater layer has been formed by rainwater during these five years on the top of the saltwater layer in unconfined aquifer. The objective of this study is to clarify the applicability of single scavenger well for pumping freshwater without saltwater upconing. **Design and methodology-** The study area Watari district, located on the east coast of northeastern Japan, was damaged by the tsunami to 5km from the coast line. We conducted pumping test at a well on March, 2016. In the test, groundwater had been pumped simultaneously from two depths, one was freshwater zone and another was saltwater zone, of one well. In order to cut off the flow of groundwater in the well, a packer was installed to the depth of the boundary of freshwater and saltwater. We set the threshold of freshwater and saltwater to 70mS m of EC. The depth of groundwater level and boundary was 1.7m and 5.0m respectively. The length of packer was 1.0m. Pumping test was conducted for three hours and groundwater pumping ratio of two depths was 1-3 liter minute respectively. EC, pH, DO, and ORP of groundwater that was pumped were measured during the pumping. For comparison, we also carried out pumping test that did not use the packer on October, 2015. **Conclusion-** In pumping test that did not use the packer, EC of groundwater drawn from freshwater zone rose from 30mS m to 70mS m in 5 minutes. On the other hand, in pumping test using the packer, EC of groundwater drawn from freshwater zone and saltwater zone had been 44mS m and 0.24S m respectively during the test, both were stable. There also were little fluctuations to other indicators of water quality. These results shows that there is possibility to pump freshwater sustainably using this method.



## **An Exceptional Mineral Water Type in the Polish Lowlands Abstract n°2204**

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KEYWORDS: bore-hole, Jurassic, Miocene

The name Polish Lowlands corresponds to central and NE part of Poland. The part of this province belongs tectonically to the Caledonian platform and is typical for its thick, often folded, Paleozoic and Mesozoic series covered by Tertiary and Quaternary (glacial and interglacial sediments). The occurrence of numerous Upper Permian salt diapirs formed during Mesozoic tectonic movements are of particular importance for the chemical composition of mineral waters occurring often in Mesozoic and Cenozoic sedimentary series. Their mineral content often results from leaching of these salt bodies. Another reason for their salinity may be also the presence of relic seawater possibly present in marine sediments of the Jurassic and the Cretaceous. In any case the main ions present in all mineralized groundwaters found till now the Polish Lowlands are- Cl<sup>-</sup> and Na<sup>+</sup>. Their TDS varies between 1 to many thousand ppm depending on the depth of occurrence and other local hydrogeological conditions. In 1922 a bore-hole has been drilled at Wieniec, a village in the center of Poland. The aim of the drilling was to explore the possibility to find brown-coal deposits in Miocene sediments underlying Quaternary sands. Instead, an important aquifer was found at the depth from 110m in Upper Jurassic (Oxfordian) oolitic limestones containing gypsum. The water-bearing horizon was drilled-through only to the depth of 130m. The spontaneous outflow from the well is 27m<sup>3</sup> h, water is of SO<sub>4</sub>-Cl-Ca-Na type, its TDS is 3500ppm, it contains 1,5 ppm H<sub>2</sub>S+HS<sup>-</sup>. Wieniec became an important medicinal spa with large prospects of development. It must be stressed that in the drilling profile thin layers of brown-coal (Miocene) and some black clay layers (Valanginian) were found. Both types of sediments contain organic matter indispensable to bacterial reduction of gypsum and H<sub>2</sub>S production. It has been found that the area of gypsum-bearing limestones has the surface of ca 200km<sup>2</sup>. This is the unique area of potentially successful prospection for precious medicinal water.



**LINKING HYDROGEOCHEMISTRY AND GROUNDWATER ECOSYSTEMS IN THE LIGHT  
OF THE WATER FRAMEWORK DIRECTIVE IMPLEMENTATION**  
**Abstract n°2207**

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**KEYWORDS:** microbial communities, crustaceans, water quality

Monitoring of groundwater quality is based on physical and chemical parameters, which are believed to describe properly the conditions of health of a groundwater body. Groundwaters host many organisms and basic research is still needed to understand the effects of environmental stress on biological communities. In this research, we analyze the links among the hydrogeochemical facies, the microbial community structure and the invertebrate assemblages within a quaternary volcanic aquifer in central Italy. The key issues are related to the occurrence of arsenic and fluoride from natural sources. Groundwater samples were collected from private wells and springs under a low anthropic impact during two surveys in 2015. Besides a complete hydrogeochemical characterization, we assessed the occurrence of coliforms and *E. coli* (Colilert), the total prokaryotic abundance by flow cytometry, the microbial metabolic profiles (BIOLOG test), and the presence of crustacean stygobionts. Results show a relevant invertebrate diversity, with a total of 117 specimens belonging to 12 species 9 of which obligate groundwater-dwellers. Groundwater samples with sulphate concentrations >10 mg L harbored no or very little invertebrates. The prokaryotic abundance was in the range of 10<sup>3</sup>-10<sup>4</sup> cells ml with most cells showing a low nucleic acid content. The microbial metabolic profiles (BIOLOG EcoPlates) from different groundwaters show patterns surprisingly different for all the five classes of substrata analyzed (amines amides, amino acids, carboxylic acids, carbohydrates, polymers), implying a high metabolic diversity. The preliminary results show that differences in the microbial crustacean communities might be related to environmental changes, including natural and anthropic pressures, with novel insights toward the definition of the good environmental status.



## **Improving groundwater development for rural and urban water supply in Uganda- the role of groundwater mapping Abstract n°2208**

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**KEYWORDS:** groundwater, coverage, mapping, potential, development

Groundwater plays a significant role in both urban and rural water supply in Uganda but its development has previously been made with very little information on the hydrogeological conditions and groundwater potential of various areas. Groundwater development started in 1930s and has been done mainly through construction of deep boreholes and protection of springs. The Government of Uganda has a target of providing safe water and sanitation for all by the year 2025 although safe water supply coverage currently stands at 65%. There is however concern that water supply coverage has not increased substantially over the last few years despite increased funding to the sector. This has been attributed partly to water sources being constructed in areas with very low groundwater potential resulting in low drilling success rates and also water sources yielding inadequate quantities of water, water sources being constructed in areas with poor water quality leading to either abandonment or limited use or due to resources being spent on very expensive water supply options when cheaper options are available. These challenges have been caused by lack of tools in form of maps for use in planning water development programmes by decision makers at both national and district levels. Groundwater mapping outputs are facilitating faster achievement of the national water supply targets and the Sustainable Development Goals. Groundwater mapping involves preparation of maps representing groundwater resources in terms of their quantity and quality and summarizing this information spatially. Six different types of maps are prepared and include- water supply coverage map, hydrochemical characteristics map, water quality map, hydrogeological characteristics map, water supply technology options map and groundwater potential map. Experiences so far shows that groundwater development for rural and urban water supply in Uganda can be greatly improved as result of the guidance from groundwater maps.



**NATION-WIDE GRIDDED BASEFLOW FROM RECHARGE AND GROUNDWATER  
MODELS**  
**Abstract n°2209**

**KEYWORDS:**

Groundwater-surface water interaction (GWSWI) is the assessment of baseflow, which is usually defined as the sum of deep subsurface flow and delayed shallow subsurface flow. At catchment scale, long-term baseflow can be estimated using rainfall recharge data, or vice-versa. Models of rainfall recharge are often challenged, as they combine uncertain estimates of rainfall, evapotranspiration, terrain slope, and unsaturated zone parameters. Rainfall recharge is therefore easiest to estimate on a local scale, as it can be easily calibrated against observations. This process fits in the policy framework for water allocation. However, a consistent overview of rainfall recharge is difficult to obtain at catchment and national scales. This is partly due to data uncertainties, but also because data formats, density of ground observations and local models often differ per region. The aim of this research is to estimate baseflow in New Zealand using a nation-wide rainfall recharge dataset and a simplified groundwater model. For this purpose, a nation-wide model of rainfall recharge was developed, which used estimates of hydraulic conductivity, topography, rainfall, satellite evapotranspiration, and soil data. Uncertainty of all input parameters was propagated through the model equation. Then, a water table was estimated using a loosely coupled system of rainfall recharge and the Equilibrium Water method. The resulting nation-wide datasets are- an estimate of seasonal contribution of each model cell to baseflow at 200 x 200m resolution)+ a 1km x 1km monthly rainfall recharge estimate+ and a seasonal 200m x 200m natural water table estimate. The rainfall recharge data validates well with known lysimeters and local model data in two regions. Model results in ungauged areas show that it is likely that recharge is higher than expected in some mountainous regions. This higher rainfall recharge results in high shallow baseflow. Nation-wide water tables point out zones where shallow water tables exist.



## Geological potentials of aquifer thermal energy storage in North Algeria Abstract n°2210

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KEYWORDS: aquifer thermal energy storage, ATEs, hydrochemistry, hydrogeology, system, direct, North Algeria

We present an overview for aquifer energy storage in North Algeria, and the subsurface environment often let the recent technological development of growing demand for this renewable energy source. The technology may be compromising the natural resilience of the subsurface environment. The main selected aquifers ( Mitidja, Sebaou, Soummam and middle Chélif ) which are intended for thermal energy storage have the following requirements- Max depth of 800 m, approving variant for the installation of low-enthalpy stores in terms of cost. Following the local geological knowledge, many exploratory wells data analyzed on the site, helping by geophysical logging. This let us to have an idea about, depth and thickness of the aquifers and the existence of impermeable layer in the under and overlying sections of the aquifer intended for thermal energy storage. Add to field works we have a net working of pumping and injection well to recording the changes of the water temperature chemical parameters. In the laboratory analysis, we take care for the geological layers distribution and reservoir petro physical parameters. Some Isotope-hydrochemistry analysis to determine the residence time of the groundwater and to derive a potential communication among neighboring wells. Concluding, both field and laboratory works suggest that a good geological condition like the Mididja, chelif and soumman sedimentary basin to this aquifer thermal energy storage in different seasons, there is one thing to take care of groundwater chemical quality during the water temperature variation.



**Potential Release and Sink of Natural Volcanogenic Contamination from Thermal Water**  
**Abstract n°2211**

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**KEYWORDS:** volcanogenic natural contaminant, hydrothermal, Bandung Volcanic Basin

This study aims to understand potential release and sink of dissolved hazardous elements that released from geothermal fluids as natural volcanogenic contaminant. Potential of hazardous elements releases process occurred in volcanic area. The presence of these elements (i.e As, Li, Cl, F and B) in hot springs water is potentially contaminates surface water and soil in the area. Water resource in Bandung Volcanic Basin is very important to analyze, because the population in this area grow and need additional water resource. In this study 20 water samples were taken and analyzed to find out potential hazardous contaminant for environment. Based on this study, it can be distinguished that the potential hazardous elements from southern part is higher than northern part of Bandung Volcanic Basin. It can be concluded that of water resources in northern part in term of water quality is better than southern part of Bandung Volcanic Basin.



**Effects of Land Use Changes to Hydrogeology Condition of Northern Part  
Cikapundung Rivershed  
Abstract n°2212**

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**KEYWORDS:** Cikapundung rivershed, Aquifer, Isotop, Baseflow

Many investigations have been conducted in the upstream part of Cikapundung rivershed over last 13 years to determine the characteristics of aquifer hydrogeological and land use changes. Land use change in this area is potentially decreasing groundwater resources as result of reduce of recharge. Cikapundung rivershed area plays important role as recharge zone for groundwater in northern part of Bandung Basin. Aquifer of Cikapundung rivershed is composed by quaternary volcanic materials e.g. tuff, volcanic breccia and lava with hydraulic conductivity values range  $1.56 \times 10^{-6}$ - $4.77 \times 10^{-8}$  m s. Measurements of groundwater level in last 5 years shows that groundwater level are 2 meter decreasing down. Isotopic analysis of groundwater H2 and O18 then strengthen by tritium result indicate that groundwater are classified as submodern mixing new and meteoric water seeped and aged younger than 10 years. Based on the simulation of water balance, the river baseflow discharge give 18.5% of the average river discharge. This study also shows that the baseflow discharge decreased from 0.26 m<sup>3</sup> s to 0.16 m<sup>3</sup> s with a value Base flow index (BFI) in dry 0.64-0.80 and 0.76-0.93 in the wet season.



## **Assessment of Fault Zone Properties for Groundwater Models Abstract n°2213**

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**KEYWORDS:** fault parameterisation, regional models, hydraulic properties

Increasingly there is a need to understand the influence of faults in basin management where energy resource development can impact groundwater resources. Faults can exhibit a wide variety of hydraulic properties and where resource development induces changes in pore pressure the effective stress and thus the permeability can be transient. We look at strategies for characterising fault zone properties that can be incorporated into regional groundwater flow models to more accurately represent stress, strain and the resulting transmissivities. This includes the effects of fault zone architecture, fault core smear or shale gouge and across fault flow, damage zone characteristics and up fault flow and fault reactivation geomechanics. We use a case study example of the Gloucester Basin of New South Wales in eastern Australia to demonstrate how some of these techniques can be applied. The Gloucester Basin has been subject to exploration of coal seam gas with some pilot testing. It also contains data from monitoring bores and surface water features. The methodologies described can be applied to other basins where faults play a key role in determining flow system characteristics, and capturing their properties in groundwater models is important for robust basin management strategy.



**Changes in groundwater age and source during drought conditions and connections between surface water and groundwater in the Lower Wairau Valley, New Zealand  
Abstract n°2214**

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KEYWORDS: tritium, groundwater-surface water interactions

Groundwater is an important water source for horticulture and viticulture in the Wairau Valley. To maintain minimum flows for healthy river environments during dry spells, groundwater usage may need to be restricted. To enable robust policy development for the aquifer we are investigating (1) how shallow groundwaters and surface waters are connected, and (2) how the dynamics of the shallow groundwaters are changing in view of potential increases in dry spells related to climate change. Tritium was measured in surface water and groundwaters during normal base flow and during the extremely low-flow conditions in the 2014/15 summer in the northern Wairau Plains. Paired water samples from surface water flows and nearby shallow groundwater wells were used to identify the hydraulic connection, and samples from a coastal well to identify the cause for large seasonal changes of hydrochemistry. All shallow groundwaters and re-emerging surface waters close to the Wairau River are very young, indicating direct recharge with little reservoir storage to buffer against periods of high abstraction or low rates of natural recharge. Towards the southeast, with increasing distance from the Wairau River source, the water becomes older (up to 5 years). Tritium concentrations between all paired surface and groundwater samples are similar, indicating interconnected water resources. Therefore, good aquifer and land management is essential for maintaining minimum spring flows and water quality standards. In the coastal well, large seasonal changes of groundwater age were detected (from less than a year to over 10 years). During normal baseflow conditions the well contains young water, which is consistent with locally recharged, oxic water with high nitrate concentrations from nearby land-use activities. During extreme low baseflow conditions, the fresh young water from the last recharge season has depleted, and the well taps into older, anoxic, groundwater, consistent with recharge from areas further from the nitrate sources. This provides the geochemical explanation for seasonal variations in nutrient concentrations in groundwater and the presence of species such as arsenic.



## **Presenting the rejected hypothesis – it's contribution to science success Abstract n°2215**

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### KEYWORDS:

Hydrological conferences are typically overflowing with success stories. For example, how a scientific hypothesis or research question was supported or answered by experimentation, or how well a model represented reality. What are often not presented (for obvious reasons you may say) are the scientific hypothesis that were refuted, research questions that were not able to be answered, or models that were found to be a poor representation of reality? However, these “non-success” stories can also inform science knowledge, and influence future scientific hypothesis, research questions, and methodologies. Airing the hydrogeological dirty laundry may well stop the next researcher from repeating the same flawed approach. Furthermore, the crooked pathway of arriving at the supported hypothesis may have involved some kind of error oversight learning experience along the way, which helped to achieve the success, but was not presented. This presentation provides examples of hydrogeological related research for which the scientific hypothesis was rejected, and or the error or oversight made helped to inform future research direction and paid a positive contribution to the body of scientific knowledge.



**Advanced techniques for groundwater investigation of saline water intrusion in a coastal sedimentary aquifer**  
**Abstract n°2216**

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**KEYWORDS:** Saline intrusion, Submarine Groundwater Discharge, Monitoring, Fiber Optic Cable, Electrical Tomography



The characterization and monitoring of saline water interface is a key issue to understand the evolution of groundwater resources in coastal areas. In order to go beyond the current knowledge in this issue a new experimental site has been constructed in the lower part of an alluvial aquifer north of Barcelona (Spain). In this zone the seawater interface is being monitoring by different techniques and parameters to understand how the saline-fresh water interface behave along different seasons under different recharge-discharge conditions (wet and dry seasons, pumping, etc). The site, between 30 and 90 m from the seashore comprises 16 shallow piezometers with depths ranging between 15 and 25 m. All piezometers are equipped with Fiber Optic cable to perform distributed temperature measurements. Two single steel armoured fiber optic cable lines of around 600m length were installed in all boreholes. On the one hand, the cable is used as passive sensor for the continuous monitoring of temperature. On the other hand, as an active temperature sensor to monitor different in situ experiments. Furthermore, deepest piezometers are also equipped with electrodes in order to perform cross-hole electrical resistivity tomography (CHERT). Periodic CHERT measurements are carried out between the piezometer equipped with electrodes, resulting in parallel and perpendicular vertical cross sections of the site resistivity. The position of the fresh-salt water interface can be identified due to the resistivity contrast between the saline and fresh water. Together with the fiber optics and CHERT investigations, groundwater geochemical characterization (Rn, Ra isotopes, trace metals, nutrients) are analysed in different piezometers. Preliminary results indicated that the combination of both methodologies is a useful technique to investigate and monitor the discharge of groundwater into the coastal sea, which may have relevant implications for both groundwater resources and coastal biogeochemical cycles.



**Epikarst- perched subsurface aquifer with high environmental heterogeneity specific ecological conditions – a long-term study on groundwater communities in a shallow cave in Slovenia**  
**Abstract n°2218**

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KEYWORDS: KEY WORDS- epikarst, ecology, microcrustacea

The epikarst zone is located at the top-most layer in limestone and dolomite rocks. Epikarst has, due to intensive weathering and geological activity, a high permeability, enabling fast water infiltration. As the extent and frequency of fractures diminishes gradually with depth, epikarst permeability decreases as well. After recharge due to rainfall or snow-melt, percolating water is retained in the thin zone of epikarst leading to the formation of a shallow and perched aquifer characterised by a mosaic of water saturated and un-saturated parts. Water retained in the epikarst percolates downwards through the vadose zone forming drips in caves. Epikarst aquifers host a peculiar groundwater fauna, with some specific morphological adaptations. In the case study carried out in the 120 m long Velika Pasica Cave (central Slovenia) located only few metres below the surface in a karstified dolomite formation at the elevation of about 600 m, the results of seven-years study on hydrology, water chemistry and fauna composition of four permanent drips are presented. Each drip showed specific hydrological and environmental features depending on local habitat structure, and differed from neighbour drips in response to rainfall, discharge times and water chemistry. Environmental diversity was reflected by faunal composition. Microcrustaceans were studied in detail+ one species of Ostracoda and ten species of Copepoda were recorded from the four drips. Some of them were site specific, demonstrating very narrow ecological preferences and a high value as potential hydrological tracers. Less than 2,000 specimens were collected during the seven-years study. No relationship between discharge and number of specimens washed out from the epikarst was detected. Indeed, the strong species-environmental relationships and spatial structure of metacommunities showed no significant variation during the long-term study.



# GROUNDWATER USE FOR AGRICULTURE AND SUSTAINABILITY CONCERNS

## Abstract n°2219

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KEYWORDS: Groundwater, Punjab, Pakistan, Quality

Groundwater is an essential part of the hydrology cycle which not only supports the life and ecosystem on planet but also plays the role of backbone in many commercial, industrial and development activities. Pakistan is 4th largest user of groundwater after India, USA & China. In Punjab Province (food basket for Pakistan), groundwater resource is being extracted through about 1 million tube-wells installed by the farmers. This natural resource is contributing about more than 40% crop-water requirements at farm gate and thus has gained the vital potential in irrigated agricultural economy of the country. Groundwater has helped in increasing cropping intensity from 60% in 1947 to 150% or even more in 2015 to meet the increasing needs of food and fiber. Groundwater budget for Pakistan is negative i.e. abstraction exceeds recharge. Besides agriculture, groundwater is also used for drinking, industrial, livestock purposes as well. A monitoring network of about 3000 piezometers has been installed to observe the groundwater levels in different 7 units in the province and groundwater quality is being tested from about 2500 tube-well twice in a year to see the temporal trends in the groundwater regime. Results have indicated that the groundwater in sweet areas is depleting at very alarming rates ranging from 1 to 2.5 ft. per year. This situation has put extra burden on the end users as the cost of pumping groundwater has increased abnormally taking groundwater away from the limits of poor farmers. It has further been confirmed that quality of this precious resource is also deteriorating with the passage of time which has caused secondary salinization in many areas, turning the fertile lands into barren belts. Impact of flood 2014 in Pakistan on groundwater has also been evaluated which showed 2.5 ft. rise in water table. Results have been shared with the farmers by arranging training and capacity building workshops in field.



**Studies of Springs and Hot Springs Genesis Using Stable Isotope in Southern Ridge Bandung Basin**  
**Abstract n°2220**

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**KEYWORDS:** Bandung volcanic basin, stable isotopes, hydrothermal, mixing ratio

Abundance of geothermal manifestation widely distributed in southern ridge Bandung volcanic basin such as hot springs and springs. Isotope studies were carried out to clarify details of hydrothermal system in southern ridge Bandung volcanic basin. Deuterium and  $^{18}\text{O}$  employed to study the genesis and origin of the water samples, while Tritium used to determine the age of the geothermal fluids. For further analyses, stable isotopes composition used to identify hydrogeological process and mixing ratio of the waters in each area, Two End Member used as method to determine ratio in mixing process. Water samples taken from the southern ridge Bandung basin, western Indonesia. There are 21 water samples collected consist of 3 crater, 16 hot springs, and 2 springs. As result, most of water samples fall between evaporation and water-rock interaction line and some of samples fall near meteoric water line. It indicates that hot springs and springs samples are enriched in heavier isotopes and deviate from local meteoric water line. This enrichment is commonly due to near surface evaporation, mixing between meteoric waters and isotopically enriched deep magmatic waters. Two End Member method suggest that the portion of meteoric water is higher than magmatic water. It indicates that hydrogeology of geothermal system in study area belong to low-medium temperature geothermal systems of convective type.



# The changing role of groundwater in regional economic development

## Abstract n°2221

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**KEYWORDS:** climate change, regional economic development, groundwater, crop modelling

In Australia, groundwater makes up about 17% of available water resources, and in some regions accounts for 30% of consumption. In fact, in many regional areas it is the only source of water. However (and perhaps because it is important mainly to regional and rural communities), groundwater remains a poorly understood resource. Yet, as climate changes and water becomes scarce, it is anticipated that groundwater use will increase. This study looks specifically at a groundwater-dependant region of southwest Victoria, and the possibility of expanding agricultural production (both of existing commodities and new commodities) to meet the food demands off a growing population. The work was initiated on the request of local government and water authorities. We developed expert-system models to quantify the potential impact of climate change on the yield of eight agricultural commodities. The results indicate that some rain-fed crops will require more water to maintain current production levels, while the geographic extent of others could be substantially increased (for example, to double production volume) if access to water is possible. However, the complexity of the water situation was not well reflected in the models – specifically the likely competition between different groundwater end-users as the region embarks on one development path over another. As such, new models are being developed to address the impacts of alternative agricultural development pathways on the groundwater resource, and how supply-demand changes relative to competition between agricultural and domestic users. This paper therefore outlines how groundwater considerations can be integrated into regional crop-climate models and how the results can be used to inform strategic planning to take advantage of economic development opportunities. We also investigate the implications for agricultural development under a changing climate where water supplies from more traditional sources are under increasing stress.



# Advanced Geometrical Characterization of Fracture Networks via Tomographic Imaging

## Abstract n°2222

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**KEYWORDS:** fractured aquifers, discrete fracture networks, hydraulic tomography, tomographic inversion, Monte Carlo methods, tracers

Characterization of naturally fractured reservoirs and aquifers plays a critical role in various disciplines such as hydrogeology, hydrocarbon exploration production and geothermal, as fractures provide the main pathways for transport. While fracture orientation and spacing can be easily determined from borehole geophysical logs and core images in boreholes, reconstruction of cross-hole fracture geometry still is a challenge. Modern hydraulic investigation methods such as hydraulic tomography or thermal tracer tomography can provide more insights in fractured media than traditional pumping or tracer tests. However, interpretation of tomographic data recorded in fractured media is not straightforward. In this study, we propose to extract the physical properties of complex fractured media, such as fracture geometry, by means of a multi-level Bayesian inference method. This method handles all information as a random variable. For application to tomographic inversion, it requires appropriate parameterization of the fractured media. This is accomplished using the discrete fracture network concept. As for an application case the number of fractures is not known, the number of parameters needs to be variable during the inversion. This is obtained by using a reversible-jump Markov chain Monte Carlo (RJMCMC) algorithm. This method is trans-dimensional and so it can change the dimensionality of the parameters. Initiated by a randomly generated DFN realization, this candidate solution is iteratively updated and evolves in a Markov chain using the Metropolis-Hastings-Green acceptance ratio. The used updates are fracture addition, deletion and movement and they obey prior statistical rules such as fracture intensity and fracture length distribution. For successful RJMCMC simulation, a large number of iterations is required. Here, a fast implicit upwind finite difference method is used for pressure and transport calculation to keep the computational time within reasonable limits. The result of RJMCMC algorithm application is an ensemble of DFN realizations, which represents the posterior of the tomographic inversion problem. This ensemble can be used for both deterministic and stochastic model-based investigation.



**The Groundwater Interoperability Experiment 2- developing an international  
groundwater data exchange standard  
Abstract n°2223**

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**KEYWORDS:** groundwater data, GroundwaterML2, interoperability

The groundwater interoperability experiment 2 was initiated by the Hydrology Domain Working Group of the Open Geospatial Consortium (OGC) to develop an international standard for the exchange groundwater data via the internet. The experiment focused on harmonising and extending previous initiatives such as the European Commission's INSPIRE geology hydrogeology package, the initial groundwater data interoperability standards developed by the Canadian Geological Survey (GroundWaterML1) and other models. The result is GroundWaterML2 a specification proposed by the OGC in 2016 as a standard for the transfer of groundwater data, including water wells, aquifers, flow, physical and chemical parameters and management. The experiment was designed around five use-cases to test the commercial, technical, scientific, environmental and policy applications. The collaborators in the interoperability experiment were a dozen government and academic research organisations from North America, Europe and Australasia, who regularly convened through a series of more than 50 teleconferences and two face-to-face meetings over four years. Three main steps were involved- 1) constructing a conceptual model using Unified Modeling Language (UML) representing the semantics of the groundwater domain+ 2) developing a logical model, as a GML schema that utilised the OGC suite of standards, and 3) encoding an extensible mark-up language (XML) schema. The results of the experiment were positive, with seven of the participating organisations successfully mapping core components of their groundwater data to GroundWaterML2 and streaming it via OGC-compliant web services. It clearly demonstrated the seamless integration of groundwater data and information using international data exchange standards, federating all or parts of large groundwater databases with disparate schemas and stored on disparate systems. It heralds a new opportunity in groundwater data accessibility and the ability to further hydrogeological science through the new discoveries in federated international and multidisciplinary data sets.



**TunWaterFlow V1.0- a software to estimate the groundwater seepage during drilling and calibrate the hydraulic parameters (K, Ss) that generate an observed flow in a tunnel**  
**Abstract n°2224**

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KEYWORDS: TUNNEL, TUNWATERFLOW, GROUNDWATER SEEPAGE

One of the most important problems in the construction of tunnels in porous and fractured media, is the groundwater infiltration. The lack of knowledge and due quantification can generate instability of the rock mass, increases pressure on temporary support systems and permanent changes in the geomechanical properties of materials, ground movements (subsidence), reduction of surface and groundwater resources, environmental impacts, increase time and cost of the project, among others. Some authors have studied this subject with analytical models to quantify the infiltration flows in a tunnel, from formulations at steady state with constant hydraulic head, instant drilling, etc. However, the behavior of the excavation is progressive and the tunnel drilling heterogeneous formations and the application of these formulations at steady state are not recommended. Perrochet [2005a] established a formulation in transient state that considers the progressive drilling in homogeneous and heterogeneous media [Perrochet and Dematteis, 2007]. This last approximation considers a simplification of geology in vertical layers with different hydraulic parameters (K and Ss) and with a convolution integral, it is possible to calculate the discharge into the tunnel (direct problem). However, there is not a tool to do a calibration of flow observed in a portal automatically (inverse modeling). To solve this limitation, in this work, it was adopted the formulation proposed by Perrochet and Dematteis [2007] and solve the inverse problem with a software developed in Matlab R2013a and called "TunWaterFlow V 1.0". This software makes a coupling of the existing mathematical model and two calibration algorithms- evolutionary algorithm + simplex algorithm (SCE-UA) and MonteCarlo simulations (GLUE) to allow automatic adjustment of the flow simulated with the observed flow, is possible with comparison the objectives functions. For purposes of showing the utility of this software, it has tested with calibration exercises in three tunnels that were presented during excavation, peak flows infiltration of 200 L s each one (La Línea Tunnel – Colombia, Modane Tunnel– France Italy and Pajares Tunnel – Spain).



# GROUNDWATER FLOW SYSTEM MODELS AND INTERPRETATION OF VARIABLE INTERACTIONS AT GUASCA MUNICIPALITY IN COLOMBIA

## Abstract n°2226

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KEYWORDS: Remote Sensing, Stella, Multiple Regression

In order to understand the groundwater flow behavior and interaction with various measurable parameters, the Generalized Watershed Loading Functions model using the STELLA software (ISEE Systems), as well as multiple regression analysis and fittings were implemented. The former provided information about the characteristics of the unsaturated zone, saturated zone and stream discharge, based upon information provided by meteorological stations (HOBO and Campbell), piezometers and divers placed in two zones at Guasca Municipality. The discharge results from the STELLA model were compared to the measured values from 2008 to 2010, after Fourier fittings transformations using MATLAB. The groundwater measured by the piezometers and the calculated by Fourier transformations had R2 of 0.89 for the year 2008, 0.94 for 2009 and 0.99 for 2010. Best fittings on monthly basis were found during rainy season with R2 up to 0.9, worst fittings were obtained for monthly rain values lower than 1.8 mm. Average peak discharges measured and calculated had similar results. For example- for the year 2008 the measured average peak discharge value was 5 m<sup>3</sup>s<sup>-1</sup>, while the calculated was 4.27 m<sup>3</sup>s<sup>-1</sup>, for 2009 the measured average peak discharge value was 5.01 m<sup>3</sup>s<sup>-1</sup> as compared to 4.94 m<sup>3</sup>s<sup>-1</sup> calculated, and 3.08 m<sup>3</sup>s<sup>-1</sup> measured average peak discharge value for 2010 versus 3.04 m<sup>3</sup>s<sup>-1</sup> calculated. The Normalized Difference Vegetation Index (NDVI) from MODIS images were studied for the year 2008 and compared with the groundwater conductivity at the selected sites. Results show a relationship between these two variables for the dry and rainy season with R2 greater than 0.8. Groundwater level fluctuations were also analyzed and compared with rain patterns. Multiple regressions show relationships between average groundwater level changes per day and daily rain at various time periods (t, t-1 to t-4) with measured and predicted results with R2 of 0.86 for one site and R2 of 0.98 for the other.



## Using hydrocarbon system analysis to evaluate seal transmissivity Abstract n°2228

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**KEYWORDS:** hydrocarbon systems, aquitard performance, resource management, fugitive methane

The development of significant coal seam gas (CSG) resources in Queensland (Australia) involves the depressuring of coal measures located between 300 and 1000m depth. Adjacent aquifers of the Great Artesian Basin are monitored and modeled to predict any impacts such as water level decline or increase in methane content. Early in the resource development cycle there is little data to constrain such models and thus uncertainty is high. We propose to use hydrocarbon systems analysis to examine the generation of hydrocarbons from source rocks and their subsequent trapping and leakage, to highlight the locations where aquitards and faults have allowed hydrocarbons to migrate in the geological past. A "hydrocarbon habitat" provides the basic data to assess key leak points through aquitards, and on faults, which are the first locations to look for hydraulic communication between the CSG reservoir and adjacent aquifers. We give examples from the Surat Basin in Queensland and compare the results of our approach with the Office of Groundwater Impact Assessment regional simulation of predicted impacts. The methodology we describe provides a means to define a baseline of hydrocarbons naturally in the system prior to energy resource development and also to highlight regions of apparent seal vulnerability to direct monitoring and more detailed analysis.



**Occurrence and fate of antibiotics in soils fertilized with manure and evaluation of their persistence and potential to migrate to groundwater bodies**  
**Abstract n°2229**

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**KEYWORDS:** antibiotics, manure fertilization, agricultural soils, groundwater quality

Animal manure is extensively used as fertilizer in agriculture because it contains essential nutrients for plant growth. However, fertilization of crops using animal manure may lead to contamination of groundwater resources by the introduction of organic pollutants, such as antibiotics and pharmaceuticals used in veterinary medicine. Once animal manure is applied as fertilizer in agricultural soils, recalcitrant pharmaceuticals may persist and accumulate in the soil while others may leach to groundwater bodies. In the present work, the occurrence, distribution and fate of 40 multiple-class antibiotics and veterinary pharmaceuticals was investigated in two field experiments fertilized with animal manure at a rate of 170 kg N ha per year, one with dairy cattle manure and the other with pig slurry (plots size- 3x8 m and 3x10 m, respectively), including control plots without fertilization. Soils under study were very deep, sandy loam textured and calcareous. The fields were cultivated with wheat and barley, alternatively, since 2001. Soil sampling was performed in December 2015, prior to fertilization, and in February and June 2016, two and six months after fertilization, respectively. Moreover, manure used as soil amendment was also analyzed. Soil samples were taken at different soil depths, covering from 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm. Analysis of veterinary antibiotics and pharmaceuticals was performed by liquid chromatography tandem mass spectrometry to investigate the persistence and mobility of target substances along the soil column. Antibiotics and pharmaceuticals detected in manure (ng g – lg kg range) were matched with those detected in soil samples (found at low ng g levels). Differences in pollutant concentrations before and after fertilization indicated that repeated fertilization may contribute in building up persistent residues that accumulate in the soil over time. Moreover, the analysis at different depths was useful to identify the pollutants with the highest mobility and those that are more liable to leach to groundwater bodies and deteriorate the quality of aquifers.



**Comparing the effects of climate change and mitigation measures on urban groundwater resources**  
**Abstract n°2230**

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**KEYWORDS:** climate change adaptation groundwater modelling extreme value analysis

Future groundwater conditions are directly affected by changed quantity, spatial and temporal structure of precipitation, temperature and evapotranspiration. The future climate is predicted to be both dryer and wetter depending on location but a common situation is that extremes will be larger and occur more often. The anthropogenic response, in terms of adapting to, for example extreme urban runoffs, can also in a more indirect way have an effect on groundwater conditions. The impact on groundwater conditions from both direct and indirect effects are presented in a study from the City of Silkeborg, western Denmark. Climate change effects, representing the last decades of the 21st century, are simulated by a hydrological MIKE SHE model. The model encloses an urbanized area where adaptation strategies include diversion of rainwater from traditional urban storm water systems to new Local Forced Infiltration (LAR) systems (also termed Low-Impact Development or soakaways). LAR systems infiltrate surface water locally or in an end-off-pipe system, with larger common infiltration basins. The model calculates daily hydraulic head of the upper unconfined aquifer for the reference period (1990-2012) and based on this data, an extreme value analysis is performed to extract hydraulic heads for return periods of 50 and 100 years. The extreme values analysis is also performed for the future period and for a scenario where LAR is an integrated part of the urban rainwater management. With this methodology it is possible to analyse not only average future groundwater conditions but also extreme conditions important for vulnerable infrastructure. The study illustrates the need for local analysis of the combined effects from both climate change but also the effects from different adaptation strategies. At the city of Silkeborg, the effect from adapting to climate changes with LAR solutions, clearly overrule the effects from increased precipitation, temperature, and evapotranspiration.



## **A Three-dimensional hydrogeological model of the Djeffara aquifers, Tunisia Abstract n°2232**

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**KEYWORDS:** hydrogeological model, oasis, ecosystem, Djeffara, Tunisia

Gabes area (south-eastern Tunisia) is well known for existence of specific ecosystems, the coastal oasis. In the same time, the multilayered aquifer of Djeffara, has been intensively used as a primary water source to meet the growing needs of the various economic sectors (drinking, agricultural and industrial purposes). This overexploitation led to spring depletion, groundwater level decrease, groundwater salinization and degradation of ecosystems. The Gabes coastal aquifer project aims to protect these aquifers by the means of geological and hydrogeological study, analysis of socio-economic uses of water, analysis of ecosystems sensitivity and hydrodynamic modeling, to enhance groundwater resources management. The geological study highlighted a very complex system with more than twenty layers and a large network of faults which provoked hydraulic connections between the different aquifer horizons. This is mainly the case of the El Hamma–Chenchou area which is the outlet of the deep Intercalary Continental (IC) by the means of several faults.. Hydrodynamic modeling of such a complex system involves a precise geometry of aquifer and non-aquifer units. That is the reason why a geological model was built with Geo-modeler software by using more than 200 deep wells, and by the reinterpretation of several seismic profiles. It enabled an assessment of structural and conceptual hydrodynamic models.. The groundwater flow modeling is under construction by the Modflow software taking into account the geological model and the boundary conditions. The project is intended to develop innovative tools for combined management of water resources, soil and ecosystems, and to assess their states according to different scenarios.



## **Groundwater quality risks in a densely populated rural coastal area- Kwale, Kenya Abstract n°2233**

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**KEYWORDS:** Hydrochemistry, Groundwater, Kenya, rural area

As the global population grows, so does the demand for fresh water. In rural Africa and Asia, many communities rely on groundwater for their drinking water, making groundwater quality vital to the social, economic and physical well-being of rural people. This presentation characterizes current and future potential risks to groundwater quality in a densely populated rural area on the southeast coast of Kenya. This work is part of the “Gro for Good- Groundwater Risk for Growth and Development” project, one of a number of consortium projects funded through the UPGro Programme - Unlocking the Potential of Groundwater for the Poor (<http://upgro.org> consortium gro-for-good ). Focusing on Kwale County, a rural area where industrial irrigated agriculture, and heavy mineral mining have recently been established, our study captures the complex reality of Africa’s groundwater science and policy challenges at a time of social, economic and environmental change. The goal of this interdisciplinary project is to analyse and synthesise a broad spectrum of natural and social data to promote improved groundwater governance that balances economic growth with poverty reduction and groundwater sustainability. As one aspect of this, the potential risks to groundwater quality posed by industrial activity and population growth in the region are being investigated via a series of water quality surveys (dry and wet season) covering shallow and deep wells as well as surface water across different geological



formations. Analysis includes isotopes, major and minor ions, TOC (Total Organic Carbon), Faecal Bacteria, Alkalinity and Ammonia (in situ). Our initial results show that multiple factors are affecting the chemical and biological quality of groundwater throughout the study area. Acknowledgements The research is supported under the NERC ESRC DFID Unlocking the Potential of Groundwater for the Poor (UPGro) as a Catalyst Grant (NE L001950 1) with work extending until 2019 as a Consortium Grant (NE M008894 1), see <http://www.upgro.org>. Our gratitude to all contributors, Base Titanium Ltd, Kwale International Sugar Company and Water Resource Management Authority.



## **Is there overexploitation in the coastal Recife aquifers (Brazil)? Abstract n°2234**

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**KEYWORDS:** coastal aquifer, cost of groundwater extraction, overexploitation, seawater intrusion

The expression groundwater overexploitation has been used in scientific literature and media in an unrestrained way. Usually overexploitation is characterized when stakeholders perceive the negative aspects of groundwater exploitation. Despite its technical uncertainty, this term makes the society aware of aquifer situation and it can be used when at least one of these problems is the case- 1) aquifer hydraulic exhaustion+ 2) water quality deterioration (including seawater intrusion)+ 3) increase of pumping costs to a level where other water sources are more suitable+ 4) aquifer discharge reduction into water-bodies+ 5) land stability problems+ and 6) social inequality problems caused by not fair water distribution. This study applied all of these overexploitation concepts in an extensive exploited aquifer in the coastal city of Recife (Brazil) that is facing issues related to- very fast increase of well drilling, uncontrolled pumping, water level drawdown and water quality deterioration. For this purpose, historical chemical data, water well inventory and water level logging were performed together with three sampling isotopic and geochemical water campaigns. It was possible to delineate an area of intense overexploitation (potentiometric water level < 90 mbsl), which has not been related to any seawater degradation yet. Although the cost of groundwater extraction has increase two times (compared to 1980), it is still half the cost of water from the public water company. Users have not described any ethical problems yet. Based on an aquifer numerical model and keeping the current pumping rates, a saline intrusion into aquifers is expected by 2030.



**Modeling of the geological evolution of the Red River delta, Vietnam in the context of arsenic contamination of aquifers**  
**Abstract n°2235**

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**KEYWORDS:** geological modeling, meandering river, arsenic in aquifers

Contamination of aquifers by geogenic arsenic is a common problem in south-east Asia. Arsenic concentration in groundwater is controlled by the sediment age and is lower in the older deposits due to the decrease over time of the reactivity of organic matter and arsenic-bearing iron hydroxides. Development of detailed geological models of floodplains is crucial for groundwater resources management in terms of delineating areas with low arsenic concentration. A geological model of the Red River delta was set up by combining the borehole data and 2D resistivity profiles with the results of the analysis of the satellite images. The interpreted stages of the river evolution during Holocene were validated against the sediment dating and compared with the arsenic distribution in the aquifers. Geological and geophysical data interpreted with the use of geostatistical methods allow for a description of regional geological conditions, but rarely tell anything about the order of the river avulsions and palaeo river courses. Analysis of the satellite images provides information about palaeo fluvial structures and movement of the river, but cannot tell anything about subsurface geology. Only an approach integrating these two methods allowed to model the geological complexity of the studied fluvial system and interpret its changes over time. The Red River migrated throughout Holocene from the mountain range bordering the floodplain at south-west towards north-east. Three major channel belts can be distinguished. The sediments are dated from 5900 to 460 years. Meandering of the river within single channel belt took place for up to 2000 years, while the abandoned meanders were filled up with the sediments within less than 100 years. The major avulsions of the Red River are related to the sea level changes, increased sediment aggradation due to the development of the agriculture and construction of the dikes. The arsenic concentrations increase from 1  $\mu\text{mol L}^{-1}$  in the oldest channel belt to 7  $\mu\text{mol L}^{-1}$  in the aquifers sands deposited by the most recent meanders of the Red River.



## Abstract n°2236

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KEYWORDS: <p>Small Island Developing States, Sustainable Development Goals, Climate Change

<p>Pacific Small Island Developing States (SIDS) are constrained by their size, isolation, natural vulnerability and limited natural and financial resources. Freshwater resources, limited to groundwater in many cases, are exposed to extreme weather events, threats to water quality and increased exploitation due to increased water demand. SIDS, as UN Member States, have adopted the Sustainable Development Goals (SDG) and are expected to monitor and achieve the proposed targets until 2030. Implementing Goal 6 on water and sanitation means achieving a number of targets related to water quality, water-use efficiency, and integrated management and protection of water resources. Progress towards target achievement will be monitored via flexible indicators able to capture the required changes at various national scales and settings. Many Pacific SIDS rely heavily on groundwater and therefore implementation and achievement of Goal 6 essentially translates to protection and sustainable management of the limited groundwater resources. These aspects may be known to water specialists in Pacific SIDS but may require specific adaptation in the context of the proposed, globally compliant, indicators. We present an overview of the ability of Pacific SIDS to identify, quantify, monitor, and sustainably manage their groundwater resources. The applicability of the proposed indicators is evaluated in the context of Pacific SIDS based on existing conditions, capacity, and infrastructure. Groundwater investigations from a case study in the Pacific Region (Republic of Marshall Islands) served as the basis for this analysis and provided examples to assess the feasibility of calculating the proposed indicators at country level. We finally give recommendations related to the calculation of indicators and highlight knowledge gaps and deficiencies in capacity and infrastructure to carry out the monitoring required for the proposed SDG targets.



**Facing climate change- Development of a participatory water management in urban slums in Jaipur, India**  
**Abstract n°2237**

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**KEYWORDS:** participatory water management, India, urban slums, interdisciplinarity, climate change

Women in urban slums in India are most affected by climate change. The interdisciplinary project "Women's Action towards Climate Resilience for Urban Poor in South Asia" aims at finding solutions especially for this target group. In this frame, a participatory water management based on hydrogeological research is currently being developed in two peri-urban slum areas in Jaipur, Rajasthan. The study sites were chosen to represent typical settings in India, both in a social and in a hydrogeological context. The first area is situated in the northern outskirts of the city on a hill slope. The shallow aquifer is characterized by high nitrate concentrations (up to 500 mg L) and elevated electrical conductivity (up to 3000 IS cm). The slum is well established and has a Hindu population of about 1200 people. The second site is located in a lowland area towards the eastern boundary of Jaipur. Frequent flooding from an open drain and insufficient sanitation in this newly emerged slum makes the wells prone to microbial contamination. The slum has a Muslim population of about 3000 people, but is expected to expand rapidly. In this project, methods which are used in social sciences, especially human-centered-design tools (e.g. interviews, camera-user-studies) are applied to optimize the water supply on a community level. These methods help to understand the community's point of view and priorities. The main goal is to explore, how communities, represented by women groups, can be enabled to make own reasonable decisions about their water supply, thus creating a sense of ownership and responsibility, which should prevent the relapse in old behavior patterns and guarantee a long-term success. The close cooperation between a hydrogeological research group with a local and experienced NGO, consisting of social scientists, urban planners and health experts, influences both the way of working and the perception of water challenges and allows developing new and innovative approaches, which are planned to be transferred to similar places throughout South Asia.



**Karst conduit geometry- reduction of ambiguity by using a multiple signal approach  
for numerical hybrid models  
Abstract n°2239**

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KEYWORDS: karst conduit, numerical modeling, heat transport

Karst aquifers exhibit complex flow patterns as a result of the large contrast in hydraulic parameters between the conduits and the permeable fractured matrix. Especially the presence of highly conductive karst conduit systems embedded in the fractured matrix with substantial storage poses a challenge for the assessment and prediction of water resources. In mixed flow karst systems flow pattern are dominated by conduit flow. The differentiation and consideration of flow patterns at different scales are required for the investigation of complex processes, for example dual flow, heat and or solute transport. Therefore distributed numerical models have major advantage above lumped parameter models. Normally the distribution of the karst conduit network is unknown and its implementation in distributed numerical models is difficult. Hybrid numerical modeling approaches such as MODFLOW-2005 Conduit Flow Process Mode1 (CFPM1), which couples a discrete conduit network to a groundwater continuum, allows the analysis of the effect of different conduit networks on the evolution of large-scale flow patterns. The application of pattern matching combined with inverse calibration of multiple signals (e.g. drawdown of a large scale pumping test, 1D- heat solute transport) can reduce the ambiguity resulting from the unknown location of the highly conductive features. The study demonstrates the implementation of different karst network geometries generated with a random walk approach. The geometry is supported by (hydro)geological information and covers a wide range of different networks (from single conduit up to meshed conduit network). Each realization can be classified in terms of hydraulic (e.g. conduit diameter, roughness, anisotropy) and geometrical properties (e.g. 'Strahler'-approach). Finally, the stepwise addition of processes and objective functions helps to reduce the number of possible network realizations and uncertainty of the parameter set. The approach is validated by high resolution measurements of multiple signals during a pumping test at the mixed flow karst regime of Cent Fonts (Languedoc, France).



**Elaboration d'un modèle caractéristique des zones favorable à l'implantation des ouvrages de captage dans les aquifères du socle fissuré - Cas du bassin versant d'Ehania (Sud- est de la Côte d'Ivoire).  
Abstract n°2240**

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**KEYWORDS:** Modèle, zones favorables, eaux souterraines, Aquifères du socle, SIG, Côte d'Ivoire

Les aquifères du socle ont toujours été considérés comme des milieux très complexes et donc difficile à caractériser. L'approvisionnement en eau potable, à partir de ces aquifères, reste par conséquent problématique. L'objectif de cette étude est de mettre en place un modèle pour la caractérisation des zones propices à l'implantation des forages. Plusieurs méthodes ont été combinées pour la mise en place de ce modèle. Il s'agit de la télédétection, du modèle pluie-débit GR2M et de la modélisation du toit du socle fissurés. Les couches thématiques issues de ces traitements ont été croisées à deux niveaux sous SIG à partir de la méthode d'analyse multicritère pour produire la carte de potentialité en eau souterraine. La validation de cette carte s'est faite à partir des données de débits exploitation. Les résultats obtenus sont constitués d'un ensemble de cartes que sont la densité fracturation, l'épaisseur d'altérite, la pente, la recharge de la nappe qui, en plus du niveau d'eau, ont été croisées pour produire la carte des zones favorables ou potentielles. La validation à partir des débits d'exploitation révèle qu'environ 40% des forages ayant un débit supérieur à 5 m<sup>3</sup> h coïncident avec les zones favorables ou potentielles. Cependant, la quasi-totalité des ouvrages de gros débits observés dans les zones dites de bonne et moyenne potentialité se rencontrent au niveau des méga-fractures. L'analyse de cette carte met en évidence trois classes que sont celles de bonne, moyenne et faible potentialité en eau souterraine. Parmi ces classes, celles de bonne potentialité qui couvrent environ 25% de la zone d'étude se rencontrent principalement dans les zones sud où l'on rencontre une couche de formations sédimentaires généralement captées par les forages. Cette classe de bonne potentialité se retrouve aussi dans la partie nord du bassin versant d'Ehania où les épaisseurs d'altérite sont relativement importantes.



**Calibration of transient transport model for fissured-karstic aquifer in southern Poland  
with the aid of tritium data  
Abstract n°2241**

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**KEYWORDS:** transport model calibration, tritium data, fissured-karstic aquifer

Numerical transport models used to predict migration of pollutants in groundwater systems are traditionally based on groundwater flow models calibrated against observed hydraulic heads and recharge rates. However, flow model calibrated against hydraulic heads does not guarantee that transport model will perform well and transport model needs independent calibration. A 3D flow and transport model was build for phreatic, fissured-karstic limestone aquifer of Jurassic age located in southern Poland. The aquifer is a sole source of potable water for Czestochowa agglomeration and neighboring municipalities. The aquifer surface area of 951.5 km<sup>2</sup> was subdivided into a grid of 100 by 100 meters. Twelve horizontal layers were distinguished in the model. The MODFLOW and MT3DMS codes were used. Groundwater flow was simulated for steady-state conditions, while transport was simulated under transient conditions. The flow model was calibrated using observed hydraulic heads. Tritium concentration was measured in total 21 sites (mostly abstraction wells). They were sampled over the period 1991-2015. The tritium data available for the studied system were used to calibrate the transport model. Initially, the modeled tritium concentrations revealed significant disagreement with respect to the measured concentrations, while good fit between calculated and observed hydraulic heads was maintained. In the course of the calibration process the recharge rate and hydraulic conductivity were modified in some parts of the aquifer such a way that measured and modeled tritium concentrations converged for most of the investigated wells. For some wells, however, still significant discrepancies remain. This disagreement suggests that some changes in the conceptual model of the studied system are still needed. Acknowledgements. The study was supported through the statutory funds of the AGH University of Science and Technology (projects No.11.11.140.026 and 11.11.220.01) and the BONUS-185 programme (project Soils2Sea).



## Review of Groundwater Pollution in Gediz Graben (Turkey) Abstract n°2242

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KEYWORDS: Water pollution, Gediz, enrichment factor

Gediz Graben has become the largest industrial and agricultural area in the Western Anatolia, Turkey with a total population exceeding 300,000. The important streams in the study area are Gediz River, Alasehir Creek, Irlamaz Creek, Kursunlu Stream, Tabak Stream and Sart Stream. The streams in the study area meet the Gediz River having a mean annual flow of 46 m<sup>3</sup> s and a length of 276 km. Drinking water is delivered by natural springs and shallow wells that lift groundwater with 5–45 l s discharges from a depth of 60-150 m in the Gediz Graben. The irrigation water in and around the study area are provided by wells and channels from a dam or pipes from streams. There are several geothermal areas from west to east as Turgutlu, Salihli and Ala ehir towns. Outlet temperatures have been measured in the thermal waters from 20 to 220°C. The thermal waters have been used in spa facilities since ancient times. Electrical product, district and greenhouse heating applications using geothermal energy are intensively used in the area. The properties of waste solutions obtained from industrial and thermal fluid effects on the environments were discussed in this study. Concentrations of some elements (As, B, Fe and Ni) are higher than the tolerance limit of international drinking water standards. Enrichment factor (EF) values indicate that the sediments can be classified as 'extremely severely enriched' for Ba, Mn and Sr. The EF values of As, B, Li, Ni and Zn in the stream sediments indicate 'very severe enrichment'. Whole contaminant analyses support that the environmental pollutants in groundwater aquifers, surface waters, and soils in agricultural areas of the Gediz graben are likely to be both geothermal and anthropogenic activities in the study area.



**Contamination of the Albian freshwater aquifer with desorbed metallic trace elements (Zn(II), Ni(II) and As(V)) during a potential leak of CO<sub>2</sub> from a geological storage**  
**Abstract n°2243**

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**KEYWORDS:** Albian Aquifer, CO<sub>2</sub> leakage, TME sorption, glauconite

The Trias deep salt aquifer in the Paris Basin is identified as a potential site for the geological storage of CO<sub>2</sub>. This aquifer is located under the Albian freshwater aquifer. This geologic structure implies that a possible CO<sub>2</sub> leakage from storage formations could alter groundwater quality. Two glauconites issued from Albian formations were studied. The first sample (ARD sample) came from an outcropping of the formation. The second (GADP-2) came from a deep well of about 800 mn. The mineralogical and chemical characteristics of glauconites were determined. Both samples were weakly disordered glauconites (1Md type) with approximately 10% of swelling layers. GADP-2 sample was more mature than ARD. Their reactive surfaces and the cationic exchange capacity (CEC) were determined. The two glauconites had approximately the same specific surface ( 65mC.g-1). The CEC was between 20 and 28meq 100g. The adsorption capacities of samples were analyzed from adsorption isotherms of three TME - Zn(II), Ni(II) and a metalloid (As(V)) which are naturally present in glauconite minerals and Albian waters. Experiments were realized at pH 7 and pH 5 for reproducing the pH of Albian aquifer water in environmental condition and after a leak of CO<sub>2</sub>, respectively. The experimental and modeling results revealed that profiles of absorption differed with the TME and the pH while the different maturity of the glauconite samples appeared to play a minor role. Similar profiles were obtained for Zn(II) and Ni(II) and differed from those obtained with As(V). The equilibrium constants associated with Langmuir and Freundlich models pointed out the highest affinity of glauconites for Zn(II) and Ni(II) at pH 7. On the contrary, for the As(V), the adsorption was reduced at pH 7 in comparison to pH 5. This study anticipating the consequences of a potential leak of CO<sub>2</sub> in the Albian freshwater aquifer shows that the quality of potable groundwater can be altered by increasing the concentration of metal trace elements.



**Infiltration Trench - As a Model for Hydrogeological Artificial Recharge at Bandung City, West Java, Indonesia**  
**Abstract n°2248**

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**KEYWORDS:** Infiltration, artificial recharge, Groundwater level

Groundwater reserve is one of the most priceless resource in a city. Nevertheless, based on data from the Ministry of Energy and Mineral Resources in wells around Bandung Station, there has been decreases in groundwater level which is around 80 meters within 20 years. This decrease is caused by population growth that led to the uncontrolled use of groundwater as a main source of domestic and industrial water, it is also caused by a lot of infrastructure development around groundwater recharge area which covered open area and reduced groundwater infiltration. The purpose of this study is to create artificial recharge model in Bandung to optimize groundwater infiltration as part of a groundwater restoration. Geological and hydrogeological data is collected to help determine best location of the model. These data also help to maximize model effectiveness by selectively choose main target aquifer and infiltration trench location. Infiltration trench location is targeted alongside the river for a stable water supply throughout the year. Infiltration trench is modelled based on previous data, so the model is suitable for the area. This trench will infiltrate river water to the aquifer and groundwater reserve will increased. This will help to restore groundwater condition by adding more water to the aquifer. Overtime, this will help to stop groundwater level drops and also help to increase groundwater level



**A multidisciplinary approach based on PSI- derived ground motion, hydrogeological and lithological data to estimate the Chalk aquifer properties in the London Basin  
Abstract n°2249**

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**KEYWORDS:** Persistent Scatterer Interferometry (PSI), Chalk aquifer storage, London

In London, the Chalk aquifer has been exploited both for public and industrial supply since the 1850s and is one of the most monitored and managed aquifer-systems in the United Kingdom. Although several authors have previously investigated the hydraulic properties of the Chalk aquifer using traditional field and laboratory measurements and experiments, characterization of the Chalk aquifer properties resulting from the presence of discontinuities, and across large spatial-scales, is still a complex task. In this paper, we apply Persistent Scatterer Interferometry to ERS-1 2 and ENVISAT satellite data covering the periods 1992-2000 and 2002-2010 respectively, to investigate the Chalk aquifer properties across the London Basin. The analysis of the relationship between ground motion, hydraulic head changes and lithological data, allows us to estimate the aquifer storage and compressibility over an area of ~1,360 km<sup>2</sup>. The storage values obtained using the satellite ground motion data agree with those obtained in situ via pumping tests. The results reveal that the variations in storage coefficient are correlated with changes in hydraulic head and the hydrogeological setting of confining layers. The influence of fractures and discontinuities on aquifer storage is also observed. As a consequence, different policies and zonal planning for certain parts of London are essential to manage the available resource. The results confirm the usefulness of an integrated approach using PSI, hydrogeological and lithological data to detect the spatio-temporal variability of aquifer properties over wide urban areas, such as the London Basin in the UK.



# PFASs in groundwater – a threat for future drinking water supply?

## Abstract n°2250

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**KEYWORDS:** Drinking water, Groundwater, PFOS

Perfluoroalkyl and polyfluoroalkyl substances (PFASs) are a group of anthropogenic environmental pollutants that are found worldwide in the aquatic environment, wildlife and humans. They are among the ever growing group of emerging organic contaminants and have recently attracted huge attention. The most prominent PFASs compounds discussed in research and practice are PFOS (perfluorooctane sulfonate) and PFOA (perfluorooctanoate), as they are most commonly found in the aquatic environment but also in the blood of humans. Sources for PFASs in groundwater are mainly firefighting training areas, landfills and wastewater treatment plants. Groundwater samples worldwide show occurrence of PFASs, and PFOS was found in concentrations up to 1,200,000 ng l at firefighting training sites [1]. PFOS has been banned in the EU 2008 and is listed in the Stockholm Convention. However, as PFOS and other PFASs are very persistent will remain a problem for a long time. Moreover, e.g. PFOS is simply replaced by other PFASs, which are often not properly studied in terms of their potential harmful behavior. The contamination of groundwater with PFASs already has severe implications for drinking water supply today as, e.g. in 2011 and 2013 two waterworks in Sweden had to cease operation after PFASs concentrations of up to 10,000 ng l were detected in the produced drinking water [2]. As groundwater is used worldwide to provide drinking water for millions of people it is of utmost importance to maintain groundwater free from PFASs. Here, we present properties and transport behavior of PFASs in groundwater, examine the sources of groundwater contamination and its extent, and discuss implications of groundwater contamination by PFASs in the future.

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# **SIMPLIFIED GIS MODEL OF AGRICULTURAL CONTAMINANTS TRANSFERS FROM SOIL TO DRINKING WATER CATCHMENT AREA**

## **Abstract n°2251**

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**KEYWORDS:** water catchment area, modeling, GIS

For regulatory groundwater agricultural pollutions risk assessment of drinking water catchment, simple models are usually implemented to assess the potential groundwater contamination. These models consist in weighting hydrogeologic parameters which affect transport from soil surface to aquifer. Results from such simulations are not very accurate. It is nevertheless used to implement agricultural pollutions reduction programs on groundwater catchment areas. Recently Agriculture stakeholders have criticized this methodology and expect a more solid scientific one. Complicated models to completely describe groundwater vulnerability could be implemented but are cost expensive and need a lot of data. Therefore such models would not likely be useful for clients needs. Geo-Hyd Antea Group has developed with the University of Orléans for Chartres Métropole local water utility the so-called DARCI tool which relies on a quantitative simulation of agricultural pollutants transfer from soil to groundwater. Based on a simplification and integration of transport equation in Residence Time Distribution (RTD), the method consists in cutting the watershed into parallel flow threads, each of them corresponding to a pre-determined surface units. When pollutant flows are applied in entry of this simplified model, for each flow thread, concentrations in water table out of this flow thread are calculated. Convolution, or the sum of each single concentrations series, allows to simulate evolution of pollutant groundwater contamination in the catchment area. In addition, as each water thread is related to a watershed surface unit, it is possible to identify at a time the most contributive geographic zones. DARCI tool has been tested and validated for simulation of nitrates in Chartres catchment area for Chartres Métropole local water utility and for simulation of atrazine transfer in Orléans catchment area for Orléans local water utility. Finally a dedicated interface was developed which allows clients to run several scenarios of nitrates pesticides surface reduction programs over the water catchment, with a spatial analysis.



## **Evidence and modeling of perchlorate biodegradation in streambed sediments**

### **Abstract n°2252**

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**KEYWORDS:** Perchlorate, biodegradation, geochemical model

The contamination by perchlorate is revealed in an increasing number of groundwater and surface water bodies. Ion perchlorate is an endocrine disruptor, which affects thyroid hormone production. In this context, a better understanding of the migration of this contaminant in water resources now becomes a critical issue. We conducted field and modeling investigations to characterize the transfer of perchlorate at the stream-aquifer interface with a focus on the potential biodegradation in streambed sediments. The study site is located in Gironde (France) on a well field subject to contaminated stream water intrusion in a carbonated aquifer. The study is based on in-situ geochemical monitoring, laboratory experiments and geochemical modeling. The transfer of perchlorate is first analyzed by the comparison of geochemical composition (major ions and the perchlorate concentrations) of stream water and groundwater. We highlighted an important inconsistency between stream water intrusion and perchlorate concentrations- the observation wells nearest to the stream are devoid of perchlorate. This can be explained by a natural attenuation of perchlorate contamination at the stream-aquifer interface. Secondly, the biodegradation in the streambed has been investigated at the laboratory on a streambed sediment column. The injection of water composed of nitrate, perchlorate and sulfate highlights a fast perchlorate attenuation in the streambed sediments along the redox sequence- oxygen nitrate perchlorate sulfate. The variability of injected flows allows determining the dynamic kinetic of perchlorates degradation. Perchlorate biodegradation is modeled with a Monod equation in a reactive and transport model. These results revealed a fast natural degradation of perchlorate in streambed sediments rich in organic matters. This implies that perchlorate transfers in similar contexts, notably in the presence of organic matters should not be considered as non-reactive. These findings may have important practical consequences for the monitoring and remediation of sites contaminated by perchlorates.



## **Eco-Cattle System for Groundwater Conservation in Jatinangor, West Java Abstract n°2254**

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**KEYWORDS:** Eco-cattle system, groundwater conservation, rain water harvesting, recycling water.

Water is one of main resources in dairy industry. However, due to assumption that abundant amount of water are available, farmer usually neglected water usage. On top of that, much of water is used every day. An adult cattle can consume at least 15-20 liter of water every day, and famer need around 20-25 liter of water to bath one cattle and clean its cowshed. An individual farmer may have around 1 – 20 cows, on larger scale they may have 20 – 100, and for industrial scale they may have thousands of cows. This huge amount of water that being used for the cattle is taken from groundwater. Moreover, wastewater produced from this farm are mixed with cow feces. This can be dangerous if not treated, and may polluted surface water and further groundwater. In fact most farm throw their wastewater to the public sewer or directly to the river. This study is aim to produce environmentally friendly water management system for cattle farm. Eco-cattle system for groundwater conservation is focused on how to save water (reducing groundwater usage) and manage the wastewater so it won't polluted surface water and groundwater. To achieve this, recycling water and rain water harvesting method is utilized. Recycling water can reduce the amount of water that being wasted, while rain water harvesting can provide alternate source of water. Using this method groundwater usage can be minimized to support groundwater conservation.



## **Assessment of measures for reducing pesticide load in groundwater drinking wells Abstract n°2257**

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**KEYWORDS:** Drinking water quality, groundwater extractions, pesticides, groundwater quality

Pesticides are entering the soil - water system and will be subjected to transport and degradation processes. A fraction of the pesticides, and its residues, might reach drinking water abstraction wells, impose a threat to human health, and increase the costs of groundwater purification. The objective of this study was to identify measures to reduce the pesticide (residue) load in groundwater drinking wells. To this purpose, the presence of pesticide (residues) near drinking water abstraction wells and in the shallow groundwater in the Netherlands was evaluated. Moreover, relevant European, national (Dutch) and regional policies and regional initiatives that impact pesticide application were reviewed. Consequently, 43 measures were selected. The measures were categorized into five categories, i.e., 1. National policy implementation+ 2. Pesticide authorization procedure+ 3. Information, education and conscious raising+ 4. Pesticide use, application and disposal procedures+ and 5. Law enforcement. Subsequently, the measures were scored by a group of experts on a 1-5 scale, regarding two criteria- 1. Effectivity and 2. Feasibility of the measure. Representatives from both agricultural and environmental backgrounds were included in the expert group. With the purpose to increase consensus, plenary discussions took place after individual scoring, focused on the measures that showed the widest variation in scores. The exercise resulted in the ranking of measures for reducing the pesticide (residue) load in groundwater drinking wells in the future. The top three most promising measures relate to sustainable agricultural practices in groundwater protection areas, legal implementation off so-called 'Groundwater protection area files' (including threats and measures for specific groundwater abstractions), and the use of mechanical – non chemical - weed control. Moreover, the combination of using measured data in groundwater in the authorization procedure with a systematic monitoring program ('the pesticide Atlas') was identified as a promising measure.



**Calibration and Uncertainty Quantification of a Highly Parameterized Surface water -  
Groundwater Model in a Vulnerable Well Field  
Abstract n°2258**

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KEYWORDS: modelisation, calibration, uncertainty

The protection of a well field subject to surface water intrusion goes through a phase of description and quantification of stream-aquifer exchanges. Due to the spatial and temporal variability of stream-aquifer flow, numerical groundwater modeling is a suitable tool to simulate stream-aquifer exchanges at the median scale [100m – 10km]. However, groundwater models are often ill-posed which may lead to large uncertainties on model predicted stream-aquifer flow. The quantification of uncertainties associated to a model prediction is thus necessary to review alternative management scenarios. A case study considering a stream, located close to the city of Bordeaux (France) is lead. This area is of critical interest because it supplies ca. 20% of the urban area of Bordeaux and the stream is a potential vector of contamination. A 2D highly parameterized transient flow and transport model is developed with MODFLOW and MT3DMS. The calibration is completed with the Gauss-Levenberg-Marquardt Algorithm (GLMA) implemented in the PEST++ suite. The heterogeneity of hydraulic parameters is handled with a large set of pilot-points and constrained by Tikhonov regularization. Different mitigation scenarios are then reviewed so as to reduce the vulnerability of the well field to river water intrusion. The uncertainty on estimated stream aquifer exchanges around the well field is eventually quantified. This kind of approach aims at proposing trustworthy alternative management scenarios.



**Smart collection of prior information to reduce the predictive uncertainty of  
groundwater management models  
Abstract n°2260**

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**KEYWORDS:** prior information, uncertainty analysis, aquifer test, recharge monitoring

The definition of the sustainable yield of an aquifer is usually conducted with a groundwater model, where pumping rates are adjusted so as to avoid long term stock depletion and preserve environmental flows. As parameter values are poorly known, they are usually adjusted by calibration. However, many parameter sets may calibrate equally well the model and lead to markedly different outputs for management issues. This predictive uncertainty can be mitigated by two complementary approaches- (i) the collection of prior information on model parameters and (ii) the extension and diversification of observations to strengthen the calibration dataset. In this contribution, we focus on the first approach through the development of an efficient hydrogeological monitoring station. Specific yield and hydraulic conductivity can be estimated by aquifer tests with at the minimum two boreholes. These estimates are subject to two sources of uncertainties- (i) the subjective part of observed dataset selection and (ii) the uncertainty associated to measurement noise. To address these issues, we promote the use of the diagnostic plot (derivatives analysis) associated with a linear uncertainty analysis. Another parameter of importance, groundwater recharge, can be investigated with a joint analysis including (i) a 1-D physically based soil water flow model constrained by measurements of soil water tension and soil water content and (ii) a water table fluctuation (WTF) method based on high-resolution groundwater level records. From these results, we propose an efficient low cost method to collect reliable information on model parameters prior to calibration, which leads to a reduction of predictive uncertainty. Water managers are invited to replicate this efficient hydrogeological monitoring station over their water basins of interest so as to reduce the uncertainty of the sustainable yield estimated by groundwater management models.



## Climate Change Impact on Water Resources in Northern Chile Abstract n°2261

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KEYWORDS: climate, Northern Chile, precipitation, temperature, groundwater

Northern Chile is characterized by desert-like climate. Five regions are recognized based on their geomorphological features which are grouped into four areas, these are the Coastal Plain and Range (Area I), the Central Depression (Area II), the Precordillera (Area III) and The Western Range (Area IV+ including the Altiplano). Streams are very restricted in the Tarapacá region, distributed mostly in the Altiplano and Precordillera where they flow downwards through narrow ravines ("quebradas") until infiltrating when reaching the Central Depression, which concentrates the majority of groundwater resources. The study aims to understand how climate change affects water resources by calculating Extreme Climate Indices (ECI). The methodology encompasses the use of precipitation and temperature data from 75 meteorological stations from the XV, I and II regions in Northern Chile, as some neighboring stations in Bolivia and Northern Argentina in the monitored period 1983 to 2012. ECI calculations were carried out using RClindex script in the R software. Variations in ECI are stronger in Area II. In this area maximum daily temperature tends to increase whereas the minimum decreases producing an augmentation in temperature daily oscillation. Evaporation is already very high in the Central Depression and this temperature rise may trigger an increased rate in evaporated water during aquifer recharge. Likewise this may also produce an increased rate in Prosopis Tamarugo (broadly present) transpiration causing higher aquifer discharge. Consequently the water budget in Central Depression aquifers may be reduced. Effects in other areas can also be observed- in



Area I the opposite effect to Area II occurs generating the increase of stratocumulus clouds and augmenting fog availability something that coastal communities may take advantage of. In Precordillera the flush-flooding likelihood is bigger as evidenced by an increase in the R10mm index. Although there are 27 extreme climate indexes, only a few of them showed clear trends in the monitored period but evidencing important effects on water resources, especially in the most important aquifers in the Tarapacá region of Northern Chile.



**Infiltration in five artificial and natural wetlands downstream of wastewater treatment plants (France)**  
**Abstract n°2264**

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KEYWORDS: infiltration, water balance, wetland

The ZHART research project (2012-2016) aimed at designing artificial wetlands downstream of wastewater treatment plants, so as to improve the water quality on emerging contaminants, to become a source of biodiversity, and to have a better landscape integration. In this project, five existing wetlands located downstream of wastewater treatment plants were surveyed in France (one natural and four artificial wetlands). The current presentation focuses on the hydrologic part of this study performed by Suez, with a more detailed insight on the water infiltration in these wetlands. Infiltration can have an impact, not only on the treatment efficiency of the wetlands, but also on the partitioning of the water output between surface waters and aquifers. It can then be a key element for designing the new artificial wetlands, and for that reason it was characterized for the studied sites. For each of these sites, a hydrologic balance was calculated, from which the infiltration fluxes were defined by differences with the other parts of the water balance. These results enabled to estimate the permeability of the various wetlands, and its variability with time at the St Just Wetland site (based on a one year survey). Globally, the infiltration ranges from 2 to 30% of the inputs, and the permeability varies from  $10^{-6}$  to  $5 \cdot 10^{-9}$  s with a mean value around  $10^{-7}$  m s. A more specific analysis of St Just site confirms the impact of bottom's clogging on infiltration capacity, as well as that of storm events, and of water level in the wetland and in the aquifer. These results will be useful to establish the capacity of infiltration of artificial wetlands, and their potential impact on the aquifer recharge.



## **Adaptative planning for securing drinking water supply on the long term Abstract n°2265**

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**KEYWORDS:** drinking water+ adaptation pathways+ uncertain future

In the Netherlands, about 60% of the drinking water is groundwater. In a few eastern provinces, this percentage even exceeds 95%. The drinking water policy in the Netherlands emphasizes the importance of a reliable drinking water supply, which must be robust and or adaptive to withstand 1) disasters (sudden large scale events), 2) short-term variation in the supply at the local scale (less than 10 years) or 3) uncertain developments in supply and demand in the long-term (10 to 25 years). The provincial governments are responsible for the third point. To deal with the long-term uncertainties surrounding climate change and socio-economic developments influencing the demand and or supply of drinking water, the provinces decided to apply the Dynamic Adaptive Policy Pathways approach. This planning approach has been originally developed in the context of fresh water supply and flood risk management. In this article, we report on how the approach was translated to this sector and this government context. Three basic components of the approach were discussed extensively in a series of workshops with officials from the various provinces- a vulnerability analysis based on identifying adaptation tipping points, the exploration of multiple adaptation pathways and a monitoring plan to get adaptation signals. The adaptation tipping points were identified by considering thresholds under which the drinking water supply no longer meets the demand, a point at which additional measures are necessary to secure drinking water supply. Multiple possible pathways were explored based on which the participants identified the most critical developments that should be monitored to get information on when a tipping point is approaching. Co-designing the multiple adaptation pathways appeared to be helpful in showing the different options and their pros and cons, for instance it provides insights in which paths are flexible and which paths lead to lock-ins. This study suggests that with the adaptive approach the decision making process on how to manage groundwater on the long-term becomes more transparent and flexible.



**A multi-scale and multi-partner program in search of water within hard rock aquifers-  
from decision making tool to the borehole completion and use  
Abstract n°2266**

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**KEYWORDS:** Hard rock aquifers, multi-scale approach, decision making tool, GIS tools, groundwater resource, boreholes

The eastern part of the region Midi-Pyrénées (south-western Massif central, France), about 7500 km<sup>2</sup>, mainly stands on hard rock formations. This area has low density population with limited ability to tap surface water or small spring water due to their significant seasonal variations (drying during summer). This setting challenges water supply for human and livestock watering. This context has led to a multi-year process to gather every stakeholders working in the field of water resource, from research community to local water supply managing body. First the BRGM (French Geological Survey) developed a decision making tool map (GIS) at regional scale based on scientific findings from geological research on the ability for hard rock formations to develop a weathered, productive aquifer. Then, the Department of Lot wished to use this tool in order to tap new hard rock groundwater resources within the Ségala district to help local water supply managing company. The Department of Lot was assisted by the consultancy company Calligée in identifying sites with the highest profile based on technical and human multicriteria assessment. Geophysical investigations were used in the field for these high profile sites to set the final locations of the exploratory drillings which were tested consecutively. This initiative has been supported financially all along by the Adour-Garonne Water Agency, from the very first steps, with research and development, to the last steps, with in the field implementation, meanwhile gathering feedback to consolidate further similar process. This approach allowed for the work to focus on the best profile sites, offering a diversity of exploration techniques to further improve wells location. The field results of the pumping tests completed are promising and it paved the way for similar integrated process to be implemented to increase success rates for productive water well drilling within hard rock aquifers.



## Artificial recharge in the Mitidja (North Algeria) - water quality of Wadi El Harrach Abstract n°2268

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KEYWORDS: Water quality + artificial recharge, over-exploitation, Mitidja, Algeria

The Mitidja coastal groundwater which extends over an area of 1 450 km<sup>2</sup> is a strategic resource in the Algiers region. The high dependence of the regional economy on the use of this groundwater forces us to have recourse to its artificial recharge from the Wadi El Harrach in its upstream part. This system of artificial recharge has shown its effectiveness in the development of water resource mentioned in the succeeding works in several regions of the world. The objective of this study is to-

- Increase the reserves of water inputs by infiltration.
- Raise the water level and its good quality in wells and boreholes.
- Reduce losses to the sea.
- Address seawater intrusion by maintaining balance in the freshwater-saltwater interface in the downstream part of the groundwater basin.

After analyzing the situation, it was noticed that a qualitative monitoring of the Wadi water for the groundwater recharge has to be done. For this purpose, we proceeded during three successive years (2010, 2011 and 2012) to the monthly sampling of water in the upstream part of the Wadi El Harrach for chemical analysis. The variation of the sediment transport concentration will be also measured. This monitoring aims to characterize the water quality and avoid clogging in the proposed recharge area. The results of these analyses showed the good chemical quality according to the analyses we performed in the laboratory during the three years, but they are too loaded with suspended matters. We noticed that these fine particles come from the grinding of limestone of sandpit located upstream of the area of the proposed recharge system. This problem can be solved by a water supply upstream of sandpit. For the recharge, we propose the method of using two wells for dual use, which means that it can be used for water supply and extraction. This solution is inexpensive in our case and could easily be used as wells are already drilled in the upstream part.



**Groundwater and surface water withdrawals during the XXth century- a global comparison of their evolution**  
**Abstract n°2270**

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KEYWORDS: global groundwater+ silent revolution+ historic withdrawals

In a context of a lack of historic data and statistics on global groundwater withdrawals, this work aims to present an overview of the global trend of groundwater withdrawals during the XXth century. Based on the observation that around 80% of current withdrawals, which amount to nearly 1,000 km<sup>3</sup> yr, are located in a few countries (around 10), with the first three countries – India, China, and the U.S. – comprising half of the global value (Margat & Van der Gun, 2013), the approach consists in retracing the history of the withdrawals in these countries, to deduce the probable trend in the worldwide groundwater withdrawals on the second part of the XXth century. This has been possible with some interpolations for the period 1950 to 2000. Comparing these results with the trend for total water withdrawals in the XXth century, a main conclusion is that the growth of the global groundwater withdrawals may have been much steeper than the growth of the surface water withdrawals in the last decades, with groundwater withdrawals multiplied by ten between 1950 and 2010. The share of groundwater withdrawals has also notably raised- from less than 5 % in 1950 to 25 % in 2010. This observation may be explained by the increase in individual users (mainly farmers), who directly pump groundwater, mainly for irrigation. There are now millions of them. As a comparison, use of surface water has been, and still is, mainly realized by (public or private) collective actors. In addition to the discussion of the different steps for this overview and the reasons and main implications of the rise in global groundwater use, the presentation will highlight the challenges and the limits of this global approach while promoting a better and more systematic knowledge on groundwater withdrawals.



## Sixty years of progress in research and practice of Managed Aquifer Recharge Abstract n°2271

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**KEYWORDS:** managed aquifer recharge, artificial recharge, research

Managed aquifer recharge has become a tool that is increasingly used to maintain, enhance and secure groundwater systems under stress. The evolution of managed aquifer recharge has reached approximately 5km<sup>3</sup> (0.5% of global groundwater extraction) based on a long history of research on hydraulics and design of facilities, tracer studies, managing clogging and recovery efficiency, and water quality including aquifer-water interaction, and fate of organic chemicals, colloids and pathogens. New methods such as recharge wells have greatly accelerated recharge particularly in urban areas and for mine water management. In recent years research into governance, operating practices, reliability, economics, risk assessment and public acceptance of managed aquifer recharge has also developed. This review paper looks at the history of the research base that underpins modern practice, showing for a number of disciplines the research publication profile in literature, international conferences, and major research programs. It also includes some of the more important discoveries and their implications for uptake of managed aquifer recharge, and identifies key remaining knowledge gaps. IAH has made a contribution to this field, particularly since 2001 through its Commission on Managing Aquifer Recharge, but this is a field to which many people have contributed over a sustained period of time. Some of the new knowledge generated has also contributed to the understanding of physical and chemical process in aquifers which have much broader benefits in hydrogeology.



**Results and lessons learned from the analysis of groundwater related coastal wetlands and ecosystem services evaluated in the GEF Medpartnership project  
Abstract n°2272**

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**KEYWORDS:** groundwater related coastal wetlands, ecosystem services, hydrogeological characteristics of wetlands

Groundwater related coastal wetlands frequently occur in areas where water tables are shallow or where groundwater discharges to the surface. They provide a wide range of ecosystem services that contribute to human well-being. Anthropogenic activities and natural processes can change the landscape and modify water flows at the basin scale, which can significantly impact coastal wetlands and their functions and consequently lead to deterioration of their ecosystem services. The presentation will focus on results and lessons learned from the analysis of ecosystem services provided by 26 groundwater-related coastal wetlands in the Mediterranean which have been evaluated in the context of the GEF MedPartnership project performed under the coordination of UNESCO's International Hydrological Programme. A map of the hydrogeological and ecosystem services classification of these wetlands will also be presented. The main conclusions of this analysis are that- 1) groundwater is a main supporting factor to the ecology of most of the Mediterranean wetlands studied+ 2) the functions of all wetlands studied have been altered primarily by intensive water exploitation, land use changes and modification of the water cycle+ 3) most of the provisioning, regulating and cultural services studied are performing at a low level with respect to their contribution to human well-being in the wetlands evaluated+ 4) although many of the services were characterized as 'non-existent', there are strong reasons to believe that this characterization is not accurate. A main lesson learned is that there is abundant and good-quality technical and scientific information available to evaluate the ecosystem services. However, in order to draw the most benefit from these resources, it is necessary for those responsible for monitoring and assessing wetlands and groundwater and their services to have a sound training on ecosystem services and groundwater hydrology, and furthermore to be familiar with the connections between groundwater resources, ecosystem services and human well-being.



**The Chalvet watershed observatory- a reliable monitoring to enhance understanding the hydrogeological functioning and pesticides transfers of pyroclastics aquifer.  
Martinique – FWI  
Abstract n°2273**

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KEYWORDS: Volcanic aquifer, pesticides transfers, groundwater observatory

Martinique island drinking water supply, a tropical volcanic island located in the Lesser Antilles archipelago, is achieved predominantly by means of dams located on rivers (94% of drinking water). Considering the intensification of dry seasons during last years and the difficulties to maintain a minimal dry-weather flow in rivers, the water resource's diversification become a key objective for the island environmental policy. Then groundwater is targeted as a suitable alternative resource. However, the intensive agricultural practices on some parts of this small territory of 1024 km<sup>2</sup> involve an improvement of pesticides transfers' knowledge in order to better define the vulnerability of groundwater and for their adapted management and protection. In partnership with the water agency of Martinique (ODE), a hydrogeological observatory has been set up on the east flank of the Mount Pelée. Intensive agriculture predominates in this area, and groundwater's, located within pyroclastics aquifers, suffers high pesticides pollution. This observatory is composed by two main boreholes. The water level monitoring started 10 years ago. A monthly monitoring of pesticides and majors and traces elements started in 2008 in the downstream borehole and in 2011 in the borehole located halfway up the mount flank. In March 2013, a helicopter-borne TDEM survey was conducted with SkyTEM 304 system to enhance the characterization of geological and hydrogeological structures of the volcanic edifice. Geophysical data also allow building a conceptual geological and hydrogeological model and joint analysis of hydrogeological data, introduced in this poster, allows highlighting relationships between rainfall, groundwater levels variations and pesticides and major elements concentrations. Finally, our data help to improve understanding the hydrogeological functioning of this aquifer and pesticides transfers on volcanic islands, and confirm the effectiveness of this groundwater watershed observatory.



**Improving the science-based management of groundwater resources- conditions of success and challenges for a knowledge exchange among scientists and decision makers**  
**Abstract n°2274**

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**KEYWORDS:** Knowledge exchange strategy, Keys of success, Knowledge transfer

Facing the uncertainty and the unpredictability of environmental change, the management of groundwater resources needs adaptive governance. In that context, improving knowledge exchange between scientists and environmental managers is fundamental. The objective of this presentation is to identify some conditions of success and challenges facing the knowledge exchange. On the basis of a literature review on the barriers to knowledge exchange and on the frameworks proposed to overcome these barriers, we expose how a knowledge exchange strategy on groundwater was developed in the Province of Québec (Canada). Acknowledging the importance of filling the gaps in groundwater knowledge, the Quebec government launched a unique and systematic program to characterize its regional aquifers in 2008. Conducted in partnership with regional environmental managers, this program has constituted the first step of knowledge exchange. Meanwhile, interviews conducted with 50 water managers revealed key challenges to ensuring that the knowledge generated by this program contributes to the resource's sustainable management. On this basis, a second step of knowledge exchange was deployed to allow the appropriation of hydrogeological information, its integration in the decision-making process and strengthening collaborative capacities of water stakeholder to manage and protect groundwater regionally. Knowledge exchange workshops enabled the implementation of this step. These workshops rely on the interaction of scientists and managers through active learning methods. For the moment, 21 hydrogeologist and 200 environmental managers were involved in 16 knowledge exchange workshops. The conditions of success for this strategy have been identified. They include involving environmental managers from the start in the production of hydrogeological information, and explaining to the scientists the challenges encountered by environmental managers when integrating this information in the decision-making process. This strategy is a first step toward a science-based management of groundwater resources. We will conclude the presentation with suggestions on how to maintain a dynamic bilateral exchange of knowledge on the long term.



## **Geological controls on groundwater flow into the Salalah plain, Sultanate of Oman Abstract n°2275**

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**KEYWORDS:** Oman, groundwater, 3d geology

The Salalah coastal plain in southern Oman covers an area of about 500 km<sup>2</sup> and is bounded by the Arabian Sea in the south, and the Dhofar Mountains towards the north. Salalah forms the largest city in southwestern Oman and is located in the plain's center. Public and agriculture water needs fully relate on groundwater resources. The main aquifer of the plain is formed by neogenic lithologies of the Fars Group whereas the mountain region is represented by sedimentary rocks of the paleogenic Umm Er Radhuma aquifer. Both aquifers mainly consist of highly karstified limestones. The hydrogeological transition between the mountain and plain aquifer is poorly understood. In general, freshwater input to the coastal aquifer is caused by inflows from the Dhofar Mountains. Regional groundwater monitoring shows that the plain's center receives significantly higher inflows than neighbored regions towards the west and east. This causes the formation of a central fresh water zone – here, most of the groundwater development takes place - and eastern western brackish zones where water quality is not suitable for drinking or irrigation purposes. These hydrogeological characteristics are most likely caused by complex structural settings of regional geology. Using different information, such as borehole logs, geological maps and satellite images a 3D structural model was generated. One focus was on including faults and dipping of formations, another on a coherent structural representation of the transition zone between involved aquifers. Usage of geological 3D modelling affirmed the previous assumption that regional groundwater flow is predominately controlled by structural geological features. The groundwater flow pattern observed from hydro chemical and isotopic data is now far better understood and therefore principally improves the coastal water resource management while the generated model additionally serves as a favorable basis for future groundwater modeling.



**Quantifying resident injection travel time distributions from discrete fractured network  
modelling with the tempered one-sided stable density  
Abstract n°2276**

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**KEYWORDS:** Transport, Dispersion, Travel times, One-sided stable density, Modelling

Analysing flow and transport in sparsely fractured media is important for understanding how natural geological environments function as barriers for transport of contaminants from subsurface repositories for spent nuclear fuel. Crystalline bedrock is a favourable environment due to relatively weak advective flow and strong retention properties, where the interplay between advective and dispersive flow strongly impacts both inert and reactive transport. The natural geological environment can delay transport of radionuclides, allowing sorption and decay processes to limit release to the biosphere. There are however many challenges involved in quantifying and modelling subsurface transport, especially in fractured media, mainly due to geological complexity and variability. This even applies to flow pathways of water parcels corresponding to the case of inert, non-reactive transport. Variability in arrival times then mainly depend on heterogeneity of the system and effects of boundary conditions. The analytic tempered one-sided stable density has been proposed as a flexible universal model for tracer transport in subsurface environments since it generalises a wide range of distributions used in groundwater modelling. Here we demonstrate its capacity in quantifying the specific problem of uniformly injected particles in heterogeneous and sparsely fractured rock. Numerical discrete fracture network models consistent with representation of the Forsmark site in Sweden are used to simulate flow to a scale of 1 km. Particles are injected uniformly in a manner consistent with a stochastic representation of subsurface diffusive leakage. Resulting travel times at multiple distances are evaluated against the analytic distribution, considering both early arrivals as well as tails. We show how travel times change with scale and how the analytic distribution can readily accommodate the full range of change behaviour using moments. We also highlight how resulting dispersion is not only caused by geometric heterogeneity but also by low-flow features captured by the injection mode which otherwise would typically be bypassed, significantly dispersing transport and contributing to further delayed breakthrough.



# Climate-induced warming imposes a threat to North European spring ecosystems

## Abstract n°2277

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**KEYWORDS:** Northern Europe, aquifers, groundwater dependent ecosystems, cold climate, climate change.

This study reports a long-term water temperature trends in northern European cold-water springs. The study rely on a good set of data from 66 springs in Finland and Sweden and bryophyte and macroinvertebrate species data from s subset of Finnish springs. Mean spring temperatures were closely related to regional air temperature and global radiative forcing of the corresponding year. Most springs (82%) in our data responded rapidly to changes in local climatic conditions during 1968-2012. This is due likely to the fact that the aquifers were mostly unconfined glaciofluvial deposits, being relatively small and shallow. The few karst springs in Sweden showed no or weak response to climate. Moreover, our results suggest that springs fed by aquifers with a small recharge area and low storage volume are more prone to climate-induced warming than those associated with larger aquifers. Based on the three alternative climate scenarios representing low (RCP2.6), intermediate (RCP6) and high emission scenarios (RCP8.5), we estimate that increase of mean spring temperature in the region is likely to range from 0.67 °C (RCP2.6) to 5.94 °C (RCP8.5) by 2086. According to the worst case scenario, the water temperature of these originally cold-water ecosystems (regional mean in late 1970's 4.7 °C) may exceed 12 °C by the end of this century. Our results show that several degrees shift in the thermal regime of springs will have substantial biodiversity impacts and result in regional extinction of native, cold-stenothermal spring specialists, whereas, in contrast, species diversity of generalist taxa is likely to increase in future. Even a slight (by 1 °C) increase of water temperature is likely to eliminate rare and sensitive spring-preferring species thus altering bryophyte and macroinvertebrate assemblages in spring-fed streams but much less so in streams with lower groundwater input. Our results provides the first empirical evidence that climate change is warming groundwater and associated ecosystems in the northern hemisphere.



**Conceptual hydrogeological model of Alpine Corsica metamorphic formations from a pluridisciplinary, multi-scale approach  
Abstract n°2278**

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KEYWORDS: Alpine Corsica, conceptual hydrogeological model

Alpine Corsica is located in the northeastern part of the Corsica Island (France). It consists of a series of metamorphosed units including (1) the meta-ophiolite unit which mainly consists in metabasalt, metagabbro and serpentinite and (2) the “Schistes Lustrés” complex formed of metasediments such as calcschists or marbles. The Alpine Corsica groundwater body is a key water source for drinking supply that represents nearly 25% of the groundwater withdrawal in Corsica. However, the geological and hydrogeological properties of these formations are poorly known and differ from those of granite. A conceptual hydrogeological model of these hard-rock aquifers based on the results of a multidisciplinary approach performed at several spatial scales, from the lithological contact (meters) to the catchment (kilometers), was developed in order to improve the knowledge of these complex aquifers. Lithology and tectonic determine the groundwater circulations inside the Alpine Corsica massif. A statistical analysis based on air-lift flow measurements performed during the drilling of sixty boreholes has been conducted. It provides a qualitative characterization of the vertical distribution of permeable zones which are, statistically, mainly located within the first 40 m from the ground surface but may reaches up to 70 – 80 m deep in schists and marbles. Distribution and location of springs, and the measurements of differential stream-flow during base-flow periods allowed identifying aquifers and estimating their hydrodynamic properties. Hydraulic conductivity of the meta-ophiolite unit is found homogeneous and estimated between  $1.10^{-8}$  and  $2.10^{-8}$  m s (minimum estimates of K). For this unit the hydrogeological model of these formations is similar to the “classical” granite model. On the contrary, the hydraulic conductivities of schists and marbles show a wide variability -from  $1,4.10^{-9}$  to  $4,2.10^{-8}$  m s, which reflects the heterogeneous and compartmentalized characters of these aquifer systems because of local dissolution of marbles.



# Remote sensing and hydrogeophysics for hydrogeological conceptual models of hard rocks

## Abstract n°2280

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**KEYWORDS:** remote sensing, hydrogeophysics, conceptual model, hard rocks

Remote sensing and hydrogeophysical methods supported by field observation, were applied in the Sardon (Spain) experimental hard rock catchment (80km<sup>2</sup>) to define its conceptual model, further used to develop integrated hydrological model of that area. In line with a general conceptual model of hard rock aquifers, we identified two main hydrostratigraphic layers - a saprolite layer and a fissured layer. Both layers were intersected and drained by fault zones that control the hydrogeology of the catchment. The spatial discontinuities of the saprolite layer were well defined by RS techniques while subsurface geometry and aquifer parameters by hydrogeophysics. The processing of high-resolution satellite images and digital terrain model allowed mapping efficiently the main fault zones and the horizontal distribution of the hydrostratigraphic layers. The GPR method was able to detect shallow water table although the quantitative assessment of the water table depth could not be made routinely because it required local calibration based on measurements made in piezometers and soils and was restricted to the locations with water table depth <3 m b.g.s. The ERT method allowed to confirm local subsurface hydrostratigraphy and provided input for the MRS inversion. The multi-frequency FDEM method combined with the laterally constrained inversion technique showed to be very efficient, providing long cross-sections depicting large hydrogeological structures coherent with direct field observation, geological mapping and drilling. The MRS provided valuable results in the saprolite layer, but only in the locations with sufficient signal to noise ratio. The proposed multi-technique method of hydrogeological characterization of complex hard rock catchments, involving non-invasive, so cost effective techniques such as remote sensing and hydrogeophysics, turned to be highly suitable for development of hydrogeological conceptual models in hard rock environments.



## Qualitative interactions between forest and the water resources Abstract n°2281

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KEYWORDS: Forest, nutrients, water quality

If forests have generally a negative quantitative impact on the hydrological budget of watersheds due to their higher evapotranspiration, they generally have a positive impact on water quality. Forests collect and accumulate atmospheric deposits and pollutions, increasing the transfer of these elements to the soil. But these inputs are consumed by the trees and accumulate in the biomass (leaves, branches, trunks, and roots...), or are fixed in the soil, and only a part percolates through the sub soil to the aquifers and the rivers. A crucial effect of forests is their capacity to structure the soils, increasing their capacity to filter solutes and to store suspended matter+ this capacity is however hindered for some years after strong forest fires. Another key positive effect of forests, is that forest requires few polluting anthropogenic interventions. Even if the forestry activities can temporary lead to an increase of sediment and nutrients flows, and in some rare cases to the use of pesticides, these impacts are very limited compared to other land uses. Then, water quality from forested watershed appears to have generally a lower level of suspended solid, nutrients, organic matter, toxicants and pathogens. This global positive impact of forests on water quality can be used to protect the watershed of drinking water resource intakes, opening the way to the notion of Payment for Environmental Services (PES). More globally the interactions between the trees, soil and water is dependent of several key parameters, such as meteorology, the proximity of atmospheric pollution sources, the composition of the soil, the trees species and density, the soil microfauna and microflora, the proximity of the aquifer, and the stability evolution of all of these elements with time. The forestry practices can affect these equilibriums. Global warming is also expected to have an impact on them.



**Assessment of the impacts of future scenarios of rainfall recharge and land use change in the “Plana Oropesa-Torreblanca” aquifer.  
Abstract n°2282**

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**KEYWORDS:** global change impacts, coastal aquifer

Any change in the components of a coastal aquifer balance can modify the seawater intrusion process. Climate change and Land use change (LUC) can produce significant influence on water resources availability. The freshwater-seawater interaction in these coastal systems forces to perform an integrated analysis of quantity and quality issues using density dependent flow solutions. In the Plana Oropesa-Torreblanca aquifer (in the Spanish Mediterranean coast) important LUC has been produced during the last decades. The transformation from dry to irrigated lands has provoked an important increment in the pumping volume in the period 1975-1995, producing significant drawdowns and intrusion problems. Important future LUC (eg. a 70 % of the irrigated area will be transformed to Urban and Industrial Use+ 3 new golf areas) have been also approved for the future decades. In this work we propose a method to perform an integrated analysis of the potential impacts of global change (GC) scenarios in a coastal aquifer. A multi-criteria analysis has been proposed to assess different techniques to generate future scenarios of climatic variable. They use the available information about Regional Climatic Model simulations performed in some EU Projects. An integrated modeling framework will be defined by coupling a hydrological balance model and a density dependent SEAWAT flow model. It will be used to assess hydrological impacts for GC scenarios taking into account quantity and quality issues. The models have been calibrated with the available historical data (1973-2010). They allow testing a conceptual approximation of the aquifer and performing sensitivity analysis to future GC recharge scenarios. This method can be valuable to improve our knowledge about the aquifer being a helpful tool to design sustainable management strategies. This research has been supported by the CGL2013-48424-C2-2-R (MINECO) and the PMAFI 06 14 (UCAM) projects.



## The interaction between surface reservoirs, multi-layered coastal aquifer and the sea Abstract n°2283

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KEYWORDS: aquifer-sea relations, surface reservoirs impact

The hydrological relations between a multi-layered coastal aquifer and the sea and the impact of surface reservoirs (fish ponds) on the aquifer were studied in the coastal aquifer of Israel. The Quaternary aquifer in the studied site is sub-divided into three units – a shallow, phreatic unit (A) and two confined units (B and C). Chemical measurements suggest that there is infiltration of water from the fish ponds into the phreatic unit A, while the connection with the confined units B and C is very limited. The phreatic unit is OM-rich (TOC=3.8 mg/l), characterized with low oxygen concentration (1.1 mg/l) and high concentration of ammonium and phosphate (713 and 17 IM, respectively), and it is isotopically-enriched, with  $\delta^{18}O$  of -1‰,  $\delta^2D$  of -4.6‰ and  $\delta^{13}C = -8.6‰$ , probably due to enhanced evaporation. On the other hand, the water in the confined units is OM-poor (0.5 mg/l TOC), having low concentration of  $NH_4$  (6 IM) and  $P_04$  (0.3 IM) and depleted isotopic composition ( $\delta^{18}O = -4.3‰$ ,  $\delta^2D = -20.4‰$ ,  $\delta^{13}C = -11.2‰$ ). The CHIRP mapping suggests that the sub-seafloor extent of the clay, which separates the confined from the phreatic units, is variable from 100 m to more than 1000 m offshore. In the numerical model, this resulted in different extent of seawater intrusion into the shallow confined unit. In places, where the clay is limited to 100 m offshore, the interface reached the Shoreline just a few years after pumping commenced, while the water is fresh at the area where the clay layer extends farther offshore, and seawater intrusion is expected (by the simulation) only some years later. These results are consistent with those of the TDEM, which shows relatively fresh groundwater in unit B where the clay extends 1,000 m offshore, while saline water in the site with limited clay extension offshore.



**Longterm Saltwater injection into a confined aquifer- A density-coupled mass-transport model taken to the max?  
Abstract n°2284**

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**KEYWORDS:**

In the vicinity of a potash mine, highly saline production waters have been injected into a con-fined, deep carbonate rock aquifer for over 90 years. This carbonate rock aquifer is a regional aquifer with naturally occurring, extensive salinity variations of its formation waters. Alternating duration, location, and timing, 62 wells were used to inject highly saline production waters. The aim of the project was, based on available data and results of geological works and mining investigations, to develop a numerical groundwater model capable of simulating the impact of the injection regime of the past 90 years on regional flow patterns and solute transport under-ground, and identifying possible relations between saltwater injections and non-point saltwater inflows into the nearby river. The model has thus been taken to its limits with regards to three aspects- 1) simulation of density dependent flow of highly dense waters and strong gradients of salinity+ 2) a simulation length of 90 years for past and current conditions complemented by additional 45 years of scenario simulation time+ and 3) the aquifer itself as well as the large overburden are included in the 3D modelling space to give a holistic picture of the total groundwater flow behaviour in the region for an area of 1220km<sup>2</sup> with a maximum depth of 1000m. Modelling was carried out with the three-dimensional density-coupled flow and mass-transport simulation system FEFLOWy. This contribution will discuss obstacles and challenges involved in the whole modelling process, from model set-up over actual simulation, verification and interpretation of results. Owing to the large 3D modelling space and the long simulation period, the clash of scales of measured field data (point measurements) and expected regional interpretation of flow behaviour became particularly obvious. Specifically in the light of public perception and political decision making, two almost opposing requirements of representing locally anthropogenic and natural impacts and characteristics while interpreting regional flow pattern and density-dependent system behaviour had to be overcome.



**Application of Multivariate Statistical Analysis and transport modeling to assess PCE diffuse pollution in Functional Urban Area of Milan, Italy**  
**Abstract n°2285**

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**KEYWORDS:** Multivariate statistical analysis, groundwater quality, diffuse contamination

The Italian law 152 2006 adopted the EU Water Framework Directive principles and entrusts to the Regions the task of identifying areas subject to groundwater diffuse pollution and to assess the contamination level. In the Lombardy Plain area, the qualitative groundwater conditions is affected not only by a high soil vulnerability but also by a huge concentration of industries and anthropic activities. In this study tetrachloroethylene (PCE) diffuse pollution has been assessed in the Functional Urban Area (FUA) of Milan where chlorinated solvents are the main groundwater contaminants and have been monitored for several years by public authorities. First hotspots have been identified in the FUA through Cluster Analysis (CA) applied to concentration values collected in unconfined confined aquifers during the period 2003-14. Then, 2 different approaches have been used to assess the PCE contamination level related to the diffuse component. In the first, a numerical transport model was implemented to study the hotspot plumes extension in reason to identify monitoring wells not affected by diffuse pollution but related to specific sources. Consequently, it was possible to erase this data from the dataset in order to have dataset containing only diffuse concentrations. Interpolating them through geostatistical methods, PCE iso-concentrations maps have been prepared identifying areas where values are over the Maximum Contaminant Level. The second approach consists of using Multivariate Statistical procedures, such as Principal Component and Factor Analysis and k-means CA. Although these techniques were already used to study groundwater quality, this is the first time they have been applied to separate the diffuse pollution component from the pollution related to identified sources. The 2 approaches give very similar results- the higher PCE estimated median value (8 microg l) is representative of Milan city, whereas in the hinterland it is up to 3 microg l.



**Thermal use of aquifers- insights on propagation of temperature disturbance from numerical modeling**  
**Abstract n°2286**

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**KEYWORDS:** groundwater heat pumps, temperature disturbance, MODFLOW-MT3DMS

Prediction of thermal impacts induced by the use of heat pumps coupled with groundwater (GWHP) has strategic role in order to avoid efficiency depletion within the system -or with adjacent plants- and to define subsequent interferences between downgradient concurrent uses of groundwater and thermal plumes developed by reinjection wells. The evolution of temperature plumes is strongly related to thermophysical properties of the aquifer, as well as designing parameters of GWHP system. Numerical modelling is a valid tool for predicting the thermal disturbance propagation. The present study investigates the role of hydraulic and thermic parameters on the reinjection of thermally altered water connected to the operation of GWHP system through the use of a numerical heat transport model. A theoretical flow and heat transport model is built by means of the coupled use of MODFLOW and MT3DMS codes. A homogeneous, unconfined and porous aquifer is considered with thermal and hydraulic properties comparable to coarse alluvial medium. A uniform initial groundwater temperature is set. The GWHP system is simulated by a doublet of pumping and injection well, designed on a seasonally variable thermal energy demand. In order to understand the most influencing factor on the development of thermal plumes, a diversification of scenarios is obtained by varying Darcy velocity, aquifer dispersivity and reinjection rates. Long-term simulations show that pronounced differences in longitudinal extension of thermal plume occur as long as Darcy velocity rises. At the same time, dispersivity plays a major role in reducing the absolute temperature values and the lateral boundaries of thermal plume. In short-term simulations the temperature of reinjected water is tailored on a seasonally cycle and colder or warmer water is reinjected respectively for summer and winter. In this case, the expected groundwater temperature deviations become negligible few hundreds of meters downstream the reinjection well. These results allowed a better understanding of the influence of thermophysical properties on temperature perturbations produced by a GWHP system in a porous medium.



# The Role of Hydrogeologists in Drinking Water Source Protection

## Abstract n°2287

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KEYWORDS: drinking water, source protection, hydrogeology

Drinking water source protection began in Ontario in response to the Walkerton tragedy in May 2000, when seven died and thousands became ill from drinking municipal water contaminated with E. Coli and Campylobacter bacteria. The public inquiry that followed recommended a multi-barrier approach to protect drinking water from source to tap. In response, the province passed the Clean Water Act in 2006 as the first barrier. The intent of this new legislation was to protect the sources of drinking water before it enters municipal water systems. Scientists across the province were tasked with developing Assessment Reports to characterize the quality and quantity of drinking water resources. In addition, these reports documented the human and ecological features, mapped areas vulnerable to impacts from human activities, and enumerated significant drinking water threats. The technical work included integrated mapping of surface and subsurface features, groundwater surface water modelling, contaminant transport, capture zone analysis for municipal wells, and enumeration of significant drinking water threats. At Toronto and Region Conservation, 456 significant drinking water threats were identified with respect to municipal wells, and locally developed policies were developed to eliminate or manage these threats. The source protection policies were developed into a Source Protection Plan by scientists, engineers, and planners who worked in partnership with a local Source Protection Committee. Each of the 19 committees across the province included a mix of municipal appointees, industry representatives, and watershed residents. The policies for the jurisdiction of Toronto and Region Conservation took effect December 31, 2015. These policies are based on science, and yet recognize the existing fabric of land development and the effects of human activities on the landscape. We have met the challenges of implementation of new policy tools by a variety of government agencies by ensuring rigorous public consultation, inter-agency meetings, and provincial oversight.



## **An Experimental Setup for Stream-Aquifer Interaction Modeling Abstract n°2288**

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**KEYWORDS:** hyporheic flow experiment, sloped stream boundary, stream-aquifer region

Groundwater modeling is important to understand the effect of the hydrogeological parameters. While the analytical and the numerical models represent the theoretical point of view of the problem, the experimental studies represent the physical insight and help improve the theory. An experimental setup is designed to model the groundwater flow in an unconfined aquifer which is in interaction with a stream. The setup is developed by considering a special 2-dimensional problem which includes a stream boundary with constant slope. The rest of the boundaries are no-flux boundaries which are represented by Neumann boundary conditions. A plexiglass box, which has 50 cm length, 50 cm width, and 10 cm depth, is placed on a movable table whose slope may be adjusted depending upon the physical problem. Inflow and outflow pools are placed at the inlet and outlet points of the stream in order to establish constant water depth along the stream. At the left hand side of the aquifer, the sloping stream boundary is put along y-direction with a length of 50 cm and width of 1.5 cm. In order to adjust the constant bed slope, a wooden stick (50x1.5x0.4 cm) is placed. The rest of the box is filled with sand. A special filter is used to avoid the sediment transport between stream and aquifer. Several wells are placed into the aquifer to measure the groundwater head. The experiment is run for selected sloped stream head values and the groundwater level in wells is measured. The observations are compared with the analytical & numerical model results. The comparison shows that the experimental measurements match with the analytical and numerical model results. It is concluded that the experimental setup represents the groundwater flow accurately and can be used for the other scientific investigations.



## **Long-term hydraulic behavior of heterogeneous aquifers under transient conditions. Abstract n°2289**

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**KEYWORDS:** long-term, transient, destabilization, analytic, superposition

With the increase of water consumption, the knowledge of recharge mechanisms in heterogeneous aquifers is of major importance, in particular to understand how human pressure and climate stresses destabilize natural systems to face possible evolution through time due to climate change. The equivalent response of a groundwater system is generally interpreted as complex, non-linear and hysteretic. Another point of view would consider the current response as the superposition of numerous transient events in a complex medium, which necessarily depends on the past trajectory of the GW and boundary conditions. Here, we present a new method to better model long-term impact of anthropic and climatic destabilization. Indeed, the current aquifer state can be reconstructed as the cumulated impact of past boundary conditions, which are therefore naturally considered as non-stationary. We derive several parsimonious semi-analytical models based on various types of boundary conditions. These models are set up to interpret the hydraulic response of a pluri-kilometric aquifer system in fractured context, based on 25-year long head time series. This experimental field is part of the H+ hydrogeological sites located in Brittany (France). 2 systems in a similar geological context are compared, one being pumped at a rate of 1.1 Mm<sup>3</sup> year since 1991, the other one still in a natural state. Our models could predict the behavior of hydrogeological systems in response to climate variability and estimate the perturbation of water balance and natural flows induced by pumping. We show the importance of integrate transient behaviors in modeling systems for a precise water management of GW resources.



## Multidisciplinary groundwater research in springs and their catchment area Abstract n°2290

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KEYWORDS: springs, groundwater fauna, isotopes

Since 2007, the Baumberge area with more than 100 springs and several groundwater monitoring and domestic wells was the aim of multidisciplinary studies, including hydrogeology, hydrochemistry and isotope geochemistry as well as spring and groundwater ecology. The study area "Baumberge" is a small, agriculturally characterized mountain ridge with a height of 186 m a.s.l. in north-west Germany influenced by the last glacial maximum. Jointed and slightly karstified marlstones form, due to relief inversion, a bowl-like structure, which can therefore be considered as a closed and isolated, but hydrogeological uniform groundwater system, characterized by a Ca-HCO<sub>3</sub>-water type, neutral pH values, an electronic conductivity between 700 and 900 S cm and TOC concentrations in the range of 0.75 and 2.20 mg l. Due to a high depth of the groundwater table (up to 70 m), hydrological interaction is limited to leachate from precipitation infiltration. Stable sulfate isotopes, however, presume that the majority of springs is influenced by the input of manure in their catchment area and show that sulfide oxidation is an important process in the deeper groundwater body. Nitrate concentrations are generally high (up to 60 mg l) and stem from manure and or artificial fertilizers, as indicated by stable nitrate isotopes. Oxygen concentrations of > 2.5 mg l, the presence of stygobiotic crustacea in most springs and the absence of ocher and oligochaeta indicate a good ecological condition, according to the groundwater assessment scheme of Griebler et al. (2014). The macrozoobenthos community that inhabit springs occurs due to three different habitat groups and seems independent of hydro(geo)chemistry. The absence of groundwater fauna in some springs as well as the seasonal and spatial variability of microbial indicators, isotope geochemistry and selected substances (e.g. nitrate, phosphate) show structural factors of the spring sampling method as well as external impacts on the groundwater ecosystem. \*



**Modelling of groundwater flow and radionuclide migration in fractures and granitic rock matrix**  
**Abstract n°2291**

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**KEYWORDS:** granite, modelling, migration

Crystalline rocks are considered as potential host rocks for deep geology repositories (DGR) of radioactive waste in many European countries. The main transport mechanism in the crystalline rock is advection, however migration processes from fracture through fracture coating into unaltered rock has also to be studied. The conceptual model is based on the presumption that non-advective migration is driven by diffusion into both altered mineral layers and undisturbed rock matrix, adjacent to water bearing fissures. Radionuclide migration from fracture towards granitic rock matrix is studied using laboratory block-scale samples (cm to dm size) and radioactive tracers ( $^3\text{H}$ ,  $^{36}\text{Cl}$ ) within CZ project PAMIRE (TA04020986). The results are implemented into the study of scaling up radionuclide migration processes towards the in-situ experiments in the Josef Underground Laboratory (<https://ceg.fsv.cvut.cz> en). Simulation codes MODFLOW MT3DMS and NAPSAC NAMMU (continuous porous medium and discrete fracture network models) were used for the evaluation of flow and transport through the granite samples and in the granite host rock. Inverse modelling was utilised in order to calibrate the heterogeneous flow-diffusion macroscopic characteristics - fracture transmissivity, porosity, hydraulic conductivity and effective diffusion coefficient of the fresh and disturbed rock matrix.



**The iah-cad.czm.net website- a tool to share and make information on coastal aquifers available**  
**Abstract n°2292**

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**KEYWORDS:** Coastal Aquifer Dynamics, Seawater Intrusion, Coastal Zone Management

The IAH Coastal Aquifer Dynamics and Coastal Zone Management (IAH-CAD-CZM) Network has organized a website ([http- www.iah-cad-czm.net](http://www.iah-cad-czm.net) ) aiming at collecting georeferenced data, and sharing information on coastal aquifers from all over the world, so as to let them available for researchers, professionals, and stakeholders. The overall focus of this network is to understand better hydrological process dynamics in coastal areas and improve the most effective long-term management strategies for water resources endangered by saltwater intrusion. The IAH-CAD-CZM website presents data on coastal aquifers in the form of a brief questionnaire so that researchers may compare and share their knowledge on the coastal aquifers they have under study. The questionnaire includes information about lithology, hydrogeological and hydrochemical characteristics, salinity sources, special features, applied monitoring methods, numerical modeling, management strategies, and in case seawater and brackish groundwater desalination technologies. The structure of the website is hierarchically organized into six pages, containing the lists of coastal aquifers present in six macro-geographical regions (Northern and Central America, Europe, Asia, Latin America, Africa, and Oceania). Data referred to more than one hundred coastal aquifer studies were collected. About forty questionnaires were fulfilled, partly directly by the authors of the studies, partly by the authors of this paper, who uploaded the data on the website after having them validated by the researchers responsible for the investigations. Up to now, more than 50 questionnaires have been reviewed and are shown on the website, and about 100 are under validation. The development of the IAH-CAD-CZM website is in progress. The data collected so far on coastal aquifers from all over the world constitute the basis for a comparative analysis of the most adopted investigation and monitoring methods for seawater intrusion, vulnerability mapping, groundwater protection technologies, and institutional planning and management.



**An experimental lab approach of morpho granulometry on suspended particle matter to identify particle transfer properties in karst aquifer**  
**Abstract n°2295**

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**KEYWORDS:** suspended particle matter, morpho granulometry, hydrogeology, karst

Morphometry of particles is widely used in sedimentology to identify source-to-sink transport, sedimentation mechanisms and different sedimentary stocks. Usually, morphometry analysis is used on centimetric to millimetric quartz grains. But in hydrogeology, suspended particle matters (SPM) are mostly micrometric. Currently, morphometry analysis is realized by scanning electron microscope coupled to image analysis in order to measure various size and shape descriptors on particles like flatness, elongation, circularity, sphericity, fractal dimension. This technique is complex and takes a big time. Moreover, transport processes of SPM in karst aquifer are very variable in time due to hydrological changes and complex recharge conditions. So, in order to measure the morphometry parameters of SPM during karst flash floods, it's necessary to develop an easy, quick and exhaustive method. The aim of this study is to present the first results of an experimental lab approach of morphometry analyses of SPM in order to identify transfer properties and sedimentary stocks of different particles recovery in karst springs. A morpho granulometer (CCD cam coupled to peristaltic pump) is used to measure different artificial and natural stocks of particles (different size, shape, nature, origin). From the measurements, the parameters allowing the identification of the different stocks are known by statistical analyses. Then, mixes of different particles stocks have been realized in order to verify the capability of the morpho granulometer to identify the particles of the stocks. These results show the capability of this approach to identify the different stocks of sediments by morpho granulometry and offer the perspective to use this method in continuous at karst springs.



## Importance of immobile water for transport in porous aquifers Abstract n°2297

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KEYWORDS: diffusion, reactive transport, dual-porosity

Targeted provisional session N°8.04 Porous aquifers can be heterogeneous containing immobile water regions characterized by low hydraulic conductivities. The diffusive mass exchange into such regions influences the fate of solutes in the subsurface. Consequently, transit times of solutes are larger compared to estimates from water fluxes. However, the spatial distribution and properties of immobile water regions are often unknown. Therefore, new tracer tools and modelling approaches are needed to quantify properties of mobile and immobile water regions. This information is important for evaluating the influence of immobile water regions on contaminant transport. In addition, contaminant plumes can have different densities than the ambient groundwater resulting in density-driven flow. Here, little is known about the influence of immobile water regions on transport. An analytical model was directly and indirectly validated for porous media by conducting multi-tracer experiments in a well-defined dual-porosity system at different pore-velocities. We showed that it can be used to estimate properties of both regions even if immobile water regions are randomly distributed. An extended version of this model, accounting for sorption and degradation, was used to quantify the transport of contaminants like nitroaromatic compounds or radioactive cesium ( $^{134}\text{Cs}$ ) in dual-porosity column experiments. Fitted first-order decay rates and retardation factors were found to be independent of pore-velocity. Sorption within immobile water regions enhances the mass exchange into such regions+ for  $^{134}\text{Cs}$ , sorption is more important compared to diffusion. Degradation of nitroaromatic compounds results in cuts of tailings caused by back diffusion which reduces the risk of a contaminant rebound after a site remediation. Experimental and numerical results on density-driven flow indicated that instabilities tend to move along the boundary surfaces and that the diffusive mass exchange into immobile water regions inhibits the growth of instabilities. These findings advance our understanding about the influence of immobile water regions on reactive transport which is important for prediction of contaminant rebounds and of transit times of contaminants in heterogeneous aquifers.



**Hydrothermal circulations in Eastern Pyrénées - brittle and ductile faults both act as drains for upward circulations.  
Abstract n°2298**

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**KEYWORDS:** hot spring, fault, Pyrenees, hydrothermal

Hydrothermal systems in orogenic contexts without a heat source such as volcanic or plutonic activity are poorly studied. These systems are characterized by a fast upward ascent of hydrothermal fluids from a possible hot reservoir at depth to the spring at the surface. Faults are zones of heterogeneity of permeability acting as drains or barriers for hydrothermal fluids. In Eastern Pyrénées, hot spring alignment along the major Têt fault is an ideal case to understand the relations between faults and hydrothermal circulations. Cartography and field study shows that hot springs always emerge in crystalline rocks, especially at the contact between gneiss and metapelites, and mostly in the Têt fault footwall. Hot springs are located near two types of faults- 1) Near the Têt brittle fault, at the intersection with other subsidiary faults, in the highly fractured damage zone. The core zone is composed of fine matrix rich cataclastic faults rocks. 2) In ductile faults, where we observe intersections between dissolution caves along the mylonitic foliation, and the regional fracturing parallel to principal faults. Numerical models coupling the Darcy law with heat transfer equation in a porous media shows that fluids with temperatures corresponding to our study area emerge in the permeable damage zone in the footwall of the fault. The permeability of the different constituents of the area (fault core, fault damage zone, bed rock) is the major factor controlling temperatures. So, faults control upward circulations of hydrothermal fluids by further processes- 1) The juxtaposition between impermeable metapelites and cataclasite with fractured permeable gneiss force fluids to stay in the Têt footwall. 2) The connexion of the Têt fault with other subsidiary faults induces damage zones, and thus fractures intersections, forming very efficient drains. 3) Ductile faults are anisotropic drains, with a good permeability parallel to the mylonitic foliation. This last point has practically never been identified. A better comprehension of these hydrothermal systems has important implications for geothermal exploration and permeability of basement aquifer.



# Investigating the Impact of Sustainable Drainage Systems on Groundwater Abstract n°2300

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KEYWORDS: SuDS, recharge, soil moisture

Since April 2015, in the UK, local flood authorities have been expected to ensure that sustainable drainage systems are incorporated into the design of housing and commercial developments. By mimicking natural drainage regimes, the application of infiltration Sustainable Drainage systems (SuDS) aims to reduce surface water flooding and improve water quality, although the impact of enhanced recharge on groundwater quality and level, are poorly understood. A SuDS Observatory has been established where a permeable pavement car park was constructed in 2005. The car park is made up of permeable block paving at the surface, with graded gravel layers and a geotextile below for bio-attenuation. The underlying geology of the area is made ground and river terrace sand and gravel, underlain by glauconitic marl. The Observatory has been upgraded and now contains a number of different types of soil moisture sensors at different depths within the SuDS and the adjacent natural grassland. Within the SuDS, the upper sensors are in the fine gravel layer above the geotextile and the lower sensors are in coarser gravel below the geotextile, in an effort to investigate the flux of water through the unsaturated zone. A rain gauge is also now used to trigger higher frequency measurements during rainfall periods. The preliminary data from the sensors highlight that in the grassland, water is stored even after rainfall events+ the SuDS act effectively by holding very little water and completely draining at certain points. Groundwater levels also appear to impact on the efficiency of these systems+ an increase in hydrostatic pressure can slow down drainage from the SuDS, even though groundwater levels may still be below the system. An understanding of the surface and subsurface (vadose and water table) components can greatly improve an assessment of the efficiency of these SuDS.



**The Effect of Stream-Aquifer Interactions On Groundwater Flow- An Analytical Approach**  
**Abstract n°2302**

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**KEYWORDS:** hyporheic zone, sloped stream boundary, stream-aquifer region, Visual MODFLOW

Stream-groundwater interaction has an important effect on water quality & control, water supply, and contaminant transport. Stream-aquifer interactions have been studied by many researchers in terms of different aspects but there are still issues that need to be clarified with further research studies. This research focuses on the effects of the stream-aquifer interactions on the groundwater head distribution. Water exchange between stream and aquifer is known as hyporheic flow. Hyporheic flow rate is typically determined by using Darcy's Law depending upon the stream head and groundwater head. The effect of the interaction is taken into account with an additional source sink term in the groundwater flow equation which is calculated by Darcy's Law. This research makes a contribution to the stream aquifer interaction studies by developing an analytical solution for the groundwater flow equation in which the hyporheic flow is considered by a source sink term. The 2-dimensional analytical solution is done for an unconfined, homogenous, and isotropic aquifer. The sloped stream boundary is used and the rest of the boundaries are assumed as no-flux boundary. A synthetic example is solved and the results are obtained for steady state conditions. A numerical model is developed by using Visual MODFLOW to verify the analytical solution results. Stream package of Visual MODFLOW is used to generate the considered problem conditions. The comparison of the analytical and numerical models results shows that the analytical solution performs well.



**Disaggregating the effects of climatic and anthropogenic drivers on groundwater availability in the Arkavathy watershed, India.  
Abstract n°2303**

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**KEYWORDS:** groundwater, climate, anthropogenic, India, hard-rock

Urbanization, intensifying agriculture, industrial and population growth are changing groundwater extraction patterns in India. Human actors are also rapidly altering catchments by building thousands of recharge structures. At the same time, climate change is altering rainfall patterns. Our research in the upper Arkavathy watershed in South India (1447 sq km) aims to disaggregate the influence of climatic and anthropogenic stressors on hydrologic partitioning -- the ratio of runoff, recharge and evapotranspiration -- and consequently water availability. The interdisciplinary study involved secondary (census, agricultural statistics, satellite imagery and meteorological data) and primary data (weather stations, stream gages, borewell monitoring, borewell camera scans, isotopic analyses, and farm surveys) over two years. Secondary data show that both stream flow and groundwater levels have declined since the 1970s but these historical trends cannot be explained by past climate change+ groundwater over-exploitation and eucalyptus plantations are the most likely causes. Additionally, the shallow weathered rock aquifer dried up in the early 1990s and current pumping is from deep fracture aquifers. Models calibrated using primary data show that interventions like farm bunds and check dams have increased percolation and decreased stream flow, especially during low to moderate rain events. Paradoxically, the shallow aquifer has not recovered despite hundreds of recharge structures because dewatering has induced flow into deeper fracture aquifers which are being pumped. Total evapotranspiration has increased considerably over the last three decades driven by market demand for produce from nearby Bangalore. Climate models project a decrease in moderate rainfall events and an increase in intense rain events. Under such a regime, the strategy of distributed recharge structures could in principle allow a greater fraction of rainfall to percolate, improving climate adaptation. The problem remains however, the inability to control pumping. Severe groundwater overexploitation, not climate variability, remains the primary concern.



## The H2020 FREEWAT platform for water resource management Abstract n°2304

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**KEYWORDS:** GIS-integrated simulation environment, FREEWAT, open source software, QGIS, MODFLOW

During the last decades, degradation of ground- and surface-water resources is matter of concern in terms of quantity and quality, mostly due to intense human exploitation and climate changes, especially in the EU. The EU HORIZON 2020 FREEWAT project (FREE and open source software tools for WATER resource management+ [www.freewat.eu](http://www.freewat.eu)) aims at promoting the application of EU-water related Directives. This is achieved providing an open-source and public-domain, GIS-integrated platform for the simulation of water quantity and quality in ground- and surface-water, with an integrated module for water management and planning. Such platform is expected to help in producing scientifically and technically sounding decision and policy making based on innovative data analysis tools, and a participatory approach not only in the final stage of result discussion, but also during the phase of scenario generation. The FREEWAT platform is integrated within the open source QGIS GIS, allowing the simulation of the whole hydrological cycle and the analysis of several water data, where input and output data are managed through a Spatialite Data Base Management System (DBMS). The FREEWAT hydrological model is based mainly on the open source USGS MODFLOW family integrating MODFLOW-OWHM. FREEWAT capabilities include- • solute transport in groundwater flow systems and in the unsaturated zone+ • tools for the analysis, interpretation and visualization of hydrogeological data+ • tools for dealing with groundwater quality issues through analysis of hydrochemical data+ • time-series processing to support advanced model calibration+ • a whole module for sensitivity analysis, calibration and parameter estimation+ • a dedicated module for water management and planning, with particular focus on rural environments. As such, the FREEWAT platform is conceived as a canvas, where several simulation codes, based on the hydrological cycle, hydrochemical or economic-social processes, might be virtually integrated. Due to the open source characteristics of the platform, contributions to further development by research institutions, private developers etc. are welcome, in the view of an initiative ad includendum.



**Combining hydrochemical, piezometric and geophysical evidence to analyse seasonal groundwater dependence of wetlands – case studies in the Cauca Aquifer, Colombia  
Abstract n°2305**

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**KEYWORDS:** Wetland-groundwater interactions, Hydrochemistry, Piezometric time series, Electrical resistivity tomography, Cauca

Wetlands are susceptible to climate extremes (floods and droughts), as well as to the impacts from human activities, and a good understanding of the groundwater -surface water - wetland interactions is required to help protect and preserve them. Such studies are increasingly performed, but often focus only on quantitative hydrology (surface water balances, groundwater discharge estimates), or water quality aspects (using chemical or isotopic tracers). In the current study we integrate different tools, including hydrochemistry, piezometry, water balances and geophysics, to provide a more comprehensive and validated analysis of groundwater dependence of wetlands and its seasonal and spatial variations. For a period of approximately one year we studied two wetlands located in the Cauca Valley in Colombia, an area that is characterised by an intensive use of water, mainly for irrigated sugarcane cropping and public water supply to the city of Cali and surrounding municipalities. The main sources of water are surface water from the Cauca River and its tributaries, and groundwater from a large multi-layered alluvial aquifer. Several wetlands with important ecological and cultural functions are located in the area, and understanding their sensitivity to natural and human impacts is important to the regional Water and Environmental Authority (CVC), who have had a highly active role in the current study. The two wetlands were equipped with rain gauges and with piezometers at strategic locations in and around the wetlands. Automated water level, temperature and EC loggers were installed, and geophysical campaigns using electrical resistivity tomography were conducted. Groundwater, wetlands, river water, and rainfall were sampled during two campaigns



for chemical analyses of major ions, silica, carbonates, nutrients and several metals, following a (moderately) wet season and a (very) dry season. The obtained data set was analysed using time series analysis, geostatistical tools and hydrochemical (modelling) techniques. This resulted in important findings on the seasonal variation of the groundwater signature in both wetlands, as well as on the spatial dependence of the influence of the river Cauca and its tributaries.



## **Analysis of nitrate attenuation conditions in groundwater from an ecological approach Abstract n°2306**

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**KEYWORDS:** nitrate, denitrification, functional gene abundance

Nitrate pollution is one of the main concerns for water management in the Osona region (NE Spain), as high nitrate concentrations are frequently found in groundwater, reaching up to 500 mg NO<sub>3</sub>- L. The main source of nitrate in the Osona aquifers is slurry and manure applied to crops as fertilizers. Nitrate can be reduced by dissimilatory nitrate reduction to ammonia (DNRA) or by denitrification, being the later the unique process that could ensure nitrogen removal in groundwater. Although several studies have observed natural groundwater denitrification in Osona area, mainly related to pyrite oxidation, little or no attention has been made on bacterial functional marker genes involved in nitrate reduction. In this work, functional gene abundances together with hydrochemical and isotopic characteristics (by means of +15NNO<sub>3</sub> and +18ONO<sub>3</sub> isotopic signatures of NO<sub>3</sub>-) were used to characterize nitrate reduction conditions from an ecological approach. Samples were taken from eight wells in similar geological formations in the Osona area. Hydrochemical and isotopic data were measured jointly with those of genes implied in the two key steps of denitrification (nirK, nirS, nosZ1 and nosZ11). According to the 18ONO<sub>3</sub> enrichment factor, three wells showed a degree of denitrification from 10 to 25%. The relative contribution of nirK and nirS were on the range of 0.76-3.30 and 0.02-0.32 respectively. The abundance of nosZ genes was one order of magnitude lower than for nirS and nirK suggesting a limited complete reduction. Wells with different denitrification percentages show similar abundances of denitrification genes. Such finding suggest that genetic potential for groundwater denitrification exist overall the study area, yet the appropriate conditions depending on the hydrogeochemical environment are key factors to locally trigger denitrification rates at efficient levels.



**Contribution of multicriteria analysis in the cartography of zones favorable to the establishment of drilling in the Gagnoa region (west central of the Ivory Coast)  
Abstract n°2307**

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**KEYWORDS:** Fracture, favorable area, multicriteria analysis, drilling, recharge, water resources

In Ivory Coast, groundwater is main drinking water reservoir. However, lack of drinking water points pushes these rural people to use ponds and rivers. This study was carried out in Gagnoa region in west-central Ivory Coast. It aims to map out favorable productive drilling areas. Satellite Landsat 7 ETM + hydroclimatic data, topographic and geological maps and technical data sheets of boreholes of the Gagnoa region were used. As methodology, we evaluated aquifer recharge, realized fracturing map, and used multicriteria analysis to assess water resources. This methodology helped to establish potential indicators maps, accessibility and exploitability of groundwater resources in that region. Then, these indicators are combined inside a Hydrogeological Information with Spatial Reference System (HISSR) by the codification using aggregation technique to generate the suitable of productive drilling in Gagnoa area. The result of this study reveals that the region has a dense fracture network. The potential and accessibility of groundwater are good to excellent covering respectively 65.22% and 50.41% of the territory with 73% of moderate to poor exploitability due of high cost of drilling. In general, favorable areas of good drilling site occupy 45% of the territory. The result from this study will amply guide hydrogeological prospecting during the implementation of future drilling in Gagnoa region to help rural population to have access to drinking water.



**Combining geological mapping, aerial photos and geophysical methods to enhance groundwater abstraction**  
**Abstract n°2308**

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**KEYWORDS:** crystalline Bedrock, geophysics, groundwater wells

Targeted provisional Session N8.03 Høgevarde hyttefelt at Gulsvikfjellet in Flå municipality in Norway, is a large aggregation of cabins supplied by groundwater from crystalline bedrock. The plan is to build several more cottages in two new areas (A and B). Consequently, there is a need for more water. The capacity of existing wells varies, but most have low yields (< 200 l hour), although they are located close to assumed fracture zones. To enhance the possibility to drill new wells with larger yields, Sweco has combined the use of aerial photos, geophysical methods and geological mapping. Profiles for geophysical measurements were located based on fracture mapping from stereoscopic aerial photos of the area. Geophysical methods used were 2D resistivity (CVES) and VLF. The latter method was not successful, but the resistivity measurements indicates fracture zones with high permeability where the possibility of high water yield is larger than in the surrounding bedrock. Area A is close to existing roads, and two wells have been drilled towards two different fracture zones in this area. Both wells are 120 m deep. The capacity measured by the driller was about 1300 l hour for well BH1 and next to nothing for well BH2. Therefore, hydraulic fracturing was utilised in well BH2. After a period of pumping the capacity is now about 4000 l hour for well BH1 and 500 l hour for well BH2. Comparing the results to earlier drillings, the use of 2D resistivity seems to have been successful to enhance the well yield. In area A four additional well locations are picked out, and three possible locations are picked out in area B.



## **A REVIEW OF GROUNDWATER ISSUES IN JAKARTA**

### **Abstract n°2310**

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**KEYWORDS:** Jakarta, groundwater, groundwater depletion

Studying the Jakarta groundwater basin has revealed opportunities to improve groundwater planning and management. This paper reviewed about some groundwater issues in Jakarta regarding its problems to develop the solutions. This paper aims to- compile the comprehensive hydrogeology information of Jakarta Basins, establish links between the social and technical aspects of groundwater management regarding rapid groundwater depletion and aquifer degradation, and find out guiding principles and criteria for establishing a sustainable plan of groundwater management through practical actions. The existing groundwater problems in Jakarta have been known, i.e. polluted groundwater, seawater intrusion, land subsidence, and depletion of groundwater. The polluted groundwater is indicated by nitrate contamination impacted by human activities. The seawater intrusion has been proved by Na-Cl water from well about 40 km inland. The land subsidence occurs in Jakarta due to the rapid abstraction of groundwater accounted for 17.5% of all factors. The depletion of groundwater has been identified from expansion and movement of groundwater potential depression in the northern Jakarta from 1985 to 2008. Some solutions are proposed to tackle the problems. To reduce groundwater pollution which 70% contributed by domestic sewage can be solved by installing an integrated sewage treatment should be built in Jakarta to reduce the domestic contamination. Seawater intrusion can be reduced by injecting groundwater into the deep aquifer to increase hydraulic potential in the deep aquifer near the coastal area. Land subsidence can be tackled by stopping groundwater abstraction and injecting water to the aquifer to maintain pore pressure. The groundwater depletion would be prevented by limiting groundwater abstraction and considering use other water sources, i.e. surface water, rainwater, and used water. Recharge area which lies on Bogor area should also be managed to maintain recharge of rainfall back to the aquifer.



# Crucial Role of Managed Aquifer Recharge as an Adaptation Strategy for Groundwater Sustainability in the Face of Climate Change in India

## Abstract n°2311

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**KEYWORDS:** managed aquifer recharge, energy-irrigation nexus , intelligent power rationing

As per key findings of climate change projections for India, the increase in the frequency of extreme precipitation, will also mean that much of the monsoon rain would be lost as direct run-off resulting in reduced groundwater recharge and increased ground water withdrawal ,which might further exasperate the present scenario of imbalanced development. The adaptation strategies proposed for mitigating the increasing stress on ground water resources due to climate change for enhancing recharge of groundwater aquifers, mandating water harvesting and artificial recharge in urban areas, ground water governance, incentivising to promote recharging of ground water, intelligent power rationing for irrigation ,optimizing water use efficiency, conjunctive management etc. have been examined at great length in terms of the technical feasibility as well as social relevance of implementation in the light of extensive experience gained in the country. Sustainable development of ground water resources and various mitigation programs required in the event of possible climate change in the country can be accomplished only with the help and active cooperation of all stakeholders such as the Ministries of Government of India for Water Resources, Environment & Forests, Power, Rural Development, Agriculture, Science & Technology and the institutions working under them+ State Governments & their organizations+ Associations of Industry, Non-Government Organizations, District Administrations and Panchayati Raj Institutions and the individuals users. To be successful in this mission we also have to create conditions for complete synergy in the activities of all the stakeholders. The role and space for various stakeholders namely Farmers, NGOs, local communities, Canal system managers and Groundwater Recharge SPV, in groundwater recharge strategy as a major response to climate change is outlined.



# **A hydrodynamical approach to understand sediment fluxes in a karstic aquifer**

## **Abstract n°2312**

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**KEYWORDS:** Karst, turbidity, particle transport, modelling

High flows at karstic springs are often associated with strong turbidity peaks. The observed turbidity signal results from the contribution of two potential sources of suspended solids- intra-karstic sediments (autochthonous) and soil particles (allochthonous), as well as from the integration of different processes- erosion, transport and deposition of particles. This study aims at characterizing particle transport in a karstic aquifer by confronting a hydrodynamic model of the system with observations of sedimentation processes in the cave and at the springs. The Milandre karstic catchment, located in the Swiss Tabular Jura, hosts a major speleological network. The hydrodynamics of the system are investigated by monitoring hydraulic heads in different cave passages and building a variably saturated pipe-flow model. The sedimentation processes have been monitored using a set of sedimentation plates that are distributed at different heights along a section of the stream conduit. At the springs, bacteriological and particle-size distribution analyses were performed to characterize the suspended solids content within the course of a flood event. To gain more insights into the sedimentation processes, flow velocities and conduit saturation computed by the model are analyzed. In the first stage of a flood event, the velocity in the stream conduit shows a steep increase. Due to the morphology of the conduit cross-section, in a second stage the computed velocity decreases as flow further increases and the conduit gets filled up. These results are consistent with the sedimentation plate observations- erosion is recorded only in the lower part of the conduit, and sediment accumulation is observed in the upper part of the conduit. At the main outlet, a first peak of larger particles is observed, followed by a second peak characterized by smaller particles and a simultaneous increase of E.coli content. These results converge towards a conceptual model of transitioning contributions of sources and of processes- erosion of autochthonous sediments in the early stages of the flood, followed by the transport and deposition of allochthonous particles.



**InSAR to understand groundwater flow systems and support groundwater management**  
**Abstract n°2313**

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**KEYWORDS:** InSAR, Remote sensing, groundwater depletion, subsidence, gravity, GRACE

Interferometric Synthetic Aperture Radar (InSAR) is used increasingly more in hydrogeology. According to the poro-elastic model, hydrostatic pressure changes induce grain-to-grain spacing changes within an aquifer matrix and deformation at the surface. Pressure changes can be related to either natural processes, e.g., temporal patterns of recharge discharge which induces storage variations, or have anthropogenic causes- e.g., pumping, artificial recharge. Aquifer storativity and confinement are among the main governing parameters controlling the amplitude of the deformation, as it relates to the pressure changes implied by a given inflow or outflow rate. InSAR efficiently monitors these ground deformations. It is non-invasive, has large spatial coverage, a temporal frequency of at least 24 days, and a precision of up to a few mm yr. Through different case studies conducted by our research group in Canada and Mexico, this presentation provides an overview of the applicability of InSAR for groundwater studies. At local scales, InSAR provides important spatial information related to the lithological heterogeneity of depleting compressible aquifers- e.g., litho-stratigraphic boundaries or clay interbed thickness. It also provides information related to groundwater flow patterns, e.g., temporal variation of recharge and pumping areas. In karstic settings, Persistent Scatterers Interferometry (PSI) is particularly suitable to reveal preferential flow path and mitigate related damages to infrastructures. From regional to continental scales, InSAR provides guidance to improve large-scale groundwater governance schemes. By yielding the missing spatial details within GRACE-derived groundwater storage trend estimates, it could be used to improve its precision and scale of application. Thus, integration of InSAR-derived ground deformation maps into GRACE data holds promises in the perspective of high resolution and volumetric mapping of depleting groundwater resources.



**What is the impact of land use change on the behaviour of shallow aquifers ? A comparison of particle-tracking and lumped-parameter models for evaluating the groundwater age distributions**  
**Abstract n°2314**

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**KEYWORDS:** groundwater, recharge, irrigation, isotopes

The Crau aquifer in the Mediterranean irrigation area (France) is a major resource for drinkable water supply. This aquifer, mainly recharged by gravity irrigation, is today threatened by environmental changes (expected changes in the irrigation pattern, urban expansion, increasing groundwater demand, climate changes). In order to evaluate the actual impact of land use changes on this resource, the groundwater behavior must be well defined. As irrigation water is clearly depleted in  $^{18}\text{O}$  and  $^2\text{H}$  compared to local rainfall, we propose to use the isotopic approach ( $^{18}\text{O}$   $^2\text{H}$ ) associated to groundwater modeling to quantify (i) the respective influence of the different input variables contribution and (ii) the distribution of residence times of groundwater. A monthly sampling of groundwater and recharge water has been carried out for four years, for chemical and isotopic analyses. First isotopic results confirmed that recharge resulted mostly from irrigation (80-85% under meadow) but variable in space and time. A lumped parameter model (exponential transfer function) applied to one observation well showed a mean residence time of three months. This approach will be applied to other wells in relation with land cover (irrigated area, steppe, urban area) in order to highlight the impact of land cover on residence time distribution. Baillieux et al. (2015) developed a 3D groundwater flow model of the Crau aquifer. To complete and validate the lumped approach, the distributed model will be used to run particle tracks to create a transit time distribution. Measured tracer concentrations will be used to validate or refine this model. These first results open up new perspectives in the use of environmental tracers in highly transient hydrosystems highlighting the interest of coupling isotope monitoring and conceptual or numerical modeling. Baillieux A. et al., (2015) *Géologues* 187, 85-92.



**Column experiments on the attenuation of organic micropollutants during bank filtration- The relevance of the hyporheic zone  
Abstract n°2315**

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KEYWORDS: wastewater-derived contaminants, redox

The hyporheic zone, i.e. the interface between surface- and groundwater is considered to be a highly reactive ecotone, and represents the very first part of the flow path of surface water entering the subsurface via bank filtration. Bank filtration typically leads to an improved quality of the infiltrate due to physical filtration, sorption and biodegradation processes that decrease the concentrations of undesirable constituents such as bacteria, viruses or anthropogenically-induced (trace) contaminants. But to what extent does the hyporheic zone contribute to this quality improvement? In order to estimate its cleaning capacity with regard to the elimination of organic micropollutants, we performed column experiments using undisturbed sediment cores, which originated from a bank filtration site in Germany. The columns were fed with surface water taken from the same field site in order to mimic field conditions as close as possible. As part of a partly closed water cycle, the utilized surface water receives wastewater treatment plant effluents. Thus, the investigated organic micropollutants - a total of 14 frequently applied pharmaceuticals and metabolites - were already present in the water and it was not required to artificially add them. After an adaption phase of several months three depth-dependent sampling events were carried out, considering the hydrochemical conditions along the flow path as well as the fate of the organic micropollutants. Whereas several of the investigated compounds were more or less unaffected (e.g. carbamazepine, candesartan), other compounds were significantly attenuated along the flow path (e.g. acesulfame, metoprolol). Due to chemical and physical differences regarding the core materials the (degradation) behavior of the investigated compounds clearly indicated site-specific variabilities. Data collected during this study emphasizes the relevance of the hyporheic zone within a partly closed water cycle, as it considerably contributed to the attenuation of surface water constituents.



## **A two-step calibration procedure for continental hydrosystem models Abstract n°2318**

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**KEYWORDS:** parameter optimization, hydrosystem modeling, hydrograph separation, stream-aquifer interaction

This study describes a 2-step methodology for hydrosystem model calibration, which ensures consistent (i) long-term global water balance and (ii) separation of surface and subsurface flow. In addition to classical observations (total river discharge rates and groundwater levels), the calibration methodology relies on a proper hydrograph separation. It therefore opens a new way of posing model calibration issues, from blind trial error procedure to constrained calibration algorithms. The first step consists in the calibration of surface parameters alone with a process-based multi-objective function, which accounts for cumulative total river discharge and runoff dynamics. The minimization of the objective function reduces the equifinality of parameter estimation compared to the classically used trial-error calibration. Thus, this first step ensures consistent long term estimations of the surficial water cycle components (including actual evapotranspiration, runoff and infiltration rates), and the proper runoff dynamic simulation. In a second step, subsurface parameters are calibrated given the infiltration rate calculated previously. This new procedure is applied to the Seine river basin (76 375 km<sup>2</sup>). The 2-step calibration procedure relies on river discharge observations measured at 30 gauging stations along the Seine river network and groundwater levels obtained at 192 piezometers. The hydrograph separation of the observed river discharge has been conducted with the Chapman filter technique. The simulation of the hydrosystem with the optimised parameter set reproduces the contrasted hydrological settings of the Seine basin, thus proving the robustness and the efficiency of the 2-step calibration procedure. The model simulation provides a description of the hydrosystem behavior and permits to report the stream-aquifer exchanged fluxes for water management purposes with regards to variations in both anthropogenic (with and without pumpings) and climatic (dry, humid and pluri-annual) parameters. Results of the simulation were synthesized in a database, ultimately providing a valuable tool to assess in-stream waters vulnerability to groundwater contamination and resource depletion.



## **Transboundary water management issues of the Island of Uznam, Poland Germany Abstract n°2319**

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**KEYWORDS:** transboundary water management, water supply, water shortage

Island of Uznam is a Baltic Sea island in Pomerania that has been split between Germany and Poland in 1945. About 80% of the island belongs to the German district of Vorpommern-Greifswald in the state of Mecklenburg-Vorpommern. The eastern part and the largest city on the island, winoujcie, are part of the Polish West Pomeranian Voivodeship. The island's total area is 445 km<sup>2</sup> and its population is ca. 75,000 citizens, which doubles at summers. Three major groundwater intakes, two on the Polish side (Granica and Wydrzany) and one on the German side (Zirchow) compete for water from a quaternary aquifer of a transboundary coverage. Positioning of the island in vicinity of many surface water systems including the Szczecin Lagoon, the Bay of Pomerania, harbor canals and the wina river makes the aquifer vulnerable to ingression of salt waters. High abstraction volumes needed to supply potable water can locally cause ascension of mineralized water from Cretaceous aquifer that lays below the Quaternary aquifer. Management of water resources in the Island is treated with high priority and for many years has been undertaken in cooperation between the Polish and the German governors. Groundwater monitoring on the Polish side of the island has been introduced in 1970ties. At present there are in total 46 monitoring locations with regular observations of groundwater quantity and quality. 28 of these sites constitute a transboundary monitoring network in which bilateral monitoring is carried out under the Polish-German Working Group on Water Management of the Eastern Part of the Uznam Island, which was set up in 2000. The group undertakes biannual measurements in selected 88 measuring locations including groundwater and surface water. Despite monitoring results showing transboundary impacts from abstraction sites located on both sides of the border, this article gives an example of good cooperation between neighboring countries, that is based on scientific approach, which leads to creation of optimal rules for sustainable groundwater management in transboundary areas.



**Global changes impacts on water fluxes of the critical zone for the sudanian area in  
West-Africa  
Abstract n°2321**

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**KEYWORDS:** critical zone model, land cover changes, subtropical West-Africa

West-Africa undergoes global changes which affect water redistribution within its critical zone (CZ). Particularly, strong demographic rates (about 3%) have implied rapid changes in land use and land cover (LC) in the past, which continue nowadays. Climate has also changed significantly, with a marked drought starting in the 70's-80's and, at least over the Sahel, significant evolution in precipitation temporal distributions. The consequences of these global changes on water fluxes (discharge, recharge, evapotranspiration) within the CZ are not well known for the hard rock aquifers of the subtropical sudanian area, both in past conditions and for the future. Overall, it has been observed that discharge has decreased in sudanian climate since the 80's, but the impact on other fluxes and groundwater storage is not known. In this presentation, we aim at addressing the issue of the impacts of LC changes on water fluxes of a 13000km<sup>2</sup> sudanian catchment in northern Benin, using a physically-based critical zone model (ParFlow-CLM). This model simulates flow in saturated and unsaturated zones (ParFlow) and couples the energy and water cycles through a land surface scheme (CLM). Model simulations are compared to the observations from the long-term AMMA-CATCH observing system to diagnose model performance. Specific targets are the lower evapotranspiration observed over herbaceous fallows and associated shallower water table as compared to woody cover. We are interested in simulating the impact of past LC changes, given the observed precipitation inputs, and at running sensitivity experiments with LC changes for the future. We are particularly interested in the space-time evolution of the river-water table connections which are expected to produce non-linear and step-like system responses.



**Karst flow system information from shape analysis and numerical modeling of tracer concentration curves**  
**Abstract n°2322**

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**KEYWORDS:** Carbonate karst aquifer, tracer test, numerical modeling

Dye tracing constitute a very valuable tool for investigating the origin of groundwater and delineating flowpaths in karst media, providing direct and quantitative information about the hydraulic properties and solute transport dynamic within a conduit (and or fracture) dominated system. In this sense, data obtained from 8 single- and multi-injection tracer experiments performed during last years in different carbonate aquifers located in Malaga province (southern Spain) have been re-examined following the numerical solutions provided by a dual process-based approach- advection–dispersion model (ADM) and two-region non-equilibrium model (2RNE). Tracer tests were conducted under different hydrological conditions (high-intermediate-low flow) affecting the aquifers, and the fluorescent substances were injected into sinkholes (5), losing streams (4), karrenfields (1) and dolines (1), while springs commonly served as detection points (manual sampling and eventually field fluorimeters). Flow and transport parameters estimates obtained from the simulation of 13 tracer breakthrough curves (BTCs) provided mixed information on a wide range of hydrogeological behaviors- from well-developed conduit flow paths to flow and storage modalities in a fissured-like systems. The statistical treatment of the analytical and numerical results, jointly to the field observations, has been especially useful for the characterization of the predominant solute transport processes in the studied experimental sites, given the significant deviations that have been eventually found between the shape of the measured and modeled curves (marked skewness, single multi-pulse geometry, long-tailing effect, etc). These findings will allow for a better understanding of the structure and dynamic of the karst systems investigated and will may help to protect and preserve karst water resources in the region.



**World Groundwater Mapping - WHYMAP- the Global Map of Groundwater Vulnerability to Floods and Droughts and the World Map of Karst and Carbonate Aquifers  
Abstract n°2323**

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KEYWORDS: groundwater mapping+ karst aquifers+ groundwater vulnerability

One third of the global population depends on groundwater for their drinking water, in arid and semi-arid areas the dependency is between 60 and 100%. About 40% of the world's food is produced by groundwater-irrigated farming. While surface water is much more vulnerable to pollution and climatic variations, groundwater plays a vital role for water and food security. But this security might be at risk by natural hazards like floods and droughts. Especially in emergency situations, decision makers need to know where to access safe groundwater resources for drinking water purposes. To convey groundwater vulnerability-related information in a way appropriate at the global scale, the World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP) recently published the "Global Map of Groundwater Vulnerability to Floods and Droughts" under the auspices of BGR and UNESCO. As karst aquifers constitutes a particularly vulnerable environment, this map is complemented by the new "World Map of Karst and Carbonate Aquifers", currently under preparation. In addition to presenting the main outputs of these initiatives, i.e. the two maps, and their background data and methodology, this contribution aims to share and discuss the process and challenges linked to the preparation of such products, undertaken at the global scale, with the objective to present appropriate information for global discussion on water issues and to emphasize the presence of underground water resources.



**Geochemical and isotopic tracing of salinity loads into the RAMSAR listed Verlorenvlei freshwater coastal estuarine lake, Western Cape, South Africa.  
Abstract n°2324**

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**KEYWORDS:** Verlorenvlei catchment, wetlands, salinity sources

This study characterises the nature of salinity within surface water and shallow groundwater in the Verlorenvlei catchment to develop better water management strategies for the RAMSAR listed Verlorenvlei estuarine system. It is assumed that all salts in the Verlorenvlei River are transported downstream to the Verlorenvlei estuarine wetland, and the increase in salt load has led to the degradation of this water resource. Samples were collected on a monthly basis to account for seasonal variation, and major ions, stable isotopes of O and H, strontium isotope ratios, tritium activities, EC, T, pH and selected trace elements were analysed for, to delineate salt load flow paths. The amount of salt contributed from each tributary into the Verlorenvlei River varies considerably- the Krom Antonies River has the lowest salt loads reflected in relatively low EC < 300 mS m<sup>-1</sup> the Kruismans River is considerably higher, 500 mS m<sup>-1</sup> < EC < 2000 mS m<sup>-1</sup> the Hol River is intermediate with 400 mS m<sup>-1</sup> < EC < 1500 mS m<sup>-1</sup> and the Bergvallei River 500mS m<sup>-1</sup> < EC < 800 mS m<sup>-1</sup>. The Verlorenvlei River showed lower salt loads, with values between 80 ms m<sup>-1</sup> and 300 mS m<sup>-1</sup>. Stable isotopes indicate that the Kruismans River is strongly influenced by evaporation, but the Hol River, also with high EC values, does not show the same evaporation trend and suggests a different source of salinity. Major ion data indicate high concentrations of Na<sup>+</sup> and Cl<sup>-</sup> associated with elevated Mg<sup>2+</sup>. The Krom Antonies and the Begvallei Rivers reflect mean Na Cl molar ratio of 0.56, the Kruismans a mean Na Cl molar ratio of 0.45 while in the Hol and Verlorenvlei the mean Na Cl molar ratio is 0.61. The low Na Cl ratios result in a decrease of Na<sup>2+</sup>, due to ion exchange with clay minerals associated with the geology of the catchment The high Cl<sup>-</sup> values are derived from rain and marine aerosols.



**Estimating groundwater recharge in an arid region in Central Tunisia using Chloride Mass Balance and Unsaturated modeling**  
**Abstract n°2325**

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**KEYWORDS:** recharge, Chloride Mass Balance, Hydrus

Central Tunisia is characterized by a semi arid to arid climate where groundwater is the primary source of water supply. Oum Ali-Thelepte aquifer, located in Kasserine (Central Tunisia) with an arid climate, is among the most available water resources in the region. Natural recharge quantification is thus a crucial issue for a better evaluation of this resource. The present work aims to estimate and study groundwater recharge processes at the long term in an arid context. Chloride Mass Balance (CMB) and variably saturated numerical modeling are the retained methods to fulfill these objectives. Potential recharge areas of the aquifer were already identified using hydrogeological, geochemical and isotopic methods. Selected sites (in the recharge areas) were then retained to perform soil sampling. In the present study we are presenting investigations carried out in one representative site located near the North West of the Algerian border. 18 interstitial water samples have been obtained from the unsaturated zone using a dry drilled soil profile of 8m depth (reaching groundwater level). Soil texture, bulk density, gypsum content, water content and physico-chemical analyses (pH, Temperature, Electrical Conductivity, Na, Ca, Mg, K, HCO<sub>3</sub>, Cl, SO<sub>4</sub>, F and NO<sub>3</sub>) were performed. CMB was applied for both groundwater and the unsaturated zone (chloride profile method). Hydrus-1D was calibrated using field and climate data at a daily scale and for a long time period to reach a nearly steady state regime. The mean annual recharge calculated was 7.13 mm year (2.34% of the mean annual rain) using the chloride profile method and 3.81 mm year (1.26% of the annual rain) using the CMB for groundwater. Model calculations showed that the average annual recharge was about 11.28 mm year (3.7% of the mean annual rain). The recharge rate obtained from these different methods is relatively of similar range values. Calculations are to be continued for the remaining selected sites in order to attribute recharge rates for each recharge area.



**PROTECTION AND SUSTAINABLE USE OF THE DINARIC KARST TRANSBOUNDARY  
AQUIFER SYSTEM (DIKTAS)- from the identification of threats to joint international  
action  
Abstract n°2326**

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**KEYWORDS:** Karst+ vulnerability+ groundwater dépendent ecosystems+ international cooperation

The DIKTAS project is a regional project implemented with the purpose of improving management of karst groundwaters in the Dinaric karst region shared by several countries of South-East Europe. It is the first global example of introducing the principles of integrated management of transboundary karst aquifers of this magnitude. Groundwater resources (both in terms of quantity and quality) were reviewed in the entire DIKTAS project region, and analysed in detail in the transboundary aquifer areas. In that process numerous data gaps were identified, resulting primarily from the fact that certain areas haven't been investigated enough, lack of adequate monitoring and integrated databases, as well as inadequate inter-state exchange of available data. In a context where groundwater is extensively abstracted for public water supply, it was identified that, among other factors, there is no coordinated criteria to define the boundaries of water source protection zones. Additional problems are, the insufficiently analysed and appreciated characteristics of karst groundwater-dependent ecosystems, and the insufficient public awareness about the importance and specifics of the karst. In addition to presenting the main results of the assessment regarding the status, and main threats and vulnerability of the system regarding quantity, quality and the dependent ecosystems, this communication aims to share the challenges of establishing cooperation mechanisms for- 1) improved knowledge on karst groundwaters in the Dinaric region (by collecting, structuring, harmonising and interpreting data and information)+ and 2) fostering long-term joint actions. Indeed, the final results of the project suggest that the current approach to managing this resource, without a coordinated joint approach to solving problems and appreciation of karst specifics, can negatively affect the future economic development of all the participating countries.



**Assessing vulnerability to droughts by combining statistical, field and hydrogeological modelling approaches**  
**Abstract n°2328**

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**KEYWORDS:** drought, surface water groundwater interaction, numerical modelling

Periods with scarce water availability tend to be more frequent and intense under changing climatic conditions. Even temperate and relatively humid regions like Switzerland are affected by low-flow issues. It is thus essential to characterise the vulnerability of watersheds to droughts in order to manage water supply. Groundwater, as one of the main fresh water reservoirs, greatly impacts hydrological catchment dynamics. Especially river low-flows are strongly dependant on the surrounding hydrogeological settings. Numerous studies have analysed watershed processes under dry conditions. However, they have mainly concentrated on surface flows. Our approach is thus to improve the understanding of low-flow watershed dynamics by characterising the storage processes occurring in various geological units. The relationship between low-flow dynamics, storage processes and hydrogeological properties of 50 Swiss watersheds is analysed. For basins with mainly quaternary geology, a clear correlation between aquifer volume and low-flow behaviour is observed. However, for non-quaternary basins, no clear correlations between hydrogeological properties and low-flow dynamics are detected. The combined control mechanism on streamflows of the various physical and climatic factors is highly complex. Synthetic catchments are thus developed with the physically based numerical model HydroGeoSphere. This allows the quantification of the influence of hydrogeological properties on low-flows systematically and independently from other factors. Parallel to that, a field study is carried out on two small creeks with contrasting low-flow dynamics. These two catchments are similar in terms of meteorological conditions, size and topography, allowing a comparison focused on hydrogeological features. Besides, the configurations of these two basins offer an ideal scenario to assess the applicability of synthetic models to the real world. Owing to the better understanding of storage processes, the vulnerability of regions to droughts can be assessed based on their geological settings.



**Hydrogeophysical investigations and numerical modeling of infiltration capacity at an  
Artificial Recharge site  
Abstract n°2329**

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KEYWORDS: Artificial recharge (AR), ERT imaging+ infiltration test, Hydrus2D

Artificial recharge (AR) techniques are used to cope with groundwater depletion caused by excessive extractions. Hydrodynamic Characterization of potential sites intended for AR projects is of great importance for both engineers and decision makers. The present work aims to study the soil infiltration capacity of a future surface infiltration system s...



**Stable isotope composition of rainwater as a proxy to delineate recharge processes to  
Mediterranean coastal aquifers  
Abstract n°2330**

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KEYWORDS: Stable isotopes, Rainwater, Recharge

Understanding groundwater behaviour means considering the rainwater role in the aquifer recharge processes. Mediterranean coastal areas often display intense touristic, industrial and agricultural activities and groundwater resources are usually over exploited due to low seasonal recharge conditions. This problematic is particularly strategic for southern Corsica (France) where the only available, but not sufficient, water resource is the Bonifacio aquifer. Insofar as no seawater intrusion is yet detected in this aquifer, the isotope composition of groundwater is expected to reflect the signal of rainwater. The Bonifacio aquifer corresponds thus to an interesting study site to observe the recharge processes of Mediterranean coastal aquifers. It is a calcareous plateau filling a fractured granitic depression. Precipitation have been monthly sampled for  $^{18}\text{O}$  and D from January 2013 to December 2014. Groundwater have been sampled during the same period and with the same frequency. The survey allows a local meteoric water line to be identified for Bonifacio, characterized as follows  $D = 7.39 (A0.19) ^{18}\text{O} + 6.03 (A0.53)$  considering deuterium excesses higher than 3 ‰ and rainfall amount higher than 10 mm. This equation is consistent with that of precipitation found in Sicily by Liotta et al. (2013). The rainwater  $^{18}\text{O}$  and D values range respectively from -8.31‰ and -53.9‰ during winter to -3.69‰ and -21.6‰ during summer. Same seasonal variations with lower intensities are observed in groundwater. Indeed, groundwater  $^{18}\text{O}$  and D means are about respectively -5.97‰ and -35.8‰ but samples from the surrounding granites and from the plateau recharge area displays temporal variability up to  $\pm 1.27\%$  for  $^{18}\text{O}$  and  $\pm 8.6\%$  for D. Nevertheless, the presence of important mixing with older groundwater implies less variability for the deepest aquifer. Stable isotope composition of rainwater is thus a relevant proxy to delineate recharge processes to the aquifer but a good definition of the flow conditions is necessary to interpret the signals.



**Should we collect more K data or more aquifer samples for effective subsurface characterization? A comparative study based on reproducibility of flow and transport modelling results.  
Abstract n°2331**

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KEYWORDS: modelling, heterogeneity, subsurface characterization

Accurate numerical models of groundwater flow and solute transport behaviour require realistic conceptualizations of subsurface heterogeneity, and in particular of the hydraulic conductivity (K) field. In a stochastic framework, such conceptualizations can be generated with geostatistical methods, and depending on the type of conditioning data, two approaches can be taken to generate multiple realizations of the K field. One approach (here referred to as the hydrological approach) consists in an explicit reconstruction of the 3-D K field conditioned to available K measurements at selected points in the domain of interest. The second approach (here referred to as the geological approach) consists in an initial step in which realizations of the distribution of geological units with similar hydraulic properties are generated conditioned to aquifer samples along boreholes, and in a second step in which K values are mapped on the basis of distribution of these units. Because collecting observations of hydrological and geological properties is expensive and time consuming, it is important to evaluate the minimum amount of data that can provide accurate predictions of groundwater flow and solute transport. In this study, we analyse the sensitivity of results from numerical simulations of groundwater flow and advective transport with respect to the amount of conditioning information, here measured as the density of conditioning data points in the model domain. The domain considers the shallow aquifer underneath an industrial megasite (Porto Marghera, Italy). A series of stochastic models were implemented, each considering a different number of conditioning points in the generation of the K field, either with the hydrological or geological approach. Results were then compared to those from the model with the highest density. Comparisons show that the reproducibility of the results from models based on the geological approach is less affected by the loss of information caused by a lower number of conditioning points. This indicates that taking into account the geological structure in the K field is a cost-effective strategy for subsurface characterization.



**Developing a programme of measures to reduce groundwater pollution a collaborative approach**  
**Abstract n°2332**

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KEYWORDS: agriculture, nitrate, measures

Agriculture can have a profound impact on groundwater quality with often nitrate the main pollutant of concern. Within the Eden Catchment in Northwest England intensive agricultural practices have resulted in a rising groundwater nitrate trend in its principal aquifer. With nitrate concentrations varying from less than 4 mg l to in excess of 100 mg l (as NO<sub>3</sub>). The variability is presumed to be due to land use and the main source of the nitrate is believed to be the nitrogen applied to grassland, both as slurry and as inorganic fertilizers. Recent modelling has indicated that the nitrate remaining in the groundwater will affect the long-term quality of surface water and hence the ecological quality in the study area. However, where rapid recharge to shallow groundwater takes place, travel times through these systems can be relatively short and impact on both baseflow and water quality of rivers can be instant but short lived if recharge reduces. Within the Eden catchment secondary aquifers such as the Carboniferous Limestone where fracture flow is dominant recharge in bedrock near the surface is often rapid during high rainfall events. Therefore understanding better understanding nutrient fluxes helps develop time frames to assist in assessing the success in programmes of measures at the catchment scale. Additionally targeting of specific measures for differing systems will help reduce pollution both in the short and long term. Improving farmyard infrastructure can help improve shallow groundwater quality over a short time scale but to help reduce nitrate loss at the catchment scale broader mitigation options are often required such as nutrient management advice. This paper will present an approach to enable a programme of measures to help reduce nitrate pollution at both the local and catchment scale within the Eden Catchment. It required a greater understanding of how the catchment functions both physically and socially and through a collaborative approach has now developed a better understanding of what measures are required and where.



# **Modeling of groundwater artificial recharge in a heavily exploited coastal aquifer- The case of Mornag (Tunisia)**

## **Abstract n°2333**

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**KEYWORDS:** Artificial recharge, Modeling, Mornag, Tunisia

In the framework of an integrated water resources management project, different options of artificial groundwater recharge are studied as means to mitigate the effects of over-exploitation of the Mornag coastal aquifer in Tunisia. While the aquifer is also utilised for drinking water supply, the over-exploitation is primarily due to an increasing irrigation water demand caused by a substantial expansion of irrigated agriculture during the last decades. In recent years, the number of wells has dramatically increased, leading to a drawdown of groundwater levels of more than 20 m in some locations. Starting in the 90s, artificial groundwater recharge using fresh water is being practiced in two former quarry sites at outcrops of the deep sandstone aquifer. In the present study different artificial recharge options are compared, e.g. activation of further quarries, intensification of recharge in the non-perennial river beds (wadis), construction of injection wells and recharge ponds. Re-use of treated wastewater is also considered, given the quality complies with the national standards and does not adversely affect the aquifer chemistry. The impact of the different alternatives is assessed using FEFLOW, a 2D 3D finite element saturated unsaturated subsurface flow and transport modeling software. The regional scale conceptual model is based on an existing study (with Processing Modflow) where the aquifer is represented by a shallow phreatic and an underlying confined part. Grace to a local refinement of the finite element mesh, the important recharge structures like wadis or recharge ponds are precisely modeled. At recharge sites where a significant distance to the groundwater table exists a vertical unsaturated approach is used to model the respective flow. First results show that, because of unfavourable vertical hydraulic conductivities at the possible recharge pond sites, a combination of several recharge alternatives is necessary. As today's quality of the treated wastewater is not appropriate for injection into the groundwater, temporal recharge scenarios are presented that bridge the deficit until treated wastewater of sufficient quality is available.



## **Bioremediation in saline lagoon groundwater Abstract n°2334**

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**KEYWORDS:** chlorinated compounds plume, hydrocarbon plume, bioremediation system

An old industrial waste landfill close to the Venice lagoon, has produced a groundwater contamination plume with hydrocarbons and chlorinated compounds. Emergency P&T system was realised but with low efficiency so a bioremediation system was plan to improve the in situ remediation. The area is subject to land reclamation with drainage pump because is set below the sea level and let the saltwater intrudes. Microbiological and chemical laboratory tests confirmed the feasibility of microbiological system and a field test was design. Two different test barriers were planned and realized- an anaerobic barrier close to the landfill to start the reductive dehalogenation of the chlorinated compounds and an aerobic one to decompose by-product of reductive dehalogenation and hydrocarbons. In some anaerobic barrier's wells was injected an organic compound able to increase the reductive dehalogenation of chlorinated compounds. In some wells of the aerobic barrier was activated an air sparging system and in other was injected nutrients to treat hydrocarbons and promote co-metabolism reactions for chlorinated compounds. In both the barrier was plan the re-circulate of the injected substances. The efficiency of each barrier was checked each three months for a 16 months' period with in situ chemical-physical parameter and laboratory chemical analysis both upgradient and downgradient of each barrier. Data of the field test and pumping test will be use to calibrate the pumping rate of the wells of the barriers and to realise a groundwater flow model to evaluate the effects of barriers with and without the P&T system activated and the enlargement of the field tests barrier. The efficiency of each barrier was evaluated to be over 90% in the monitored period and the model show any problem to the enlargement. The positive results of the field tests and of the numerical model lead to the enlarge the barriers to the entire side of the landfill and once activated to deactivate the P&T system.



**The use of geostatistical methods to investigate nitrate contamination in groundwater-  
case studies from Central Italy  
Abstract n°2335**

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KEYWORDS: nitrate, contamination, Indicator Kriging

Nitrate is among the most common pollutants in groundwater worldwide. Its natural concentration generally does not exceed 10 mg L but human activities, such as agriculture, industry, domestic effluents can largely increase NO<sub>3</sub> in groundwater with adverse effects both on human health and on the water ecosystems. In this study, different algorithms were used for predicting spatial distribution of groundwater nitrate concentration in three different sites belonging to the northern-central sector of the Latium Region (Central Italy). The aim of this research is to investigate the processes leading to the overlapping of natural and anthropic pollution in groundwater through a case study approach. Groundwater sampling from wells and springs, was conducted between 2011 and 2015 using standard procedures. Nitrate values range of 4 orders of magnitude in the three case studies, showing a diffuse spatial contamination. Nitrate distribution maps (both of natural and anthropic origin) were compared with the Corine Land Cover IV level maps, revealing that highest NO<sub>3</sub> concentrations are mostly due to agricultural activities. Normal and Log-normal Quantile-Quantile plots have been realized for assessing the Natural Background Level of nitrate in the three sites. NBL was estimated 4 mg L, in line with the international literature. Indicator kriging was then used to indicate the spatial distribution of the probability of exceeding the NBL or the DWD standard (10 mg L) in the study areas. IK allowed us to visualize the zones where most likely nitrate represent the background as well as the areas with the highest risk for human health and groundwater related ecosystems.



# **Comparison of 2D simulated flow pattern and measured hydraulic data for a confined aquifer to reveal the influence of gravity and heat on flow pattern**

## **Abstract n°2336**

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**KEYWORDS:** gravity-driven groundwater flow, confined aquifer, heat transport, numerical simulation

The gravity-driven flow concept was originally developed for unconfined sedimentary basins. However, the aquifers are often confined in different rate. This issue is especially important for confined carbonates, where the fluids are sources for geothermal utilization and hydrocarbon exploration. The basic issue of the paper is the hydrodynamic behaviour of confined aquifers, i.e. what is the role of different driving forces, heat and gravity. For the first step the effect of the water table undulation was examined on the flow pattern, afterwards the influence of the heat was investigated on the flow pattern and vice versa. It was found that with real water table differences and basin conditions and parameters, the gravity is the main driving force in the area. The temperature distribution however, is determined primarily by the advective heat transport due to gravity-driven flow and influenced by the insulation effect of low permeability confining layer. These results were compared with the results of hydrodynamic data analyses based on preproduction hydraulic data of water and hydrocarbon wells for the Hungarian Paleogene Basin. The study revealed the existence of dynamic fluid flow systems including gravity-driven flow in carbonate aquifer. Not only the horizontal connections with unconfined carbonates but also the vertical interaction were revealed between confining strata and aquifer sequences. Finally, numerical simulation was again executed by the involvement of findings of data evaluation. Therefore it could be revealed that this iteratively used approach can be used in regional groundwater-flow system evaluation. The significance of gravitational driving force in confined aquifers could be established. The research was supported by OTKA NK 101356.



## Soil Aquifer Treatment in coastal areas Abstract n°2337

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KEYWORDS: Soil Aquifer Treatment, Coastal Aquifer, Wastewater Reuse and Groundwater

Soil Aquifer Treatment (SAT) is one of the broad collection of practices for groundwater recharge and storage for its recovery. Climate change, population growth and economic development may be behind the acute tension over water resources, particularly in coastal areas where population increases. In these areas, recourse to new sources of water has to be considered in order to secure water supply for drinking, irrigation, tourism and domestic using. Artificial groundwater recharge using different water resources (desalted waters, river waters, treated wastewater, etc.) appears as one of major solution to the recurrent issue of water scarcity and supply security. It is also potentially a pragmatic way to store and restore water in the environment allowing to- i) maintain necessary water supply levels, ii) alleviate salt water intrusion into coastal aquifers, iii) store water avoiding evaporation as it happens for dams, and iv) make it available at any time for all needs. Collaborative projects have been developed by BRGM and Veolia since 2006 aiming to develop concepts and transferable technology for SAT based on the control of the key physical, microbiological and chemical processes. As the successful establishment of a particular aquifer cannot be reproduced elsewhere due to different hydrogeological and geochemical settings, climate conditions and economic contexts, great care has to be made to ensure the success of any given SAT scheme. Every aquifer recharge design is highly specific, and must encompass a number of scientific disciplines (geology, hydrogeology, geophysics, geochemistry ...). Indeed, the reactive transport modelling is often carried out in order to identify the relevant processes controlling the filtration capability (permeability) of the soil, the compatibility of injected water with soil mineral reactivity (i.e., favourable water - rock interactions) and the design of permeable reactive barriers.



**Prediction of turbidity using neural networks- application on chalk aquifer of  
Normandy (France)  
Abstract n°2338**

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KEYWORDS: Hydrogeology, Karst, Turbidity, Neural Network

Approximately 25% of the world population drinking water supply depends on karst aquifers. Understanding and protecting karst aquifers is thus a crucial task whose development increases with fresh water needs. In Normandy, northern France, drinking water is provided by the chalk aquifer which is a highly capacitive and intensively karstified aquifer. In this context, the Yport pumping well managed by the CODAH delivers half of city of "Le Havre Great Le Havre" area, drinking water. Due to the high infiltration properties of the alimentation basin, the rainfall water washes the compound of the surface (biological organism, chemical product,...) and brings them rapidly to the pumping well. This phenomenon causes turbid events forcing the manager (CODAH) to decrease the pumping rate in order to allow treatment. In this context, the aim of the present work is the prediction of turbid event to allow the CODAH to optimally adapt its production process (create water storage before the turbid event to compensate the pumping rate decreasing). Due to the lack of knowledge about (i) physical



## Socio-hydrogeology and the case for water-budgets Abstract n°2339

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KEYWORDS: groundwater, budgets, socio-hydrogeologist

Groundwater is playing an increasingly important role in India's economy but overexploitation is a concern. The way India regulates groundwater does not reflect scientific reality. Like many other countries, ground and surface water are regulated by different agencies that do not properly account for the dynamic linkages between them. Already, depleting groundwater is resulting in drying rivers. The fragmented view results in solutions that exacerbate the problem. Much of the current action on groundwater focuses rain water harvesting structures. These are non-controversial and would not be a problem if each community only harvested and used its fair share. But evidence suggests that in the absence of limits, some users greatly expand their water use, while users further downstream experience a gradual, inexplicable decline in surface flow. The other popular solution has been efficiency improvement. Again, drip irrigation and efficient pumpsets often result in farmers expanding irrigated area with no decrease in total water extracted. Techno-efficiency measures alone cannot make a dent in the groundwater problem! Given the zero-sum nature of the game, comprehensive, integrated water budgeting is needed simultaneously at the local level and river basin. Water budgets at the local scale allow for corrective action+ communities can decide how to share and use what is available within. Water budgets for the river basin aquifer scale will ensure the resource is allocated between communities fairly and transparently. While this may seem an obvious solution to many and has long been the thrust of IWRM - in fact it has not made a dent in Indian government policy, agency structure or donor funding which continue to focus on technology-fixes. In these efforts, hydrogeologists tend to act as technical experts and eschew their role in framing debates on what sustainable groundwater use means. We need socio-hydrogeologists who can do both.



**USE OF ISOTOPES FOR THE CHARACTERIZATION OF SHALLOW AQUIFERS (CHOTT DJERID, SOUTHWESTERN TUNISIA)**  
**Abstract n°2340**

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**KEYWORDS:** shallow aquifer, isotope tools, recharge, mixing

The characterization of shallow aquifers in Chott Djerid lake were carried out by using isotopes method based on oxygen-18 ( $^{18}\text{O}$ ), deuterium ( $^2\text{H}$ ), tritium ( $^3\text{H}$ ), carbon-14 ( $^{14}\text{C}$ ) and carbon-13 ( $^{13}\text{C}$ ). Geological and hydrogeological studies indicated that shallow waters in the south western Tunisia could be classified into oasis and Saharan aquifers. The potentiometric flow direction was from East and South to Chott Jerid. Hydrochemical analyses indicated a Na-Ca-Cl-SO<sub>4</sub> water type for the oasis and the saharan shallow waters with enrichment in bicarbonates for the waters located in the piedmont of Dahar. the salinity spatial distribution indicated two groups of water with a salinity limit of 2 g l. The less mineralized waters are located in the piedmont of Dahar . The oxygen-18 and deuterium showed that the Saharan shallow waters in the piedmont of Dahar originated from meteoric precipitations. They have probable effect of mixing with the waters of underlying aquifer (i.e., Senonian aquifer). The oasis shallow waters resulted from the irrigation return flow. Deuterium excess show that the dissolution of evaporates is considered the main processes of salinisation contributing up to 90% compared to evaporation, for oasis and drainage waters. Tritium data indicated the presence of a locally recharge in the Saharan region. This recharge was estimated by the chloride mass balance to be 2,58 mm year. The combination of carbon-14 and carbon-13 showed two main groups of water- (1) recent water represented by the oasis shallow aquifers and (2) old waters represented by the Senonian aquifer and some samples from the Saharan shallow aquifers. Another intermediate group seemed to be the result of a mixing phenomenon.



**Modeling of the palaeo-hydrogeological evolution of a fractured-rock aquifer following the Champlain Sea Transgression in the St. Lawrence Valley (Quebec)**  
**Abstract n°2343**

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**KEYWORDS:** deglaciation, salt migration, fingering, groundwater quality

A quantitative reconstitution scenario has been developed for the evolution of groundwater salinity within a regional aquifer system following deglaciation. In our study area, Montérégie Est (~9 000 km<sup>2</sup>, in southern Quebec, Canada), brackish groundwater at shallow depths is related to large palaeoenvironmental changes that took place over North America during the last glacial-deglacial cycle and the ensuing postglacial period. The region was covered by the Laurentide Ice Sheet for ~20 ka, until about 13 ka BP, at which time it was invaded by an arm of the Atlantic Ocean, thus forming the Champlain Sea. The seawater salinity eventually decreased, due to sustained meltwater production and isostatic rebound, until it formed a shallow freshwater basin, Lake Lampsilis. Subsequently, the drainage system evolved towards its present-day configuration through continued isostatic adjustment. Along with these spatio-temporal variations in water level and salinity, silts and clays were deposited during the flooding episodes. These fine sediments formed thick low-permeability units that retarded the transfer of saline seawater into the underlying fractured rock aquifer, but also impeded the later flushing of brackish water from the aquifer system, which still contains brackish groundwater of marine origin over a 2 200 km<sup>2</sup> area. A fully coupled vertical 2D density-dependent flow and mass transport numerical model was set up to simulate the marine and post-marine migration of salt within the study area. The relative influence of various processes and parameters was then assessed. The model was then further constrained with present-day observed groundwater salinities. Results show that salinization of the rock aquifer was a density-driven convection process, and that the accumulation of fines had a profound influence on salt migration, leading to the currently incomplete and uneven desalinization of the regional aquifer system. In practical terms, this study offers a better understanding of regional groundwater dynamics and quality changes, along with improved estimates of groundwater age and vulnerability, which are key to sustainable management of the resource amid conflicting uses.



**Hydrochemistry, stable isotopes and groundwater modelling to delineate groundwater flows in complex aquifer systems of the upper part of Awaj River (Syria)  
Abstract n°2344**

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**KEYWORDS:** stable isotopes, geochemistry, groundwater

Barada and Awaj basin is the most important and extensively used water basin in Syria. The upper Awaj River forms the recharge area and occupies the southwestern part of this basin. In this arid region, groundwater is considered to be the major source of water supply. In order to assess the main features which characterize the hydrogeological system, a multi approach methodology using hydrochemistry, environmental stable isotopes and groundwater modelling was used as integrated tools. Detailed description of hydrogeochemical conditions has underlined the very complex variability of the stratigraphic sequences and the numerous hydrogeological units within the study area. Hydrogeochemical evolution reveals the domination of dissolution precipitation of carbonate rocks as a main mechanism controlling groundwater chemical composition and to less extend, the silicate hydrolysis, dissolution of gypsum and reverse ion exchange. Consequently, hydrochemical patterns did not give enough evidences for the expecting of huge feeding flow from Jurassic aquifers towards the Neogene Quaternary aquifer. The similarity in water type tends to express the existence of a unique hydrochemical system where the individualised groundwater flow paths are difficult to delineate. The isotope compositions imply an important rapid infiltration of atmospheric precipitation before significant evaporation takes place. Hence the infiltrated precipitation provides the main source of groundwater recharge all over the study area and mainly throughout the mountainous parts. The study area can be dividing into two main sub-regions. A sub-region characterized by active dissolution phenomena and deep vertical groundwater flow. And a sub-region characterized by shallow horizontal flow component associated with active interaction between groundwater and hosting rocks. The result of groundwater modelling indicates hydraulic connection between the deep aquifers and the overlying upper aquifer through upward leakage of groundwater. The components of the water budget of the upper aquifer have been determined. The lateral discharge from the Jurassic aquifer as well as the meteoric recharge is the most contributing component to this budget. The upward leakage of groundwater from deeper aquifers also plays an important role.



## **Why groundwater recharge does not play a real role in Barcelona water cycle? Abstract n°2345**

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**KEYWORDS:** hydrogeologist's role, water policy, water management

Although being considered an integral part of the water cycle, the role of groundwater is often neglected when facing new challenges and therefore strategic planning including these resources are not in the spotlight of decision-makers. In the case of the Barcelona's Metropolitan Area (the place with bigger water demand in Catalonia), groundwater is considered an strategic resource but as a simple replacement of surface water when the quality of the river deteriorates. On one hand, on the low Llobregat, recharge has been practiced by different technologies since the mid of the 20th Century, but in practice at a very small scale. Nonetheless, numerous studies of the aquifer and related papers on groundwater recharge have been presented at national and international conferences, being the aquifer of the lower basin of the Llobregat River one of the most popular in terms of publications. The range of practical implementations in this geography...



**New insights on the changes induced by a potential CO<sub>2</sub> leakage on the fate of trace metals in fresh groundwater- The case of the Albian aquifer**  
**Abstract n°2346**

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**KEYWORDS:** CO<sub>2</sub> geological storage, modelling, trace element, surface complexes, Albian aquifer

To mitigate CO<sub>2</sub> emissions into the atmosphere, the geological storage of CO<sub>2</sub> in deep saline aquifers is one of the main options. One potential risk associated with the geological storage is a potential leakage to fresh groundwater. The CIPRES project, co-funded by ANR, has been done to assess the impact of CO<sub>2</sub> leakage to the Albian aquifer, a strategic water resource in the Paris basin, overlying deep saline formation suitable for potential geological storages. One task of the project aimed to determine how chemical properties of the Albian waters are affected by CO<sub>2</sub> leakage, with a special focus on the fate of three trace metals (Zn, Ni and As(V)). For this purpose, an approach combining long-term batch experiment (1 month) and modelling has been conducted. The batch reactor was filled with water and rocks issued from Albian aquifer and enriched by CO<sub>2</sub> gas phase. Major and trace elements in water samples were analysed regularly during the experiment. The geochemical model accounts for various concomitant mechanisms including aqueous complexation, kinetically-constrained dissolution precipitation reactions for primary minerals, formation of secondary phases, protonation deprotonation and surface complexation reactions involving major and trace elements at the quartz surface sites and at the edge surface site of clay phases and cation exchange on the basal sites of the clay phases. The simulations reproduce correctly the pH drops and the increase of alkalinity. The behavior of the main major elements was correctly simulated. The results highlight that the pH drop promotes the release of Zn and Ni initially sorbed onto glauconite. In contrast, the measured increase of As(V) concentration seems to be induced by the dissolution of fluorapatite. This work shows clearly that complex geochemical mechanisms control the fate of trace elements in water-rocks-CO<sub>2</sub> systems.



## Abstract n°2347

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KEYWORDS: <p>Neural network, modelling, karst, water resource

<p>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 sometimes the unique water resource of their territory and that they are often underexploited. The site of the C&egrave+ze River (Rh&ocirc+ne river tributary) is subjected to important anthropogenic impacts linked to drinking water, irrigation, and seasonal increasing population (tourism). Interactions between C&egrave+ze river and karst aquifer of M&eacute+jannes-le-clap are interesting because the complexity of the aquifer can be related to the existence of a possible deep reservoir (Messinian episode). Moreover the Mediterranean climate leads to rainfalls heterogeneous in time and space making the behaviour difficult to characterize. Due to 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. This project investigates the karst river exchanges thanks to several approaches- thermic infrared imagery, analysis of interstitial invertebrates, analysis of major ions, and hydrological modelling. This presentation aims to present this last issue using neural network modelling, that are well-known for their ability to represent non-linear and badly known functions. Thanks to a 19 years daily database, an original architecture was proposed for rainfall-water level modelling at the station of Tharoux. A specific architecture was designed in order to distinguish the influence of hydrologic withdrawal of evaporation and transpiration, upstream rainfalls and lastly local rainfalls. Using 17 years training set, and two years for validation, modelling appeared satisfying with an average Nash criterion around 0.8 and a good representation of the drought period. Illustrations will be provided on the year 1994 that was used to compare the efficiency of various architectures of neural networks. Using scenarii of rainfalls, the quality of the model will thus allow to design a useful tool for helping water managers to anticipate about water conflicts and adapt to water scarcity.



**Evolution of regional groundwater flow and heat distribution over geological time scale at the margin of unconfined and confined carbonate sequences  
Abstract n°2348**

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**KEYWORDS:** unconfined and confined carbonate sequence, heat transport, scenario modeling

Hydrogeological processes acting at the margins of confined and unconfined thick carbonate sequences are particularly interesting due to a complex system evolution including partial uplift of fully confined carbonate systems and subsequent erosion of cover layers. We provide insights into this evolution by simulating coupled density-dependent fluid flow and thermal transport based on the Buda Thermal Karst (BTK) system (Hungary) in a 2D vertical plane. Applying an equivalent porous medium (EPM) approach using the Heatflow-Smoker finite element model, scenario modelling of three evolutionary steps was carried out between the fully-confined carbonate stage through to partly and completely unconfined conditions over the western ridge. The numerical simulations were used to derive the main evolutionary characteristics of groundwater flow and heat transport patterns for the unconfined and confined parts of the hydrogeologic system. The initial fully-confined state led to the development of thermal convection cells due to the insulating role of the low-permeability confining layer, which facilitates buoyancy-driven flow by restricting the dissipation of heat. Over geological time, these cells were gradually overprinted by gravity-driven flow and thermal advection due to uplift of the west ridge. The limited thickness of the cover still allowed sufficient water infiltration into the system, which led to increased cooling. Further uplifting led to a prevalence of gravity-driven groundwater flow. The results highlight the critical role of confining formations on flow patterns, and their effect on heat distribution and dissipation over geological time scales. The results have important implications for heat accumulation as well as for the development of a deep geothermal energy potential in confined carbonates. The research is supported by the OTKA NK 101356.



## Enhancing water resource management in rural areas by means of simulation tools Abstract n°2349

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KEYWORDS: FREEWAT, Farm Process, Crop Growth Module

Conjunctive use of ground- and surface-water in agriculture is of paramount importance in many rural areas of Europe, where freshwater resource is facing growing pressure, due to both human impacts and climate changes. In this framework, the development of open source public domain GIS-integrated, fully distributed and numerically-based simulation platforms may provide powerful tools to support planning, management and monitoring activities. The HORIZON 2020 FREEWAT (FREE and open source software tools for WATer resource management, [www.freewat.eu](http://www.freewat.eu)) implements the Farm Process (FMP) embedded in MODFLOW-OWHM to simulate conjunctive water use in rural areas under demand-driven and supply-constrained conditions, taking also into account constraints on well abstraction and water-rights ranking of water accounting units. The choice to integrate the FMP, after a careful review of the available codes, is related to the rigorous approach in dealing with the groundwater component. Thus the FMP allows to dynamically integrate infiltration, surface runoff and deep percolation components, to effectively balance crop water demand and supply from both sources of water. The FMP is further coupled with the Crop Growth Module, a free and open source module based on the EPIC family models, to estimate crop water uptake and provide crop yield at harvest. The CGM is a radiation-based model requiring few input data, most of which are also used as input parameters for FMP. The coupling between the two of them is easily achieved as the water uptake is computed by the FMP and then used in the CGM. Needs and priorities highlighted by the project partners include also the integration of simulation tools for nutrient transport from agricultural areas to ground- and surface-water bodies. Such integration is considered as a priority for future developments of the FREEWAT platform.



## **Accounting for Groundwater in Future City Visions Abstract n°2351**

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**KEYWORDS:** Groundwater balance, city, future visions, city-interventions

As urban populations continue to dominate globally, city planners, urban innovators and researchers are increasingly working on joint initiatives to investigate the physical, social and political aspects of harmonised urban living. Many city initiatives tend towards broader 'future city' concepts where knowledge dissemination, cooperation, policy reform and urban design run in parallel with big data and smart technologies. Despite this, sustainability principles are often lacking in future city visions and the importance of urban groundwater systems and the ecosystem services provided by urban underground space are not yet appreciated by city representatives. However the importance of groundwater for cities is well-recognised by expert practitioners, for example+ the role of groundwater for water supply and geothermal resource, baseflow contribution to urban rivers, flood risk, management of blue-green infrastructure, effects on underground infrastructure. Practitioners are equally aware that future interventions planned for cities, such as sustainable drainage systems, rainwater harvesting and use of geothermal heat will greatly affect the urban groundwater system. Using London as a case study, we use data from water resource management plans and local planning strategies to account for changes in the urban groundwater balance which may arise as a result of planned city interventions. The groundwater accounting is completed for two future city scenarios for London in 2036, one informed by current organisational policy and one which adopts an 'aspirational' future. Outcomes from the accounting exercise may be used in conjunction with social and political insights to guide plausible and scientifically informed city visions and interventions.



**Numerical model of groundwater rise mitigation actions effects in Grandate area  
(Como, North Italy)  
Abstract n°2352**

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**KEYWORDS:** groundwater rise, mitigation actions, numerical flow model

During November 2014 Grandate municipality near Como (North Italy), experienced a series of flooding events in industrial areas located in its territory due to the raising of the groundwater level. The owners of the factories and the municipality authorities worked hard in those days to manage the emergency but still the flooding had a strong influence on the industrial production and caused great damages in the impacted areas. Grandate municipality then entrusted Politecnico di Milano with the hydrogeological study of its territory in order to understand the causes of the flooding and prepare a pre-feasibility study concerning the possible action to be taken. The study started from a bibliographic research of previous surveys carried out in the area and with the collection of data regarding stratigraphic logs, existing wells and their pumping rate, piezometric levels and climate information. As the study area is located in the Prealpi zone, the hydrogeological structure is rather complicate and required an extensive and time consuming reconstruction of the conceptual site model. A flow model using Modflow-2005 was then implemented and calibrated with the aim to set a tool to support the understanding of the hydrogeological system, to analyze its behavior in different scenarios and evaluate the actions that could be undertaken by public authorities for controlling the groundwater level variation. The interaction of the new highway foundations with the groundwater body has been investigated too. The pre-feasibility study has been developed with reference to 3 kind of possible mitigation actions- 1) river Seveso levels control, 2) public wells relocation and pumping rate increase, 3) large scale low enthalpy geothermal open loop systems implementation.



## Land use and vulnerability of the coastal aquifer of Biguglia lagoon (Corsica, France) Abstract n°2355

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**KEYWORDS:** coastal alluvial aquifer, anthropogenic impact, vulnerability mapping

The alluvial aquifer (90 km<sup>2</sup>) connected to the Biguglia lagoon is a crucial resource for the urban and agricultural development of the economic basin of Bastia city (30 % of the population of Corsica). Rates of urbanisation and land cover change in the Biguglia coastal plain are among the highest in Mediterranean France. The groundwater is also of major ecological importance for the Biguglia lagoon (RAMSAR site) due to the hydraulic connection between the two water bodies. To evaluate the groundwater behaviour, two hydrogeochemical sampling campaigns were carried out (major ions, trace elements, <sup>18</sup>O, D and <sup>3</sup>H) in April 2015 (high-water period) and in September 2015 (low-water period) on 42 groundwater points, 6 river samples, 1 canal and 4 brackish water lagoon sites. In addition, four of the most popular index-based groundwater vulnerability mapping methods (DRASTIC, SI, SINTACS and GOD) were compared and validated according to the results of field investigations results. Results show a clear impact of surrounding anthropogenic activities on groundwater quality (especially on nitrate concentrations) of the alluvial plain of the Biguglia lagoon. The multi-decennial residence times of groundwater suggest an archiving process within the aquifer and the potential further release of stored anthropogenic pollution to the lagoon. In the near future, this may also constitute a potential threat to the local drinking water supply quality and other groundwater uses. The DRASTIC and SINTACS methodologies best transcribe the field observations and adequately highlight the most vulnerable zones which are clearly correlated with the highest concentrations of anthropogenic nitrates. This study was supported by CNRS Labex DRIIHM OHM Littoral Méditerranéen (HYDROGEO-LAG project).



# **Characterization of shallow aquifers for the identification of suitable zones for manual drilling by integration of different data sources. The experience of UNICEF in Africa Abstract n°2357**

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KEYWORDS: “manual drilling”, “shallow aquifers”, “data integration”

Manual drilling refers to several drilling methods that rely on human energy to construct a borehole and complete a water supply. In the last years it has been considered a potential solution to increase the access to groundwater in low income countries. Although different techniques for manual drilling are available, they can be applied only where shallow geological layers are relatively soft and water table is not too deep. Therefore it is important to identify those zones with suitable shallow hydrogeological conditions. Since 2006 country maps of suitable zones for manual drilling have been produced at country level in 15 African countries by UNICEF. These maps are based on the interpretation of different categories of existing data- a) thematic maps, especially geological map+ b) water point database at country level, containing the information about static water level and type of water point+ c) stratigraphic logs, elaborated using a semiautomatic procedure to extract textural characteristics of shallow layers+ d) available digital elevation models and extraction of morphometric parameters+ e) multitemporal analysis of satellite images and extraction of environmental indicators potentially related to shallow hydrogeological conditions+ f) Interviews with local key informants (hydrogeologists, drillers, water technicians) in the country, and systematization of their qualitative experience+ g) field observation of landscape features+ h) records of water level and pump tests in large diameter wells. The method of interpretation has been adapted to the available information, the scale of the analysis, and the specific geological and morphological characteristics of each country. This paper presents a critical review of the different approaches that have been tested in the whole set of 15 countries where this mapping activity has been completed and recommendations for the exploration of shallow hydrogeological conditions by integrating different categories of existing data in Africa.



**Fractured-rock surficial aquifer studies with optical borehole-wall imaging in support of hydrogeology**  
**Abstract n°2358**

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KEYWORDS: Surficial fractured aquifer, limestone

Subject to licensing, Cigeo, a deep geological disposal facility for radioactive wastes will be built along the border of the Meuse and Haute-Marne departments in eastern France, where research conducted since the 1990s has identified a site with geology favourable to its siting. Cigeo will consist of an underground (about 500 m depth) facility in which packages of radioactive waste will be emplaced and surface facilities used to receive, inspect and prepare waste. A comprehensive understanding of the shallow groundwater circulations in the outcropping "Calcaires du Barrois" formation (upper Kimmeridgian to lower Tithonian alternation of limestone and shale) is required for the setting of surface facilities and for the environmental impact assessment. Characterizing water storage and flows in these fractured and weathered limestones with a mechanistic approach depend on a good knowledge of the fracturation process. Recent geotechnical campaigns, preliminary to the construction of surface facilities, gave us an opportunity to perform an intense set of logging on 21 core drilled boreholes associated to the piezometric monitoring with sample interval of 15' on 10 piezometers. The combined application of optical imaging, core description, wireline logging (natural gamma-ray and imaging with optical borehole imager), seismic refraction and piezometric survey provides critical information for geometric modeling of geological units with emphasis on fractured and weathered zone and for conceptual modeling of hydrodynamic model of the site. As a perspective of this study, hydrogeological test monitoring, in-situ wells characterization and tracing experiments should provide further support of the interpretation of Magnetic Resonance Sounding.



**New insights on the dynamic of the Vaucluse hydrological system from long base  
tiltmeter data  
Abstract n°2359**

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**KEYWORDS:** tiltmeter, high stability, mass transfer.

The deformation of natural systems in response to subsurface water storage and redistribution provides insights into the main water flow path within heterogeneous systems, including the role of faults or fractures. A long baseline tiltmeter was installed in the low-noise underground laboratory of Rustrel (LSBB) to study the response of the Fontaine de Vaucluse (FDV) karst hydrosystem to water cycle. Tilt data and piezometric levels recorded in a borehole close to the LSBB show a strong correlation with the discharge of the system observed at the FDV spring 50 km away. Over several months, tilt data were recorded on three base lines, thus allowing, for the first time, to study the tilt gradient variation that appears homogeneous. Such information provides a significant constraint on hydrological processes leading to the measured deformation. Several deformation models were tested using the ADELI code to estimate the type of hydro-mechanical structure that could reproduce the measured tilt and its gradient. On one hand, models show that uniform loading at the surface produces a much smaller signal than observed on measured data. On the other hand, the deformation related to the filling of a single fracture following a precipitation event requires unrealistic fracture size. Finally, we found that a suitable hydro-mechanical model corresponds to the loading of numerous fractures at the interface between the saturated and unsaturated zones. Such a configuration predicts a tilt distribution in agreement with observations. This study suggests that tilt networks into a karst system should provide key observation for deciphering hydrological processes.



**Climate change impacts on flash flood in Mediterranean mesoscale catchments- the Lez basin.  
Abstract n°2360**

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KEYWORDS: Climate Change, Hydrological model, Flash flood, Lez, Karstic aquifer

The Lez catchment is a meso-scale karstic basin covering 114km<sup>2</sup> in Southern France. This Mediterranean river is subject to extremes floods events linked to intense convective precipitation along with a karstic aquifer contribution. The Mediterranean region is known to be one of the most affected areas by global warming, and hydrological cycle changes are likely to be expected. The aim of this study is to assess local climate change impacts on flash flood events using a so-called “futurization” method, in which a transfer function is built by comparing the distribution quantiles for both current and future climate precipitation. A number of historical flash flood events within the Lez catchment, previously selected using rain gauges’ data, are “futurized” using the precipitation outputs from Regional Climate Models. Once the future counterpart precipitation event is determined, it is used as input to Lez catchment hydrological models. The results are used to quantify the past future differences in terms of flood peak amplitude, discharge volumes as well as frequency. ATHYS is an event-based, distributed, parsimonious hydrological model. It has been calibrated and adapted to the Lez basin by Coustau et al. (2012) for the 1994-2008 period. The parameters, once calibrated, remain fixed for all events, except for the initial soil moisture which control the infiltration capacity. Currently, past and future flash floods events are simulated using the same infiltration capacity parameter, which is determined through a piezometrical level measured the morning before the event. Model sensibility tests have been done on this parameter by using random values around the past level. The effect of this parameter on the runoff production function is stronger than the precipitation change. Therefore, its future optimization is mandatory to only extract the climate change effects on flash floods.



**CLIMATE CHANGE AND ANTHROPIC IMPACTS ON GROUNDWATER - INSIGHTS  
FROM KARSTIC SPRINGS IN THE MEDITERRANEAN AREA  
Abstract n°2361**

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**KEYWORDS:** karstic springs, NAO, groundwater indicator

The effects of climate changes on water resources are described in numerous research paper using different tools, from simple statistical exploration of hydrological time series to sophisticated models considering the range of GHG emissions in the SRES scenarios. As for the Mediterranean area, water availability is expected to decrease, especially during summer, while the frequency and intensity of droughts could increase. Groundwater is less sensitive to droughts than surface water bodies, due to storage capacity, hence it represents an important buffer to sustain ecosystem and human needs. The decrease of precipitation often triggers an increase of impacts on groundwater, due to withdrawals. The so called “secondary impacts of climate change” are expected to have the largest short-term effects on groundwater resources, and separating climate change from the effects of anthropogenic activities is still challenging. Monitoring of groundwaters is mostly based on heads, which provide an estimate of groundwater storage variation. Unfortunately heads are affected by withdrawals and they can hardly relate to climate change only. The discharge of springs in mountain aquifers, which are very little or not affected by pumping, could be used as indicators of climate change effects instead, to evaluate the primary impacts on groundwaters. In this note, the discharge of a few karstic springs in Central Italy, with average discharge ranging from 120 L s to nearly 18 m<sup>3</sup> s, is examined with simple statistical tools. They exhibit consistent signals of the precipitation decrease observed in Mediterranean areas in the last decades. An inverse correlation with the winter NAO Index is also observed. Besides of a decline of about 20% of the discharge rate in 60 years, this analysis aims at estimating primary effects of climate change also on heavily impacted groundwater bodies, comparing them to the analysed springs.



## **Analytical strategies to highlight and identify organic compounds in groundwater Abstract n°2362**

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**KEYWORDS:** groundwater, organic compounds, screening, High Resolution Mass Spectrometry

One of ongoing challenge is to protect and preserve water resources. Nowadays it is increasingly important for public policy to know what compounds are present in groundwater, which of them must be monitored and their transfer behavior. This implies the need of specific analytical methodology to identify these micropollutants, including emerging substances or transformation products potentially present at low concentrations. The high resolution mass spectrometry (HRMS), complementary method to routine quantitative analytical ones, has gained increasingly in importance for monitoring these organic compounds but application to groundwater samples remains rare. Its high resolving power, mass accuracy and the sensitive full spectrum acquisition are the key points to identify compounds. Groundwater samples were analyzed by liquid chromatography coupled with hybrid quadrupole time-of-flight mass spectrometry (LC-QToF). All organic compounds present in samples are acquired and recorded to the extent that compounds are analyzable by the analytical methodology. No component is targeted before analysis. Results depend of raw data process, three types are identified- target, suspect and non-target screening. The first one is based on research from compounds listed on our homemade database (around 450 with experimental data) and suspect screening from bibliography and online databases. This suspect list will be supplemented by compounds of interest for studied area. The non-targeted screening compares samples to each other by statistical tools such as principal components analysis (PCA) and gives multidimensional visualization of chemical patterns such as molecular fingerprints. Trend plots are also used to highlight relevant compounds for their identification. This methodology was applied during several months on four groundwater sites impacted by agricultural, or urban pressures and has demonstrated its interest in environmental monitoring. Indeed several compounds were identified as targeted and suspected compounds including transformation products. The workflow used allows identifying sentinel molecules and molecular clusters as compounds never in these sampling sites.



**Conceptualization of a complex coastal aquifer in volcanic context from time-series harmonic analysis and field investigations**  
**Abstract n°2363**

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**KEYWORDS:** coastal groundwater, volcanic aquifers, time-series harmonic analysis, airborne geophysics, major elements molar ratios, La Reunion Island

In volcanic aquifers, underground structures, such as buried paleo-valleys, exert a predominant role on the hydraulic properties contrasts and the groundwater flow pathways. Otherwise, the knowledge of the hydrogeological functioning of these systems is fundamental for a sustainable management. In this study, innovative signal processing methods are applied on high-frequency hydraulic head time-series recorded in ten coastal boreholes. Our study is aiming at demonstrate the relevance of integrated approaches including signal-processing for the hydrodynamic characterization of these heterogeneous fields. Hydrogeological time-series were recorded on ten piezometers situated throughout the coastal aquifer of Pierrefonds, in La Reunion Island. Water electrical conductivity logs were performed on five piezometers at quarterly frequency and chemical analyses were carried out on six neighboring operating boreholes at biannual frequency. Firstly, the harmonic decomposition of the piezometric signals allowed discriminating two hydrodynamic behaviors, correlated with the geostructural context- i) boreholes located outside a permeable paleo-valley (identified by geological and airborne geophysical datas) showed water levels variations widely controlled by the tide and ii) boreholes located within the permeable paleo-valley showed water levels variations influenced by the tide and by the recharge signal. The physical-chemical monitoring and the Na Cl and SO<sub>4</sub> Cl molar ratios values revealed the presence of a saline water body at the shallow part of the coastal groundwater within the permeable paleo-valley, attributed to a discharge of domestic wastewater and or an agricultural effluents leaching. These results demonstrated that the paleo-valley corresponds to a preferential recharge channel. This permeable structure enhances not only the underground circulations but also anthropogenic contaminants transfers.



**MYRE POOL SPRINGS AS INDICATOR OF REGIONAL DEPENDENT GROUNDWATER  
FLOW – CASE STUDY FROM LJUBLJANA MARSH SLOVENIA**  
**Abstract n°2364**

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**KEYWORDS:** intermediate regional groundwater flow, alluvial fan, artesian aquifer

Springs are important indicators of the hydrogeological conditions in the supplying aquifer. At the same time they are important natural heritage. South of Ljubljana (central Slovenia) extends 120 km<sup>2</sup> of the former marsh where extensive bog deposits were formed in the past. Wetland was recharged with water from several rivers and springs flowing out from the karstic aquifers in the south. One system of the springs is positioned in the contact between large alluvial fan and marsh sediments. Springs appearance is variegated and their different morphologies are presents. In majority these springs are formed as pools where groundwater is ascending clearly indicating presence of the artesian pressure in the recharge area. Other springs are represented as pools where only moderate seepage of water is present. In the paper morphology of the springs and their genesis is described. Appearance of the springs is related to the groundwater circulation in the alluvial fan where two aquifers are present+ one shallow unconfined and another deeper under confined conditions. Both aquifers are recharged from the extensive karstic aquifer surrounding the alluvial fan. Groundwater flow in the area and appearance and morphology of the springs in the contact area between alluvial fan and marsh sediments can be only understood with the concepts of local and intermediate regional groundwater flow (sensu Toth).



**Challenges faced and approaches used by hydrogeologists in environmental baseline monitoring related to shale gas developments. Two case studies from active areas in northern England.**  
**Abstract n°2366**

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KEYWORDS: environmental baseline monitoring, shale gas

The British Geological Survey (BGS) has initiated science-based environmental monitoring programmes in Lancashire and Yorkshire in northern England where planning applications were submitted by energy companies for the development of shale gas. This monitoring is independent of the industry and regulators and represents the first independent, integrated monitoring programmes to characterise the environmental baseline areas subject to interest from the shale gas industry. We present our perception of the challenges we faced in presenting our role to the general public and landowners in these areas, how we addressed these and what we have learned in the process. We also present a chronology of how we planned and undertook the establishment of the groundwater monitoring networks to complement existing surface and groundwater monitoring sites and how we supported related monitoring activities including seismicity and soil gas assessment. We will demonstrate how the data will be useful to inform communities and regulators and how the data is being made available in traditional summary form and in real time. \*



**The synergy between analytical and numerical technics to estimate the groundwater seepage during drilling and calibrate the hydraulic parameters in observed flow in a tunnel**  
**Abstract n°2367**

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KEYWORDS: TUNNEL, ANALYTICAL AND NUMERICAL MODELING, GROUNDWATER SEEPAGE

Since a quantitative point of view for the hydrogeologist, one of the most important design and security issues that present with the excavation of deep tunnel in heterogeneous and saturated geological formations, is give a good estimation of the rate of discharge of groundwater with the construction, estimate the magnitude of peak flow that will flow through in the tunnel contour, the time period will remain infiltration and variation of the flow rate over time and his stabilization (steady state). These predictions can be possible using analytical and numerical models with enough data recollected in field, but almost always is not possible for their high costs and the estimations will have erroneous approximations given the input data. In the actually, the analytical formulations may be provided the hydrogeologist modeler a tool to approximate quickly the seepage flow in the drilling with several simplifications of problem and few parameters used in the calculus. Then with this results, the modeler can improve the numerical model and in some cases to rule hypothesis for the conceptual model. An example of the above, is evidenced in this work using analytical and numerical models to estimate the seepage flow and calibration the hydraulic parameters with an observed flow in several case studies in Colombia (La Linea Tunnel) and France Italy (Modane Tunnel). To achieve this synergy, it was necessary to use a software developed by the author (TunWaterFlow) which bases its calculation on the proposed analytical formulation for deep tunnels of low diffusivity by Perrochet and Dematteis [2007] and commercial software (FEFLOW V6.2y) that provide the best tools to the modeler for make two-dimensional and three-dimensional models an easy and quick way. Some interesting results in seepage flow were found for the numerical models with the mesh, time step and BC's...



**The pretext of foresight to debate on irrigation groundwater management- lessons from six cases 'studies in France**  
**Abstract n°2368**

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**KEYWORDS:** focus groups, irrigation management instruments, foresight scenarios, groundwater management, participatory approaches

The transcription of the 2000's European Water Framework Directive in France has led to define maximum volumes that can be abstracted in water bodies. In many French contexts, it requires reducing more or less drastically current water consumption, especially in agriculture where farmers were granted permits by the water policy authority, regardless the real level of water availability. To do so, French water law imposes, where water bodies are structurally in water scarcity, to create irrigation associations charged to share available water between farmers. And the challenge is particularly high in the groundwater case, where farmers are not embedded in collective irrigation schemes. Sharing rules have then to be designed from the ground up. This communication presents and criticises the way that innovative management instruments were explored in six cases' studies representative of the diversity of agricultural products and hydrogeological situations. These instruments were debated during 18 foresight workshops held with institutional representatives (50) and farmers (87). Foresight workshops had the advantages to make credible institutional and resource changes, and to retrieve from current but side-debates. In five cases, researchers took the lead of these workshops, and in the last one it was directly carried by a stakeholder (an Agriculture Chamber), which allows to test the transferability of such a method in real context with a direct implementing goal. Lessons are drawn at several levels. Firstly, debating on contrasted scenarios is a robust way to facilitate discussions on something not implemented yet in France. Secondly, the context highly matters, in particular the perception of the reality of groundwater scarcity level. Thirdly, to debate on groundwater management tools has to be firstly embedded in a more general discussion, on the future of agriculture or at least on more broadly water challenges (like in terms of quantity and quality).



**Providing elements to adapt groundwater management facing evolving hydrogeological conditions**  
**Abstract n°2370**

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**KEYWORDS:** surface water groundwater interaction, water resources management, impact of climate change

On going climate change processes start to show effects on water resources in temperate climate, although often a lack of data does not make it very easy to demonstrate this impact. Nevertheless, the last decades saw accelerating rates of natural erosion processes in several areas, leading for example to increased landslides, cliff deterioration and rock falls, as well as to epi karst development. This appears to be the case in Eastern Normandy where the impact of climate change on water resources in the Chalk aquifer system starts to show its first signs. For example the Risle river, in its middle portion, has recently shown increased frequency in the episodes of major sinkhole development+ indeed, in the last decade, two major sinkhole developed (a third one is underway) leading to a complete river loss in the underlying groundwater and a dried river course over distances of several kilometers downstream during summer. This resulted in major modifications in hydrogeological and in surface – groundwater interaction processes, with consequences which were important on the local water use, water quality and water dependent ecosystems. To counteract this phenomenon, adapting water resources management is necessary. In order to properly adapt water management techniques to these changing climatic conditions, it is necessary to acquire all pertinent data and knowledge and to develop proper tools. This paper intends first to describe the consequences engendered by the river loss which occurred in the summer 2012 on the local hydrogeological processes, water uses and ecosystems. Next it will describe the data that was collected through monitoring networks which were implemented, as well as innovative exploratory tools and methodologies which were developed to provide the quantified items needed to adapt water management to an evolving hydrogeological situation. The work carried out in this project notably included setting up monitoring networks for groundwater level, water river level and yield measurement , temperature and conductivity surveys in groundwater, karst springs and river, ecosystem surveys (fishes, macroinvertebrates, vegetation), modelling surface, karst and groundwater flow...



**A clay-sealed canal to manage water supply and irrigation cohabitation within an arid delta having sea water contaminated water table.  
Abstract n°2371**

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KEYWORDS: Senegal, infiltration, soil, user, clay liner, earthwork

This agricultural area, between the delta of Dagana and Podor Middle Valley, in Senegal, is a semi desert zone with fragile ecosystem almost at sea level. The coast is within 10 km therefore groundwater has a high salinity. A structuring water development was built to improve agricultural productivity through irrigation with water from the Senegal River. In parallel, water uptake from the Senegal River increases also, after treatment, to meet the drinking water needs of Saint-Louis City. Major work is first earthworks in the adductors rehabilitation- weed cutting and cleaning, setting to dimensions and containment dikes, raises or reinforcement of existing dikes. Then there was construction and rehabilitation of hydraulic structures such as bridges, valves, water flow controlling facilities and culverts to cross over the Gandiol Channel. Conditions are not simple- exchanges between surface water and groundwater must be avoided to preserve water within irrigation and drinkable water supply system from salt contamination+ works must be carried out while water supply should not be interrupted and environmental impact due to civil works could be damageable if strong protective measures were not taken. The decision was to construct earthen canals and reservoirs with clay seal coating. Clays are located mainly in crops areas+ their extraction causes alteration of the quality of soil and affects its further productivity. A geomembrane liner would have been a perfect seal for canals and reservoirs to prevent infiltration from the water table into irrigation water, and would have saved local resources in clays. This solution would have been more eco-friendly but it was not adopted due to economic considerations. In view of increasing the durability of the canal, know-how was transferred to the communities for the facilities maintenance and water management.



**Impact of deep saliferous Triassic deposits on groundwater mineralization in a  
Mediterranean costal aquifer  
Abstract n°2372**

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**KEYWORDS:** Deep water, saliferous triass, geochemistry, Cl isotopes, pyrenean overthrust

In the context of global climate change and the increasing pressure of water resources in the Mediterranean basin, understanding the salinization process is essential to the management of groundwater resources. The aim of this study is to investigate the hydrogeochemical evolution and the mineralization mechanisms of groundwater through the study of a major spring water in the Gulf of Lion continental. Based on an adequate set of geochemical and isotopic tracers including cosmogenic, stable and radiogenic isotopes, we have revealed complex hydrogeochemical processes that cannot be tracked with the traditional hydrochemical and isotopic tracers. The high  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of the spring water associated with relatively high concentrations in trace elements (Cs, Rb, Sr, B, Li) suggest the influence either of brine from the Triass deposits containing saliferous clay or of saline fluids from the fractured basement. Contrasting with marine primary brine and current seawater, the relatively high  $+37\text{Cl}$  (0.22 and 0.39 ‰) of groundwater attests the non marine origin of chloride ion.  $^{36}\text{Cl}/\text{Cl}$  shows that the spring water is issued from a mixing process between recently recharged water, lightly mineralized but significantly marked in  $^{36}\text{Cl}$  by the thermonuclear bomb pulse, and a saline deep end-member at  $^{36}\text{Cl}/\text{Cl}$  secular equilibrium with the matrix. This indicates that  $\text{Cl}^+$  in these springs are primarily derived from subsurface, non-meteoric sources. The deep saline water results from the infiltration of meteoric water into the lower Jurassic aquifer in contact with Triassic deposits and potentially basement uprising. High temperature promotes water-rock interaction enhancing leaching of saliferous Triassic deposits.



## Woodlands for drinking water- for the value of forest services Abstract n°2375

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KEYWORDS: contracts, drinking water, forest owners

It is widely recognised that forests play an important role in maintaining water quality, but they have to be cared for to make their protective role as effective and enduring as possible. This work involves associating forest managers in the achievement of good water quality for drinking purposes, through innovative contracting methods. Accordingly, French private forest organizations (the National Centre for Forest Owners and National Federation of Forest Owners Unions) are developing solutions for partnerships between forest and water stakeholders. A first work in collaboration with INRA (French National Institute for Agricultural Research), developed methods capable of producing reliable economic figures on the environmental services rendered by forests. The issue of absorbing additional forestry management costs incurred to safeguard the water remains to be resolved. The second step aimed to draft contracts defining mutual commitments. Thus, contracts models are available. We also carried out technical projects to optimize forest practices for protecting water. One main result is the publication of technical guidelines for good forest management practices to protect drinking water resources. The third step was to validate partnerships at sites between private forest owners and water operators. One particularly innovative example is the partnership with the Syndicat Intercommunal des Eaux des Moises (SIEM, water management board in the Haute-Savoie region, France). To improve coordination between silviculture and protection of catchments, the SIEM and forest owners formed an association. Initiatives introduced range from a concerted Plan Simple de Gestion (forestry management plan) to forestry operation specifications, which when implemented, grant entitlement to compensation. Land use management is a part of the process of producing drinking water. Private forestry organizations in France developed operational solutions to protect water quality. However, political support and improved communication between the forest and water sectors are required before the model can be applied on a large scale. Financial resources, or more specifically different ways of using these resources, are also required as it is usually more cost-effective to fund prevention than remediation.



**Surface water- Groundwater interaction and aquifer recharge in different lacustrine systems from Lake Chad Basin- 14C and 36Cl age determination  
Abstract n°2376**

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KEYWORDS: recharge, groundwater, 36Cl and 14C isotopic tracers,

In Lake Chad Basin (LCB), changes in mean annual rainfall have seriously jeopardize the availability, quantity and quality of the freshwater resource. Besides Chad Lake itself, several lacustrine systems play locally a pivotal role for populations who directly depend on this resource for their domestic, agro-pastoral and fishing activities. These lakes experience important and frequent surface changes, up to drying, and local aquifer systems play the role of alternate resource for population particularly during the dry season. Sustainable management of this water resource requires further understanding of the relationship between lacustrine water and groundwater to assess the recharge mechanisms of these aquifers. Isotopic tracers provide us with invaluable information on this question, illustrated here by using  $^{36}\text{Cl}$ , and  $^{14}\text{C}$  as tracers of the recharge dynamics. Here, two different lacustrine systems of LCB were investigated. With a mean surface of 800 km<sup>2</sup>, Lake Fitri is a terminal lake fed by the ephemeral Batha river. Further South, the Lake Iro (95 km<sup>2</sup>) is connected with the Bahr Salamat river - during the wet season, the river feeds the lake, the situation is then reversed during the dry season. Lake, river and groundwater samples were collected in 2015 and analysed at the Artemis-AMS-Facility for  $^{14}\text{C}$  and at the Aster-AMS-Facility for  $^{36}\text{Cl}$ . Groundwater samples have  $^{14}\text{C}$  content varying between 103 and 27 pmc.  $^{36}\text{Cl}$  Cl ratios ranged between about  $200 \times 10^{-15}$  at.at-1 and  $3000 \times 10^{-15}$  at.at-1. Previous results obtained in LCB indicate that natural background  $^{36}\text{Cl}$  Cl ratio is around  $200 \times 10^{-15}$  at.at-1. Groundwater samples characterized by  $>200 \times 10^{-15}$  at.at-1 are therefore clearly affected by a contribution of bomb-produced  $^{36}\text{Cl}$  released during the 1950' thermonuclear tests, indicating that most of the recharge of aquifer systems occurred after 1950. These results show that  $^{36}\text{Cl}$  is a promising tracer of modern recharge and that it can be a reliable alternative to tritium.



## Source Water Protection- A Case for Aquitard-Focused Characterization Abstract n°2377

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**KEYWORDS:** Aquitards, Sedimentary Rocks, Source Water Protection, Multilevel Wells

Vertical flow is commonly observed in bedrock boreholes and long screened wells allowing water with different hydrochemistry, and possibly contaminants, a rapid pathway across lower permeability hydrogeologic units. In sedimentary sequences, these aquitard units are presumed to be associated with thick, lithostratigraphic horizons that may be laterally continuous over various distances, ranging from plume (1-5 km) to watershed (10's km) to basin (>100 km) scales. Aquitards, and their hydrogeologic characteristics (position, thickness and hydraulic properties), are key to understanding groundwater flow systems and aquifer vulnerability. This talk will focus on new data sets used to hydraulically characterize these units through identification of vertical permeability contrasts, by utilizing high resolution vertical profiles of hydraulic head. Each of the commercially available multi-level systems (MLSs) were used to collect high resolution head data at several sedimentary rock sites across North America. The MLSs were designed to minimize cross-connection by using numerous, short-interval monitoring ports and maximizing lengths of seals to specifically target zones informed by numerous continuous logs from core and hydro- and geophysical logs. A typical high resolution MLS monitoring the 70-100 m thick Silurian dolostone aquifer in and around Guelph, Ontario has 10-45 monitoring intervals, each typically 1.5 - 3 m in length and separated from adjacent intervals by bentonite or packer seals. The head differentials between adjacent monitoring intervals is key to identifying the position and thickness of distinct head loss zones and several MLS are used to determine the lateral continuity of these aquitard units. Observations show large head loss occurring over thin layers, repeatable in time and space and indicating relatively low bulk vertical hydraulic conductivity and connectivity. These large head losses may occur over intervals much smaller than lithostratigraphic frameworks suggesting that lithostratigraphy alone cannot predict the location of aquitards. Therefore, many existing wells may be compromising the natural integrity of our sedimentary rock aquitards and increasing our aquifer vulnerability unnecessarily.



**Study of the persistent drought in seven plains of Oranie (Northwest Algeria) by use of Markov chains  
Abstract n°2381**

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**KEYWORDS:** Oranie region, Algeria, Markov chains, rainfall, drought

The Oranie region (Northwest Algeria) has experienced several droughts during the last century accompanied by a marked lack of rainfall in recent decades. This raises many socio-economic problems, especially for agriculture in the plains of the region (Maghnia Henaya, Mlata, Sidi Bel Abbes, Sig Habra, Ghriiss and Down Cheliff) known for their great agricultural potential. To continue to produce, farmers employ supplemental irrigation use to meet the needs of their crops which affected groundwater, causing a significant drop in groundwater level. To cope, managers have great interest in planning water requirements satisfaction priorities. As well as anticipate the relative frequency of an event such as drought, which can be studied in terms of probability. To do so, the methodology of the order Markov chains I and II is applied to the rainfall series of representative stations plains studied the annual scales. By this technique, we want to shed light on the persistent drought and the results will be used to establish a strategy against agricultural drought. In general, we found that there is a strong tendency to have a series of two or three dry years in the plains of the study area. A situation that must be taken into account in order to limit the impact of a limiting factor (water) on agricultural production in the Oranie region.



**A workflow for inferring vertical profiles of hydraulic conductivity in regional rock aquifers from specific capacity data affected by drilling and testing biases  
Abstract n°2383**

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**KEYWORDS:** specific capacity, hydraulic conductivity, well driller bias, stochastic simulation

Specific capacity ( $Sc$ ) data from well-performance tests are commonly used to estimate transmissivity ( $T$ ). Since  $Sc$  data are much more abundant than  $T$  data from hydraulic tests, they allow an analysis of the spatial variability of  $T$ . The objective of our study was to define a representative vertical profile of hydraulic conductivity ( $K$ ) in a fractured-rock aquifer on the basis of  $T$  values derived from  $Sc$  data. Although the estimation of  $T$  from  $Sc$  is apparently simple, wellbore storage significantly affects short duration tests, which is generally overlooked. Also, as poor shallow  $T$  preferentially leads to deeper wells, water-well drilling involves an important sampling bias due to non-random well depths. Moreover,  $T$  cannot be used as a direct estimator of  $K$  variations with depth, as  $T$  is the depth-integrated  $K$ . Considering these complications, we developed a methodology to infer regionally representative vertical trends of  $K$  from  $Sc$  data affected by drilling and testing biases. First, a conceptual model relates large-interval  $T$  estimates from  $Sc$  data to the actual vertical profile of  $K$ . Second, a new approach based on the Papadopoulos-Cooper solution is used to estimate  $T$  from  $Sc$  data considering wellbore storage, and to identify a  $T$  threshold below which  $Sc$  cannot be used to assess  $T$ . Reliability of  $T(Sc)$  estimates is assessed through a sensitivity analysis, in order to compute a corrected depth trend for  $T(Sc)$ . A stochastic modeling workflow is then used to define the actual  $K$  trend with depth through simulation of the driller-biased decreasing  $T(Sc)$  depth trend. The original Monte Carlo approach developed for this purpose thus provides the best-suited fracture and hydraulic parameters related to the actual aquifer heterogeneity. This methodology was applied to the Montérégie Est study area (~9 000 km<sup>2</sup>, in southern Quebec, Canada) for an 18 000  $Sc$  data set, providing a rigorous quantitative model of  $K$  variation with depth in its regional fractured-rock aquifer.



# Deep Groundwater Systems in Southern Africa - from occasional findings towards an exploration strategy - Abstract n°2384

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**KEYWORDS:** groundwater Exploration, hydrogeology, geophysics, palaeo-hydrogeology, climate change

The Federal Institute for Geosciences and Natural Resources (BGR) developed new methods for hydrogeological exploration on deep fossil and semi-fossil aquifers within a number of technical cooperation and scientific research projects. BGR and partners found a deep fresh water aquifer in the Cuvelai Basin of Northern Namibia which is separated by a confining layer from overlying salty groundwater horizons. First geophysical soundings in the late 1990s and later drillings showed that the extension of this new aquifer is extremely large, indicating that a sedimentary palaeo-delta might serve as a groundwater reservoir. In the meanwhile a complete core comprising nearly the entire Kalahari succession has been drilled and evaluated with regard to sedimentary structures and genetic aspects. A separate but comparable and presumably tectonically controlled deep Kalahari aquifer system has been identified in the Eastern Zambezi Region. The obtained results lead to the conclusion that exploration for new aquifers should follow a strategy which is used in hydrocarbon exploration. Hence, first of all the question has to be answered, whether there exists an appropriate reservoir structure to store large volumes of groundwater. A next step must include the search for bounding tectonic features and or sedimentary structures as confining layers. Last but not least, the recharge area has to be identified which either contributed to the groundwater reservoir in the past or still replenishes it today. Although this approach seems to be plausible it requires the combination of various interdisciplinary investigations such as remote sensing and structural geology, geophysical soundings, palaeo-hydrogeological investigations and isotope and hydro-geochemical investigations. This approach has been tested to new promising aquifer structures especially in the Eastern Zambezi Region of Namibia where groundwater exploration ended up often by detection of fresh water resources in the direct vicinity of salt water bearing formations. First results are promising and are giving hope that new aquifers might be found along a very old tectonic axis which is still active and part of an abandoned rift system.



## Groundwater under the Risk of Climate Change in Guinea Conakry Abstract n°2385

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KEYWORDS: Climate Change, Sustainability, Guinea Conakry.

Ground water (GW) has a pivotal role as a life-sustaining resource. With intensifying climate change (CC), GW has a growing importance to develop adaptation strategies. On a short-term, GW represents a buffer against CC variability effects, but, on a long-term, it is affected by CC and land-use. In this respect, the UNESCO program of GRAPHIC -GW Resources Assessment under the Pressure of Humanity and CC- shares important information on GW risks under the effects of human and CC in the developing countries. A region severely affected by a multiple range of livelihood and poverty issues intertwined to the availability and quality of GW resources is West Africa (WA). Guinea Conakry, in particular, is very rich in water resources, but poses many socio-political challenges e.g. the reliance on GW for food production and for ecosystem maintenance. Guinea's water and development potential are further at risk because CC superimposes effects difficult to forecast e.g. rainfall reduction and spatial-temporal irregularity coupled with the temperature rise. Under the GRAPHIC, the scope of this work is informing policy makers and managers both on GW data gaps and on possible threats under CC and human pressures in Guinea. Available data from documentary analysis were first explored and presented here. Secondly, the future GW recharge stress in Guinea is shown under the highest CO<sub>2</sub>-emission scenario using a new global model. Thirdly, preliminary results from simulations of another global model on GW nonrenewability in presence of abstraction are shown. Overall, this study stimulates not only compelling GW observations to corroborate and expand results, but also a GW spatial and temporal analysis in vulnerable areas.



## **KINDRA Project- End user requirements Abstract n°2388**

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**KEYWORDS:** groundwater classification, research topics, survey

In the first year of the implementation of the KINDRA project (Knowledge Inventory for hydrogeology research) a survey was carried out assessing the needs and requirements of the potential project end-users. The task was evolved via an online survey and the work also included the identification of potential project stakeholders and the development of a corresponding database. We received 161 responses from 132 organisations in 22 countries. Results confirmed the interest on the activities previewed in the KINDRA project, giving useful information for a fruitful development of the project. According to the results, 82% of the responders use reports on groundwater research during their work and have a high interest towards the project objectives. The most frequent types of groundwater research information are mapping and monitoring (31% and 23,6 % of the responders). Other frequent keywords used are research on geological information, modelling, hydrochemical, stratigraphic, groundwater level, quality, assessment results and aquifer parameters, including borehole data. The responses about the used Hydrogeological Research Classification indicates that there is a lack of a common understanding on what a classification system means as well as the range variety of different classification systems used by the responders. This result justifies the need for KINDRA that has the primary objective to create a uniform, EU-harmonised categorisation approach terminology for reporting on groundwater research- a Hydrogeological Research Classification System – HRC-SYS. The vast majority, 88% of the participants were in favour of a more harmonised categorisation approach terminology for reporting groundwater research. Immense proportion, 89% of the respondents were convinced that the EU-wide assessment of existing practical and scientific knowledge from hydrogeology research and innovation in Europe would be relevant for their professional activity.



**Vulnerability assessment of risk pollution groundwater in hard rock fissured- cas watershed of Lobo (Buyo, southwest of Côte d'Ivoire)**  
**Abstract n°2389**

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KEYWORDS: DRASTIC, pollution, groundwater, bedrock aquifers, GIS, Lobo, Côte d'Ivoire

Groundwater is one of the most important natural resources to supply in drinkable for drinking water especially in countries who is in the way of development. However, the rapid and uncontrolled urbanization and agricultural activities would be considered as the risks and potential sources of groundwater pollution. This could affect water's quality and reduce its value. The objective of this study is to evaluate the risk of exposure to this resource pollution. The method adopted was to integrate all the factors that may contribute or influence the exposure of these groundwater level pollution. To do this, the DRASTIC method that seems, from literature to be the most suitable method for our study area was adapted. The map produced from this method has been crossed subsequently with two other layers. It is the land use that influences the vulnerability to pollution and the quality factor that includes all the quality parameters identified from a statistical test (method of Principal Component Analysis Normalized (PCAN)) as threatening the quality of water resources. These three maps or layers, according to their importance, have been crossed for the mapping of the unprotected area to pollution. Preliminary results allowed us to adapt the method DRASTIC by integrating the thickness of the weathered layer to change the nature of the vadose zone making this criterion more robust and therefore more important than the type of aquifer. Regarding the land use, the map generated from the Landsat images highlights areas where activities threaten water quality. For quality factor, the statistical test used and the results that are being will allow us to determine the parameters which influences the quality and that constitute the quality factor. The combination of these three factors DRASTIC, land use and quality will allow us to map risk areas



## **Economic issues of the protection of water resources by forests Abstract n°2390**

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KEYWORDS: Forest, Payment for Environmental Services, drinking water

Forests have a global positive impact on water quality (concerning suspended solids, toxicants, organic matters, phosphorus, pathogens...). As a consequence, forests play a protective role for various functions and uses of the forested watersheds. It is for instance the case for environment and biodiversity protection, it improves touristic and leisure activities, but it is even more interesting for protecting drinking water resource intakes. However, the adoption of best management practices for these aims can lead to an increase of the forestry costs. Even if additional costs for protecting forested watersheds are less than the extra-cost of drinking water treatment of low quality raw water (it is the case in cities such as Lausanne (Switzerland) and New York City (USA)), to be economically optimal is not sufficient. Indeed, except in the case of cities that own the forests from which they extract their drinking water, there is generally no true payment for the services provided by foresters. It is the central issue to solve, and the solution is the Payment for Environmental Services (PES) that can provide a lot of positive effects. Costa Rica is a true example of such direct and indirect economic and social impacts. But in order to provide PES, it is first necessary that people delivering these services and the beneficiaries paying for these services are well defined. It is also essential that the users are organized in structured communities with clear and legally established rights (it is generally not the case in France due to parceling of properties). Other key issues are the origin of the funding, and the monitoring. It is then crucial to help both parties to structure and build their contractual arrangements in order all of these aspects being solved and managed at a local scale.



## **Fact and figures about transboundary groundwater and international cooperation Abstract n°2392**

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**KEYWORDS:** transboundary aquifers, transboundary river basins, GIS, maps

Shared groundwater resources have long been neglected by water law. While there are more than 450 agreements on international waters which generally focusing on surface water, , there are only 6 agreements squarely addressing shared groundwater resources. As a result, the rules governing the use, management, and conservation of transboundary groundwater resources are often unclear to water practitioners. However, groundwater resources are an inseparable component of the total water system and interact with other components of the water cycle, both in terms of flow between these components and by being to some extent, substitutable in meeting water demands. The objective of this contribution is to present appropriate data and information for global discussion on the status of transboundary aquifers, particularly regarding cooperation aspects in order to provide both the general public and practitioners with information on transboundary aquifers, in order to facilitate their understanding of the challenges and a better consideration of the need for conjunctive management of both ground and surface waters. The communication will present outputs from a GIS database compiled by the UNESCO International Hydrological Programme (IHP) aimed at providing a first attempt to represent cases where conditions for establishing integrated management of transboundary groundwater and transboundary surface water are both relatively favourable and in tune with governance priorities. It was created in order to identify aquifers located in river basins exposed to risks whether they be political, hydrological or environmental, and provides a wide range of indicators on 276 transboundary river basins, and 592 shared aquifers. The contribution builds also on the results of the groundwater component of the Transboundary Water Assessment Programme (TWAP) undertaken by UNESCO-IHP, which constitutes the first comprehensive indicator-based global assessment of status and trends in 199 transboundary aquifers around the world, covering physical, socio-economic and governance aspects.



**Evaluating BTEX concentration in soil using a simple one-dimensional vadose zone model- application to a new fuel station in Valencia (Spain)**  
**Abstract n°2394**

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KEYWORDS: BTEX, Vadose zone, Finite-Difference, Millington Equation

Specific studies of the impact of fuel spills on the vadose zone are currently required when trying to obtain the environmental permits for new fuel stations. The development of One-Dimensional mathematical models of fate and transport of BTEX on the vadose zone can therefore be used to understand the behavior of the pollutants under different scenarios. VLEACH - a simple One-Dimensional Finite Different Vadose Zone Leaching Model - uses an numerical approximation of the Millington Equation, a theoretical based model for gaseous diffusion in porous media. This equation has been widely used in the fields of soil physics and hydrology to calculate the gaseous or vapor diffusion in porous media. The model describes the movement of organic contaminants within and between three different phases- (1) as a solute dissolved in water, (2) as a gas in the vapor phase, and (3) as an absorbed compound in the soil phase. Initially, the equilibrium distribution of contaminant mass between liquid, gas and sorbed phases is calculated. Transport processes are then simulated. Liquid advective transport is calculated based on values defined by the user for infiltration and soil water content. The contaminant in the vapor phase migrates into or out of adjacent cells based on the calculated concentration gradients that exist between adjacent cells. After the mass is exchanged between the cells, the total mass in each cell is recalculated and re-equilibrated between the different phases. At the end of the simulation, (1) an overall area-weighted groundwater impact for the entire modeled area and (2) the concentration profile of BTEX on the vadose zone are calculated. This work shows the results obtained when applying VLEACH to analyze the contamination scenario caused by a BTEX spill coming from a set of future underground storage tanks located on a new fuel station in Aldaia (Valencia region - Spain).



**Global change and groundwater resources increase in the Iullemeden basin (SW Niger)- pond groundwater relations and new associated uses  
Abstract n°2395**

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**KEYWORDS:** Surface-water groundwater relations, Semi-arid areas, Niger

In SW Niger, close to Niamey, a detailed hydrological survey has been developed for the last 25 years over 10 000 km<sup>2</sup> by the international experiments Hapex Sahel and AMMA. Quality and consistency of these long-term observations allowed assessing the causes and the consequences of global change in the region. The most original and paradoxical scientific result is the continuous rise of the water table, proven to have existed even before, during the severe droughts of the 1970s and 1980s. This rise (about 4 m in 40 years) is explained by a change in land use from natural woody savannah to rain-fed crops that led to an increase in Hortonian runoff collected in numerous temporary endoreic ponds where surface water infiltrates and recharges the aquifer. Our study focuses in a subpart of 900 km<sup>2</sup>, in the SE of the long-term site, where the water table has risen up to outcropping in the lowest valley bottoms, and creating permanent ponds. Their number and size have increased over the past 20 years, as well as the irrigated areas around them during the six-to-seven-month dry season. We supplemented previous measurements with a dense hydrodynamic, geochemical and isotopic (<sup>18</sup>O, <sup>2</sup>H) survey as well as topographic campaigns (between 2013 and 2016). The new permanent ponds reflect groundwater dynamics while ordinary temporary ponds only reflect surface dynamics. Evaporation strongly affects the permanent ponds and increases significantly its electrical conductivity (EC up to 1000 IS.cm<sup>-1</sup>) while the natural mineralization of groundwater (i.e. at distances larger than 200 m from a pond) is very low (EC between 20 and 100 IS.cm<sup>-1</sup>). This increase in salinity due to evaporation is confirmed by the isotopic survey (<sup>18</sup>O, <sup>2</sup>H), showing a progressive enrichment but less than that of temporary ponds water. The use of groundwater for irrigation could avoid soil salinization and also help to mitigate the impacts of rainfall variability on rain-fed crop production.



**Analysis by cross plot method for anticipating seepage during operation of unlined underground storage caverns**  
**Abstract n°2396**

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KEYWORDS: unlined mined caverns, hydrodynamic containment, seepage

The topic addressed in this presentation is on early detection of unconformity of the seepage evaluated during construction compared to the expected seepage during the operation of unlined underground storage caverns for LPG or Oil. A first objective is the early identification of potentially de-saturated joints and therefore the implementation of remedial actions while access is still easy to the underground works. A second objective aims at optimising the seepage pump capacity prior to starting operation. The methodology is based on cross plot analysis of seepage rate versus the hydraulic margin. The combination of both these parameters allows for calculating the productivity of a system. Therefore, as long as the hydraulic boundary conditions remain unchanged, the seepage is following a linear correlation with the hydraulic margin. Any change in the correlation between both these parameters hints at a change in hydraulic boundary conditions or a change in saturation conditions. The considered case assumes that there is no significant change in permeability (either by clogging or grouting works, nor by washing out of joints) during the period over which this analysis is made. Illustrations are presented for different stages of underground cavern testing and commissioning, by focusing on the seepage measurements during the water curtain system testing (full size hydraulic test, FSHT), seepage measurements during the access tunnel flooding (pre-CAT), and seepage measurements during the cavern acceptance test (CAT). The main implications are- - early detection of problems, such as de-saturated joints potentially leading to insufficient hydrodynamic containment, this to allow for remedial works when construction is still on-going, - early evaluation of the final seepage for operation such as to allow for adapted seepage pump capacity for operation, - management of groundwater around the underground facility by improving grouting works or adapting the future operating procedures.



**Quantitative analysis of fault and fracture systems and their impact on groundwater flow in Irish bedrock aquifers**  
**Abstract n°2397**

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**KEYWORDS:** Faults+fractures+ groundwater parameters.

Faults and fractures are the most important store and pathway for groundwater in Ireland's bedrock aquifers either directly as conductive structures or indirectly as the locus for the development of dolomitised limestone and karst conduits. Through quantitative analysis in a range of Irish bedrock types, we have developed generic conceptual models of depth dependency, lithological control and scaling systematics for the different fault and fracture systems, linked to observed groundwater behaviour. Quantitative characterisation of the main post-Devonian fracture systems in over 100 outcrop, quarry, mine and cave locations shows that their geometry and nature varies with lithological sequence and with spatial controls, such as depth and regional variations in deformation style and intensity. The nature of fracturing and faulting directly controls aperture distribution, size and geometry, which in turn influences karst conduit geometry in limestones. Determining these attributes is, therefore, key for groundwater flow parameter estimation. We briefly describe how the most conductive structures (Tertiary strike-slip faults), and the most common structures (joints) can be linked to critical groundwater parameters, such as transmissivity, storage and connectivity, at both regional and local scales. We show that structural parameters critical to groundwater flow (including orientation, spacing and aperture) can be used to compute ranges of hydrogeological parameters (fracture porosity and permeability), which in combination with hydraulic data (groundwater levels, volumetric flow and recharge) can be used to provide constraints on permeability anisotropy and heterogeneity at different scales.



**Constraining the impact of weathering intensity, its associated heterogeneities and climate on recharge processes using non-invasive geophysical methods on a crystalline fractured aquifer in a semi-arid environment**  
**Abstract n°2400**

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**KEYWORDS:** hard rock aquifer, recharge, semi-arid climate

In arid and semi-arid environments, hard-rock aquifers often constitute the only perennial source of freshwater. The short-term and long-term viability of these groundwater resources as well as the ecosystems and livelihoods they sustain depend on the replenishment of groundwater by recharge. The aim of this study is to improve the understanding on recharge processes by analysing cross-scale recharge processes (both natural and artificial) in a hard-rock aquifer in Southern India. Here, we take advantage of a well-studied site where a dense observation network and boreholes are available to test the contribution of non-intrusive methods such as electrical resistivity tomography. First, the mapping of the critical zone was performed by implementing electrical resistivity tomography profiling at different key locations on the selected study zone, which were chosen to represent the range of weathering observable at the catchment scale. Then, in order to link the shape and thickness of the critical zone to recharge, subsequent ERT profiling has been performed at the same locations after recharge events. The ratio between the resistivity before and after these events will be an indicator of the entering or exiting of water into the system. Finally, it will be necessary to link qualitative information of recharge distribution to actual recharge values. It is important to note that all quantitative relationships established between structure and recharge will be thoroughly tested at our densely equipped experimental hydrological park. This should allow us to constrain and quantify the modalities involved in the recharge process, and obtain relationships which can be extrapolated onto further research zones using non-invasive methods. The obtained results will be compared with classical methods to estimate the accuracy of our methodology. This final aim of our study is to improve the understanding of the links between structure, climate and recharge in hard-rock aquifers under semi-arid climates, and allow easier estimation of recharge distribution and quantification in order to ameliorate groundwater management and decision-making processes.



**Assessment of climate variability impact on rainfall regimes and groundwater resources in southern Tunisia**  
**Abstract n°2401**

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**KEYWORDS:** arid climate, groundwater recharge, precipitation

In arid regions where precipitation is weak and intermittent, the aquifer recharge is an important issue to evaluate groundwater resource and its future evolution in a context of excessive water request increase and climate change. A Multivariate statistical analysis of rainfall variables and atmospheric conditions factors was applied in an attempt to define the climate variability in Tataouine basin (107 mm of mean annual rainfall from 1987 to 2014), and assess its impact on rainfall regimes and the recharge of the Continental Intercalaire aquifer (CI). The present work is based on a dataset of 11 variables over the period from 1984 to 2003 (i.e. rainy days frequencies, P1 (1-10 mm), P2 (10 to 30 mm), P3 (30 to 50 mm), P4 (> 50 mm) and P0 (number of no rainy day between 2 events), mean monthly rainfall (Pm), mean monthly temperature (T), mean maximum temperature (T1), mean minimum temperature (T2), thermal amplitude (TA= T1-T2) and the mean monthly relative humidity (H)). The linear regression predictive model applied to assess the long-term trends of rainfall variation showed that the annual variation of rainfall is related to the changes of Pm, P3, P4, T1, AT, and H rather than P0, P1, P2 and T2. It appeared that annual rainfall variation is related to rainfall frequency and depends on the amount of rainfall events. Also the air temperature and the relative humidity of the air are factors of the temporal variability of the rainfall regimes. The analysis of rainfall variability based on 'Nicholson' over the time series extending from 1987-2014 has allowed to highlight the presence of an excess period from 1987 to 1999 and a deficit period from 1999 to 2014. It was shown that the recharge process is not correlated with soil humidity state but with higher rainfalls involving surface flow concentration through wadis, the main recharge mode, spatially limited in this context.



**Isotope hydrological and hydro-chemical characterization of groundwater in Lower Saxony, Germany**  
**Abstract n°2402**

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**KEYWORDS:** Stable isotopes, hydro-chemistry, groundwater, Lower Saxony

Groundwater samples are collected on a routinely basis in Lower Saxony (47.618 km<sup>2</sup>) in Germany using a special field sampling vehicle for groundwater which allows in-situ and online monitoring of pumping rate, conductivity, temperature, pH-value, turbidity, and redox potential. Besides hydro-chemistry, stable isotope analyses (deuterium, oxygen-18) have been conducted at the BGR LBEG laboratories in Hannover for the last three years (since 2013). More than 300 samples have been analyzed to date and are interpreted for seasonal and spatial patterns as well as for surface water influence. Stable isotope concentrations vary between -3.17 ‰ and -9.31 ‰ for delta 18O and between -21.4 and -66.6 ‰ for delta 2H, respectively. Deuterium excess values vary between 14 ‰ and 3 ‰. The isotopic characterization of groundwater in relation to precipitation and surface water patterns might allow a better understanding of recharge processes and aquifer vulnerability on the large scale.



**Identification of risk for interference between nearby unlined underground storage caverns based on seepage analysis**  
**Abstract n°2403**

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KEYWORDS: unlined mined caverns, hydrodynamic containment, seepage

The topic addressed in this presentation is on the analysis of the seepage rate for unlined underground storage caverns for LPG or Oil, and more in particular on how seepage evolution may reveal hydrodynamic interference of nearby caverns during operation. For general understanding, a brief summary is given on the principle of unlined underground storage caverns, and more specifically on the aspects of seepage and hydraulic margin. While in general a linear correlation exists between the water seepage and the hydraulic margin for caverns with an efficient hydrodynamic containment, non-linearity is observed in a particular case of two nearby underground facilities (case study). Beyond the hypothesis of a leaking cavern, another hypothesis consisting in a hydraulic interference is suspected. The methodology is based on numerical modelling in order to identify how such hydraulic interference may affect the water seepage versus the hydraulic margin correlation. Calculation are conducted by varying the configuration of the water curtain system and by varying the hypothesis on the permeability distribution. The results confirm that in case of interfering caverns the water seepage versus the hydraulic margin, deviates from the linear correlation. These results also show that a hydraulic interference between two nearby storage units does not necessarily stand for a risk of leakage, but rather for a diminished capacity of the hydrodynamic containment. However, under certain conditions of permeability distribution the containment capacity of the system may become so low that leakage occurs. This analysis allows for more insight in the dynamics of hydraulic containment. This insight is useful for defining remedial actions, whether by the implementation of additional water curtain boreholes in between the interfering units, or whether by defining operating rules for both caverns based on the maximal difference in operating pressure or liquid filling (LPG or crude oil).



**Karst flash floods characterization and tools for warning system management (KRHU projet)  
Abstract n°2404**

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**KEYWORDS:** Karst, flash floods, chart tool, forecasting, modelling

Forecasters working on basins with carbonate outcrops have difficulties to anticipate karst systems response to rainfall event. This is related to their duality of functioning. In low water stage, karst can store water+ At the opposite, in times of high water, karst is saturated, its storage capacity is limited, resulting in increasing the part of runoff and quick underground transfers that can amplify flooding downstream of the basins. With the understanding of these phenomena that depend on the filling of the aquifers, tools were developed by brgm to anticipate the response of systems to rainfall event (Fleury et al., 2010+ 2011+ 2015). Several systems in South of the France have been studied partly during KRHU project (Lez, Nîmes, the Avene and L'esquielle and the Nartuby. Their functioning was obtained from characterization of aquifers saturation. An indicator of the filling of the karst (followed by representative piezometers of the karst aquifer behavior) has been defined. The latter is called KI (Karst Indicator). First, the potential of karstification of the basins is spatialized. This work allows locating the karst compartments in the basins. Two cases arise then- most of the basin is karstic, either it's a mixed one. Studies differ then. For essentially Karst basins, only the IK is characterized from a classic hydrogeological study. Nartuby system will be presented. For basins mixed, a preliminary study of the karst compartment is performed to characterize the IK and then the groundwater component from the karst downstream of basin study. Charts presenting the evolutions of piezometric level in karst compartments are being implemented (KI). They allow define before rainfall event karst reducing capabilities. Then, an evaluation of the response of the system is proposed according to IK initial level and upcoming precipitation (total rainfall and intensity). A classification of the response is proposed as the risk associated. Monitoring levels are then proposed (monitoring, enhanced monitoring, and extreme monitoring). Information are presented in a usable real-time chart tool destined for forecasters.



**Insights into karstic systems through inverse application of discrete conduit-continuum models**  
**Abstract n°2405**

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**KEYWORDS:** Inverse numerical modeling, karst systems, catchment scale

Numerical models can provide enormous insights into the functioning of karst systems. However, design, setup, and application of karst models are rather challenging due to distinctive heterogeneity and anisotropy as well as reduced accessibility of real karst systems. In particular, model parametrization frequently involves a cumbersome calibration procedure. To some extent, this step can be supported by coupling automated parameter estimation (e.g. based on PEST, Doherty 2015) with a numerical hybrid karst flow and transport model like CFP (MODFLOW-2005 Conduit Flow Process). In this paper we apply this approach to the Sheshpeer catchment, situated in Iran. Here, the spatial as well as the temporal scales involve flow and solute transport over approximately 20 kms within months to years. A stepwise procedure, starting with highly idealized models and subsequently added complexity, allows to handle the inverse modelling application. Highlighting aspects of the results are the possibility to exclude conceptual representations of the karst systems together with achieved parameter sensitivities and ranges for adequate conceptual models, which can be further investigated in upcoming, more detailed numerical experiments.



**Possibilities of deep geothermal energy utilization in the frame of climate change –  
an example of a basin with gravity- and buoyancy-driven flow  
Abstract n°2407**

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KEYWORDS: climate change, numerical simulation

The climate change influences the capacity of all energy-production technology, especially power generation. The efficiency of classical, fossile and nuclear power generation is descending if their cooling is decreasing due to increase of water or air temperature. The renewable energy resources such as biomass, wind, solar energy and hydropower are not exceptions and they react with the descend of capacity due to the changes of surface temperature and precipitation. However, the climate dependence can be correlated with the depth of resources, therefore the geothermal energy is the less influenced by human scale climate change. It is true for the fluid based deep geothermal resources as well. The question of the study is how can we characterize the climate dependence for these resources. The issue is examined for a sedimentary basin with gravity- and buoyancy-driven flow. It is supposed that the influence of climate change is conveyed by the alteration of the water table elevation. During the evaluation semi-synthetic numerical flow and heat transport simulation were used. The parameters of the simulations were derived and simplified from the hydrogeological environment of the edge of the Duna-Tisza Interfluve area of the Pannonian Basin, Hungary. Generally, it could be concluded that renewable geothermal energy can be characterized as less climate-dependent, therefore it worth to deal with their utilization.



**The importance of an effective and adequate baseline for shale gas- the UK  
experience  
Abstract n°2409**

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KEYWORDS: shale gas, environmental baseline, monitoring, groundwater,

The UK Government is committed to supporting the development of a shale gas in the UK but both it and the research community recognise that before any activity should start there is a need to adequately characterise the baseline. The British Geological Survey (BGS) have a long history of carrying out baseline monitoring and characterisation of aquifers, with much of the published results routinely used to support regulation including implementation of the European Water Framework Directive. With growing interest in shale gas in the UK, BGS recognised that the existing national baseline dataset needed to be supplemented and more detailed, with methane in groundwater identified as one of several parameters for which there were few data. After completing a national survey of methane in groundwater there is now a focus on two areas of England where there are current planning applications for hydraulic fracturing. With a limited window of opportunity BGS initiated a comprehensive programme of monitoring utilising a combination of existing boreholes (private supplies) and newly drilled boreholes to establish a monitoring network. Site selection was informed by new geological interpretation and 3D conceptual models. Although monitoring is continuing, the results are already showing the importance of understanding both the spatial and temporal variation in parameters that characterise the baseline. The study has shown that, as would be expected by hydrogeologists but perhaps not by the public, a wide-range of anthropogenic compounds are present both reflecting current and historical land use. Methane has also been found to be present and in much higher concentration than would be expected in some locations, with its provenance not easy to ascertain. The talk will describe the approach, the data and the value of the results for informing public debate and policy.



**The case of Biscayne Bay and Aquifer near Miami, Florida- Density driven flow of sea water or gravitationally driven discharge of saline groundwater?  
Abstract n°2410**

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KEYWORDS: Biscayne Bay and Aquifer, seawater intrusion, variable density flow

Coastal groundwater flow investigations at the Biscayne Bay south of Miami, Florida (Cooper et al., 1964 in USGS WSP 1613-C) gave rise to the dominating concept of density driven flow of sea water into coastal aquifers indicated as an invading sea water wedge. Within that wedge convection type return flow of seawater and a dispersion zone were concluded to be the cause of the Biscayne 'sea water wedge'. This conclusion was merely based on the chloride distribution within the aquifer and on an analytical model concept by Henry (1964 in USGS WSP 1613-C) which postulated, for the Biscayne site, convection flow within a confined aquifer without taking non-chemical field data into consideration. The concept was later labelled as the 'Henry Problem' which any numerical variable density flow program code has to simulate to be considered acceptable. Revisiting the summarizing Biscayne publication by Cooper et al. (1964) with its record of piezometric head data showed that the so-called sea water wedge was actually caused by discharging deep saline groundwater driven by gravitational flow and not by dense sea water. Density driven flow of seawater into the aquifer was not found reflected in the head measurements which had been taken contemporaneously with the chloride measurements. These head measurements had been ignored by Cooper et al. (1964). The head measurements also showed that a dispersion zone and a convection cell did not exist at the Biscayne site. Instead there was a sharp dividing line between shallow local freshwater and saline deep groundwater flow. The Biscayne case re-emphasizes the need for any chemical interpretation of flow pattern to be backed up by head data as energy indicators of flow fields. At the Biscayne site density driven flow of seawater did and does not exist. Instead this coast line is the end point of local freshwater and of regional saline groundwater flow systems.



**Management of compounds of emerging concern in indirect potable reuse practice-  
insight into new modelling tools  
Abstract n°2411**

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**KEYWORDS:** Indirect potable reuse, compounds of emerging concern, reactive transport modelling, soil, mitigation

Compounds of emerging concern (CECs) such as antibiotics or household chemicals are partially removed depending on the type of wastewater treatment processes. Consequently, indirect potable reuse (IPR) practices recycling water to augment drinking water supply sources (groundwater or surface reservoir) have the potential to result in a continuous discharge of contaminants. In this context, overall evaluation procedures are needed enabling a comprehensive assessment of efficient and cost-effective options to minimize the risks associated with CECs in the practice of IPR. This is the main aim of the on-going EU-funded FRAME project involving seven institutes in four countries. One of the project's tasks is to determine the transport and fate of CECs and of their transformation products considering various strategies of soil-based treatment processes to determine the efficiency of these mitigation strategies. For this purpose, an innovative reactive transport model is currently being developed by coupling the MARTHE hydrodynamic transport code and the PHREEQC geochemical code. This new reactive transport code, named MARTHE-PHREEQC, enables to describe precisely hydrodynamic, transport and geochemical mechanisms governing the fate of CECs at various scales. A first model accounting for a fully-detailed description of mechanisms governing the fate of CECs is tested. This model will be used to simulate the fate of CECs in a generic field case (from 1D up to 3D). Based on these simulations, a more generic and robust model accounting only for the main mechanisms governing the fate of CECs at 3D field scale will be developed. This robust model will be used to estimate the removal of some CECs and the water quality under various and different IPR conditions. The results of modelling will lead to the development of an evaluation scheme regarding CECs for IPR strategies considering potential environmental effects.



## Managed Aquifer Recharge as to supply Libreville water-stressed city (Gabon) Abstract n°2413

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KEYWORDS: karstic aquifer - Managed Aquifer Recharge - aquifer storage measurement - geophysical prospecting - sea water intrusion

Objective- supplying a water-stressed city Libreville has been implemented on a peninsula, where most groundwater is brackish and far from any large surface water resources. Since the 70's, the city has been supplied with surface water, collected from 5 small watersheds and treated in a single main plant located in Ntoum, 40 km eastward of Libreville. There are little additional surface water resource in the nearby and SEEG is desperately seeking for alternative cheap water resources. Design and methodology In 2007, SEURECA and HYDROCONSEIL provided SEEG with hydrogeological expertise, as to develop groundwater resources in the nearby of existing facilities. A thick limestone layer had been previously drilled by oil-companies- Madiela limestones whose outcrops are very limited (4 km<sup>2</sup>). Madiela proved to be very productive (2,000 - 7000 m<sup>3</sup> day per borehole) and we have developed a new well field. As (a) the aquifer extension is limited and (b) sea water intrusion is at risk, the well field was developed step by step, with a careful monitoring of water quality (i.e. conductivity, as a signal of sea water intrusion) and water level. Data and results The aquifer storage capacity has been measured through the long dry season drawdown as 6.3 million m<sup>3</sup>. This is unneglectable, but far to meet SEEG expectations. For this reason, we have also monitored aquifer recharge during rainfalls and it proved to be impressive (> 20 million m<sup>3</sup> year). Such a large recharge is more than direct infiltration in the tiny aquifer outcrop. It led to us to seek for other recharge areas through geophysical prospecting. Ntoum aquifer recharge is more complex than initially expected and the hydrogeological model has been accordingly updated. Conclusion Taking into account the recharge efficiency, we have developed a MAR strategy, with additional wells. Presently, Ntoum well field produces 55,000 m<sup>3</sup> day of good quality water, without any significant impact on resource quality or quantity (i.e. no significant drawdown of the water table has been recorded).



## Abstract n°2415

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KEYWORDS: <p>urbanization, groundwater, land use, speleothem, monitoring

<p>Urbanization is a complex process that can lead to a huge disturbance of both groundwater quantity and quality. Direct recharge can be reduced by impervious surfaces, while other sources of recharges can occur, such as leaks in water supply systems or sewers (Lerner, 2002). Identifying the separate effects of different anthropogenic activities is often impossible because of the multiple sources of disturbance as well as the lack of information on the pre-urbanization period. This study presents the combined use of groundwater monitoring, urban speleothems analysis and historical data for the reconstruction of 300 years of groundwater evolution in the NE part of Paris. On the study site, two independent groundwater aquifers were first drained in the 1100s to supply the City of Paris with water. Artificial underground water supply systems in calcareous geological context has locally lead to the formation of secondary carbonate deposits, that develop on the walls or on the floor. Speleothems sampled in an ancient aqueduct have then recorded groundwater chemistry evolution through their continuous growth over 300 years (Pons-Branchu et al., 2014, 2015). Dating of the speleothems and analyzing heavy metal composition and isotopic imprint show that several processes linked to progressive urbanization steps seem to have been recorded- (i) agricultural activity, (ii) road-building,



(iii) influence of wastewater collection system (iv) technological innovation. Today even with the global soil sealing of the watershed, the historical drainage network is still active. Quantitative and qualitative monitoring of this network indicates that rainwater infiltration is still occurring but that the main recharge to groundwater comes from the anthropic water network (sewer, drinking water, &hellip+). From a qualitative point of view sulfate and nitrate concentration in water are still the main indicators of urbanization. As stormwater infiltration is becoming more and more encouraged in many urban areas, developing new methods can help understanding the consequences of such stormwater management policies on groundwater quality and quantity.



**Groundwater development strategies to optimize water capacity and quality in South America hard rock aquifers from three case studies in Brazil and Uruguay  
Abstract n°2420**

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KEYWORDS: Groundwater development, hard rock aquifers, Latin America

Bottled Natural Mineral Waters factories of Salus (Uruguay), Jundia and Tingua (Brazil) are located in hard rock aquifers (granitoid and metamorphic formations). The development of news boreholes for these three factories must comply to the following criteria- i) geological protection from surface influence, ii) required water chemistry profile, iii) sufficient capacity. As regards the local hydrogeological context (weathered hard rock aquifers), field investigations include- study of regional fracture directions, detailed geological (lithology, weathering) and structural field mapping, electrical tomography, hydrochemistry analyses. Video inspections of the open hole section of existing and new boreholes were performed to locate and characterize the fracture zones. The experience feedback from recent exploration campaigns (2014, 2015, 2016) confirms the conceptual model of hard rock aquifers where groundwater development takes place in the weathered and fracture zones, particularly in the stratiform fissured layer of the aquifer located below the low hydraulic conductivity saprolite, and also in some other weathered discontinuities, mostly subvertical, such as ancient faults of joints, veins, lithological contacts. These case studies are among the few examples of a demonstration of this conceptual scheme in South America that, in all these studied sites shows a polyphased weathering process. In parallel to the exploration campaigns, the analysis of monitoring data (water level, discharge, physicochemistry) of the existing borewells that are operated for several years and piezometers constitute an original data set that provides a closer understanding, and rather unique in South America, of the weathering profile hydrodynamics. A methodology for an optimized management of the wellfields (pumping regime, maintenance...) and a better design and construction of the future boreholes will then also be presented.



**Characterisation of aquifer properties in data-scarce fractured rock aquifers- the Irish example**  
**Abstract n°2422**

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**KEYWORDS:** fractured aquifers, aquifer parameters, hydrogeological properties, hard rock aquifers

In the Republic of Ireland groundwater is an important resource, providing drinking water to approximately one third of the population via public and private water supplies, and sustaining rivers, lakes and groundwater dependent ecosystems. The vast majority of groundwater resources in Ireland are found in bedrock aquifers, generally within sedimentary, metamorphic and igneous rocks of Upper Carboniferous age or older. Due to the age of the rocks, and their many cycles of burial, deformation and uplift, primary porosity is nearly always absent. Fissure porosity and permeability is dominant in the non-carbonate rocks. Carbonate rocks, depending on the proportion of clays, can also have solutionally-enhanced permeability, with the pure limestones being highly susceptible to karstification. Typically, fracture density and aperture, hence permeability and transmissivity, decrease with depth although flowing fractures and fracture zones can be encountered at depth. A 'transition zone' of highly weathered bedrock can occur at the top of all bedrock aquifers, with thickness varying rapidly from zero to a few metres. The Geological Survey of Ireland (GSI) have classified the bedrock aquifers in a holistic manner by using lithology, structure, presence absence of large or small springs, borehole 'productivity', yield, karst features, baseflow signals and hydrographs. However, specific aquifer parameter information such as transmissivity is quite sparse. Representative aquifer hydraulic parameters for each of Ireland's aquifers and rock unit groups have been established using a combination of high confidence data contained in the GSI database, and transmissivities derived from the more numerous, but lesser quality, specific capacity data in the GSI database using equilibrium approximation formula. Typical or representative values for a given rock unit group or aquifer are described using Best, Upper and Lower Estimate values, using a statistical characterisation based on summary descriptive statistics and graphical plots distributions. Characterisation of the transition zone focusses on capturing spatial variability statistics, together with hydraulic parameters.



**Climate Change and its impact on the environment of the Oranie region (Northwest  
Algeria)  
Abstract n°2424**

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**KEYWORDS:** Oranie, Algeria, water, climate change, periods of ruptures, rainfall series.

The climate changes for a long time ceased being a scientific curiosity. They constitute the major environmental question which dominates our time and the major challenge to which must answer the environmental organizations of control. Water is one of the most important raw materials in Algeria. Because of its importance, it is essential to know its evolutionary and its impacts on agriculture, which plays the role of maintaining the country's food security. The analysis of long climate series is of utmost importance to be able to lead a modern agriculture that is both balanced in ecologically plan and profitable economically. 26 rainfall series of the region of Oranie (Northwest of Algeria) (Source from N.M.O and N.H.R.A.) which covers periods ranging from 63 to 137 years are analysed. We observe a marked decline in rainfall characterized by stationarity breaks between 1974 and 1980. Significant decreases in annual rainfall are systemically observed. They vary among the stations between 11.2 and 46.8%. This drastic rainfall diminution directly affects agricultural yields including field crops, as they are often driven by a pluvial system.



**AQUARENOVA project - Active management of the Bas Gapeau aquifer to prevent saline water intrusion**  
**Abstract n°2428**

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**KEYWORDS:** Managed Aquifer Recharge (MAR), saline intrusion, costal aquifer, Mediterranean sea.

The city of Hyères-les-Palmiers (France, Var) and Suez Water France (operating the drinking water service since 2012), now develops AQUARENOVA, a program of abstraction control and restoration of natural resource, leading to a sober economic development. This project is declined in two main axes. The first one aims to reconquer network performance in a context of sharp increases in the summer consumption (x4). The second axis is the restoration of the main water resource of the city, the Bas Gapeau aquifer. It is first of all a real-time abstraction control, based on a continuous monitoring of water level and conductivity on some piezometers. The gradients method shall optimize abstraction without risking saline intrusion (detected early 2000). The results measured since 2012 are very significant. Suez Water France also conducts aquifer recharge works by winter abstraction into the coastal river Roubaud, in order to form a piezometric dome to be used in summer. This replenishment is operational from November 2015 to ensure the city water autonomy and to protect the groundwater resource against saline intrusion even under severe drought.



**Palaeotopographic Reconstruction of a Sedimentary Environment of Hydrogeological Interest. Ranchería Basin – Guajira, Colombia  
Abstract n°2429**

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**KEYWORDS:** Geospatial Modeling, Palaeotopographies Reconstruction, GIS

The depositional environments generate stratigraphic sequences that are reflected in complex interbedded facies that difficult the lateral continuity and physical system domain definition+ these parameters are investigated in order to establish the hydraulic system conditions. The ability of GIS to generate digital models through geospatial modeling, in which more than cells with thick attributes (dimension z), prisms with their own identity are generated, allow the analyst to have a roadmap that enables to display and rebuild paleo-topographical sequences and hydrogeological conceptual models more coherent and understandable. Sources of information required for these purposes include, in addition to basic mapping and geology data, attributes for defining boundary conditions and control variables with hydrological and hydraulic properties. In Ranchería basin in northern of Colombia, the Oca fault marks the boundary between two clearly different geological domains+ this geological structure of regional character separate a continental environment, to the south, with a transitional environment into the Colombian Caribbean, to the North. The sedimentary basin of the Rancheria river contains carbonate formations (Cretaceous), large-scale coal deposits (Neogene) and sequences of alluvial deposits (Quaternary) arranging them on an underlying of igneous and metaphoric rocks. The role of Oca fault as hydraulic border, and its influence over the lateral continuity of hydrogeological flows at different depths, was analyzed from the individualization of the different hydrogeological units identified and reconstructed from palaeotopographies that marked them by different sedimentation processes. The modeling and reconstruction exercise was supported by an interactive process in which the three-dimensional elements representing each prism, as a finite elements according to hydrostratigraphy, were adopting the attributes that allowed harmonizing different sources of information that sometimes were consistent and in many other cases showed discrepancies. The final result was corroborated by overlaying satellite images and quantitative information from the fieldwork, drill logs, piezometric and hydraulic tests.



# Groundwater Basin Definition in Fractured Media from Detailed Scale Digital Models Abstract n°2430

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**KEYWORDS:** Hydrogeology in fractured media, GIS, High precision DTM

Groundwater presence in hard rocks is conditioned by the existence of fractures that allow adequate conditions of porosity and secondary permeability. The development of saprolite profiles in igneous rocks, which are classified between intermediate and acid, can generate considerable weathering profiles favoring infiltration and deep recharge into the middle fractured. Therefore, direct exploration and spatial modeling of the extent of different horizons of soil profiles are powerful methodological tools to trace drains, to define water tables, to identify hydrological flow directions and hydrogeological basins extension in fractured media. Given that definition of environmental measures on mining exploration, projects demand high accuracy in surface and groundwater flows identification in order to prevent the most negative impacts that future exploitation could produce+ in Antioquia (Colombia ) a battery of procedures using high-precision geodata and geographical information systems was developed to achieve the goal above enunciated For an experimental area of 17 km<sup>2</sup>, several analyzes were developed from multiple overlapping sources of information that included a Digital Terrain Model (DTM) LIDAR (resolution 0.5 x 0.5 m), a DTM SRTM (resolution 30 x 30 m), detailed aerial photographs and field control. These sources allowed to correct and to define a DTM adjusted to abrupt changes induced by drains and small scarps. This High precision DTM at ground level, would be the precursor data source for three-dimensional reconstruction of aquifer in Z direction, for which we also had the information from 22 Vertical Electrical Sounding (VES), 34 drilling columns, an inventory of natural spring and a hydrogeochemical validation of underground streams. As a final result we have the definition and differentiation of surface and groundwater basins and one model of hydrogeological flow validated with a level of precision of 95%, by comparison between a water balance per unit of soil with a balance obtained by numerically modeling and field instrumentation.



**Uses of multiscale fracturation study approach to estimate artificial groundwater recharge in arid regions (exemple of Segui region, South of Tunisia)  
Abstract n°2431**

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**KEYWORDS:** fracturation, artificial recharge, arid region

In Tunisia, arid regions are characterized by scarce water resources, and phreatic aquifers have especially a bad water quality with a very high salinity, due to the abundance of large salt flats like chotts and sebkhats. These salt flats have an important role in the contamination of phreatic aquifer by salinization process. To avoid the problem of water resource availability in porous phreatic aquifer, carbonate rocks aquifer in fractured media are productive and abundant in these regions. As an illustrative example of the water quality in arid region, Segui aquifer system, situated in the southeast part of Gafsa city, in the south of Tunisia, suffer from the contamination of the water in the phreatic aquifer. The salinity exceeds 11g/l in the most of wells and water points. This region is also characterized by tectonic complexity. It is located near the Gafsa accident, which is a segment of the regional tectonic accident of the South Atlas in Tunisia. The multiscale analysis of the fracture in the outcrops is based on two approaches - (1) the study of regional tectonics and main faults at the scale of satellite imagery of Landsat L8 OLI TIRS, and (2) the measurement of metric fractures with the outcrop scale in carbonate formation of upper Cretaceous. The results show that the groundwater flow system is controlled by fracture network. The major faults network with a N100-N130 direction have an important role in blocking groundwater flow process. It has the role of geological threshold at surface, and hydrogeological threshold at subsurface. The qualitative analysis of the fracture network shows that they promote water circulation and the quantitative analysis shows that the importance of the special distribution of fractures promotes the formation of a fractured carbonate aquifer. The combination of all these results with topographic data extracted from SRTM (digital elevation model), geological and hydrological data, gives a very hopeful tool for the artificial groundwater recharge in fractured carbonate aquifer.



# KINDRA Project- Hydrogeological Research Classification System (HRC-SYS) Abstract n°2436

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**KEYWORDS:** groundwater classification, societal challenges, research topics

The first activity developed by Horizon2020 KINDRA project, focused on groundwater knowledge and research in Europe, was related to the proposal of a new classification system. Firstly, a list of keywords derived from EU directives and scientific journals publishing groundwater research with impact factor has been created. In addition, the selected keywords constituting the terminology, have been organised following a hierarchical structure. The Hydrogeological Research Classification System (HRC-SYS) has been developed by dividing groundwater research in three main categories- 1) Societal Challenges, 2) Operational Actions and 3) Research Topics. The selection of research topics was made in relation to the major natural science disciplines to which groundwater research primarily belongs. For operational actions, the selection was made according to keyword searches in scientific web-databases, groundwater science journals and EU directives and guidances. Further, the societal challenges defined by the Horizon 2020 - the EU Framework Programme for Research and Innovation - have been considered, to make the classification as relevant as possible at EU scale. Each of these three main categories includes 5 overarching sub-categories for an easy overview of the main research areas. These sub-categories are - A) for Societal Challenges- 1. Health, 2. Food, 3. Energy, 4. Climate-Environment-Resources, 5. Policy-Innovation-Society B) for Operational Actions- 1. Mapping, 2. Monitoring, 3. Modelling, 4. Water Supply, 5. Assessment & Management+ and C) for Research Topics- 1. Biology, 2. Chemistry, 3. Geography, 4. Geology, 5. Physics & Mathematics. The complete merged list of about 240 keywords has been organised in a tree hierarchy. The classification system maps the relation between the three main categories through a 3D approach, where along each axis the 5 overarching groups are indicated. This approach allows for a 2D representation for each of the Societal Challenges, wherein Operational Actions and Research Topics intersect in a 5x5 matrix. This 2D structure and representation renders a 2D analysis and report of the relationships between groundwater research easier to perform and comprehend than 3D analyses.



**When companies support protection of water resources- the co-creation of territorial value on Natural Mineral Water watersheds**  
**Abstract n°2437**

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**KEYWORDS:** Groundwater protection, cocreation of territorial value

For more than 20 years, Evian (Danone Waters) has been implementing an innovative approach to protect natural mineral water resources. Based on cooperation between the company and local elected representatives, this approach is unique in the panorama of bottling companies. If land acquisition, or at least imposition of strict environmental standards and constraints related to protection of water resources are common practices in the areas where the risk of groundwater pollution exists, Evian chose to set up an institutionalised public-private dialogue, to make corporate interests converge with local development (see Session 7.06 for the description of the applied governance principles). To ensure a greater flexibility in deploying different water protection initiatives and guarantee higher engagement of all stakeholders, Evian decided to concede the management of cocreation to dedicated non-profit organizations. Detailed study of this kind of management shows that, in order to cocreate territorial value benefiting to all stakeholders (especially farmers inhabitants) living in the watershed area, the initiatives need to be co-designed with various actors representing all interested parties. In this way, beyond their first (environmental) objective, which is to protect natural mineral water resources from potential deterioration, the initiatives create an enlarged value- in terms of socio-economic development for farmers, higher comfort and better health conditions for inhabitants, etc. It appears that only this cooperative principle and enhanced dialogue can guarantee the multidimensional aspect of territorial contribution+ the interferences between economic, environmental and social impacts of the initiatives need to be apprehended and evaluated, as the organisations draw their legitimacy from their effectiveness. For this reason, specific framework to “reveal” and evaluate this value was implemented and will be described in this presentation. Going beyond quantitative evaluation, this framework also places particular emphasis on the qualitative revelation of immaterial value whose importance is significant. This dynamic re-examines the theoretical status of the company considering that this economic value is created in partnership with other territorial players, traditionally judged as non-economic actors.



**Conjunctive Water Supply Management through the Calibration of a Discrete Continuum Flow Model in a Fractured Karstic Aquifer. Example of the Castel De Vide Aquifer (Portugal)  
Abstract n°2439**

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KEYWORDS: Karst, Drought, Numerical Model, Management, portugal

The Algarve region, south of Portugal, is one of most tourist destination in Europe. Its population triples during the peak holiday season, and it receives an average of 7 million tourists each year. As its popularity grows, so does the demand for water. Due to the overexploitation of existing aquifers and climate change, the availability of water in the region keeps decreasing. The Castelo De Vide Aquifer is a karstic aquifer located in Algarve. This aquifer has always been critical for Algarve's water supply program. This is particularly evident by looking at the water shortages that happened due to the severe drought that affected Portugal in 2004 and 2005. During this drought, the water levels of the large dams used by Algarve's Water Agency were severely depleted causing the water supply program to be entirely dependent on groundwater resources. The future water use in this region should be supported by integrated schemes of water management, including the conjunctive use of surface water and groundwater. Numerical models, such as the one presented in this paper, are fundamental tools for regional water use planning. A 3-D discrete continuum finite element groundwater & surface water flow model was built, in which fractures zones were discretely incorporated into the continuum model of groundwater flow by injecting high hydraulic features to the finite model element grid. Three sectors were defined in the Castelo de Vide karst aquifer, with different degrees of hydraulic connectivity with the aquifer discharge areas in an initially defined "artificial conduit network", controlling flow at aquifer scale. These sectors were identified by the detection of regional trends in the spatial distribution of hydraulic heads. This procedure yielded remarkably positive results in the simulation of the aquifer hydraulic behavior in both steady state and transient simulations. This proved that modeling systematic regional anomalies in the spatial distribution of hydraulic head gradients is a useful tool in the management and protection of water resources in karstic areas.



## **KINDRA Project- European Inventory of Groundwater Research (EIGR) Abstract n°2441**

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**KEYWORDS:** groundwater inventory, metadata, research, knowledge

A fundamental activity developed by Horizon2020 KINDRA project, focused on groundwater knowledge and research in Europe, is the European Inventory of Groundwater Research (EIGR), the tool which allows the application of the Harmonised Terminology and Methodology for Classification and Reporting Hydrogeology related Research (HRC-SYS), previously elaborated during the project. The EIGR is intended to be used in three different ways- i) for insertion of information pertaining to groundwater research and other available knowledge by the National Experts of the European Federation of Geologists (EFG)+ ii) for consultation during and after the project by people and organisations dealing with groundwater research, but also possibly by non experts+ iii) for analysing collected and stored information to identify trends, challenges and gaps in groundwater research, by the KINDRA partners. The EIGR is intended to be a permanent resource, publicly available also after the end of the project. The EIGR will not contain data itself, but rather metadata, referring and providing links to research that has been performed in Europe since 2000, and at the same time allowing their classification under the uniform proposed HRC-SYS. The EIGR allows for the insertion of different information products. In the process of inserting information in the EIGR, users are guided to classify the uploaded information and distinguish between 'research' and 'knowledge' according to four different classes of "knowledge" and "research" identified by the level of the performed quality assurance the uploaded work has received. The EIGR Online Data Catalogue has been recently modified from an alpha version, which has been tested and checked during the trial phase, through the help of National Experts designated by the EFG' Linked Third Parties. A beta version is being released after appropriate tests carried out during the development of the project. The EIGR is now in the population phase, by insertion of records related to research and knowledge at the national scale. All people interested in groundwater can have access to the EIGR for record insertion and for consultation.



## Hydrogeology of Limestone Formation of Sepingtiang, Lahat-Indonesia Abstract n°2445

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**KEYWORDS:** Sumatra karst, hydrogeology karst, Sepingtiang Formation

The research documented here is a report of karst hydrogeology study in Sepingtiang Formation in bid of finding an area for limestone quarry. Sepingtiang Formation is one of the oldest limestone formation in Indonesia. The formation is characterized by very hard crystalline limestone of Late Jurassic-Cretaceous. The limestone belongs to Woyla Group that is considered to be the basement of Sumatra Island. The research mostly conducted through field survey. It includes geological survey, sinkhole, sinking stream, resurgence identification, as well as hydrochemistry measurement. The results show that, the limestone outcrop of Sepingtiang Formation is inlier within younger sedimentary rocks in the slope of block faulted Barisan Range of Sumatra. The hydrogeological condition of the area is governed by allogenic recharge from the upper slope of Barisan Range. The sinking streams cross the limestone formation for about two up to 5 km in south slope and end to resurgences in the northern slope. Three subterranean river systems were found in the area namely Sungai Putih, Kepayang Kasat, and Cawang. The hydrogeological condition is mostly characterized by conduit flow component. Conduit flow with allogenic recharge is also confirmed by low HCO<sub>3</sub><sup>-</sup> content compared to generally limestone spring of which the concentration is less 4 mmol l. Diffuse flow from epikarst is also found in the smaller spring which situated in the higher altitude from the resurgence. Secondary cavities in the epikarst zone do not develop very well. Diffuse recharge mostly comes from soils which is considerably thick for limestone formation. The depth of the soil is between one up to 1.5 meter. Based on those results, it is recommended that limestone quarry should not be located in the area.



## **Shallow groundwater and Self-supply- Potential and the risks as water supply for rural Ethiopians Abstract n°2446**

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**KEYWORDS:** self-supply, aquifer, artisans

Groundwater in general, shallow groundwater in particular is the major sources of water supply for rural Ethiopians through water wells construction either by government and NGOs or by individual households self-supply. Self-supply is one of the rural water supply service provision modalities, which is acknowledged by the government of Ethiopia. It is users' investment to develop own water supply sources, mainly from shallow groundwater through hand dug wells or manually drilled wells. The 2010 2011 National WASH inventory in Ethiopia has captured some aspects of self-supply+ in one of the region alone, SNNPR, self-supply was found to be the main sources of drinking water supply for 1% of the households owning self-supplies+ while for an additional 1% of households sharing the facilities from their neighbors, which in total constitute 85,000 households (4.1 million people) at that time (L. Mekonta, J.A. Butterworth & H. Holtslag 2015). In addition there are different surveys and inventory on self-supplies in the country since 2011 until 2015 that have captured the significance of self-supply as sources of water supply for different purposes and the existing technology ladders (well construction, lifting devices, etc.). The surveys have indicated that the hand-dug wells are usually with little protection+ open or poorly constructed allowing anthropogenic contaminants to reach groundwater easily. This is witnessed by the poor microbiological water quality result analyzed for some water samples during the survey. Unlike the machine drilled wells, manually drilled wells and hand-dug wells get little attention by professionals+ and users who are constructing them receive less technical support and advice, if any, only from local artisans. Careful attention to well siting, design and construction of such shallow wells, particularly family wells through professional support not only increases water quality of the wells but also reduces the access of anthropogenic contaminants to the wider realm of shallow groundwater aquifer.



**Occurrence of greenhouse gases (CO<sub>2</sub>, N<sub>2</sub>O and CH<sub>4</sub>) in groundwater of the Walloon Region (Belgium).  
Abstract n°2447**

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**KEYWORDS:** Groundwater, GHGs indirect emissions, regional scale

Carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) can be indirectly transferred to the atmosphere through groundwater discharge into surface water bodies such as rivers. However, these emissions are poorly evaluated and highly uncertain. The aim of this work is identify the hydrogeological contexts (alluvial, sandstone, chalk and limestone aquifers) and in situ conditions which are most conducive to the generation and occurrence of GHGs in groundwater at a regional scale. To this end, CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O concentrations as well as major and minor elements were monitored (n=37 samples) in two field campaigns (09 2014 and 03 2015) in 15 groundwater bodies of the Walloon Region (Belgium). This preliminary work, which was presented in the 42st IAH conference (Rome, Italy), shown that GHG concentrations range from 5,160 to 47,544 ppm from the partial pressure of CO<sub>2</sub> and from 0 to 1,064 nmol L and 1 to 5,637 nmol L for CH<sub>4</sub> and N<sub>2</sub>O respectively. Overall, groundwater was supersaturated in GHGs with respect to atmospheric equilibrium, suggesting that groundwater contribute to the atmospheric GHGs budget. A third sampling campaign is carried out in 2016 including around 60 new groundwater samples. The combination of the results of the three campaigns allows- (1) reducing the uncertainties related to indirect emissions of GHG through groundwater-surface water interaction and (2) contributing to a better understanding of the occurrence of GHGs in aquifers. New results will be presented and discussed in detail in the presentation.



## **KINDRA Project- relevance for implementation of EU Water Directives Abstract n°2448**

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**KEYWORDS:** EU water directives, science policy, water-food-energy nexus

At the end of the first year of activity, the performed activities by KINDRA project have been compared to identify their possible relevance for the implementation of the EU Water Framework Directive and Groundwater Directive. The KINDRA classification system (HRC-SYS) is based on the relationships of groundwater research and knowledge with the EC policies, by the immediate comparison of two technical categories (research topics and operational actions) with a modified version of the Societal Challenges identified by Horizon 2020. In addition, a set of performance indicators (classes of research knowledge, technology readiness level, grants, number of patents and awards received) is considered in the related inventory (EIGR). The classification system allows a comparison of bibliometric and other indicators for each sub-field of research and knowledge, for trend and gap analysis to be conducted during the last stage of the project, taking into account the Common Implementation Strategy (CIS) of the Water Framework Directive (WFD). The obtained results will be summarised or specifically rearranged, by suitable tools, to be used at EU level for Directive revisions, for the CIS River Basin Management Plans, for driving monitoring procedures and activities, as previewed by the recent strategic documents of EU. The identification of research gaps will give useful suggestions for the actualisation and continuous development of research and innovation agendas in line with WFD. It also helps evaluate the relevance of groundwater research in relation to the objectives of the WFD GWD, group them by categories and evaluate Science-Policy feedback within water research, policy and management. Additionally, the integrated perspective of the WFD and GWD provides good possibilities for demonstrating the important links in the water-food-energy nexus, between surface and subsurface waters and dependent or associated terrestrial and aquatic ecosystems. Hence, it emphasizes the importance of groundwater in the hydrological cycle not only for drinking water and other legitimate uses but also for sustaining terrestrial and aquatic ecosystems in a changing climate where freshwater availability is under pressure.



**Spatial variability of EOCs in a shallow alluvial aquifer coupled to a geochemical approach. Case of the Vistrenque basin.  
Abstract n°2451**

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**KEYWORDS:** EOCs, water isotopes, alluvial aquifer, vulnerability.

In Europe, the occurrence of emerging organic contaminants (EOCs), especially pharmaceutical compounds and hormones, as well as their fate in the environment are better characterized in surface water and wastewater treatment plant (WWTP) effluents than in groundwater. The objective of this study is to evaluate the fate of pharmaceutical compounds during the transfer process from stream water to groundwater. The study site is that of the Vistrenque alluvial aquifer, located in southern France. The groundwater may be locally influenced by stream water infiltration of the Vistre, which constitutes with its tributaries the main recipients of WWTP effluents on this area. A preliminary study (2011 – 2012) on this site shows a quantification of 12 compounds over 44 analyzed in surface water (n=4) with individual concentrations varying between 12 and 375 ng L. While in groundwater samples (n=37), only 3 molecules were quantified with individual concentrations varying between 10 and 48 ng L. In 2015, a survey on the Vistrenque groundwater (n=54) shows the detection of 12 compounds over 18 compounds analyzed with concentrations varying between few ng L to 219 ng L. Carbamazepine and its main degradation compound (10,11 epoxy carbamazepine) showed the highest frequencies of quantification (FoQ) of 77 and 42 % respectively. Analyzed antibiotics showed FoQ up to 30% and beta blockers up to 10%. 42% of private wells (n=37) showed at least a positive quantification of one pharmaceutical compound, comparing to municipal wells (n=17) that showed 76%, that may be due to their pumping rates. A geochemical approach including major elements and water stable isotopes ( $\delta^{18}O$  and  $\delta^2H$ ) is useful and necessary to answer questions about the groundwater origin and therefore of contamination sources.



# Groundwater Divides in a Fractured Crystalline Rock Setting

## Abstract n°2452

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**KEYWORDS:** fracture zone network, groundwater divides, crystalline rock

The lateral extent of a groundwater model domain is normally chosen based on topography and surface water divides with groundwater divides assumed to be coincident with surface water divides. In fractured rock settings, fracture zones may cross watershed boundaries, and surface water divides, to permit groundwater flow between watersheds, where none would be assumed based solely on surface water divides. The interconnectivity of the permeable three-dimensional fracture zone network both within and across watersheds is an important pathway for the possible migration and subsequent reduction in groundwater and contaminant residence times. A high resolution three-dimensional sub-regional scale discretely fractured groundwater flow model was developed from a larger 5734 square kilometre regional-scale groundwater flow model of a Canadian Shield setting. The discrete fracture dual continuum computational model HydroGeoSphere was used for all simulations. A discrete fracture zone network model, generated using MoFrac and delineated from surface features, was superimposed onto an approximate 1.16 million element domain mesh with approximately 1.24 million nodes. Orthogonal fracture faces (between adjacent finite element grid blocks) were used to best represent the irregular discrete fracture zone network. The crystalline rock matrix between these structural discontinuities was assigned flow properties illustrative of those reported for the Canadian Shield for the shallow, intermediate, and deep groundwater systems. Steady-state simulations are conducted with different characterizations of the three-dimensional fracture zone network, and surface boundary conditions for the groundwater system. Performance measures for the sensitivity analysis include freshwater heads, linear velocities, and mean life expectancy. The objective of the work is to determine the sensitivity of groundwater divides to the geometry and characterization of discrete fracture zone networks. This work clearly shows that discrete fracture zone networks that have significant length at divides can require modification of the spatial extent of the conceptual model.



# **Influence of groundwater exchanges on the efficiency of Underground Pumped Storage Hydroelectricity plants using open pit mines**

## **Abstract n°2453**

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**KEYWORDS:** Hydropower, Energy Storage, Open pit mine, Efficiency, Groundwater exchanges

Underground Pumped Storage Hydropower (UPSH) plants can be used to manage the production of electrical energy according to the demand. These plants consist in two reservoirs, the upper one is located at the surface while the lower one is underground. The energy is stored by pumping water from the lower to the upper reservoir and produced by releasing water from the upper to the lower one. As a result, the hydraulic head in the lower reservoir varies continuously. UPSH plants interact with the surrounding aquifers exchanging groundwater. These groundwater exchanges, which play an important role in the evolution of the hydraulic head inside the underground reservoir, are a fact of concern in the selection of pumps and turbines because their efficiency varies with respect to the head difference between the two reservoirs. Therefore, the aquifer parameters should be considered in the selection of pumps and turbines. In this context, with an UPSH plant made up by an open pit mine, we study numerically (1) the influence of groundwater exchanges on the efficiency and (2) how the hydraulic head evolution varies depending on the aquifer properties. The relation among the groundwater exchanges, the efficiency of pumps and turbines and the aquifer parameters is considered by comparing the numerical results of several simulations. It is shown that groundwater exchanges are not negligible when optimizing the efficiency of UPSH plants. A priori, low hydraulic conductivity geological media were preferred to decrease interactions with the open-pit or the cavity used as lower reservoir. Taking into account the pump turbine performance curves, it appears that, on the contrary, the global efficiency would be increased if the surrounding medium facilitates large groundwater exchanges because hydraulic head variations are softened.



## **Balancing the Needs of Human Development and Ecosystems Abstract n°2458**

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**KEYWORDS:** water budgets, land development, hydrogeology, conservation, modelling

Conservation Authorities are unique to the province of Ontario. They are local, non-profit environmental organizations that are empowered to regulate development and activities in or adjacent to river or stream valleys, Great Lakes and inland lakes shorelines, watercourses, hazardous lands and wetlands. The Conservation Authorities Act, passed in 1946, provides the legislative backbone for their existence. Funding is provided through a combination of municipal and provincial support, permit and service fees and charitable donations. Toronto and Region Conservation serves a population of more than 4,000,000 people in a jurisdiction that covers more than 2400 km<sup>2</sup>. We receive development applications for over 1000 projects per year. These files include engineering and hydrogeologic reports prepared on behalf of the development proponents that often downplay the potential impacts of their projects to the natural environment. Our role as hydrogeologists is to critically review these reports and determine if reasonable conclusions have been made based on reliable data. For hydrogeology, we consider both temporary and permanent dewatering, pre- and post-development water budgets, and consumptive groundwater use. We must then communicate our findings in clear, simple language to our in-house planning team, proponents, and sometimes members of the public. All this is done in a framework of limited funding and challenging timelines. We meet these challenges through the use of conceptual and numerical models developed in partnership with neighbouring conservation authorities and our municipal partners. These regional model results are then shared with development consultants to facilitate continuous improvement from their studies completed at the site scale. To continue to advance our hydrogeologic understanding, we also work with subject matter experts at the provincial and federal levels of government, and are working at integrating climate change into our models. This presentation will summarize some of our successes and failures over the past 15 years and provide insights to similar organizations responsible for protecting and enhancing our natural environment.



**The aquifer artificial recharge of Berrechid hydrogéological bassin(Morocco). An adaptation solution for the climate change and the aquifer over exploitation.  
Abstract n°2459**

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**KEYWORDS:** Aquifer artificial recharge, Climate change adaptation, Berrechid Aquifer.

In some areas of the world where water resources are lacking, artificial recharge (RA) technique of groundwater has become a common practice to increase the volumes of groundwater. This is done from surface water in ponds, trenches, ditches and other devices where water percolates to recharge underground aquifer the type and model of recharge depends of hydrogeological context of project. According specific studies in Morocco, the impacts of climate change on water resources will be multiple, both supply (quantity and quality) than demand. The R.A is considered an adaptation solution to the climate change. Several studies conducted by hydraulic agencies in Morocco concerned several aquifers and artificial recharge facilities are functional in some sites developed for this purpose. Despite the efforts and the high cost of these developments, few projects are monitored and few results capitalized. To limit the accelerated drawdown of the Berrechid aquifer, operations of artificial recharge are performed by the Basin Agency. The recharge is made from Oued Elhimer dam in the south of the Berrechid plain. The dam was built to protect the Berrechid city and its industrial zone against floods and the use flood water for artificial groundwater recharge during low flow periods. We have established a numerical model for the A.R. simulations. The fitting of this model has reproduced the hydrodynamic state of the aquifer under the A.R. These simulations have shown also that the efficiency of A.R. operation is about 20%.



**Determination of nitrate sources and vectors in karstic systems- multi-tracers and multi-scale approach**  
**Abstract n°2466**

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**KEYWORDS:** Nitrate, tracers, isotopes, microbiological indicators, multi-scale, multidisciplinary

In the southwest of France, Marseillon karstic spring is a strategic drinkable resource. Despite great water quality, its sustainability is threatened by increasing nitrate concentrations. Agricultural practices taken place in the region generate multiple potential nitrate sources. Additionally, alimentation of the spring and boreholes is not well characterized. Also, because of karstic properties, both groundwater (GW) and surface watershed must be considered as dynamic vectors of nitrate. We tried to characterize the sources, reactions and pathways affecting nitrate from surface to GW. Isotopic composition of N and O of nitrate ( $\delta^{15}\text{N}$  and  $\delta^{18}\text{O}$ ) were combined with host-specific fecal indicators (Bacteroidales and F-RNA phages) and dating measurements (CFCs and SF6). Monitoring was carried out at different spatial scale and under variable hydrological and hydrogeological conditions both in surface water and GW. The characterization of a 106 m borehole highlighted the heterogeneity of water alimentation of the spring. It showed old water (<1940) impoverished in nitrate relatively dominating in the down part of the borehole and increasing contribution of recent water (until 30%), enriched in nitrate in the top part. Isotopic compositions of Marseillon nitrate ( $\delta^{15}\text{N}$  from 6.0 to 12.0‰ and  $\delta^{18}\text{O}$  from 3.7 to +7.2‰) suggest an organic source such as animal and domestic wastes. Detection of both human and animal fecal indicators comforted this mixt organic origin despite low concentrations. Finally, comparison with  $\delta^{15}\text{N}$  and  $\delta^{18}\text{O}$  of nitrate in surface the surface compartment showed that contribution of surface water increased during flood events. This multidisciplinary and multiscale approach offers great potential to determine nitrate origin in complex hydrogeological contexts where multiple nitrate sources and vectors exist. This work could be the base of a methodological guide for drinking water management.



**Assessment of vulnerability in karst aquifers using a quantitative integrated numerical model- catchment characterization and high resolution monitoring - Application to semi-arid regions- Lebanon.  
Abstract n°2469**

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KEYWORDS: karst, Integrated modelling, Semi arid

Karst aquifers are highly heterogeneous and characterized by a duality of recharge and a duality of flow which directly influences groundwater flow and spring responses. Given this heterogeneity in flow and infiltration, the assessment of their vulnerability reveals to be challenging. Studies have shown that vulnerability of aquifers is highly governed by recharge to groundwater. On the other hand specific parameters appear to play a major role in the spatial and temporal distribution of infiltration on a karst system, thus greatly influencing the discharge rates observed at a karst spring, and consequently the vulnerability of a spring. This heterogeneity can only be depicted using an integrated numerical model to quantify recharge spatially and assess the spatial and temporal vulnerability of a catchment for contamination. In the framework of a PEER NSF USAID funded project, the vulnerability of a karst catchment in Lebanon is assessed quantitatively using a numerical approach. The aim of the project is also to refine actual evapotranspiration rates and spatial recharge distribution in a semi arid environment. For this purpose, a monitoring network was installed since July 2014 on a pilot karst catchment to collect high resolution data to be used in an integrated catchment numerical model with MIKE SHE, DHI including climate, unsaturated zone, and saturated zone. Catchment characterization essential for the model included geological mapping and karst features (e.g., dolines) survey as they contribute to fast flow. Tracer experiments were performed under different flow conditions (snow melt and low flow) to delineate the catchment area and reveal groundwater velocities. A series of laboratory tests were performed to acquire physical values used as a benchmark for model parameterization, such as soil hydraulic parameters. Time series used for input or calibration were collected from continuous high resolution monitoring of climatic data, moisture variation in the soil, and discharge at the investigated spring. This similar model approach used on a catchment site in Germany is validated on a karst catchments governed by semi-arid climatic conditions.



**CSI- Forensic hydrogeology**  
**Abstract n°2470**

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KEYWORDS: source identification

When contamination is detected in a drinking well, hydrogeologists have to apply our best forensic techniques to determine where and when the contamination occurred. In this presentation, a new approach for the detection of the source of a contaminant spill will be presented with application in a synthetic aquifer.



**Hydrologic Interconnection between the Volcanic Aquifer and Springs, Lake Tana Basin on the Upper Blue Nile  
Abstract n°2472**

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**KEYWORDS:** Groundwater, Ethiopia, stable isotopes, hydrochemistry, spring water, Gilgel Abay

This research wants to find out whether the high discharge springs around Bahir Dar in Lake Tana Basin are locally or regionally recharged. Water samples from boreholes and springs were collected and analyzed and compared for major cations and anions. Hydrochemical and stable isotope ( $\delta^{18}\text{O}$  and  $\delta^2\text{H}$ ) data were used to identify the recharge sources of major springs and the hydraulic interconnection between the volcanic aquifer and springs in the Gilgel Abay catchment and adjacent areas. The hydrochemical data analysis showed that all water samples of springs and shallow wells have freshwater chemistry, Ca-HCO<sub>3</sub> to Ca-Mg-HCO<sub>3</sub> types. This is mainly controlled by dissolution hydrolysis of silicate minerals. The analyzed stable isotope data indicate that springs water, except Dengel Mesk, Kurt Bahir and Bility springs, and well waters, except Dangila well, fall close to the LMWL. This clearly shows that the infiltrated rainwater did not undergo much evaporation and  $\delta^{18}\text{O}$  values for spring water and groundwater are nearly equal to the value of Ethiopian summer rainfall, which is -2.5‰. Therefore, generally both stable isotope and hydrochemical data show the recharge source to springs and shallow groundwater is primarily from precipitation. Furthermore, data suggest that rock-water interaction has remained relatively limited, pointing to relatively short residence times, and local recharge rather than regional recharge.



**Quantification of the effects of topography-driven groundwater flow by coupling field observations and numerical models in Wood Buffalo National Park, Canada**  
**Abstract n°2476**

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KEYWORDS: topography-driven groundwater flow, water chemistry, Wood Buffalo National Park

Wood Buffalo National Park (WBNP) is Canada's largest national park, approximately 45 000 km<sup>2</sup> in areal extent. Due to its protected status and poor accessibility, the hydrogeology of the area has not been extensively studied. The need for a hydrogeological evaluation arose because of potential impacts due to increased recreational use and anticipated mining activities. In this study, observed field phenomena were coupled with numerically calculated flow fields to characterize the hydrogeological conditions in selected regions of WBNP. The Park exhibits classic examples of surface phenomena thought to be associated with groundwater discharge, such as springs with variable and distinct chemical compositions, extended salt plains and or phreatophytic plant communities. Our working hypothesis is that groundwater flow in the Park is controlled by water-table relief and observed surface phenomena reflect the different orders and segments of groundwater flow systems. Chemical analyses of surface waters and springs were used to determine the hydrochemical characteristics of WBNP (e.g., total dissolved solids, TDS) and to develop a hydrochemical facies classification in WBNP. The hydrochemical analyses revealed significant variability in TDS and hydrochemical facies, i.e. TDS ranging from less than 1,000 mg L to more than 300,000 mg L and hydrochemical facies including end-members of young Ca-HCO<sub>3</sub>-type to more evolved Na-Cl-type waters. Numerical models of groundwater flow were developed to quantify the flow field and to identify recharge and discharge areas in selected regions. Comparison of numerical simulations with field data indicated strong correlations between the modelled flow fields and the chemical character of surface water samples. For example, Ca-HCO<sub>3</sub>-type waters with low TDS correspond with discharge areas of local flow systems and Na-Cl-type waters with high TDS are found in discharge areas of regional systems. The results suggest that differences in water chemical character are good indicators of different orders and segments of groundwater flow systems in WBNP and can, therefore, be considered manifestations of topography-driven groundwater flow.



**Are the Springs of the Grand Canyon At Risk? - Groundwater Exploitation and the Hydrogeology of the Grand Canyon, USA**  
**Abstract n°2480**

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KEYWORDS: Hydrogeology, Water Quality, Tracers, Environment

Grand Canyon National Park exemplifies a problem facing many western National Parks in the United States - groundwater pumping outside of the Park boundaries may influence springs and within the Grand Canyon. These springs support unique wildlife and their diminishment or eradication would have profound effects on Grand Canyon ecosystems. Groundwater pumping associated with business and municipal growth south of Grand Canyon National Park is expanding, and there is evidence to suggest that these wells tap the same groundwater system that supplies canyon springs. The impact of pumping wells on spring flow can be better determined if the age of groundwater, emerging at the springs, is known, because water's subsurface travel time gives critical insight to the source and direction of groundwater flow. In order to investigate the age of groundwater in the Grand Canyon, field and laboratory measurements were made by researchers at University of Nevada, Las Vegas, in concert with the National Park Service, the Grand Canyon Association, the Desert Research Institute, and the U.S. Environmental Protection Agency. Tritium concentrations are less than 6 TR (18 pCi l) in all spring water sampled below the South Rim between the Little Colorado River and Havasu Canyon. This indicates that this water fell as rain or snow and entered the subsurface before the aerial nuclear weapons testing which began in the early 1950's. Absence of chlorofluorocarbons (CFCs) in this water further indicates that this water may predate the introduction of CFCs as refrigerants in the early 1930s. Elevated uranium isotope disequilibrium ratios further suggest that groundwater travel times may even be longer. Long travel times for groundwater indicate a connection between the springs and the increasing depleted regional groundwater system, a situation which could have serious consequences to the ecosystems in the Grand Canyon.



## Abstract n°2481

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**KEYWORDS:** hydrogeochemistry, stable isotopes, pollution, phosphogypsum, aquifer of Skhira, Tunisia.

The activity of the Tunisian Chemical Group (TCG), in Skhira, in southeast Tunisia, for the production of phosphoric acid, leads to the degradation of the groundwater quality of the Skhira aquifer, after infiltration of phosphogypsum leachates, which are acid and charged with various pollutants. Spatiotemporal monitoring of the quality of the groundwater of Skhira aquifer was undertaken by performing bimonthly sampling between October 2013 and October 2014, in five piezometers and in a reference well. Samples were subjected to measures of physicochemical parameters and analyses of the major elements, orthophosphates, fluorine and stable isotopes of the water molecule ( $^{18}\text{O}$ ,  $^2\text{H}$ ). The results obtained show that the infiltration of phosphogypsum leachates has an effect mainly on water of the downstream part of the aquifer, where it was recorded the highest values of conductivity and  $\text{SO}_4 =$ , Ortho-P and F- contents and an acidification. Spatial and temporal variation of the conductivity and concentrations of major elements is related, in addition of the infiltration of phosphogypsum leachates, to the natural conditions of feeding (rainy or dry season), interactions between groundwater and the reservoir rock, formed by clayey sand and gypsum, and to residence time. Contents of stable isotopes of the water molecule ( $^{18}\text{O}$ ,  $^2\text{H}$ ), showed that the waters of the Skhira aquifer undergo a large evaporation and result of recent rainfall evaporated. This is facilitated by the sandy clay lithology of the unsaturated zone and the low depth of the piezometric level.



**GROUNDWATER CONTAMINATION BY PESTICIDES AND METABOLITES IN AN  
ALLUVIAL AQUIFER- TIMEFRAME AND TREND  
Abstract n°2482**

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KEYWORDS: groundwater+ pesticide+ metabolite, transfer time

Pesticides released into the environment may contribute to complex mixtures of parent molecules and metabolites in surface and ground-waters. Diffuse pollution linked to agricultural activities is a significant issue for water management policies and notably the European Water Framework Directive. Several decades may be needed to detect the effects of past and present land-use practices in groundwater. Consequently it's still a challenging task to link current pesticides uses and subsequent impacts on groundwater quality. In the "Ariège River" alluvial plain (c.a. 538 km<sup>2</sup>), a monthly monitoring of water quality was performed during four years at 16 locations. Groundwater catchment was delineated for each of these points. Land-uses and agricultural practises were determined referring to farmer declarations. A strong spatial and temporal variability of the contamination exists and the predominance of metabolites over parent molecules can often be highlighted. Short time transfers from soil to groundwater were punctually observed for different parent molecules. For these points, the annual variability of pesticides concentrations appeared to be driven by both land-uses and climatic conditions. High transmissivity of the aquifer enabled rapid renewal of the water in the saturated zone leading in some cases to a short residence time of contamination as shown by frequent measurements. At the opposite, a constant release of molecules from soil and vadose zone can lead to persistent groundwater contamination. For metabolites, some time lag between spraying at surface and impact on groundwater may exist. For example, polar metabolites of chloroacetanilides can be detected after application and also during forthcoming recharge events (next year or some years after). As for parent molecules, hydrodynamic (climatic) conditions had evident impact on observed concentrations. This long-term monitoring allowed a better characterization of trends and timeframes of metabolites that were not routinely investigated in France in groundwater. The identification of these pesticides and their metabolites is of primary importance as they can have adverse effects on current and future quality of groundwater.



# **Crash test for groundwater recharge models- The effects of model complexity and calibration period on groundwater recharge predictions**

## **Abstract n°2484**

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**KEYWORDS:** Recharge model complexity, Differential split sample test, Predictive Uncertainty

Reliable groundwater recharge predictions are indispensable. However, the choice of what recharge model to use often seems to be subjective. Furthermore, an implicit assumption is made that model parameters calibrated over historical periods are also valid for the predictions. To the best of our knowledge, there has not yet been a systematic investigation of the effects of the calibration strategy on the performance of recharge models. In addition, the missing link between the mechanics of the model structure and changing climatic forcing functions is still unclear. In our study we used a unique data set from a large-scale lysimeter in order to perform a differential split sample test with four groundwater recharge models with varying complexity and six climatically contrasting calibration periods. We demonstrate that an acceptable model performance during the calibration period does not ensure reliable predictions under dissimilar climatic conditions. The deviation of simulated from observed recharge, however, is a function of the chosen model complexity. We also show that the more complex, physically-based models best reproduced observed recharge, even when calibration and prediction periods had contrasting climatic conditions. In contrast, the soil-water balance model and the lumped model perform relatively poor and a strong dependency on the chosen calibration period was evident. It can also be shown that the uncertainty in model parameters is generally less important than the model structure itself, so that the robustness of each individual model follows the degree of model complexity. It can be argued that physically-based models have a greater potential to obtain predictions beyond the range of conditions during calibration. It is still difficult to provide general guidelines on how to choose an optimal calibration period, since model performance seems to depend more on the model complexity and structure rather than on the calibration period.



## **ASPICK project- a database for karst flash floods analyses in southern France. Abstract n°2485**

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**KEYWORDS:** Karst flash flood, hydrological database, surface groundwater interactions

Floods are among the most damaging natural hazard in the world. In south of France, most of the flood events are called 'flash flood', because of the fast response of rivers to rainfall. This is mainly due to the particular climatic setup of this area which is responsible for intense storm, with large amount of rainfall within a few hours on limited areas. In this project, we study these flood events in basins connected with karst aquifers. These 'karst flash floods' are specific because karst terrains will react differently than 'classical' basins. Depending on the initial water table level, the karst may reduce or amplify the flood in the river. This specific behaviour of karst basins is a key issue for the French national services of flood prediction which finance the project. Most of flood modelling frameworks are designed for surface processes only and do not allow the explicit representation of the karst processes. This explains the poor performances obtained by these models when applied on karst basins. On the opposite, hydrogeological models do not allow an efficient representation of surface processes. The aim of the project is to analyse karst flash flood in order to understand these processes and their influence on surface flood. This project concerns eight basins in two departments (Aude and Hérault) of southern France, linked with different karst aquifer (binary and unary karsts, from Cambrian to Cretaceous ages). The first step consisted in gathering a large database on these basins, at a specific spatial (surface basin) and temporal (flood duration) scale, and to pre-process these data. This poster presents our database, the uncertainties associated with each data, and how it will be useful for analyses and modelling. This database contains various kinds of data (rainfall, piezometric level, soil moisture, discharge, geochemical analyses of water during flood, inhabitant testimonies, flood marks and other qualitative data), but our goal is to integrate more data from post crisis enquiries in our database.



**Urban groundwater budget under evaporation-optimized pervious concrete pavements**  
**Abstract n°2487**

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KEYWORDS: Evapotranspiration, pervious concrete, water-permeable paving

Pavement systems of pervious concrete blocks have a certain water retention and storage capacity for rainwater and therefore in addition to higher groundwater recharge rates a higher evapotranspiration rate compared to a pavement system of impervious concrete blocks. Over the test period from August 2008 to November 2011 a total of 336 actual daily evapotranspiration rates were measured in a test field situated in Coesfeld, Germany, under a moderate oceanic and semi-humid climate with an average annual precipitation rate (AAPR) of 843 mm a using the tunnel-evaporation gauge. The newly developed evaporation-optimized pervious concrete pavement system as well as two groove-and-stone-systems with various seam parts has a 2.4 times higher evapotranspiration rate of 149 mm a (18 % of AAPR) compared to an impervious pavement system with 62 mm a (7 % of AAPR). A pervious concrete grass grid has a nearly nine fold higher evapotranspiration of 545 mm a (65 % of AAPR). Based on these measurements the impacts of large scale usage on urban evapotranspiration rates were estimated in Münster (Germany), a city with 300.000 inhabitants 30 km eastward of Coesfeld. In the used program GwNeu. observed data are combined to provide the annual area-weighted average evapotranspiration allowing for sealed surfaces. The estimation outcomes show significant impacts on evapotranspiration+ for example, even if only the existing interlocking concrete pavements were replaced, then 630,000 m<sup>3</sup> a additional water would be evaporated. Also, if a further 15 % of the existing sealed surfaces were replaced, 950,000 m<sup>3</sup> a more water would be evaporated. This would lead to an increased energy transfer (1.5·10<sup>15</sup> - 2.3·10<sup>15</sup> J a) to the atmosphere. The extensive future use of pervious pavements can attenuate the urban water balance to the natural state.



**Estimating amount and spatial distribution of artificial groundwater infiltration in a highly complex environment based on different tracers**  
**Abstract n°2489**

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**KEYWORDS:** Tracer comparison, Mixing ratios, Conceptual model

Drinking water supply in urban areas is challenging due to different kinds of water use and potential groundwater contamination and is recognised as a very complex issue encompassing different spatial and temporal scales. In order to protect drinking water production sites in an effective and sustainable way, knowledge about flow, transport and mixing processes of different water types in the heterogeneous subsurface is crucial. Although isotopes, organic micropollutants and hydrochemistry data such as main cations and anions are known to be powerful tools to refine conceptual groundwater models, an important question is how the drawn conclusions will change if only a subset of these tracers is used. It is of critical importance to understand how the choice of tracers will affect the conceptual understanding of processes because this provides the basis for a sustainable and robust water resources management. In this study, we first estimate artificial infiltration rates along an artificially constructed infiltration system and classify different water types based on hydrochemistry data. Those were obtained from a drinking water production area in Switzerland, where water quality is under pressure due to different potential contamination pathways. To avoid drinking water contamination, artificial groundwater recharge with surface water into an aquifer is used to create a hydraulic barrier between potential sources of contaminated groundwater and drinking water extraction wells. Here, we provide mixing ratios of different water type endmembers based on i) stable isotopes ( $^{18}\text{O}$  and  $^2\text{H}$ ), ii) organic micropollutants, iii) hydrochemistry data as well as iv) noble gas concentrations and isotope ratios, coupled with  $^3\text{H}$   $^3\text{He}$  water residence times. We systematically investigate the effects of using different tracers to study mixing processes and identify the spatial distribution of artificial infiltrated water. We compare the information content from the applied tracers and illustrate the differences in mixing ratios and distribution. Furthermore, the dating of groundwater using noble gas isotopes and  $^3\text{H}$  is used to further constrain the conceptual understanding of the groundwater dynamics and to validate the calculated groundwater mixing ratios.



# **Understand the heterogeneous groundwater behaviour within the Permo-Triassic sandstones using a framework based on time series analysis and lumped models**

## **Abstract n°2491**

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**KEYWORDS:** Groundwater level, time series analysis, lumped models, UK, Permo-Triassic sandstone

The groundwater level response in the Permo-Triassic sandstones aquifers in the Eden Valley has been studied using a combination of statistical and modeling in order to explain the heterogeneity or groundwater behaviour within these formations. The hydrographs obtained for 18 boreholes in the Permo-Triassic sandstone have been decomposed using the statistical STL technique. The results of the decomposition were analysed firstly visually then using a variety of tools involving a variance ratio, time series hierarchical clustering and correlation analysis. The groundwater level time series are then simulated using a number of lumped groundwater models characterized by different structures. Differences and similarities in terms of decomposition patterns were explained using the physical and hydrogeological information associated to each borehole, allowing the elements of conceptual understanding regarding the groundwater flow within the Permo-Triassic sandstones aquifers in the Eden Valley to be drawn together. The Penrith Sandstone exhibits vertical and horizontal heterogeneity as opposed to the more homogeneous St Bees Sandstone where groundwater hydrographs are characterized by a well identified seasonality. However, exceptions can be identified. A stronger trend component is obtained in the silicified parts of the northern Penrith Sandstone, while the southern Penrith containing Brockram (breccias) formation shows a greater relative variability of the seasonal component. Other boreholes drilled as shallow deep pairs show distinct differences in responses revealing the potential vertical heterogeneities within the Penrith Sandstone. The modeling exercise allows the identification of the model structure the most able to reproduce the characteristic groundwater level response for each borehole. As an example, some boreholes situated in the silicified Penrith sandstone require a model structure including a dual response, while in other settings a significant improvement of the performance is obtained adding the river stage time series as a stress. Among the models tested, the Impulse Response Function (IRF) methods provide an efficient way of comparing and identifying the different characteristic groundwater behaviour. A framework is therefore proposed, from the initial time series analysis techniques to groundwater modelling.



## Conceptual model of the Essaouira syncline aquifer system Abstract n°2493

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KEYWORDS: Essaouira syncline, isotopie, conceptual model, water supply.

The coastal town of Essaouira has been faced with a water supply problem because of multiple failures in the exploration based on diagraphs and regional data. The zone of study is about 300 km<sup>2</sup> and seems to draw a hydrogeologic unit well individualized. The piezometric map shows a SE - NW flow direction in agreement with the regional flow. In parallel the electric conductivities map, shows a regular increase as of its values in the direction of the flow. However in the southern part we notice concentric curves and cannot be explained suitably. The topographic map of the substratum collected at ONAREP and SCP brings back two facts (i) The Western part whose topography high was always allotted to the dunes, is actually due to a rise in the substratum caused by diapiric anticlinal, (ii) The existence of a zone having a directed slope SW. The confrontation of the piezometric map and that of the topography of the substratum made it possible on the one hand to delimit dry zones materialized by impermeable area which constitute a barrier to the groundwater flow which is re-orientate towards the southern part favored by the already detected slope. The isotopic analysis contributed to confirm the conceptual model suggested for the groundwater circulation in the Plioquaternary aquifer and to specify the Turonian origin of the ksob river's springs in its downstream. The work undertaken made it possible to improve our state of knowledge of the aquifer system, which leads to a conceptual model. This is useful for the program of mobilization of new groundwater resources to supply the town of Essaouira but raises also other questions on certain aspects, such as relations between the two aquifers in the zones where they come into contact.



**Groundwater and drinking water in France- a situation under control which highlights the impacts of different water uses on the resource quality**  
**Abstract n°2498**

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**KEYWORDS:** Nitrate, crop protection products, infiltration, public health, protection perimeter, quality criteria

Groundwater is undoubtedly one of the safest freshwater resources to human consumption. On the scale of French territory, 96% of the 33500 water catchments levy groundwater. It represents 66% of the whole collected water volume. Water catchments are generally submitted to a declaration of public interest procedure, during which a hydrogeologist approved by the Ministry of Health writes a statement on the resource and protection it needs in terms of protection perimeters. French regulations rely on EU directives (2000 60 EC establishing a framework for Community action in the field of water + 2006 118 EC on the protection of groundwater against pollution) to preserve environmental quality. On the health front it imposes strict controls of water quality intended for human consumption. According to the code of public health, it sets quality limits and referrals to achieve as well as responsibilities between the main actors of drinking water production and distribution system. Water intended for human consumption, either raw or treated, must comply with microbiological and chemical quality criteria. Thus, catchments whose raw water no longer meets the required quality limits will be subject to a prefectural ordinance prohibiting their use. On the other side, water treatment facilities, more or less complex depending on the context of catchment site, allow water to reach the quality required for distribution. Constant monitoring of water quality shows the impact of some water uses on the resource quality. In particular, the presence of nitrates and residues of crop protection products reveals the infiltration through the soil of substances used by the agricultural sector. A reflection is necessary concerning the adequation of the technical means to treat water, the incorporation of new substances that may reach groundwater and the protection of public health.



**Long-Term Precipitation Patterns Prediction- A Data Mining and Remote Sensing  
Based Water Management Approach  
Abstract n°2501**

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**KEYWORDS:** Precipitation, water resources management, neural networks, predictive tools.

We developed and applied an integrated approach to construct predictive tools with lead times of 1 to 12 months to forecast precipitation amounts over the Mediterranean Basin region. The following steps were conducted- (1) acquire, assess and intercorrelate temporal remote sensing-based precipitation products (e.g. The CPC Merged Analysis of Precipitation [CMAP], Integrated Multi-Satellite Retrievals for GPM [IMERG]) throughout the investigation period (1979 to 2016), (2) acquire and assess monthly values for all of the climatic indices influencing the regional and global climatic patterns (e.g., Northern Atlantic Oscillation [NOI], Southern Oscillation Index [SOI], and Tropical North Atlantic Index [TNA]) and (3) apply data mining methods (e.g. neural networks, principal component analyses) to extract relationships between the observed precipitation and the controlling factors (i.e. climatic indices with multiple lead-time periods) and use predictive tools to forecast monthly precipitation. Preliminary results indicate that by using the period from January 1998 until August 2012 for model training and the period from September 2012 to January 2016 for testing, precipitation can be successfully predicted with a three-months lead over Northern Morocco with high accuracy (i.e. Pearson correlation coefficient- 0.911). Future work will focus on applying this technique for prediction of precipitation over each of the climatically contiguous areas of the Mediterranean region. If our efforts are successful, our findings will lead the way to the development and implementation of long-term water management scenarios for the Mediterranean region.



**Lakes as groundwater window inferred from isotope signal, insight for sustainable management**  
**Abstract n°2502**

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**KEYWORDS:** Groundwater-surface water interactions, lake water quality, geochemical tracers, climate and environmental changes

At a global scale, lakes are under severe pressure due to an increasing anthropogenic impact from a growing population in a more developed world. Accordingly, many lakes show today a decrease of water quality. Recent studies have highlighted that global warming and subsequent change in water use will further enhance the eutrophication process in lakes. Groundwater influences lakes ecosystems but also lakes sensitivity to climate and environmental changes and therefore their resilience. However, interactions between lakes and groundwater are not well known and, most of the time, they are not considered in lakes budgets. These interactions should be thus precisely quantified for lake restoration and insight in sustainable lake management in the future. In our study, a groundwater-connected lake with a small catchment was chosen to quantify variations of groundwater-lake fluxes over time and their related influences on the lake's water geochemistry. Variations of geochemical tracers, i.e. water stable isotopes and radon-222, linked to groundwater inflows are determined through their analyses in space and time and a precise instrumentation of the lake. Results of this study at short time scale are then combined with a regional study at seasonal time scale to determine the sensitivity of small lakes to changes in groundwater in a cold continental climate. The groundwater inflows to lakes are quantified in terms of flux percentages and allow the discussion of lake evolution in a climate and environmental changes perspective.



**Regional integrated surface water and groundwater quality baseline in North East BC,  
Canada  
Abstract n°2503**

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**KEYWORDS:** Regional baseline, water quality, Peace River

The Peace River Regional District (PRRD) in northeastern British Columbia (Canada) encompasses 12 million hectares, and is undergoing intensive oil and gas industry activity. Currently, there are many entities gathering water quality data for both groundwater and surface water. However, the lack of understanding of water quality baseline conditions persists, making assessments of cumulative impacts of industrial activity in the region difficult. The lack of coordination in data collection and sharing between the various agencies is part of the problem. Therefore, one of the prime objectives of the study was to build an integrated water quality baseline for the surface water and groundwater within the PRRD that can be easily accessed and shared with the public. The integrated baseline included two major components- a) the creation of a database and b) data interpretation. The data is managed using spreadsheets and built-in macros, a GIS platform, and a water quality analysis software (Aquachem). Surface water quality data analysis is based on 12,000 samples collected from 1954 to 2014. The groundwater water quality database incorporates over 1,000 samples taken from 1943 to 2015. This covers 27 watersheds and 36 aquifers (bedrock and overburden). Data analysis was completed considering both spatial distribution, time, trend analysis, and referring to many standards and guidelines. In order to synthesize the interpretation, a water quality index (WQI) was used. This study identified that the surface water type is predominantly calcium bicarbonate. However, after the year 2000, it shows a noticeable increase and variability in sulfate concentration. Interestingly, it corresponds to the time when the oil and gas industry surged. The presentation will provide additional information about this potential connection



## Abstract n°2506

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KEYWORDS: <p>wastewater, stormwater, drainage, urban lake, eutrophication,

<p>The city of Yamoussoukro, the political and administrative capital of Ivory Coast, is characterised by a dozen of lakes which were built in the late 1970s for its embellishment. This lacustrian hydrosystem covering about 1,400,000 square meters is the receiving environment for stormwater and treated wastewater from sewage plants to which 10% of the population is connected. Indeed, on-site sanitation (OSS) is practiced by about 90% of the urban population- most of OSS systems are out of use or abandoned and some of them are connected illegally to the drainage structures. Currently, these lakes have lost their aesthetic appeal and are now almost completely colonised by aquatic vegetation. This study consisted of making a technical inventory of pollution sources, evaluating the physical and chemical pollution of lakes, and developing a morphological state of the lake beds. So, almost all collected stormwater and wastewater are transported and discharged without treatment into the receiving environment including artificial lakes. This artificial environment now has reached an advanced stage of pollution with the continuous discharge of wastewater with concentrations of BOD5 ranging from 500 to 1,600 mg L. Also, erosion products from unpaved streets are transferred by stormwater to lakes and the low collection rates of solid waste cause gradual filling of the lake bottom. Confined and submitted to numerous and high pollutant loads, these urban lakes gradually fill and become eutrophic, thus causing a significant negative impact on biodiversity and environmental and health issues in the city of Yamoussoukro. Also, the impact on groundwater and the issue pertaining to water supply is questioned.



## Groundwater pollution by nitrate of the water table in West Mitidja- Preliminary results Abstract n°2507

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KEYWORDS: groundwater, water quality, nitrate, Mitidja West

The potability of water is strongly related to its chemical quality which shows the complexity of the problem when the water becomes polluted. Our aim is to determine the origins of the pollution affecting the quality of groundwater in the West Mitidja, which is an agricultural area and knows quite a substantial population density. During two years of follow-up, a chemical analyzes of a hundred sampling groundwater aquifer (free type) were performed to assess the pollution of groundwater by nitrates. We conducted a field investigation to identify the source of nitrate pollution by prospecting at water points whose nitrate content exceeds 50mg l, the WHO standard. A questionnaire was developed to collect information on agricultural practices of farmers in particular those concerning the types of fertilizers used, the quantities supplied and the nature of installed cultivation. The hydrochemical study showed that groundwater in the West Mitidja is characterized by a neutral to basic pH and nitrate levels are significant (higher than 50 mg l) over a large part of the plain. Positive correlations between nitrate and all elements analyzed except with potassium. The survey showed a large number of pollutants, such as urban waste, landfills, farms, which do not show the use of fertilizers as the only source of pollution.



**Estimation of sorption coefficients of selected pharmaceuticals in controlled laboratory experiments**  
**Abstract n°2508**

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**KEYWORDS:** Emerging organic contaminants, column experiment, batch experiments, sorption

The presence of pharmaceuticals in the environment is of emerging public concern. Still, the transfer and fate of these and other emerging organic contaminants in water bodies are not well known yet. Improving the understanding of observed concentration patterns in heterogeneous and dynamic field studies requires the knowledge of crucial processes and parameters that are, however, difficult to determine at complex field sites. Therefore, laboratory experiments can help to identify sorption and biodegradation parameters. The objective was to determine sorption parameters and degradation rates of selected pharmaceuticals in well controlled laboratory experiments. In particular, the impact of flow velocities on sorption and degradation rates of selected compounds was studied. For the experiments, different sediment types were selected- (S1) technical coarse quartz sand, (S2) sandy loam, (S3) sandy clay loam and (S4) clay. Sediments were filled into stainless steel columns. Conservative tracers and compounds of concern were injected into the columns as a pulse. Concentration curves were measured at the columns' outlet. From the tracer breakthrough curves information about sorption and degradation rates for the different sediments and EOCs was determined and the impact of variable flow conditions assessed. Sorption was additionally determined in batch experiments. Compound specific sorption was found ranging from (highest to lowest)- Carbamazepine > Atenolol > Caffeine > Sulfamethoxazole > Oloxacin > Ciprofloxacin > Azithromycin. The results will help to better understand the fate of EOCs under hydrodynamic conditions in heterogeneous sediments.



## **Groundwater in-situ denitrification pilot plant. Design, monitoring and operation. Abstract n°2509**

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**KEYWORDS:** bioremediation, in-situ denitrification, nitrates

Nitrate in groundwater is a widespread problem around Europe. In Catalonia (NE Spain) up to 33% of the area suffers from nitrate pollution. InSiTrate project (LIFE12 ENV ES 000651) is demonstrating at pilot scale the feasibility of in situ bioremediation of nitrate-polluted groundwater for the production of drinking water. The project has also developed an innovative tool for design and prediction of groundwater bioremediation based on numerical modelling. This project is being carried out in the granitic-alluvial aquifer of Sant Andreu de Llavaneres (Cataluña, Spain) where municipal supply wells were abandoned due to high nitrates concentration in groundwater. To increase the denitrification activity of the bacteria and the removal of nitrates in supply wells, organic matter is being added to the groundwater. The denitrification process due to the biological processes is a well-known process (Rittman and McCarty, 2001+ Zumft, 1997+ Shoun, 1992). To define the optimal organic substrate for in situ denitrification, technical, economic and environmental criteria were taken into account in this project. Several column laboratory experiments were conducted. Acetic acid showed the most promising results for in situ denitrification. The pilot plant consists on one water extraction well and two organic matter injection wells. The final design was based on a complete aquifer characterization through several pumping and tracer tests. The obtained hydraulic parameters were implemented in a numerical groundwater flow to simulate aquifer response and to evaluate the proper configuration of the pilot plant. Afterwards, the biokinetic denitrification has been also numerically simulated to define the organic matter injection pulses and its concentration. The pilot plant operation started on May 2015 and will be in operation until June 2016. During this period, several operation strategies are being tested by changing the extraction flow, the acetic acid concentration and the dosage of acetic acid. Monitoring campaigns show removal rates between 50 and 70% at different distances and aquifer depths.



# Watershed-Scale Hydrologic Sensitivity to Climatic and Anthropogenic Changes Abstract n°2511

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KEYWORDS: Climate Change, Groundwater, Remote Sensing, Anthropogenic

Natural and human-induced impacts on water resources across the globe continue to negatively impact hydrologic fluxes, groundwater reserves, and alter the physical landscape. Characterizing the hydrologic sensitivity to climatic and anthropogenic changes is problematic given the lack of monitoring networks and global-scale model uncertainties. This study presents an integrated methodology combining satellite remote sensing (e.g., GRACE, TRMM), hydrologic modeling, climate projections, and radar interferometry to evaluate the impact of climatic and man-made changes on the groundwater and surface water resources. The approach was carried out in the Souss Basin, Morocco to quantify the current and projected changes in water resources, investigate groundwater storage changes, and evaluate the impacts of groundwater extraction. First, current and historical (2003-2015) water resources were estimated using a combined field-based and satellite-based hydrologic model (SWAT) and GRACE RL05 and TRMM 3B42 data. Second, the projected climate change impacts were estimated using a 40-GCM ensemble using IPCC AR5 data. Lastly, persistent scatterer interferometry (PSI) was conducted using 250 ENVISAT and ERS1 2 SLC images to estimate ground subsidence induced by groundwater extraction in the Souss Basin. Simulated (2000-2012) potential renewable groundwater resources obtained from SWAT are  $\sim 1.8 \times 10^9 \text{ m}^3 \text{ yr}$ . GRACE indicates a decline in total water storage of  $\sim 1.9 \text{ cm yr}$ , while the TMPA rainfall shows an increase in annual rainfall amounts which suggests human interactions as the underlying cause of depleting groundwater reserves. This is supported by the radar interferometry results of increasing land subsidence ( $-20 \text{ mm yr}$  to  $-0.4 \text{ mm yr}$ ). The combined approach quantified the amount of modern recharge, estimated the potential projected decreases in water resources in the future, measured the relative subsidence rates, and demonstrates the utility of satellite remote sensing data sets in developing management plans for modulating adverse impacts. Therefore, the methodology and results are replicable in similar regions and help resolve important questions relating to the future of groundwater resources.



**Importance of chemical osmosis and advection in the Boom Clay as host rock for disposal of radioactive waste**  
**Abstract n°2512**

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KEYWORDS: aquitard, chemical osmosis, faults, advection

The Boom Clay in the Netherlands is considered as a potential formation for future geological disposal of radioactive waste. Within OPERA, the current Dutch research programme on geological disposal of radioactive waste, the feasibility and post-closure safety of a repository in this formation is investigated. An important aspect of the post-closure safety assessment is whether groundwater transport other than diffusion is relevant or not. The objective of this study is to determine whether chemical osmosis or advective flow in faulted blocks are relevant transport mechanisms at the geological time scale. For this purpose a 1D-groundwater transport model incorporating diffusion, chemical osmosis and advection was built in COMSOL. Another 2D groundwater transport model was built in TOUGH2 to calculate advective dispersive transport through vertically faulted Boom Clay with an offset of 30 and 60 m. A 100 m thick clay layer was assumed+ the hydrological parameters and boundary conditions were derived from either scarce field measurements in the Netherlands or international literature. For the first modelling exercise, two scenarios were investigated- the clay separates fresh water from seawater or seawater from brine. Both are representative for the Netherlands. The osmotic flux turns out to be relevant for both scenarios. In the freshwater-seawater scenario, the magnitude of the osmotic flux is up to twice as large as the hydraulic flux. In the other scenario, it is 3 - 8 times larger, where a small reflection coefficient was used for numerical reasons. The results for the second modelling exercise indicate that 1. conductive faults could reduce pressure build-up and thus flow through the Boom Clay and 2. the impact of the fault on advective flow through the clay is gone at more than 500 m away from the fault. The centre of a block is thus hydrologically unaffected by faulting when broader than 1 kilometer.



## **Linking geochemistry and aquifer mineralogy in a groundwater body in Central Italy Abstract n°2513**

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**KEYWORDS:** groundwater, tuffs, geogenic contaminants

Several processes can affect the concentration of dissolved substances in groundwater - water-rock interaction, geothermal upwelling fluids, biological activity, residence time, human activities, etc. As long been recognized, the first two processes are often considered the main cause of the arsenic presence in volcanic or volcanic-sedimentary aquifers in Central Italy. The study area is located North of Rome. During three campaigns (from 2012 to 2015) we collected groundwater samples from several private wells. The periodical monitoring of groundwater allowed us to investigate the annual water quality variation. The investigated aquifers are mainly bicarbonate-alkaline-earth type and show variable levels of potentially toxic elements such as As, F, V and U. Some parameters (PO4<sup>3-</sup>, V and Al) show a decreasing trend from North to South, while others (As and F) showed an uneven distribution with no trend and localized peaks. In addition, 20 rock samples have been collected from outcrops, to identify the possible mineralogical source of As released in the studied aquifers. Solid and aqueous matrices have been studied, in order to evaluate any significant connections between chemical and mineralogical patterns. The area is characterized by the presence of Pleistocene volcanites (mainly tuffs) which have been sampled and analyzed, so as to determine the total content of As and other metals. Results show As rock content in the range of 10.6 - 28.5 mg kg, with a mean value of 18.4 mg kg. Selective Sequential Extraction allowed us to discriminate the different solid fractions containing As and to better understand processes governing As mobility. Leaching tests provide an estimate of the release rates of arsenic and other elements under simulated real conditions. The study of the distribution of some elements in different geochemical spheres and the analysis of water-rock interaction processes, provided a comprehensive framework on the origin and evolution of geogenic contaminants in groundwater.



**Groundwater modelling of managed aquifer recharge in infiltration ponds with reclaimed water (NE Spain)  
Abstract n°2518**

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**KEYWORDS:** Managed aquifer recharge, Reclaimed water, infiltration ponds

We present the modelling results in El Port de la Selva Demoware project site where a pilot study for Soil Aquifer Treatment (SAT) of reclaimed water is being implemented. Numerical simulations of groundwater flow through the aquifer have been used to design a proper Soil Aquifer Treatment (SAT) of reclaimed water. Port de la Selva is a coastal town in Costa Brava (Northern Catalunya) where summer population increases up to 10 times. Water supply relies mainly in groundwater as surface water is very scarce. Reclaimed water from local wastewater treatment facilities may constitute an alternative water source for local population (Sala and Serra, 2004). The system consists on 3 infiltration basins that operates alternatively. Key variables in the design of SAT systems are the travel time from infiltration ponds to downstream wells and dilution factors of reclaimed water in active nearby pumping wells. In Port de la Selva these variables are evaluated in water supply wells located 1 km downstream. Using a flow and transport Finite Element numerical model, we simulate the migration of the plume of reclaimed water through the aquifer to analyse the sensitivity of travel times and dilution factors to parameters such as rainfall, infiltration rates, pumping schemes in water supply wells, aquifer porosity and hydraulic conductivity. The model will be used to optimize quality and quantity of infiltrated water ensuring that negative potential impacts on health and environment are kept to a minimum. During the framework of this project, we monitor water quality for both native groundwater and outflows from the water treatment plant to optimize treatment needs. The numerical model is used for quantitative analyses of sensitivity to precipitation recharge and variable water demand pumping rates at water supply wells. This numerical model is capable of simulating aquifer response to rainfall events and pumping in water supply wells with reasonable accuracy.



**Multiple-step vertical colonization of the subterranean environment- Brazilian troglobitic catfishes as case studies  
Abstract n°2521**

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**KEYWORDS:** Subterranean biology, troglobites, cave fishes, Brazil, colonization of subterranean habitats.

A two-step vertical colonization model has been hypothesized to explain the coexistence of adaptations to small, confined spaces and to large spaces in the troglobitic catfish, *Rhamdiopsis krugi* (Siluriformes- Heptapteridae) found in the upper phreatic zone in Chapada Diamantina karst area, northeastern Brazil. Such adaptations are, respectively, miniaturization, reduction of lateral line, and slender, sinuous body, and very developed pseudotympanum and broadened head and snout. Herein, we propose a further step, which is the adaptation to the deep phreatic zone, for *Rhamdiopsis* sp. from the contiguous Campo Formoso karst area, characterized by dark pink coloration of skin (for hypoxic conditions), large amount of subdermal fatty tissue reserves and very slow growth rate, with extremely high longevity (up to 30+ years in laboratory) (for nutrient deprivation). Likewise, a multiple step model is proposed for troglobitic catfishes genus *Ituglanis* (Siluriformes- Trichomycteridae) from São Domingos karst area, Central Brazil. Colonization of the subterranean realm through the epikarst would explain miniaturization, as observed in *I. epikarsticus*, followed by occupation of larger spaces below it. Dispersion through epikarst explains the disjunct distribution of these catfishes inside caves. *I. bambui* and *I. ramiroi* are typical dwellers of slow-moving waters in caves. A third step, adaptation to life in a food-rich lotic environment, would account for a secondary increase on body size observed in *Ituglanis passensis*, that retains the lowered number of vertebrae and reduced lateral line as a trace of past miniaturization.



# **Monitoring and Assessment of Anthropogenic Contaminant Distributions in Karst System**

## **Abstract n°2524**

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**KEYWORDS:** karst, contamination, spatiotemporal distribution

Well-developed conduit porosity and highly transmissive zones in karst aquifers make these systems highly productive and important freshwater resources, and also impart high vulnerability for contamination. High aquifer productivity and water availability in karst regions promote industrial, agricultural, and population growth that enhance socioeconomic conditions, but also increase the potential for contamination, resource degradation, and exposure. Contamination may come from point or distributed sources, and is distributed according complex hydraulic, fate and transport processes. Assessment of the contaminant distribution is, however, highly dependent on the monitoring scheme used. This work examines the effect of contaminant source type, hydrogeological properties, and monitoring schemes on the spatiotemporal distribution of legacy and emerging contaminants in karst aquifers of eogenetic character. The study is conducted the karst system of northern Puerto Rico. GIS technology and statistical methods are applied to perform spatiotemporal analysis of the collected data. The analysis incorporates data gathered from regulatory agencies and current field measurements of groundwater samples. Results show extensive spatial and temporal contaminations of both legacy and emerging contaminants. Temporal distributions are influenced by contaminant loading functions, which are most of the time unknown, climate, and anthropogenic interventions. Although widely spread, contaminant plumes originating at point sources can be delineated spatially, depending on monitoring schemes. Contaminants entering from distributed sources are much more difficult to delineate, spatially and temporally. Statistical assessment shows that detection and contaminant distributions of contaminants originating from distributed sources are significantly related to hydrogeological properties and land use. Those originating from point sources are influenced by heterogeneous and anisotropic flow patterns induced by natural processes and anthropogenic activities. In both cases, accurate capture of contaminant distribution requires careful implementation of adequate monitoring schemes.



**Process-like modeling of aquifer architecture in fluvial sediments. The Nile River at the pharaonic time in the Theban region of the Karnak Temples complex (Upper Egypt)**  
**Abstract n°2532**

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KEYWORDS: Fluvial sediments + process-like modeling + random walk+ Nile River+ palaeogeography

Characterisation and modeling of aquifer architecture are key stages for a successful groundwater modeling. When aquifers are located in reservoirs deposited in fluvial environments, the 3D organisation and connectivity of sandstones drive the quality of the modelling. For years, the spatial distribution of properties has been addressed through various geostatistical techniques. However, all these techniques hardly honor the whole knowledge and constraints provided by sedimentology and or hydrogeology, as the algorithms don't take into account the process of sedimentation. This paper illustrates how a process-like technique can considerably improve the quality of the modeling and deliver realistic images of the aquifer. U-Like™ is a new modeling technique based on a random walk approach. Particle displacement represents the transport of sediments inside the river through time. The displacement is parameterised in order to represent the main direction of the flow, the general shape of the river, and its stochastic fluctuations. Trajectories of displacements are then dressed in order to model the envelopes of the different sedimentary bodies- channels, point-bars, fluvial bars, levees... Such data as wells descriptions, no-flow boundaries, geophysical interpretations, can be input to constrain the different realisations of the model. U-Like™ has been applied for an archaeological project on history of the Karnak Temples complex (Upper Egypt) and on the reconstruction of the landscape evolution of the Nile valley during the 2nd millenary BC. With respect to a great number of hard data, it has been possible to reconstruct in 3D the palaeogeography of the Nile system in the Theban region. This model honors stratigraphic sections (deep wells, cores), digital globe and satellite images, archaeological remains (monuments, quays), iconographic and epigraphic documents. Scenarii of the Nile River lateral mobility for the period between the 12th and the 18th dynasty (1950 – 1350 BC) have been proposed. They make possible to quantify the probability of the Nile River location during the different reigns of the Pharaohs.



**Characterizing recharge process in fractured hard rock aquifer- coupling geophysical and hydrogeological methods**  
**Abstract n°2534**

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**KEYWORDS:** Magnetic Resonance Sounding, water table fluctuation, hard rock aquifer, recharges

This study aims at characterizing recharge process in a fractured hard rock aquifer under Sahelian climate condition. For this, Sanon catchment located in the Central Plateau of Burkina Faso, which is constituted of hard rocks representative of hard rocks of Africa is identified as an experimental site. We initially described the geometry and the structure of the aquifer of Sanon site. Then, the incidence of the geometry and the structure in terms of water content is estimated by non-invasive Magnetic Resonance Sounding (MRS) measurements around existing observation wells on the site. The different water contents obtained allow at deducing from observed water table fluctuation monitored in each well the quantity of water that recharge the aquifer. We observe unequal distribution of water content at the catchment scale. The water contents obtained vary between 2 and 4.6%, the highest value is obtained in the central valley of the basin where recharge value is the highest (223 mm) and the lowest at downstream dominated by flooding areas where recharge value is lowest (22mm). The different recharge values obtained by the method described in this study are in agreement with those obtained from former studies using chemical and modeling methods.



**INVESTIGATION OF RARE EARTH ELEMENTS IN SURFACE WATER AND  
GROUNDWATER IN PARTS OF ILORIN SHEET 223, SOUTHWESTERN NIGERIA  
Abstract n°2536**

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**KEYWORDS:** Surface water, Ground water rare earth elements, Lanthanum (La), Cerium (Ce and Europium (Eu)

The occurrence of Rare-Earth Elements (RRE) in surface water and groundwaters in some parts of the Ilorin was studied for the concentrations, the controlling factors of the concentrations, fractionation patterns, Ce and Eu anomalies of rare-earth elements (REE) in surface water and groundwaters. Water samples were collected for surface water, shallow groundwater and deep groundwater each, and analyzed using Inductively Coupled Plasma-mass Spectrometry (ICP-MS). The results shown that the abundant rare earth elements are Lanthanum (La), Cerium (Ce), Neodymium (Nd), Gadolinium (Gd), Samarium (Sm) and Praseodymium (Pr). The elements with the highest concentration are La and Ce and REE with the least concentration are Lutetium (Lu) and Holmium (Ho) in all samples. The REE contents in surface water, shallow groundwater and deep groundwater samples range from 0.14 to 15.92 g/l with an average of 8.3 g/l, 0.14 to 96.29 g/l with an average of 10.11 g/l and 0.1 to 0.54 g/l with an average of 0.274 g/l respectively. The surface water, shallow groundwater and deep groundwater is characterized by temperature (ranging from 25 to 27°C, 25 to 27°C and 28 to 32°C) respectively, pH (4.5 to 6.8, 4.5 to 8.8 and 5.8 to 8.1) respectively and high total dissolved solids (TDS, 65 to 150 g/l, 20 to 580 g/l and 110 to 280 g/l). They are characterized by light rare earth elements (LREEs) depletion relative to heavy rare earth elements (HREEs), positive Eu anomalies and negative Ce anomalies different from that of surface water. The negative Ce anomalies reflect the signature of the aquifer rocks (granitic rocks), whereas positive Eu anomalies are probably attributed to the redox conditions. The similarities of REE patterns between surface waters and groundwater suggest that aquifer materials play important roles in controlling the REE characteristics of groundwater.



# **The Water Footprint of Oil and Gas Production using Hydraulic Fracturing from Unconventional Reservoirs in the U.S.**

## **Abstract n°2551**

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**KEYWORDS:** water energy nexus, hydraulic fracturing, unconventional reservoirs

There is considerable concern about the water footprint of oil and gas production from shale plays. The water footprint includes both water use for hydraulic fracturing and water produced with oil and gas production. In this study we evaluated water use for hydraulic fracturing and management of water produced with oil and gas production in shale plays in the U.S. Most shale plays in the humid eastern U.S. produce gas whereas plays in the semiarid western U.S. produce mostly oil. Mean water use per well does not vary greatly among plays for oil versus gas production+ however, there is considerable variability among wells within plays. Water use for hydraulic fracturing is used up front+ however, with only 5–10% of oil or gas resources recovered, there is concern about additional future water use. Plays that produce oil and gas (e.g. Eagle Ford Shale) show that water use for oil wells is similar to that for gas wells. Sourcing of water for hydraulic fracturing is generally not critical in the humid eastern U.S. where surface water is the dominant source. Water sourcing is more critical in the semiarid western U.S.+ however, systems are adapting by expanding brackish groundwater use and reuse recycling of flowback-produced water. Flowback and produced water, generally referred to as produced water, is managed by deep disposal in most plays, except the Marcellus Shale Play in the eastern U.S. where ~90% of produced water is reused recycled for hydraulic fracturing, accounting for 10–30% of water required for hydraulic fracturing. Injection of produced water is inducing seismicity in some regions. In contrast, the water footprint of oil production from unconventional reservoirs is in the low range of that for oil production from conventional reservoirs where large volumes of water are used for water flooding and enhanced oil recovery. Increasing reuse recycling of produced water would reduce water sourcing and disposal issues but could increase vulnerability to contamination.



**Importance of Natural and Managed Recharge in Sustainable Water Resources Management in the U.S. High Plains and California Central Valley**  
**Abstract n°2552**

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**KEYWORDS:** Groundwater recharge, managed aquifer recharge, Semiarid recharge

Groundwater recharge plays a critical role in sustainable water resources management. The role of recharge in managing water resources in the U.S. High Plains (Ogallala Aquifer) and California Central Valley was evaluated using groundwater level fluctuations, groundwater chloride data, and regional groundwater models. The results show large spatial variability in recharge in the U.S. High Plains. High recharge rates in the northern High Plains in the Sand Hills play a critical role in balancing irrigation demands in this region with little or no decline in water storage since the 1950s in much of the region. In contrast, low permeability soils in much of the central and southern High Plains greatly restrict recharge, resulting in irrigation mining groundwater and large scale depletion. In the California Central Valley, coarse textured alluvial fans in the southeastern San Joaquin Valley facilitate recharge. In the early to mid-1900s much of the irrigation in the Central Valley relied on groundwater, resulting in marked depletion of the resource in the western San Joaquin Valley. Development of large aqueducts in the mid to late 1900s allows water to be imported from the relatively wetter northern and eastern regions to the arid southwestern region. Conjunctive use of surface water and groundwater allowed groundwater levels to recover. Managed aquifer recharge systems have been developed using local and imported water sources and are facilitated by the coarse textured deposits. Management of water resources for sustainability in both the High Plains and the Central Valley should consider both natural and managed recharge as critical components of this management



**CONTINUOUS ISOTOPIC WATER SAMPLING CAVITY RING-DOWN SPECTROSCOPY  
(CIWS-CRDS) FOR REAL-TIME MEASUREMENTS OF WATER ISOTOPES  
Abstract n°2553**

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KEYWORDS: water stable isotopes, Spectroscopy

Stable isotopes of water ( $^2\text{H}$ ,  $^{18}\text{O}$ ) are unique tracers of many hydrological processes including evaporation, precipitation, reservoir mixing and residence time. Historically, discrete water samples have been collected and analyzed via either Isotope Ratio Mass Spectrometry, or more recently laser-based spectroscopic methods, such as Cavity Ring-Down Spectroscopy (CRDS). However, the analysis of discrete samples precludes the ability to construct high resolution water isotopes data sets through time and space. Previously, research groups have developed laboratory-built diffusive samplers for extracting water vapor from liquid [1,2] and then analyzed that vapor via CRDS instruments, whose continuous flow design and high frequency measurement interval ( $< 1$  Hz) makes them uniquely suited to real-time, high throughput measurements. Here we present details of the first commercially-available and field-deployable Continuous isotopic Water Sampler (CiWS) coupled to a Picarro L2130-i for isotopic water analysis. The CiWS device utilizes an expanded polytetrafluoroethylene (ePTFE) membrane to extract water vapor into a dry air stream. The resultant water vapor is analyzed by a Picarro L2130-i for  $^2\text{H}$  and  $^{18}\text{O}$ . An automated software program provides user-specified time-averaged data and switches between four ports to enable easy calibration. Tight temperature and flow rate control regulates fractionation across the membrane. In-lab testing demonstrates that the system can achieve a raw precision (1 of 3 minute average) better than 0.05 0.15 ‰ ( $^{18}\text{O}$   $^2\text{H}$ ), respectively, and a reproducibility of 0.15 0.5 ‰ ( $^{18}\text{O}$   $^2\text{H}$ ) over seven days (figure 1), even under variable ambient air and water temperature conditions.



## Developments on the Guarani Aquifer System Governance Abstract n°2554

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KEYWORDS: Guarani Aquifer, Sustainability, Governance, Argentina, Brazil, Paraguay, Uruguay

The Guarani Aquifer System Governance has been a process developed by countries in response to the vertiginous water demand increasing occurred after the 1970s in the region. Since the 1990s, countries have built national and subnational institutions on environment approving new water laws to develop management strategies with focus on water resources. With the support of the Project on Environmental Protection and Sustainable Development of the Guarani Aquifer System (2003-2009), Argentina, Brazil, Paraguay and Uruguay developed a Strategic Action Plan with specific groundwater instruments and institutional mechanisms tailored to the aquifer management. In 2010, national presidents signed an Agreement on the Guarani Aquifer to be approved by national parliaments and implemented by the countries. The countries are implementing some priorities defined in the Strategic Action Plan mainly on basic knowledge in recharging areas. In parallel regional, national and local stakeholders including in pilot areas are implementing actions and developing new plans to the aquifer sustainability. To the implementation of the agreement, countries will have to review current regional, national, state provincial and local developments in a logical framework to put institutions moving forward in a coherent way. The presentation points out current achievements and main aspects to develop the Guarani Aquifer System Governance.



**Application of a New GRACE Product for Assessing Long-term Trends in Water Storage in Aquifers Globally**  
**Abstract n°2555**

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**KEYWORDS:** GRACE satellite data, groundwater depletion, irrigation

There is increasing interest in application of the Gravity Recovery and Climate Experiment (GRACE) satellite data to assess changes in groundwater storage in aquifers globally. Here we describe a new GRACE Mascons (mass concentration) product to evaluate trends in total water storage (TWS) and groundwater storage (GWS) in combination with other land surface model output for Jan 2003 through Dec 2014 in aquifers globally. The new mascons product was developed by the Univ. of Texas Center for Space Research (CSR-M) with an equal area grid (120 km spacing between grid cells). The CSR-M product applies constraints related to the distribution of land and ocean and eliminates north-south stripes. GRACE processing for CSR-M relies entirely on GRACE data and does not use other models, such as land surface models, to constrain the data. This product represents a significant advance over traditional GRACE spherical harmonic products by increasing user friendly applications with no post processing requirements. We will provide examples of the application of the CSR-M processing to aquifers in different regions globally. Examples of aquifers include the High Plains and Central Valley aquifers in the U.S. subjected to drought and intensive irrigation. Depletion and recovery in aquifer storage in the Murray Darling Basin related to drought and floods will also be described. Irrigation impacts on groundwater storage in north-west India and the North China Plain will be shown. GRACE data processing is continually improving and becoming more user friendly for hydrogeologists to apply to different regions.



**Groundwater management strategy to sustain ecologically sensitive wetlands in a peri-urban environment, Southern Ontario, Canada.  
Abstract n°2557**

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**KEYWORDS:** Use conflict, Drainage, Infiltration, Nonpoint source pollution, Wetland, Underground parking

Surface water features in peri-urban environments face hydrogeological stresses due to alterations of groundwater flow and quality by urban development. Peri-urban context deals with conflicting stockholder needs (agencies, developers) for groundwater usage, which makes it necessary to mitigate impacts such as the decline of the groundwater table and impacts on groundwater and surface water quality. This paper presents a groundwater management strategy developed to sustain groundwater contributions to two sensitive natural wetlands located downgradient from a proposed underground parking in Southern Ontario, Canada. Permanent lowering of the groundwater table is required using a passive drainage system for the underground structure. To compensate the deficit in groundwater contribution to the wetlands, the proposed strategy consists of infiltrating the extracted groundwater upgradient from the wetland, while avoiding recirculation of infiltrated water to the passive drainage system. Preliminary geological investigations at the site encountered stratified alternating coarse and fine glacial deposits, with unconfined to semi-confined groundwater conditions. The feasibility of this approach was assessed based on a combination of pumping tests, slug tests, infiltration tests, and analytical simulations. Pre-construction monitoring using data loggers was utilized to provide baseline information on shallow groundwater regimes adjacent to the wetlands and at the location of the proposed underground structure. Recommendations for long term maintenance of groundwater management system are provided. Measures to mitigate groundwater pollution bound to this infiltration scheme and more generally, nonpoint source pollution linked to infiltration in peri-urban or rural context, will be discussed.



**Influences slug test responses in high permeable intervals in fractured sedimentary rock boreholes- overdamped versus underdamped behavior  
Abstract n°2558**

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KEYWORDS: fractured media, slug tests, critical damping

Hydraulic tests conducted in multiple depth intervals in each borehole is one method to evaluate vertical distribution of transmissivity at the borehole scale in a fractured aquifer. Straddle packer tests were conducted in 1.5 m test intervals in fractured sandstone using constant-head step injections and multiple pneumatic slug tests to assess non-linear flow conditions and increase the confidence in the transmissivity (T) value. In some high permeable zones, the slug tests produced an underdamped response (oscillations), which is generally associated with the inertia of the water column in the well casing. We observed underdamped slug test behavior in test intervals with T values ranging from  $5.0 \times 10^{-4}$  to  $2.0 \times 10^{-3}$  mC s. However, in the lower range of these T values, we also observed overdamped responses or near the critical damping value responses. In order to understand the slug test behaviors in intervals with T values less than  $1 \times 10^{-3}$  mC s, the effects of inertia in both the aquifer and the riser pipe were analyzed using models developed for underdamped slug-test responses. Comparison with other data collected in these zones, such as geophysical logs or lithology, were reviewed to understand the impact of the structure.



## **Analysis of pumping tests conducted on fault zones in sedimentary rocks Abstract n°2560**

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**KEYWORDS:** fault zone, composite reservoir, hydraulic properties

Identified reservoir geometry and hydraulic properties remains challenging especially in fractured media where groundwater flow highly depends on hydraulic connectivity of fractures. In particular, depending on hydraulic gradient and properties, fault zones can act as barriers and or flow pathways and may have a strong impact on transport of contaminants. In order to help prediction of contaminant transport in Santa Susana Field Laboratory, California, we analyzed several long term pumping tests carried out at different fault zones across the site with varying lithologic conditions. The objectives are first to estimate hydraulic properties of relevant structures and second to study the role of fault zones on groundwater flow. To analyze the pumping tests, we first applied deconvolution for removal of the effect of variable pumping rates to get constant-rate responses of the reservoir. Then, we used the drawdown derivative for analysis of flow behaviours to choose relevant solutions for data interpretation. We show that the system can be interpreted with a linear composite model with compartments of different hydraulic properties.



# **Regional Flow and Groundwater Residence Time Simulations in Chaudière-Appalaches, Québec, Canada- Implications for interpreting Regional Geochemistry Abstract n°2561**

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**KEYWORDS:** Regional flow, modelling, residence time

A two-dimensional numerical model has been developed for simulating groundwater flow and mean groundwater age in the Chaudière-Appalaches region, Canada. As part of the regional basin-scale PACES projects in Québec, the study aims to advance our understanding of regional-scale groundwater flow dynamics and natural geochemical processes, and provides insights into the extent to which regional groundwater quality is shaped by flow dynamics. More specifically, the study aims to quantify the magnitude of regional flow, to estimate the maximum depth of active groundwater flow and the distribution of groundwater residence times, investigate the influence of normal faults on regional flow, and examine the contribution of formation brines and the Champlain Sea which covered part of the basin following the last deglaciation. Physical and chemical hydrogeological data were used to generate a regional conceptual and numerical flow model oriented in the vertical 2D plane roughly south-north towards the St. Lawrence River. The numerical model was first calibrated to the average recharge values+ then the role of faults was investigated by testing various fault configurations and hydraulic conductivities. Although some evidence for deeper regional flow exists, the area appears dominated by sub-regional flow systems on maximum scales of about 10-20 km, with significant flow through the shallow fractured sedimentary rock aquifer. This regional scale model is also used to support local groundwater geochemical interpretation, by providing insight into regional flow dynamics, including the extent to which deep basinal brines or marine waters might contribute to the regional flow. Finally, the simulated flow system in a transport model to simulate the distribution of groundwater ages, which are then compared to sampled <sup>14</sup>C water ages. The use of residence times as the common parameter between flow dynamics and geochemical evolution helps verify the spatio-temporal coherence of the previously identified geochemical processes by bounding them to a time-scale. The insights obtained from the study will be used to better manage and protect the regional groundwater resources.



**Genetic Adaption by Groundwater Microbial Communities is Key to Survival after a Contamination Event**  
**Abstract n°2562**

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**KEYWORDS:** lateral gene transfer, community evolution, metagenome sequencing

How environmental contamination affects groundwater microbial community biodiversity and the adaptation mechanisms used, is a central, but poorly understood, issue in ecology. Groundwater from the Oak Ridge Integrated Field Research Center (Oak Ridge, TN, USA), representing a range of uranium (U) and nitrate concentrations and pH values, was examined using a functional gene array (GeoChip 5.0) and 16S rRNA amplicon and metagenomic sequencing to address these issues. Functional richness diversity significantly ( $p < 0.05$ ) decreased as U (but not nitrate) increased, and key functional populations (*dsrA*, cytochrome, *nirK*) significantly ( $p < 0.05$ ) increased as U or nitrate increased. Next, metagenome sequencing of pristine and contaminated groundwater was compared to



evaluate phylogenetic and metabolic diversity. The pristine community encodes redundant and mostly complete geochemical cycles distributed over multiple lineages, while in the contaminated community, many geochemical cycles appear truncated due to decreased biodiversity and dominance by Rhodanobacter populations. Sequence analysis of 16S-based amplicons confirmed the high abundance of Rhodanobacter in contaminated wells, but rare occurrence in uncontaminated wells. Lateral gene transfer (LGT) has been suggested as a major adaptive mechanism. To determine the importance of LGT in the adaptation of these communities to contamination, Rhodanobacter reference genomes were sequenced and compared to the metagenome sequences. Multiple geochemically important genes (denitrification enzymes, cytochrome), were native to Rhodanobacter, but numerous metal resistance genes within a recombinational hotspot were subjected to LGT and appeared to be highly mobile within Rhodanobacter populations, suggesting the importance of LGT for acquisition of critical genes for survival during the evolution of the groundwater communities after heavy metal contamination. Further analysis using the null model test revealed the major assembly process was dispersal limitation in uncontaminated areas and niche selection in contaminated areas, further supporting the need for genetic adaptation in contaminated environments. Overall, these studies provide insight into how groundwater microbial communities shift from high functional diversity and adaptability to dominance of single populations that were able to quickly adapt and survive abrupt environmental stress.



# Regional scale hydrogeological investigation of the Bakken Formation in the Williston Basin

## Abstract n°2563

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**KEYWORDS:** Bakken, Williston Basin, Regional hydrogeology

The Bakken Formation is currently the most productive oil producing formation in the Williston Basin, and one of the most economically important tight oil plays in North America. The Williston basin is a large intracratonic sedimentary basin located on the western shelf of the North American craton, and host to many natural resources. Within the Bakken Formation it has been shown that oil has migrated from the thermally mature central portion of the basin, outwards toward the less mature portion of the basin, and north to Canada. Despite the economic significance of the Bakken Formation, its regional hydrogeology, and the influences of groundwater flow on oil migration and accumulations have been poorly studied. To further our understanding of the regional hydrogeology of the Bakken Formation a newly created database spanning the entire Williston basin was generated. This database compiled information from historical records including drill stem tests, initial potential tests, scientific literature, government reports, and data previously collected by the University of Alberta hydrogeology research group. Once the database was assembled, an intensive iterative culling procedure was implemented to remove any data which may have been affected by nearby production and injection wells or hydraulic fracturing operations. From the culled data a potentiometric surface map and water chemistry maps were generated. The potentiometric surface map shows a large central area with greater than hydrostatic formation pressures while conditions in distal areas are near hydrostatic. Hydrochemical analyses reveal highly variable water chemistry with total dissolved solids ranging from less than 10,000 mg L to over 300,000 mg L with salinity generally increasing toward the centre of the basin. This study provides the most complete depiction of the governing hydraulic processes and water chemical characterization of the Bakken Formation across the entire Williston Basin. These results advance our understanding of the hydrogeological conditions of the poorly studied Bakken Formation and help to reveal the potential effect of regional groundwater flow on oil accumulations within this formation.



**Hydrogeological study for the enhancement of drinking water distribution in Sparouine Village (French Guiana)  
Abstract n°2564**

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**KEYWORDS:** drinking water accessibility, tomography, weathering profile

Saint-Laurent-du-Maroni is a border town in north-west French Guiana, located on the Maroni River with a high population growth (average +5,1% per year). The population is spread in areas far from the city center, with no access to drinking water distribution network. They have water wells equipped with human motorized pump, which often not sufficient to comply with the population needs and uses. The Sparouine village, with around 800 people, was chosen by the municipality to implement a proper drinking water supply. According to water consumption, the production should aim minimum 200 m<sup>3</sup> per day. The region is essentially composed of metamorphic staurotide micashist rocks. Dolerite dykes with kilometric scale and quartz veins intrude also the area. A geophysical prospection with tomography was conducted to implement four prospection cored boreholes. This work has revealed an important structure which cuts three electrical panels, first considered as a dolerite dyke and with no information on its draining properties. A cored drilling borehole was then completed to study the geology and aquifer potential of this structure. Finally, the results revealed an important weathering profile at this place, probably due to a deep corridor faults. More than 40 m of clay was first crossed and then 30 m of altered schist, before targeting the fissured hard rock. The cores obtained allowed to see a big density of cracks, very weathered, showing an important water circulation. Furthermore, no trace of oxidation was found and the presence of calco-pyrite proved that such weathering can appear in reducing environment. Whereas most of the water wells in the West of French Guiana have a production flow around 4 m<sup>3</sup> h, it is likely that the future well of Sparouine could reveal a flow rate over 10 m<sup>3</sup> h, which could enable to reach the production target with one well only. Thus this example enlightens the importance of underground water and hydrogeology contribution for drinking water access and development for isolated places.





**Using multiparametric approach for watershed delineation of karst aquifer – Case example, spring Mlava (eastern Serbia)  
Abstract n°2565**

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KEYWORDS: karst, watershed, isotop, model

It is very difficult to define real watershed spatial position in layout and vertical view in an anisotropic aquifer such as carbonate matrix. Even after many different methods which are often employed, the result in the case of karst aquifer cannot be exact and sure. Still, multiparametric approach can be provided for investigations such as combination of tree different analyses- 3D spatial modelling of karst aquifers, stochastic modelling (simulation of the daily value of a karst springs) as well as isotopic analyses. First is to determine the possible distribution of karst channels based on tectonic, morphological, geological, hydrogeological and speleological data of 3D spatial parameters (this analyses gives a spatial position of watershed as well as catchment area), second is to use transformation functions as one of the main output from the model, in addition to highlighting the value of simulation karst springs (this model gives a catchment area without spatial position) and third is T+3He method which is used for define groundwater age for inegrate first two methods. Good example of this multiparametric approach is spring Mlava, which is one of the main drainage source of Beljanica Mountain in eastern Serbia, and it is a part of the Carpathian Balkan arch (northern Alpine branch). This paper includes an analysis of the discharge regime of Mlava spring based on historical and newly collected data, the correlation of spring discharges with isotopic analyses of the spring waters, and the created 3D spatial model of karst interior. Based on multiparametric approach watershed of spring Mlava covers an area of about 120 km<sup>2</sup> with main circulation of groundwater on - 100 m, as well as period from infiltration zone up to discharge zone is around of 6 years.



**Origin of Methane in Edge Oil-field Mineral Waters of the Iwonicz Zdrój Spa, Central Carpathian Synclinorium, SE Poland.  
Abstract n°2566**

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KEYWORDS: methane origin, carbon dioxide, isotopic composition, edge oil-field water

Mineral edge oil-field waters are extracted for curative and drinking purposes by several wells and springs within the Iwonicz anticline, which is one of the several fold structures of the Central Carpathian Synclinorium, SE Poland. The waters extracted in the Iwonicz Zdrój spa are mainly Cl-HCO<sub>3</sub>-Na type, with total mineralization from 7 to 19 g L, rich in Br and I, and first of all in CH<sub>4</sub> and CO<sub>2</sub> in gas phase. Differentiation of CH<sub>4</sub> sources is based on isotopic techniques which involve measurement of isotopic ratio of both carbon and hydrogen within methane and related compounds such as higher hydrocarbons (if present), isotopic composition of associated carbon dioxide and water. For this study samples of gas phase (CH<sub>4</sub> and CO<sub>2</sub>) and water have been collected from 8 wells used by spa. The isotopic composition of methane ranged from -67‰ to -47‰ and -249‰ to -202‰, for carbon and hydrogen respectively. This suggests that CH<sub>4</sub> is associated with early maturation processes or originates from mixed source, both thermogenic and/or bacterial processes. Positive correlation of <sup>13</sup>C/CH<sub>4</sub> with depth strongly suggests that thermogenic methane is a major fraction of gas phase and the bacterial contribution may increase in shallow wells. Obtained isotopic composition of CH<sub>4</sub> may also be a result of pure bacterial activities which produce methane combined with succeeding isotopic alterations via CH<sub>4</sub> oxidation and other reactions during methane degassing. Calculated fractionation factor <sup>13</sup>C between coexisting CH<sub>4</sub> and CO<sub>2</sub> in water in the range of 1.06 – 1.09 indicates that CO<sub>2</sub> reduction is the dominant methanogenic pathway.



## Abstract n°2568

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KEYWORDS: <p>Regional Groundwater Flow, Ecohydrology, Groundwater Modeling

<p>Surrounding the north of Bogotá D.C. urban area and crossing from east to west the city, is located a Forest zone known as the Thomas Van der Hammen Forest Reserve. The reserve area is about 14 km<sup>2</sup> and is mainly composed by trees, wetlands, pasture for cow farmers, some buildings and greenhouses for flower industry. This reserve has caused an important conflict of interests due to the city expansion politics and the environmental conservation- The Reserve was drawn after some city development inside it, and aims to create the biggest urban reserve in South America, but the accelerated growth of Bogotá D.C. requires areas to develop housing projects. Currently there is a controversy of the consequences of urbanization or conservation of this Forest Reserve. There are some environmental studies but few on the actual groundwater flow system behavior and the relationship between shallow and deep aquifers with wetlands, soil, forest, the recharge and discharge zones+ but none on the hydrogeological impacts or at least good enough forecasts of land use change in this area. The main two objectives of this study are- (i) understand the natural and actual groundwater flow system in the Forest Reserve through a 3D numerical model using MODFLOW, and (ii) to simulate an urban development scenario modeling the soil replacement by impervious surface, obtained the future groundwater system behavior and the impacts on the reserve ecological components (wetlands, aquifer recharge and discharge, forest) which in turn have impacts on plants, bird species and other wild life. The results of the groundwater system analysis through a numerical model is expected to help the decision makers understand the impact of urbanize this Forest Reserve. This investigation is under development, and preliminary model results shows that urbanization will have impacts on shallow quaternary low yield aquifers and its ecosystem, but the main deep sandstone cretaceous aquifers will be not impacted, just to protect its recharge areas located in the hills near the Forest Reserve.



**Public -Private Partnership in Water Supply- Enhancing the Role of Water Vendors in the Sustainable and Safe Water Provisioning Services in Nigeria- A Proposal for Lagos State**  
**Abstract n°2569**

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KEYWORDS: groundwater, water vendor, privatisation, Public-Private Partnership

Water vendors who mostly source their water supply from groundwater respond to the needs and preferences of a clientele composed primarily of low-income families. How do they manage to do this, for customers who are said to be too poor to pay for city water? How can they provide service coverage of areas where city water authorities and concessionaires hesitate to invest? One answer, documented in a 1990 study of willingness to pay in rural Nigeria, is that water vendor services' are demand-driven and they deliver them the way their clientele needs them- reliably, and in small quantities, which remain affordable when family funds are tight, and incomes irregular. The clients these providers serve have historically been of little interest to the large concessionaires, whose primary objective is to make a profit. Water vendors serve many functions in the provision of water services. Some manage one or more water points or sell individual buckets of water from door to door. Such activities provide jobs for several thousand people in Lagos, providing a source of income to thousands of low-income families. More flexible than the concessionaires, water vendors can respond more easily to rapid changes in demand linked to the growth of unplanned urban areas. They offer a wide variety of services close to where people live, allowing them to select the most convenient. They adapt to the limitations of their clients' needs and income, and communicate face-to-face with their clients about problems, for example, with water quality, rather than at a distance and through the time consuming bureaucratic procedures of the concessionaires. For this reason, a strategy of making immediate improvements in household access to safe water necessitates starting with the service providers who are already on the ground doing the job the state is unable to do.



**Trans-boundary study of unregulated and emerging contaminants in Upper Rhine aquifer**  
**Abstract n°2573**

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**KEYWORDS:** emerging contaminants, Upper Rhine aquifer, transboundary inventory, water policies, Water Framework Directive

Upper Rhine aquifer is a very productive aquifer. But it is highly vulnerable due to very low natural protective cover at its surface. This aquifer is under various pressures (agricultural, industrial, domestic). Consequently the water body is impacted by industrial pollutions and diffuse pollutions, reason why it was classified at risk to cause a failure of Water Framework Directive objectives. Several works were undertaken during the past 20 years to characterise these pollutions and their spatial and temporal evolution. Thus, in 2016, trans-boundary inventory of water quality of Upper Rhine aquifer will be lead during the INTERREG V project ERMES under the supervision of the APRONA. The study will enable a trans-boundary research and analysis of targeted unregulated and emerging contaminants in Upper Rhine aquifer. This project aims to determine the occurrence of organic contaminants, including pesticides and metabolites, industrial compounds but also emerging contaminants (i.e. pharmaceuticals). This list of molecules was elaborated in a consensus way based on the up to date knowledge from experts of French, German and Swiss research organisms and public authorities in charge of water quality assessment of this aquifer. The selection of molecules of interest was based on availability of analytical methods, current knowledge on contaminants occurrence in groundwater and type of pressures. A list of 66 molecules has been established and will be analysed on the groundwater samples. Results will help stakeholders to better manage the groundwater resources of Upper Rhine aquifer. They would allow discriminating between patterns of pollution (diffuse or point source plume) and they would make it possible for water policies to choose the best plan of measure to undertake for achieving WFD objectives.



## Quantifying the natural protection of karst aquifers Abstract n°2578

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KEYWORDS: vulnerability, karst groundwater, tracer experiments, protection unit

Tracing experiments are recognized as an essential tool for validating vulnerability mapping in karst terrains. The proposed approach first includes the development of a standardized artificial recharge scenario for conducting and comparing tracer test in karst environments. Based on accurate discharge and tracer concentration monitoring at the karst system discharge area, non-reactive tracer attenuation, mass recovery and mean transit time over the duration of the main breakthrough curve is used for the quantitative assessment and validation of spatial groundwater vulnerability. Comparative tracer tests performed at several Swiss karst systems typically illustrate that recovery rates differ significantly for injections within the same catchment even in case of limited contrast of a single vulnerability mapping criteria (e.g. a few decimeters of soil thickness). Multi-tracer tests focused successively on each sub-system controlling the water and contaminant flow in karst settings allowing a better quantification of conservative solute concentration attenuation from the soil surface to the discharge area. Storage in the soil and subsoil thereby showed to play the most important role in relation to intrinsic vulnerability in many karst systems. A protection unit was defined based on the quantitative interpretation of numerous tracer experiments and classes of vulnerability criteria were assigned accordingly. This protection unit corresponds to the smallest protection effect or vulnerability class, respectively, that can be determined for a mapping criterion, and which generate a quantifiable influence on the tracer breakthrough curve (maximum concentration, mass recovery, transit time).



**On-site sanitation at the crossroads of public policies of soil and water, under the control of the users**  
**Abstract n°2579**

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KEYWORDS: public service, vadose zone, environmental impact, stakeholder, legitimacy

On-site sanitation (OSS) is any type of decentralised management of household waste waters, alternative to the centralised network coupled to a wastewater treatment plant. It generally uses functions of the soils for treating water before rejecting it to the aquifers or rivers. Considering the total European population (460 million people), about 150 million are in concern of on-site wastewater treatment. Besides, more than 20 million European citizens do not have access to safe sanitation (25% in centralised, 75% in decentralised systems). In France, 5.4 million of OSS systems cover the needs of 13 million people. Each year, nearly 150 000 systems are renewed or built. The main goal for scientific studies is helping the Service Public of ANC (SPANC) -- on-site sanitation public service -- in charge of OSS management. Somewhere between o the soil will do the work O and o the system must provide drinking water to the soil O a realistic position will arise from a better knowledge of what happen within the soil and the vadose zone. The missions of the SPANC, bodies of the new French politics, were based on the follow-up of the OSS devices in situ, at home, and obligation of means turning into expenditures at the user's charge. In practice, it was felt as follows- when the environmental moralism came to SPANK the users... The research project ANCRES (2010-2015) (in French- Assainissement Non Collectif - rétention et épuration par les sols OSS – retention and depurator functions of the soils) had as an objective to explain the emergence and evolution of new public policies for OSS. The need was evidenced to justify the new public policies about on-site sanitation by scientific data, to precise the fuzzy idea of environmental impact which gives its legitimacy to the SPANC, and finally to identify the point of view of the actors in order to evaluate the chance of success of the new regulations.



**Long-term anthropisation of groundwater resources in the Kairouan region (central Tunisia)**  
**Abstract n°2580**

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**KEYWORDS:** Tunisia, overexploitation, anthropisation

To the West of the city of Kairouan, in central Tunisia, the Merguellil catchment is emblematic of the rapid changes affecting water resources in the Mediterranean region. Environmental and social components of this fragile semi-arid system continuously interact and react to multiple internal and external drivers (from climate fluctuations to demographic pressure and economic development). The long-term hydrological monitoring, started by the Tunisian Ministry of Agriculture in 1968 and complemented by many other initiatives, enables to track the multiple steps that led to the present state of general groundwater depletion in the area. In the upstream part of the catchment, exchanges between surface water and aquifers and irrigation practices are affected by the numerous water and soil conservation works that significantly reduce the surface runoff and the river flow, and also by the voluntary overexploitation of one of the four small aquifers, which has been exploited since one century for the water supply to the littoral cities. Another modification of the water flows is the big El Haouareb dam (with the longest dyke of Tunisia) that definitively stops the direct recharge of the Kairouan plain aquifer by floods, and created a new location and process of recharge (by major losses through fissures of the carbonate substratum). Last but not least, the intense development of irrigation in the Kairouan plain relies only on the underneath large and thick aquifer, contributing to the continuous decrease of the water table (between 0.5 and 1 m per year). The long term large and reliable set of data outlined the spatio-temporal heterogeneity, the complex modifications of processes, flows, and locations of recharge. But many uncertainties still remain, especially regarding the water balance and the influence of extreme events. The geochemical survey (especially with isotopes) revealed an even higher degree of complexity than the hydrodynamic patterns, defying forecasts of changes in water quality.



**History and modern state of mineral water study at the Staraya Russa spa  
(Northwestern Russia)  
Abstract n°2581**

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**KEYWORDS:** mineral water, history, chemical composition, genesis

Staraya Russa is located in the northwestern part of the Russian Platform. Three types of waters of Upper-Devonian aquifers are used for medical purposes, with TDS of 3, 6 and 16-19 g/l. The hydraulic head is above land surface. At present, there are 12 flowing springs and wells. Mineral water of Staraya Russa is first mentioned in 1815, by Dr F. Hass (1780-1853), although the local people used this water from ancient times for the treatment of many diseases. Dr Hass investigated mineral water chemical composition, and its medicinal properties. In 1824, searching for traces of rock salt in Staraya Russa, Russian mining engineer I. Tchaikovsky (father of the composer P. Tchaikovsky) paid attention on mineral waters. In his scientific paper published in "Mining journal", he suggested that water mineralization is caused by the inflow from upper layers containing salts. Later, mostly physicians investigated this water for the study of its healing properties. The comprehensive study of the mineral water genesis began only in the 20th century. B.N.Arkhangel'sky, A.I.Korotkov, A.N.Pavlov, V.V.Seladyina, I.K.Zaytsev and other hydrogeologists dealt with the origin of Staraya Russa mineral water. It was stated that tectonic faults of the crystalline basement could cause the movement of sedimentary cover, and mineral water rises from the lower aquifers through the system of faults and joints. The present chemical composition of the water is formed as a result of mixing the water of upper and lower aquifers and interaction with the water-bearing rocks. Application of modern isotopic methods allowed clarifying the mineral water genesis. Comprehensive use of hydrochemical and isotopic methods made it possible to suggest that one of the mixing components is ancient infiltration water. Further investigations will be focused on the mixing ratios of different types of water and role of "water-rock" interaction in the mineral water formation.



**Evolution of the soil buffer capacity during the provision of two water related ecosystem services**  
**Abstract n°2582**

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**KEYWORDS:** Column test, sorption test, Soil buffer effect, Managed aquifer Recharge plant, Phyto-Treatment plant

The soil is the medium through which infiltration occurs, and its capacity to attenuate pollutants and allowing infiltration is critical for designing and setting up Managed Aquifer Recharge (MAR) and large scale phyto-treatment schemes. Within this work, the buffering capacity (on nutrients, pharmaceutical compounds and Terbutylazine) of two soils and its evolution under the continuous infiltration of Treated WasteWater is evaluated. The soils have been sampled at two different experimental field sites- Sant'Alessio Induced RiverBank Filtration (IRBF) plant and San Niccolò large scale phyto-treatment test-plant. Chemical analysis for pH, CEC, organic and inorganic carbon were run for both soil types, like also physical analysis for grain size and particle surface area. High differences between the two soil were detected, in particularly related to the organic carbon contents (48% and 0,9 % for the soil from the phyto-treatment test-plant and for the soil from the IRBF plant respectively). Sorption tests have been performed (in abiotic conditions) in order to evaluate the buffer effect related only to the adsorption capacity of the soils. Three columns (50 9 cm, specifically designed to minimize the pharmaceutical adsorption on the column components) per each soil were set up. There, water was continuously infiltrated bottom-to-top with a constant flow of 540 mL d (from 2 to 5 total pore volume exchanged per week, respectively for the San Niccolò and Sant'Alessio soil). The TWW used for the experiment came from a local wastewater treatment plant, weekly collected and used as infiltration source with the addition of some selected chemical compounds (pharmaceuticals and pesticides). Water quality was investigated by means of periodic water sampling from each column (4 points distributed along the column) and from the TWW collection point. The experiments presented here allowed getting further insights on soil capacity, related to its physico-chemical characteristics, to buffer peri-urban water related potentially negative effect on the beneficial result provided by MAR and large scale phyto-treatment plant.



# **Predicting Seawater Intrusion in Coastal Groundwater Boreholes Using Measurements and Modelling of Self-Potentials**

## **Abstract n°2584**

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**KEYWORDS:** self-potentials, seawater intrusion

Many coastal groundwater boreholes are under threat from seawater intrusion- this is exacerbated in summer by low water tables and increased abstraction. Existing hydrochemistry or geophysical techniques often fail to predict the timing of intrusion events. We investigate whether the proximity of seawater can influence self-potentials (SPs) measured within groundwater boreholes, with the aim of using SP monitoring to provide early warning of saline intrusion. SP data collection- SP data were collected from a coastal groundwater borehole in the fractured Chalk of England. Downhole SP monitoring was conducted at a second site, located more than 60 km inland and also within the Chalk. Spectral analysis showed that semi-diurnal SP fluctuations were several orders of magnitude higher at the coast than inland, indicating a strong influence from oceanic tides. Seawater intrusion occurred in the coastal borehole on several occasions during the monitoring period. A characteristic increase in SP (c.100-300 microvolts) was observed within the borehole array, several days before saline breakthrough. Modelling results- Hydrodynamic and geoelectric modelling suggest that observed pressure changes (associated with the streaming potential) are insufficient to explain the magnitude of semi-diurnal SP fluctuations, whilst modelling of the exclusion-diffusion potential closely matched the observed coastal data. Simulations of a homogenous aquifer consistently produced a negative precursor, although the inclusion of a fractured zone led to the development of strongly positive precursor signals, comparable with field observations. Sensitivity analysis suggests variations in the dispersion of the saline front, associated with aquifer heterogeneity, are an important control on the nature of SP precursors. Conclusions- Our results show that combined SP monitoring and modelling holds considerable promise as an early warning device for seawater intrusion. We now aim to refine our understanding of the technique by applying it to a range of aquifer types.





**Pivotal role of a Hydrogeologist for water supply arrangement in Water scarce  
Andaman and Nicobar Islands,India  
Abstract n°2586**

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**KEYWORDS:** Artificial recharge, Earth quake, Geomorphology, Hydrogeology, Rainwater harvesting, Tsunami, Water shed development.

The Andaman and Nicobar Islands, India, lies in tropical regions and house 3,80,581 population. Port Blair is the capital town. Out of 572 islands only 38 are inhabited. Total island area is 8073 sq.km. Severe water scarcity exists in the Islands. In spite of rainfall >3000 mm per annum, geomorphology, size and shape of the Islands, steep slope, low infiltration capacity of the geological formations and close proximity of the hills to the sea are the reasons for low groundwater potentials in the major parts of Andaman and Nicobar Islands. Dearth of catchments, high evaporation and environmental regulations, hinder the surface water projects. Thus the development and management of Water Resources have been a perennial problem. The exemplary research and development work by the authors reveals good prospect of water shed development through conjunctive use of surface water and ground water, rain water harvesting, artificial recharge and water conservation. The studies revealed that amongst the geological formations Marine sedimentaries are ubiquitous (>90%), while the Ophiolites, Coralline atolls and limestone have limited (5%) geographical area. The former lacks ground water potential down to 200 metre depth while the other two possess good ground water potential. Hydrological studies revealed substantial baseflow along streams. Through construction of collector wells, subsurface dam, series of check dam, ponds, huge quantity of baseflow and surplus rainwater are conserved in the valleys. These have solved the age old problem of drinking and irrigation water in the islands. The 26.12.04 tsunami and earth quake in the islands made colossal impact on both surface and ground water resources. The hydrogeological studies in post-tsunami, have been highly useful for successful construction of water resources structures as also witnessed various events which are scarce in the literature. Following recommendation, 50 collector wells for drinking water supply and 245 check dams, 1526 ponds and 2000 wells are constructed for augmentation of irrigation. Results and models from the study may be replicated elsewhere in the tropical Islands.



**SPRING- A POTENTIAL WATER SUPPLY SOURCE FOR ECONOMIC DEVELOPMENT  
IN ANDAMAN & NICOBAR ISLANDS, INDIA  
Abstract n°2587**

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**KEYWORDS:** Torrential rainfall, springs, Marine sedimentary group of rocks, Ophiolites, Coralline limestone, rural drinking water supply, urban water supply, A&N Islands, Port Blair, Rutland Island, Medium Term option , sustainable economic growth

Tourism is the backbone of economy of Andaman&Nicobar Islands,India.The tourist spots occur in rural areas of the Islands with its base at capital town Port Blair. The tourism often shatters due to water scarcity and make an impact on economic growth of the archipelago.At this juncture springs form a potential source of water supply in the entire Andaman&Nicobar Islands and play a pivotal role in proliferation of tourism.Torrential rainfall > 3000 mm,geology and geomorphology have collectively facilitate the origin of numerous springs in the islands,occur in all the three major geological formations. The springs in pervasive Marine sedimentary rocks are relatively less sustainable, while the springs in Ophiolites and Coralline limestone are highly potential and perennial.In view of recurrent water scarcity in Port Blair, a detailed hydrogeological studies were carried out in the contiguous Rutland Island to recommend the feasibility of water supply from springs.The studies revealed that the island is underlain mainly by fractured Ultramafics(Ophiolites). Prompted by the recommendation, supply of spring water to Port Blair town and ships , was immediately started through barges. The study also revealed that from 16 springs nearly 36,54,722 Gallons per day of good quality water was flowing to the sea while the daily shortage of Port Blair was estimated as 31 lakh Gallons.It was recommended that the entire water, may be sent across the strait through under sea or over sea pipelines to Port Blair for its supply to the town. It is envisaged that it could make water availability to Port Blair town sustainable for at least for 25 years. The project is approved by the Government and the work is underway.As per the recommendation the steps for catchment recharge in all the major spring-sheds in rural areas have been taken up to make the spring yield sustainable. All these efforts by hydro-geologists will usher sustainable economic growth in Andaman&Nicobar Islands.



## **Towards common groundwater management - the case of Copiapo in Northern Chile**

### **Abstract n°2589**

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**KEYWORDS:** governance, policy reform, water users' associations

In the 1980-1990's, the fruit production industry rapidly developed in Northern regions of Chile. Surface water resources being limited, alluvial aquifers were increasingly tapped and exploited above sustainable limits. This resulted in sustained groundwater level decline, reaching up to 6 meters per years. After a six year drought, the agricultural economy was on the verge of collapse (many wells went dry and some tree plantations were uprooted) and conflicts between farmers, water supply, and mining companies intensified. The paper first analyses the reasons that explain why this crisis could take place while the State theoretically had the regulatory tools to prevent it. We point at limited knowledge of aquifers+ allocation based on foreseeable use+ political lobbying from the farming sector to obtain new water rights after basin closure+ illegal abstraction+ and trade of water rights from seasonal to permanent uses. The paper then presents the water management reform implemented in response to this crisis. The reform relies on 4 pillars- increased supply with desalination+ increased irrigation efficiency+ that GWUAs may decide to shift from a water allocation to a water entitlement regime (water rights expressed in a percentage of the volume available each year instead of a fixed value)+ and the establishment of Ground Water Users' Associations (GWU). This reform faced significant opposition from the main actors attempting to protect short term vested interest+ the paper analyses this opposition using a political economy framework. The establishment of the GWUAs takes place in this context. We describe how one of these associations, CASUB, managed to gain legitimacy and move towards the implementation of the reform. This success can be attributed to its ability to deliver short term benefits to its members- production and dissemination of knowledge of the aquifer+ technical assistance in operating wells and optimizing irrigation+ obtaining public funds to create collective wells in replacement of individual dry wells... After a few years, CASUB has the required internal and external legitimacy to start implementing the water allocation reform.



# Hydrogeochemical characterization of groundwater resources in Plateaux Region of Togo, using multivariate statistical analysis and conventional graphical methods

## Abstract n°2594

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**KEYWORDS:** Hydrogeochemistry, Multivariate Statistical Analysis, Plateaux Region, Togo

In Togo as well as in other sub-Saharan Africa countries, drinking water supply (DWS) is a major challenge and boreholes are the main improved water source in rural areas. Besides the maintenance of these boreholes, the sustainability of DWS lay undeniably on that of the resource which could be affected by anthropogenic activities and seasonal variations. This study aims to characterize the hydrogeochemical processes in the basement terrain aquifer system of Plateaux Region, Togo, where various crops and cash crops such as coffee, cocoa and cotton are concentrated. Hydrogeological data of around 500 boreholes were collected and used to create an hydrochemical database (pH, EC, TDS, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup>, K<sup>+</sup>, HCO<sub>3</sub><sup>-</sup>, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, and NO<sub>3</sub><sup>-</sup>) of 336 boreholes. All water samples were collected between 2008 and 2011 during low water level period and were analyzed by methods of French Association of Standardization (AFNOR). Hierarchical cluster analysis (HCA) and principal components analysis (PCA) were applied. The results obtained are integrated with geology, geomorphology, soil and LULC data into a GIS for spatial analysis. Five geochemical groups having each two classes, are obtained by the HCA. They evolve from very fresh and acidic (Group 1) to brackish and circumneutral (Groups 2 and 5) with dominant Mixte Cation-HCO<sub>3</sub> and Ca-Mg-Cl hydrochemical facies. Samples from classes 1b, 2b and 3b are characterized by high concentrations of NO<sub>3</sub><sup>-</sup>. Water-rock interaction and anthropogenic contamination are the first two component of the PCA and account respectively for 55% and 19% of the total variance in the dataset. Conventional graphics have shown the predominance of silicate minerals weathering associated to cation exchange processes over the dissolution of carbonate minerals and evaporation process. Potential organic source of NO<sub>3</sub><sup>-</sup> and probable contribution of organic matter decomposition and or oxidation of sulfur compounds to SO<sub>4</sub><sup>2-</sup> content are highlighted. The Spatial analysis have allowed to divide the region into different hydrogeochemical zones. This study appear vital to the sustainable management of groundwater resources in the study area.



**A groundwater overexploitation without sensitive impacts- technical approaches and social perception in central Tunisia**  
**Abstract n°2598**

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**KEYWORDS:** public policy, anthropisation, water management

In Central Tunisia, the Kairouan plain is considered as a region of major potentiality for the agricultural development. In this large region, the supply of drinking water and the demand for irrigation are fundamental priorities, satisfied by the groundwater pumping. This has led to the severe overexploitation of aquifers since decades. Thousands of wells and boreholes drilled to support the expansion of irrigation are a visible expression of the human grip on the environment. Most of them are illicit, which also illustrates the complex equilibrium between the official vision (including a relevant legal framework, and efficient institutions) and the real practices in the field. More generally, the regional hydrology (in both surface and underground compartments) is deeply modified by various types of human activities. For instance water and soil conservation works induced a significant decrease of the river flow in the upstream catchment. But our interlocutors (individual and institutional) have very different perceptions of the impact of the different anthropogenic actions on water resources and on water uses. Many models of surface runoff and groundwater flows, sometimes coupled, have been built in order to represent the changes in the regional water budget, with various levels of complexity and relevance of initial assumptions. They are often of good quality and provide reliable estimates for future scenarios. Critical issues are expected in long-term trends. Nevertheless the water exploitation and management did not really change over the last decades- farmers and regional authorities in charge of the water control do not base their strategies on modelling results. This questions the importance of the scientific input from researchers in the final decision making process.



## **An innovative method for modeling the karstogenesis in carbonate reservoirs Abstract n°2609**

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**KEYWORDS:** Keywords - karst network + cellular automaton + lattice gas+ advective flow+ dispersive flow+ conduits.

Forecasting the 3D organisation of a karst network is a challenging issue since the complexity of the system is dependent on various embedded parameters - i) the heterogeneity of the matrix medium of the series in which the network has been created, ii) the multi-scales fracture network that partially drives the spatial distribution of dissolution features, iii) the multi-stages development of the karstic network through geological times, with multiple flow gradients and location of water tables. Consequently, the modeling of karstic aquifers requires to be driven by pre-existing heterogeneity in order to produce realistic images of heterogeneity. A very new method for simulating karstogenesis among other diagenetic phenomena has been developed using a cellular automaton. A lattice gas in which particles are moving mimics the fluid transportation in the aquifer and its effects on reservoir properties. The Langevin equation is solved through a stochastic process that involves both advective and dispersive flows. According to the location in the model, the original properties of the matrix, the existence of any discontinuity like pre existing fractures or beddings, particles flow in the model and modify the medium, enlarging karst conduits thanks to the memory effect. Several types of karstic reservoirs can be simulated using this innovative methodology - i) the very classic meteoric karst, with the possible representation of the epikarstic, unsaturated and saturated zones, ii) the hydrothermal karst, for which the advective flow is vertical, iii) the island karst, in which dissolution occurs in the mixing zone between the fresh water lense and the marine water. The methodology has been successfully applied on several field cases, and has been matched on actual values of karstic porosity and permeability.



**Comparative study of the evaluation methods of the vulnerability of aquifers to pollution in a porous environment with the use of SIG tools. With application to the aquifer of Souss-Chtouka, Morocco  
Abstract n°2611**

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KEYWORDS: MOROCCO, DRASTIC, DRIST, GOD, Minnesota, DRASTIV, SIG, Vulnerability, Pollution

The coastal aquifer of Souss-Chtouka is localized in the geographical center of Morocco, extends over a surface approximately 5000 Km<sup>2</sup> and circulates in plio-quaternaire alluviums of thickness varying generally between less than 10 m and 30 m. The groundwater's quality of this important aquifer (used for drinking water, agricultural and industrial requirements), is often threatened by various sources of pollution of anthropological origin (domestic, agricultural and industrial). Given the high costs necessary for the purification of groundwater, it is very important to prioritize prevention. The characterization of space distribution of the aquifers vulnerability to pollution, represents one of the most effective tools in the prevention of aquifer pollution. For a better appreciation of this vulnerability, five different methods have been tested (thanks to the use of the powerful features offered by the SIG) and their results have been compared to the location of the potential sources of the pollution of aquifers and at the same time, to the water quality in the aquifers for quite some time. The obtained results shows that the DRIST method (Sinan, 2000), using parameters related to the ground and none-saturated zone, characterizes in the best way, the spatial variation of the aquifer of Souss-Massa vulnerability to pollution. This method has also been tested successfully on other aquifers in Morocco (Haouz, Angads, Kerte, Bouarg). We recommend its use for the characterization of the vulnerability in porous aquifers in Morocco and in other countries of the world.



**Characterization of vulnerability to pollution and protection of drinking water  
abstraction of karst aquifers  
Abstract n°2612**

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**KEYWORDS:** Morocco, Pollution, Vulnerability, Aquifer, Karst, RISKE 2, Perimeters of Protection.

Karst aquifers are known to be very vulnerable to pollution, as well as wells whose water originates their. Their protection against pollution requires at first to characterize the degree of vulnerability to pollution of the aquifer that supplies them. Several methods of characterizing the vulnerability to pollution of karst aquifers are mentioned in international literature. The objective of this research is to characterize the vulnerability to pollution of the northwest part of the Middle Atlas, in Morocco (zone El Hajeb). Its area is about 500 km<sup>2</sup>. Because of the hydrogeological context and available data, the RISKE 2 method was chosen and applied to characterize the spatial variation of the vulnerability to pollution of the El Hajeb aquifer. The results indicate that the aquifer has a generally medium to high vulnerability to pollution. The areas of very high vulnerability are located in the recharge zones and at the outcrops of limestone formations to the NE of the study area. Indeed, high concentrations of nitrate (exceeding the norms acceptable for drinking water) have been identified in the northern part of the groundwater which is used for agriculture purposes. Concerning the south part, the groundwater is considered to be good quality. Protection perimeters of two wells have been delimited, referring to the vulnerability of the pollution map and the piezometric map. Within these areas, appropriate constraints will be imposed on potentially polluting activities. Finally, we have characterized the quality of groundwater in the study area, based on studies and analyses of various wells undertaken by the ABH Sebou and ONEE Water Branch. This part highlights the development of agricultural pollution in the region.



**Groundwater management strategy to sustain ecologically sensitive wetlands in a peri-urban environment, Southern Ontario, Canada.  
Abstract n°2613**

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**KEYWORDS:** Use conflict, Drainage, Infiltration, Nonpoint source pollution, Wetland, Underground parking

Surface water features in peri-urban environments face hydrogeological stresses due to alterations of groundwater flow and quality by urban development. Peri-urban contexts deal with conflicting stakeholder needs (agencies, developers) for groundwater usage, which makes it necessary to mitigate impacts such as the decline of the groundwater table and impacts on groundwater and surface water quality. This paper presents a groundwater management strategy developed to sustain groundwater contributions to two sensitive natural wetlands located downgradient from a proposed underground parking in Southern Ontario, Canada. Permanent lowering of the groundwater table is required using a passive drainage system for the underground structure. To compensate the deficit in groundwater contribution to the wetlands, the proposed strategy consists of infiltrating the extracted groundwater upgradient from the wetland, while avoiding recirculation of infiltrated water to the passive drainage system. Preliminary geological investigations at the site encountered stratified alternating coarse and fine glacial deposits, with unconfined to semi-confined groundwater conditions. The feasibility of this approach was assessed based on a combination of pumping tests, slug tests, infiltration tests, and analytical simulations. Pre-construction monitoring using data loggers was utilized to provide baseline information on shallow groundwater regimes adjacent to the wetlands and at the location of the proposed underground structure. Recommendations for long term maintenance of groundwater management system are provided. Measures to mitigate groundwater pollution bound to this infiltration scheme and more generally, nonpoint source pollution linked to infiltration in peri-urban or rural context, will be discussed.



**Comparison of main chemical composition of groundwater, mineral and thermal water originating of tectonic active areas from Eastern Turkey, Azerbaijan and Western Iran  
Abstract n°2616**

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**KEYWORDS:** main chemical composition, groundwater, mineral and thermal water, tectonic active areas

As the author had the opportunity to visit tectonic active areas from Eastern Turkey (Bingöl and Dogubayazit), Azerbaijan, Northwestern (Täbris Khoy) and Southeastern (Kerman Bam) Iran and to get samples of normal groundwater and mineral and thermal water within all these areas. This data set of the main chemical composition of these waters presents a quite unique opportunity to compare the chemical characteristics and to deduce effects of water rock interaction related a) to the mineralogical composition of rocks according to the geological structure, b) to the mixing with upwelling deep fluids and c) to chemical evolution related to the tectonic activity as e.g in contact with reactive gases.



**Role of GIS in site selection for Artificial Groundwater Recharge- A case study from north western Saudi Arabia  
Abstract n°2617**

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**KEYWORDS:** Artificial Groundwater Recharge, Arid regions, Boolean Logic

The increasing aridity and the corresponding scarcity of available fresh water resources in Middle-East Asia since the mid-Holocene climate change has resulted in human settlements relying heavily on available groundwater resources stored in the deep-seated aquifers. The exponential population growth and rapid urbanization in these regions since the mid-twentieth century has resulted in acute water stress. The need of the hour is to rely on better water management practices including artificial groundwater recharge (AGR) to augment the available groundwater reserves. Identifying the potential regions of groundwater recharge is a challenging task as it depends on a number of parameters other than rainfall. However identifying the best suited zones is a pre-requisite for any artificial recharge project to reap the maximum benefits. The present study deals with the identification of the potential AGR sites in north western Saudi Arabia. Thematic layers of parameters including slope, soil texture, vadose zone thickness, groundwater quality (TDS) and type of water bearing formation were integrated in a GIS environment using Boolean logic to select the best suitable sites. The results showed that 17.90 percent of the total investigated area is suitable for AGR. In order to avoid the use of agricultural and built up areas for AGR the identified zones were integrated with the land use land cover map. This reduced the potential AGR area to 14.24 percent. Geomorphologically the wadi beds were found to be the most suitable for recharge. On the basis of the potential AGR zones proximity to the available recharge water supply (rain water, desalinated sea water and treated waste water) the potential zones were further classified into Category A (high priority) and Category B (low priority).



## Abstract n°2621

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KEYWORDS: Groundwater, GIS, Duhok

Water is arguably the most important resource of any country and as the population growth, agriculture and industries develop, the water environment is placed an ever-increasing stress, due to the frequent drought seasons many people resorted to digging wells. This study promotes the generation of spatial database for the water wells in Duhok governorate Iraqi Kurdistan region, data were collected from selected aquifers to be used in building of spatial database using Arc GIS, all input data to this database could be retrieved spatially, GIS software program has an efficient and friendly query system with help in data retrieval. The produced groundwater related database could help as information source to institution, researcher, groundwater practitioners, drilling companies, and decision makers, the outcome database will be the core for the future studies for establishing GIS groundwater database system at national level for the whole Iraq.



**Technical study to install an improved village water system (HVA) for rural populations using solar power as an energy source- case of Foula in Odienné area, Ivory Coast.  
Abstract n°2623**

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**KEYWORDS:** hydraulic improved village, design, works, photovoltaics, Foula

The study focuses on drinking water in Foula, a non-electrified village in Department of Odienné (northwest of Côte d'Ivoire). The objective of this work is to realize a technical study to install an improved village water system (HVA) for the village of Foula using solar power as an energy source. This will integrate all villages with 1000 to 4000 inhabitants in the improved village water projects even if they are not connected to the national network power. We collected data, analyzed and sized the various works of the HVA system. The solar photovoltaic system and its batteries are being dimensioned. The detailed study was carried out and the characteristics of the works to be constructed were determined. Thus, the needs of the population of Foula were evaluated at different horizons and give respectively 39+ 57 and 82 m<sup>3</sup> d based on a population of 1,314 inhabitants updated with a growth rate of 2%. Water tower will have a 20 m<sup>3</sup> capacity and will be placed on a metal base 10 m high. Borehole has a pumping flow rate of 4.5 m<sup>3</sup> h. There is a necessity to get a pump which is 1.1 kilowatts power to pump water from the borehole to the water tower on the basis of the total pressure of 45 m. The distribution of water will be at 4 fountains with two spouts. The pipeline network is made of PVC pipes with different diameters sized according to the pressure in each section. The solar system requires 14 modules of 250 Watt-peak each for the operation of the pump. However, because of changes in climate conditions and the concern to ensure continuous water service, the recommended storage capacity of the batteries is 1250 Ah. This equates to 150 Ah battery 9-48 V



**CAPACITY LOSS IN DAMS LOCATED IN ARID AND SEMI ARID ZONES. CASE OF  
GARGAR, BOUHANIFIA, OUIZERT AND FOUM EL GHERZA DAMS  
Abstract n°2625**

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**KEYWORDS:** water losses, water leakage, evaporation, siltation, dams, arid, Algeria

Most dams are subject to a loss of capacity due primarily to three factors namely- water leakage, the silting and evaporation intense. The study of these phenomenons is of great importance because they can endanger the stability of the dam and reduce its useful capacity. This is the case in particular dams Gargar, Ouizert, Bouhanifia and Foug El Gherza. Located in arid areas where water resources are becoming more and more rare. To this end, we saw useful to present this study in the balance sheet total loss of water from these dams. We estimated the average volume losses for the interannual dam Gargar 119, 014 hm<sup>3</sup> for dam Bouhanifia 45.45 hm<sup>3</sup>, to Dam Ouizert 20.28 hm<sup>3</sup> and finally to the dam of Foug El Gherza 39 hm<sup>3</sup>.



## Reflections about the desalination plants of SE Spain Abstract n°2628

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**KEYWORDS:** Desalination plants, freshwater intrusion, perverse effects

Among the provinces of Alicante and Malaga there are 20 large desalination plants essentially supplied by seawater. In addition, there are several hundreds of small plants that desalinate brackish water. All together has a potential desalination capacity of more than 500 million cubic meters. This initiative was the response to the significant shortage of water in the driest of Spain sector and possibly the biggest tourist and agricultural activity of the peninsula. However, the reality is that none of the large plants operating at rated capacity for which it was designed, which can impact significantly on the unit price of desalinated water. As is known, open intake, ie direct intake of seawater to supply the plant, are usually more expensive than coastal wells, given the need of expensive pretreatments of the water collected in the first of the cases. On the other hand, these same pumps seawater can be a guarantee of reducing the risks of seawater intrusion in the coastal aquifer captured due to the reduction of the hydraulic head of seawater into the coastal strip. In addition to the known impacts resulting from the elimination of rejection, freshwater "intrusion" can occur, localized subsidence and significant variations of water chemistry, in the case of large coastal plants+ and serious problems of salinization of soil and aquifers in small brackish water desalination plants.



**The “BD Traçages” - A french tool to manage and to value datas of tracing operations  
in groundwater  
Abstract n°2629**

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KEYWORDS: tracing, database, centralization, dissemination

In France, many tracing operations in underground environments are made each year. Hydraulic connections knowledge between an entry spot and an exit spot of the system enables the appreciation of groundwater basins area in complex environments such as karst, plutonic or volcanic aquifers. These important datas for the resource knowledge and its protection are scattered among different contributors (design offices, cavers, universities, state services, etc.). In the best case, some organizations were able to make paper or digital inventories locally stored and therefore not valued. So, the BRGM regional offices of Midi-Pyrenees, Aquitaine and Centre wished to build up a common database of tracer tests in underground environments. The BD Traçages was designed on the basis of a unique data model (with PostgreSQL system), but taking into account national tools, compatible with SANDRE (Secrétariat d'Administration Nationale des Données et Référentiels sur l'Eau) common french language for water. To facilitate data storage, an online data entry tool was built-up. This dynamic tool includes all the needed features to input information about injection spots, monitoring spots, tracer tests process and interpretation results. It also supports different user profiles - data producer, validator, “superreader”, and administrator. The data is then distributed as fact sheets available from mapping tools on SIGES websites (Système d'Information pour la Gestion des Eaux Souterraines), dedicated to groundwater in Midi-Pyrenees, Aquitaine and Centre, exchange views days are being conducted with the various organizations involved in tracing operations in order to share this tool and identify areas for improvement. The BD Traçages will then become a national database to collect, centralize and disseminate tracings operations information and improve the understanding, management and protection of complex aquifers.



**THERMAL DISTURBANCE CAUSED BY ALTERATION OF CRYSTALLINE ROCKS GUY  
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Abstract n°2631

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KEYWORDS: Stratified Fissured Layer, Heat Generation, Temperature

In crystalline rocks, a weathering profile is composed of stratiform layers following the palaeotopography. Below the upper unconsolidated layer (saprolite), the permeable layer is a fissured zone where horizontal fractures are generated by tensile stress induced through by swelling of some minerals. This chemical reaction is exothermic with heat  $E$  released per unit volume on the order of  $0.5 \text{ GJm}^{-3}$ . What is the expected temperature increase? The present 1D thermal model aims to discuss the conditions under which a substantial temperature increase can develop. Since the enthalpy of the weathering reaction  $E$  (in  $\text{Jm}^{-3}$ ) is finite, the heat is generated only during a limited time ( $Dt$ ) at an average rate  $A$  (in  $\text{Wm}^{-3}$ ) =  $E / Dt$  as imposed by the kinetics of the chemical reaction. The continuing nature of the reaction requires that the chemical front propagates downward with a velocity  $V$  into intact rock, furnishing new fuel. The thickness  $a$  of the active zone is  $a = VDt$  so that the volumic heat generation rate becomes  $A = EV / a$ . With the conductive 1D heat equation, the relevant parameter is the "integrated heat"  $Aa = EV$  which has the dimension of a heat flow and where  $Dt$  is absent. Only when  $EV$  is comparable with the natural geothermal heat flow  $q$  (about  $.1 \text{ Wm}^{-2}$ ), does its thermal effect become significant. According to the  $V$  value, two cases are considered -  $V$  is low and consistent with the erosion rate. A steady state is maintained. For  $V = 10 \text{ m My}^{-1} = 3.10^{-13} \text{ ms}^{-1}$ ,  $EV = 1.5 \cdot 10^{-4} \text{ Wm}^{-2}$  ( $\sim 0.0001q$ ) which induces negligible thermal effects.  $V$  is much larger, say  $1 \text{ mm y}^{-1} = 3 \cdot 10^{-10} \text{ ms}^{-1}$ . This leads to  $EV = 1.5 \cdot 10^{-1} \text{ Wm}^{-2}$  ( $\sim 0.1q$ ) and corresponds to substantial temperature increase. Such extreme  $V$  value can only occur for very limited time. Therefore any thermal disturbance associated with weathering implies a very transient and or local phenomenon.



## **Managed Aquifer Recharge (MAR) as to supply Libreville water-stressed city (Gabon) Abstract n°2632**

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KEYWORDS: karst - managed aquifer recharge - deep boreholes - sea water intrusion

Objective- supplying a water-stressed city Libreville has been implemented on a peninsula, where most groundwater is brackish and faraway from any large surface water resources. Since the 70's, the city has been supplied with surface water, collected from 5 small watersheds and treated in a single main plant located in Ntoun, 40 km eastward of Libreville. There are little additional surface water resource in the nearby and SEEG is desperately seeking for alternative cheap water resources. Design and methodology In 2007, SEURECA and HYDROCONSEIL provided SEEG with hydrogeological expertise, as to develop groundwater resources in the nearby of existing facilities. A thick limestone layer had been previously drilled by oil-companies- Madiela limestones whose outcrops are very limited (4 km<sup>2</sup>). Madiela proved to be very productive (2,000 – 10,000 m<sup>3</sup> day per borehole) and we have developed a new well field. As (a) the aquifer extension is limited and (b) sea water intrusion is at risk, the well field was developed step by step, with a careful monitoring of water quality (i.e. conductivity, as a signal of sea water intrusion) and water level. Data and results The aquifer storage capacity has been measured through the long dry season drawdown as 6.3 million m<sup>3</sup>. This is unneglectable, but insufficient would the aquifer be mined.. For this reason, we proposed a MAR strategy and monitored aquifer recharge during rainfalls. It proved to be impressive (> 20 million m<sup>3</sup> year). Such a large recharge is more than expected from direct infiltration in the tiny aquifer outcrop. Additional recharge mechanisms have been investigated through geophysical prospecting and the hydrogeological model has been updated accordingly. Conclusion Taking into account the recharge efficiency, we have developed a MAR strategy, with additional 4 deep wells . Presently, Ntoun well field produces 55,000 m<sup>3</sup> day of good quality water, without any significant impact on resource quality or quantity (i.e. no significant drawdown of the water table has been recorded).



**GROUNDWATER QUALITY IN THE NORTHERN PART OF SUB BASIN OUED LABIOD  
\_AURES NORTH 'ALGERIA  
Abstract n°2637**

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**KEYWORDS:** Aures, Oued labiod, sources, water quality.

The increase in the severity and length of the low water poses more acutely the question of strong seasonal demand in some areas since the summer demand could increase further, posing an additional problem of matching needs and available resources. Insofar as tablecloths, themselves, could see their recharge decrease due to climate change impacts, it becomes essential to be able to quantify these samples to ensure sustainable management of aquifers. The purpose of this study is the location of aquifer could be exploited in the valley of Oued Labiod and knowledge of hydrochemical characteristics of the water that circulate. The oued Labiod watershed may be important from the point of view hydrogeological + these aquifers consist of limestone and sandstone + aquifers that are circulating crack. Therefore their water potential depends strongly on the degree of cracking geological formations that compose them. The region is highly rugged with a typical Saharan Atlas tectonic style, giving rise to broad synclinal structures with flat bottoms separated by narrow anticlines in blanks recovered very elongated and rarely symmetrical. The main reservoirs of groundwater is formed by limestones and conglomerates of Miocene limestones in the Flint Ypresian - Lutetian (potential aquifer in the region), chalky limestone and Paleocene limestones Maastrichtian. Levels of many aquifers in the valley show a tendency to decline in recent decades, this being due, first, to over pumping of groundwater beyond their recharge, but also to a decrease in rainfall inputs. waters are less crowded north while in central and southern waters become sulfated or chlorinated, reflecting the removal of feeding areas and the dissolution of evaporates in an area subject to an arid climate.



**In situ assessment of the permeability tensor of homogeneous anisotropic  
sedimentary rocks  
Abstract n°2639**

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**KEYWORDS:** Permeability tensor, sediment dip, rock sample

Study of geological reservoirs and is a major issue for a rational and sustainable exploitation of underground resources (water, oil, gas ...). In order to estimate and take advantage of those resources, it is necessary to assess the intrinsic properties of the reservoir, such as their porosity and permeability. The latter is dependent of bedrock heterogeneity due to a variable sedimentation (e.g sedimentary lamination, cross-bedded sediments, matrix heterogeneities) or to the presence of fractures or faults. These heterogeneities can lead to anisotropic permeability properties that have been poorly studied. To characterize this anisotropy and assess a permeability tensor, many modeling approaches have been proposed but few studies propose to assess the permeability tensor of a reservoir block size on the basis of in situ permeability variability measurements. In this study, permeability tensor is determined in homogeneous anisotropic sedimentary environment (rock samples from late Burdigalian limestones without fractures). Eight cross sections (N, NW, W, ...) were performed on these blocks (= cut in to 8 faces), permeability measurements were realized with a field minipermeameter (Tiny perm II). The dip of sedimentary layers was measured near to each sampled block in order to identify possible relationships between the permeability tensor and the depositional environment. Results show a relative consistency between sediment layer dips and orientation of permeability tensor.



**Multiscale karst sediment dynamic study- from the flood scale to the pluriannual scale  
Example with Bruisseresse spring, Normandy, France  
Abstract n°2640**

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**KEYWORDS:** Karst, sedimentation rate, wavelet analysis, NAO

Karstification is an azonal process occurring in different kind of bioclimatic settings and weatherable rocks. Karst processes create voids both on the surface (e.g., sinkhole) and within the bedrock (i.e., karstic conduit) in relation to chemical weathering and or mechanical erosion. Depending on the geomorphological setting, hydrodynamics and sediment sources, karst systems may be filled with (i) allochthonous material (supply of sediments by mechanical erosion), (ii) autochthonous deposits (insoluble residues from chemical weathering of the bedrock) or (iii), a mixture of both. Usually, turbidity is the parameter used to study sediment transport in karst. Few or no work has been published on sediment dynamics using an approach coupling in situ monitoring of hydrological variables (flow, rainfall, ...) and sedimentary (altimeter mesurments, sediment cores) to identify main sediment transport or deposit controls in a karst network. Acquisition of high-frequency hydro-meteorological data coupled with sedimentary signal mesurments (turbidity, sediment cores and records of high-frequency altimetric data of a sedimentation area) allows to characterize sediment transfert controls from flood scale to annual scale. Sedimentary organisation and nature can be explained by the intensity of turbid flood events. The use of signal analysis tools on long times series allows to understand sediment transport and deposition controls at the pluriannual scale. In detail, wavelet analysis of rainfalls, piezometric level and turbidity, as well as sediment archive, all show common modes of variability. A common spectral composition emphasizes the climate control. The comparison of the wavelet spectra with the North Atlantic Oscillation (NAO) spectrum clearly highlights the control of the latter on hydro-meteorological variables at the regional level.



## Hydrogeochemical Properties of Bakircay Delta (Izmir, Turkiye) Abstract n°2643

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KEYWORDS: Hydrogeochemistry, wetland, Bakircay, Turkey

Wetlands are complex and sensitive habitats that play an important role in the hydrological cycle. Investigating the hydrogeochemical properties provide the identification for wetlands. Bakircay Delta has been progressed in the Bakircay Graben that is one of the most important river catchment NW of Turkey. Water samples were taken from both delta and hydrological basin of delta. Bakircay delta has 2 lagoons and one widespread salty swarm. Electrical conductivity (EC) of water samples range between 212 and 26500 IS cm in the whole basin. EC values increase towards the sea, especially in the lagoons the value reach the maximum level with 26500 IS cm. According to IAH water facies classification, water type is Na-Cl around the delta. When progressed towards to inland, water type changed to mix water that has not dominant anion and cation. With reference to heavy metal contents of the water samples, As concentrations are exceeded the drinking water standards with greater values than 10ppb especially in Bakircay river, many surface waters, between Candarli and Bergama groundwater samples. The delta O-18 and delta H-2 composition of water samples range between +6.66 and .43 per mille+ +37.9 and 5.8 per mille, respectively in the basin. Water samples taken from the delta are plotted on sea water mixture line.



## **Environmental modelling of the leaching test data with Python Abstract n°2644**

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**KEYWORDS:** modelling, leaching tests, Python

Waste can pose a threat to the groundwater environment. The leaching tests are used to determine a potential impact of waste on the environment. The most frequently batch tests being performed do not provide information on the dynamics of the leaching process. Laboratory dynamic tests allow us to conclude about the leaching intensity as a function of elution time in relation to a landfill site. If the precipitation which takes place at the landfill site is simulated, dynamic tests of leaching will allow us to forecast the real impact of waste on the environment. However, they are more difficult to perform and they last longer than batch tests - contaminants leaching from the sample may take even years. Implementation of modeling allows investigators to achieve the forecast of pace and scope of the pollutants releasing to the groundwater until their eventual total leaching. In this paper we are going to present our own computer application to modelling contaminants leaching which reflect the results of column dynamic leaching test. Our program allows you to interpret the breakthrough curve obtained from the experimental data. The whole program was created with the application of Python programming language and the majority of data calculation were performed with the SciPy and NumPy modules. In particular, in order to estimate parameters of the breakthrough curve, the sub-module Optimize was applied. Matplotlib which is a Python 2D plotting library was used for the graphical presentation of results. This program is an alternative for other applications such as CXTFIT or STANMOD. The program operation has been tested on results of two dynamic tests, performed on two samples taken from a steelwork landfill, located in the recharge zone of the groundwater aquifer Olkusz - Zawiercie (Southern Poland). Estimation error for the breakthrough curves was equal to 6-15%. The modelling results were used to make the forecasts of the steelwork landfill impact on groundwater.



**Coupling subsurface hydrogeomechanical assessment and groundwater mapping on fractured rock media (Caldas da Cavaca, Central Portugal)  
Abstract n°2645**

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**KEYWORDS:** Hard-rock hydrogeology, rock masses, hydrogeomechanics, GIS mapping

The present work aims to achieve and further develop a hydrogeomechanical approach in Caldas da Cavaca rock mass (Aguiar da Beira, Central Portugal) and contribute to a better understanding of the hydrogeological conceptual site model. A collection of several data, namely geology, hydrogeology, rock and soil geotechnics, borehole hydraulics and hydrogeomechanics, was retrieved from three rock slopes. To accomplish a comprehensive analysis and rock engineering conceptualisation of the site, a multi-technical approach was used, evolving, field and laboratory techniques, hydrogeotechnical mapping, hydrogeomechanical zoning and hydrogeomechanical scheme classifications and indexes. In addition, a hydrogeomechanical data analysis and assessment, such as Hydro-Potential (HP)-Value technique, Jw Joint Water Reduction index, Hydraulic Conductivity (HC) System was applied on rock masses. The hydrogeomechanical zone HGMZ 1 of Lagoa slope achieved higher hydraulic conductivities with poorer rock mass quality results, followed by the hydrogeomechanical zone HGMZ 2 of Lagoa slope, with poor to fair rock mass quality and lower hydraulic parameters. Amores slope had a fair to good rock mass quality and the lowest hydraulic conductivity values. The hydrogeomechanical zone HGMZ 3 of Lagoa slope, and the hydrogeomechanical zones HGMZ 1 and HGMZ 2 of Cancela slope had a fair to poor rock mass quality but were completely dry. Geographical Information Systems (GIS) mapping technologies were used in the overall hydrogeological and hydrogeomechanical data integration, in order to improve the hydrogeological conceptual site mode and an integrated comprehensive study of the shallow hydrogeology and groundwater resources.



**Hydrogeological impact of the access ramps and shafts of the French Cigeo deep radioactive waste disposal on the above aquifers  
Abstract n°2646**

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**KEYWORDS:** deep geological disposal, hydrogeological model, long-term drawdown

Andra, the French national radioactive waste management agency is responsible for the long-term management of all radioactive waste produced in France. Its main mission is to find, implement and ensure safe management solutions for French radioactive waste, in order to protect present and future generations from the risk of these wastes. For Cigéo project (industrial center for deep geological disposal, applied to high-level waste and long-lived wastes), Andra has to assess impact and safety, from operating phase to long-term period, based on a sound scientific knowledge deduced from in situ experiments in URL, numerical simulation, technological demonstrators, ... In the scope of assessing shafts and ramps hydraulic impact, Andra has performed numerical simulations in order to quantify hydraulic discharges and flow coming into the structures, and thus to provide useful information to the design process. The objective of this paper is to describe the entire work, from data acquisition to simulation results, including phenomenological and numerical model development, taking into account both a fine description of hydrogeological layers and the digging schedule. Description of the results will be focused on expansion of hydraulic drawdown in the multi-layer aquifer system, and its consequences on both (i) aquifer monitoring network (ii) ramp and shafts design (sealing of shafts parts, sizing of pumping system, etc..).



**Transboundary groundwater in Western Asia- A depleting resource that needs immediate attention**  
**Abstract n°2649**

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**KEYWORDS:** Technical and legal challenges, low renewability+ overexploited

The first inventory of transboundary aquifer systems in the Western Asia region was undertaken recently on the basis of rigorous scientific referencing and comprehensive bibliographies of the available information. The aim was to provide a starting point for future technical deliberations on shared aquifer systems among riparian countries. A total of 17 aquifer systems have been identified extending over an area of about 2.5 million km<sup>2</sup> across the vast arid to semi arid desert (Arabian Peninsula) and the relatively more humid areas to the north (Mashrek) and northeast (Mesopotamia). The Peninsula has provided the depositional basin (thickness- 7,500 m) for extensive sedimentary strata, which form large regional aquifer systems with very low renewability. The Mashrek and the Mesopotamia comprise highly fractured and faulted mountainous areas characterized by high precipitation falling on extremely well-exposed and highly karstified carbonate rocks and volcanic terrains. These fissured and complex aquifers receive an appreciable amount of recharge and supply springs that sustain important river systems. The majority of aquifer systems in the region are overexploited to the extent that some are near depletion or completely unsuitable for use due to quality deterioration. Analysis of the hydrogeological data information indicates important gaps that hinder a thorough understanding of the aquifer dynamics. Also, the complete lack of any form of agreements for the development and management of the systems had a serious impact on their productivity. This paper gives an overview of the existing technical and legal constraints for the management of transboundary aquifers in the region. It also describes bilateral and regional initiatives to alleviate these constraints and why they are difficult to implement. It concludes that the establishment of a regional database in parallel with trust building among riparian countries is required for enhancing cooperation in the future. These actions can only materialize through strong commitment from decision makers and good groundwater governance together with financial and technical assistance from donors and international organizations.



## Evaluation of regional groundwater storage variations in China using GRACE data Abstract n°2654

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KEYWORDS: groundwater depletion+ GRACE+ China

Countries with severe groundwater depletion problems have limited information on spatial and temporal variability in groundwater storage, as monitoring networks for groundwater systems are generally limited and it is difficult to regionalize point-based measurements. Water scarcity is a critical issue in China. The Gravity Recovery and Climate Experiment (GRACE) satellite mission provides approximately monthly changes in terrestrial water storage (TWS) on the basis of measurements of the Earth's global gravity field. With auxiliary information of soil moisture, snow water, and surface water, groundwater storage can be isolated from TWS. This study evaluate the ability of the GRACE satellite to monitor groundwater storage variations. Auxiliary data, such as soil moisture and snow water equivalent, were simulated by the Global Land Data Assimilation System (GLDAS) and used to isolate groundwater item. In situ groundwater storage (GWS) changes were evaluated using measured records from Water Resources Bulletin of China and Monthly Groundwater Dynamic by the Ministry of Water Resources, China. Results show GWS changes derived from GRACE-GLDAS compared favorably with results calculated by measure data in China and first grade unit of water resources, and the correlation coefficient ( $r$ ) is 0.84 in China. Furthermore, comparison of annual GWS changes from measured data agreed with GRACE-derived annual GWS both in Song-Liao Plain and North China, and the correlation coefficient is 0.70 and 0.57, respectively. GWS depletion rate is estimated in China and 38 provinces from 2003 to 2012, which shows that the GWS is estimated to decrease at a rate of 24.9 cm yr<sup>-1</sup> in China and Beijing has the largest depletion rate (-1.16 cm yr<sup>-1</sup>) among these representative provinces. This trend, if sustained, will lead to a major water crisis in this region when this non-renewable resource is exhausted.



## **Leros island (Greece)- how to exploit the hidden water Abstract n°2656**

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**KEYWORDS:** submarine springs, Leros island, catchment work, seawater intrusion

This paper presents an original technical proposal aimed to satisfy water demand in Leros Island, belonging to Dodecanese archipelago, in Egeo sea. The geology of Leros island is very complex and its interpretation is very difficult because of the effects a very intense tectonic activity. The morphology is characterized by impressive fault scarps. The age of the outcropping formations varies from 300 million of years to the present. The hydrogeological sequence outcropping in Leros island is made, starting from the younger formations, by beach deposits, with high permeability, overlaying Molassic sediments, very impervious, from the hydraulic point of view, and thick carbonate formations, characterized by very high permeability, which overlay a thick clayey, very impervious, deposit, Carbonate formations are very good aquifers due to the high permeability degree and the high storage capacity. When precipitations overpass Molassic sediments The vertical path of infiltrating water, percolation, stops where an impervious layer is encountered and saturated zone is formed- then the sub horizontal flow (filtration) takes place carrying groundwater to springs, which, in Leros, are mainly directly under the sea level, or through coastal (sub aerial and submarine) springs. This technical proposal deals with a catchment work design aimed to the exploitation of an hidden groundwater resource, stored in two areas the Klidi and the Skoumbarda ones, where carbonate formations, characterized by very large cavities, can store very important quantities of water. Unfortunately usually these groundwater reach the sea, after having mixed themselves with seawater and becoming unfit for human uses. This technical purpose comes from the discovering by innovative investigation tools where these storage cavities are placed and try to catch groundwater before their mixing with seawater.



## **AquiFR - a national multi-model hydrogeologic system Abstract n°2657**

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**KEYWORDS:** Aquifer modeling, forecast, management

The AquiFR project aims at taking benefits of existing groundwater modeling applications used by stakeholders to develop new products in order to provide useful information for water resources management. Indeed, it aims at providing forecasts of the groundwater resources at 10 days ahead upto seasonal scale. To do so, up to now 3 hydrogeological models covering 8 multilayers sedimentary aquifers and 10 karstic aquifers in France are included. These applications were assembled within a coupling system facilitating the parallel computation and coupled to a land surface model used in the French numerical weather model that provides the recharge. The whole system is expected to run operationally at Meteo France. To do so, a real time application will be run daily forced by an analysis of the observed atmospheric conditions. This real time simulation will then be able to



provide initial conditions for the forecasts. Ensemble 10-day forecast will then be run daily, and seasonal forecasts will be run monthly. The monitoring and the forecast could be compared to the long term reanalysis of the groundwater that is being built by using an atmospheric reanalysis beginning in 1958. Specific indicators to communicate forecasts to water resources management will be developed in close connection with stakeholders. Additionally, the same system can be used to perform climatic change impact studies, allowing comparing the impact in several aquifer systems. In order to cover a larger part of France, a special attention is given to the modeling of extended hard rock aquifers. Moreover, specific study will be made on data assimilation to improve the initial state of the groundwater forecast. The project associates hydrogeologists, meteorologists, computer scientists and stakeholders, and is now in its second year. The poster will present the AquifR system and its preliminary results.



**Carbon capture and storage in St Lawrence Lowlands- Modeling of hydrogeological potential impacts at basin scale  
Abstract n°2658**

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KEYWORDS: CO2 injection, numerical simulation, basin-scale

During full-scale carbon capture and storage operations, important quantities of carbon are injected into deep saline aquifers in order to significantly reduce greenhouse gases emissions. At the basin scale, the injected fluid can cause pressure build, brine leakage into freshwater aquifers and water table rise in unconfined shallow aquifers. In order to evaluate the suitability for long-term carbon storage in deep saline aquifers, such environmental impacts need to be predicted. However, the assessment of these impacts can be difficult due to the complex geometry of sedimentary basins. In this study, potential impacts related to an industrial-scale carbon capture and storage project in the St-Lawrence Lowlands basin (Quebec, Canada) are studied with a specific attention to the role played by regional faults that divide the basin into multiple compartments. Groundwater flow simulations were conducted with the FELLOW numerical model using a detailed geological model of the basin that includes the regional normal faults. The investigated scenarios consider an injected flow rate of ranging from 1 to 10 Mt yr over a period of 100 years followed by a post-injection period of a 1000 years. Particle tracking was used to estimate brine migration. Normal faults, which allegedly exhibit a low hydraulic conductivity, play a major role in pressure build up distribution and brine migration. The simulations suggest that neither pressure build-up nor brine leakage will occur in the outcrop zone of the basin where shallow aquifers are exploited. Sensitivity analysis also suggests that such impacts can only be achieved with an unfavorable set of parameters. It is also found that specific storage, which is the less accurately defined parameter, is the most important parameter influencing pressure build-up. This study shows that basin-scale impacts of carbon injection may not limit injection rate up to 10 Mt y in the St-Lawrence lowlands. However, normal faults are poorly investigated in the basin and a better knowledge of faults hydrodynamic properties is needed to validate these findings.



**First results of the AquifR project- assessment of the french national multimodel hydrogeologic system on past years.  
Abstract n°2659**

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**KEYWORDS:**

The AquifR project aims at taking benefits of existing groundwater modeling applications used by stakeholders to develop new products in order to provide useful information for water resources management. Indeed, it aims at providing forecasts of the groundwater resources at 10 days ahead upto seasonal scale. In its present form, the AquifR system includes 3 hydrogeological models covering 8 multilayers sedimentary aquifers and 10 karstic aquifers. These applications were assembled within a coupling system facilitating the parallel computation and coupled to a land surface model used in the French numerical weather model that provides the recharge. The whole system is expected to run operationally at Meteo France. To do so, a real time application will be run daily forced by an analysis of the observed atmospheric conditions. This real time simulation will then be able to provide initial conditions for the forecasts. Ensemble 10-day forecast will then be run daily, and seasonal forecasts will be run monthly. The monitoring and the forecasts could be compared to the long term reanalysis of the groundwater that is being built by using an atmospheric reanalysis



beginning in 1958. The oral presentation will present the first results of the AquiFR system in past years. Interest in having simultaneous modelling of several aquifer basins for water management will be presented. Sensitivity to uncertainty of the groundwater recharge and on groundwater abstraction will be presented.



**Analysis and forecasting of daily flows using the deterministic chaos in Mediterranean watersheds**  
**Abstract n°2660**

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KEYWORDS: Chaos, Daily flows, Mediterranean watersheds

The nonlinear and non-stationary character is strongly expressed in hydrological processes in semi-arid Mediterranean basins. We propose in this study, the application of analytical and simulation tools from nonlinear dynamics of complex systems. The chaotic analysis of the hydrological series of the northern Algeria using the Lyapunov exponent and the correlation dimension seems to confirm the hypothesis that it could be exist a deterministic chaotic process of low dimension. However, the topological approach based on the recurrence plot and recurrence quantification analysis show that the organization of the flow series is not only due to stochastic correlations, but also of a chaotic process. For this reason, the flow forecasting by the technique of Farmer-Sidorowich showed that the algorithm has a good capacity forecast, but only in the short term, so however the chaoticity of the series is put in evidence.



**Private, public and common pool management of natural resources in France - a comparative analysis of groundwater with marine resources  
Abstract n°2661**

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KEYWORDS: allocation policy+ collective management+ marine resources

This presentation proposes a comparative analysis of public policies implemented in France to regulate the access to and the exploitation of fresh water and marine resource. It more specifically focusses groundwater management, marine fisheries and shellfish-farming concessions. These three policies rely on a common conceptual approach in which the State assesses sustainable exploitation limits and allocates use rights consistently with that limit. Concerning groundwater, use rights are expressed in volume that can be abstracted from the aquifer+ fishing rights are expressed in total annual catch per fish species (fishing quotas)+ and shellfish-farming is regulated by restricting the access to productive coastal areas (concessions). In the three domains, the State traditionally played a key role in assessing the sustainable exploitation limit and it kept a tight control on the allocation and reallocation of use rights, and the legislator has generally opposed to transforming them into private assets. In practice, however, the State has tolerated that use rights be transferred together with private assets when private actors were selling their enterprise. Groundwater quotas are transferred with the farm+ fishing boats are transferred with their catch quota+ and shellfish concession's exploitation rights are transferred with production equipment installed in the concession. The search for economic efficiency is implicitly underlying this pragmatic approach, although it is not recognized in laws and regulation, except concerning the shellfish concession sector. At the same time, French policies implemented in the three domains have favored the development of intermediate institutions for collective management of the three resources, recognizing that the allocation of these resources should pursue multiple objectives – social, environmental and economic, which can't be achieved by the sole command and control or market-based approaches. This hybrid French model is finally compared to approaches implemented in other countries.



## **relative gravity assimilation in hydrological numerical modeling Abstract n°2662**

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**KEYWORDS:** Gravity, karst, numerical model

Karstic hydrosystems are highly nonlinear and heterogeneous but they represent one major water resource in the Mediterranean area. Neither local measurements in boreholes nor analysis at the spring can take into account the variability of the water storage. Ground-based gravity measurements allow the monitoring of the water storage in heterogeneous hydrosystems at intermediate scale between boreholes (local scale) and spring (global scale). Since five years, a geophysical observatory has been setup in the Mediterranean area (on the Durzon karstic basin in the south of France). Water level in boreholes and rainfall from rain gauges are classical hydrological observations. They are completed by evapotranspiration measurements from a flux tower and continuous gravity measurements from superconducting gravimeter. The main objective of this study is to model the whole data sets with explicit numerical models. Hydrus -1D software allows explicit modeling of water storage and 1D-flow in variably saturated media. With a stochastic sampling, we find the underground parameters (porosity, permeability) that reproduce the most the different observations (gravity, water level, evapotranspiration and rainfall). The spatial variability at ~ 100m scale is investigated through relative rigorous gravity measurements.



**First data on atmospheric chloride mass balance components in the Andean páramo in central Ecuador- implications to project climate scenarios of net aquifer recharge and potential groundwater chemical baseline**  
**Abstract n°2663**

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**KEYWORDS:** Andean páramo, net aquifer recharge, potential groundwater chemical baseline

Screening of the impact of projected climate scenarios on groundwater quantity (net aquifer recharge, R) and quality (potential chemical baseline, CR) is a challenge because alterations due to global driving forces are being detected in rivers and aquifers. However, the evaluation of steady R and CR is a complex, uncertain task which is solved by adopting non-global techniques of questionable validity when using to project future scenarios. The atmospheric chloride (C) mass balance (CMB) technique is proposed for natural R and CR from precipitation (P). This technique (1) does not include actual evapotranspiration (E) in formulae, thus reducing the uncertainty in R, and (2) allows the evaluation of CR by combining atmospheric chloride bulk deposition ( $AP = P - CP$ ) and E. The páramo, a tropical alpine highland in the 3000-4100 m elevation in the Andean region from Venezuela to Peru, is a main recharge area contributing to regional rivers and aquifers. In the Andean páramo in central Ecuador, the Pita and Tingo rivers basins, both including Neogene and Quaternary lava-flow and pyroclastic aquifers, were selected for sampling monthly P, CP, and chloride content in groundwater discharge (CR) from local aquifers having low water-rock interaction. In both cases, per 100 m in elevation, P increases by 60 mm and CP decreases by 0.2 mg L<sup>-1</sup>. Average AP is 1.65 and 2.11 g m<sup>-2</sup> year<sup>-1</sup> in the Pita and Tingo basins, respectively. As deduced from the 0.2 E-to-P ratio, average CR around 5 mg L<sup>-1</sup> and 8 mg L<sup>-1</sup> agrees with CR data reported in both basins. The Cl/Br ratio was used to identify the atmospheric origin of chloride in groundwater. Long CP and CR time series are being compiled for



modelling future scenarios of R and CR in this Andean region. Research funded by the Ecuadorian PROMETEO Research Project CEB-014-2015 and the IAEA Research Project ECU 7 006.



# Hydrological functioning of volcano-sedimentary Andean páramos- preliminary results from the Tingo river basin in central Ecuador

## Abstract n°2664

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**KEYWORDS:** Andean páramo+ volcano-sedimentary formations+ net aquifer recharge

The páramo, a tropical alpine highland in the 3000-4100 m elevation in the Andean region, is a main recharge area contributing to rivers and aquifers supplying large cities. Many studies relied on the hydrological properties of soils, actual evapotranspiration (E), and precipitation (P)–runoff (U) partitioning under natural and disturbed hydrological regimes. However, less attention was paid on the hydrogeological functioning of the páramo over fractured, moderate-permeability Neogene and Quaternary volcano-sedimentary aquifers. The 14-km<sup>2</sup> Tingo River basin, 18-km west to the Ambato city in central Ecuador, was selected to study the hydrogeological functioning of a typical páramo under natural hydrological regime. For this, geological, hydrogeological, and land-use surveys, as well as the monitoring of groundwater, surface water, and precipitation for chemistry were performed. In the basin, low-permeability Quaternary volcanic ash overlies moderate-permeability Pliocene pyroclastic, thus inducing confining flow conditions of net aquifer recharge (R) infiltrated upstream. The atmospheric chloride mass balance (CMB) technique was used to evaluate average R in the Tingo basin. For the period March 2014 to March 2015 (1) P was 1400 mm year<sup>-1</sup>, (2) the R-to-P ratio was around 0.2+ (3) atmospheric chloride bulk deposition was 2.11 g m<sup>-2</sup> year<sup>-1</sup> + and (4) chloride export flux by runoff in the outlet was 1.67 g m<sup>-2</sup> year<sup>-1</sup>. Chloride content in groundwater discharge from local aquifers having low water-rock interaction was used to evaluate R around 500 mm year<sup>-1</sup>, i.e., 0.35 P. This means that under confined flow conditions, infiltrated recharge transmits through the pyroclastic to discharge along the Ambato River. This mechanism explains the base-flow runoff of large rivers in summer, when soil moisture in the páramo reaches the wilting point and U is negligible.



This dynamics has large implications for water management in the Andean páramo. Research funded by the Ecuadorian PROMETEO Research Project CEB-014-2015.



**Evolution of water quality and water balance in coastal mediterranean aquifers- a case study in northern Morocco**  
**Abstract n°2665**

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**KEYWORDS:** semiarid climate, anthropogenic pressure, recharge

In many coastal regions of the semiarid Mediterranean area, groundwater is put under high pressure as it represents the main available resource and therefore supports the overall rapid agricultural development. Intense withdrawals often lead to overexploitation, while changes in land use and irrigation may modify recharge on both qualitative and quantitative aspects. The Bou-Areg aquifer in northern Morocco is a good example of such anthropic pressure on groundwater quality and balance. We investigate the groundwater flow pattern and the evolution of recharge using geochemical and isotopic (C-14, H-3, H-2, O-18, H-4) tracers. Results evidence the contribution of an intermittent stream (Sellouane river) to the recharge of the aquifer, the local input of deep old groundwater (>10,000 years old) at the southwestern border and the significance of modern groundwater recharge from irrigation in the whole cultivated area (elevated nitrate, average tritium of 3TU, occurrence of modern radiocarbon).



**Study of the spatial and temporal variability of surface runoff in the Mediterranean basin (case Watershed Sebaou- Algeria)  
Abstract n°2666**

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KEYWORDS: hydrologic cycle, climate change, statistical test

Study of the spatial and temporal variability of surface runoff in the Mediterranean basin (case Watershed Sebaou- Algeria) (S. Charifi-bellabas<sup>1</sup>, S. Benmamar<sup>2</sup>) <sup>1, 2</sup> National School Polytechnic, Algiers, Algeria s.bellabas@ensh.dz Abstract - The water cycle is the engine of life of living beings on earth, this cycle that is linked intimately familiar climate in recent decades a change in space and time. Indeed, The Intergovernmental Panel on Climate Evolution (IPCC) climate change means any change in climate over time, whether due to natural variability or human activity. The issue of climate change is manifested by a change in the hydrological cycle, thus affecting water resources and intensity of floods and droughts+ In this context, several multidisciplinary research has been made by combining all scales. In addition, the latest global climate projections led to identify the Mediterranean Basin as an area of hot-spot (Giorgi, 2006), that is to say for which climate change will be most severe in 21st century with a significant increase in temperature associated with a decrease in rainfall. In this context it is proposed to study the variability of rainfall and surface runoff in northern Algeria (watershed Sebaou) the spatial and temporal scale. The use of rainfall indices and statistical tests breakage detection in the observed series of precipitation and flow rates indicate a serious variability in the system of surface runoff from Wadi Sebaou in the 70+ the impact of climate change is so evident in the Mediterranean and supporting the research already carried out in the context of climate change and hydrologic cycle.



**Conceptual model of groundwater-vegetation interactions using qualitative system dynamics**  
**Abstract n°2667**

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**KEYWORDS:** Conceptual model, groundwater dependent vegetation, phreatophytes

Declining groundwater resources from intensified demand has made it more crucial than ever for us to understand the role of groundwater in maintaining ecosystem features and processes. Our currently limited understanding of this role is, at least in part, due to the lack of integrative research that explicitly addresses the interconnectedness of groundwater dependent vegetation with the key hydrological, geomorphological, socioeconomic and environmental components of its system (Orellana et al. 2012+ Griebler and Avramov 2015). We posit that the best way forward in improving our understanding of these plant communities is through explicitly recognizing their position within their broader socioecological system. This research involves the development of a conceptual model that describes the interactions between terrestrial vegetation and groundwater within the context of their socio-ecological system. The model identifies and characterizes the direct and indirect linkages between groundwater dependent vegetation and human and natural processes through a synthesis of international literature. Qualitative System Dynamics modelling is used to map the causal structure of the system. The resulting conceptual model provides a 'big picture' perspective of the drivers of change in groundwater dependent vegetation, through the amalgamation of relevant data and knowledge across multiple disciplines, including plant biology, hydrology, geomorphology and water resources management. This research also illustrates the applicability and interpretation of the model with an Australian case study of groundwater dependent vegetation within an urban water resources system. The model can serve as a tool for systemic thinking and for framing past and current research and management within the larger context of the problem. It may also provide a foundation for future work, by facilitating a more strategic and coordinated approach to research and management that targets key processes or knowledge gaps.



**A climate change impact on groundwater recharge assessment method using different analytical methods**  
**Abstract n°2668**

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KEYWORDS: Recharge+ uncertainty+ climate change

Assessing the climate change impact on groundwater recharge can represent a challenge due to the generally limited knowledge about infiltration processes, interaction with surface water or between aquifers, available data and pumping impact on it. Using different methods to estimate recharge is recommended in order to integrate uncertainties (Scanlon et al., 2006). Nonetheless, only some of the existing recharge estimation methods (ie. water balance methods) allow exploring the impact of future climate on recharge, as meteorological variables are taken as input data. A multi-method recharge estimation, combining several analytical recharge estimation methods based on climate data, discharges or piezometric levels depending on the method, has been tested over contrasted aquifers located in France. The comparative analysis of the results proves to be an interesting way to assess the main recharge processes of an aquifer and to illustrate the uncertainties linked to a given estimation method. Based on that assessment, it is possible to explore the climate change impact on direct recharge over a large spatial extent, providing results including the uncertainty associated to the recharge estimation method and to the global recharge processes.



**A pilot study to use the  $^{36}\text{Cl}$  bomb peak as a tracer for groundwater flow velocities in the Western Dead Sea catchment**  
**Abstract n°2669**

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**KEYWORDS:**  $^{36}\text{Cl}$  Cl,  $^3\text{H}$ , groundwater age dating, Western Dead Sea catchment

The aquifer system of the western Dead Sea catchment is stressed by semi-arid to arid climate conditions, limited groundwater recharge rates and increasing water abstractions for human water needs. The groundwater flow system is dominated by two main Cretaceous limestone aquifers with karst characteristics and discharging in springs in the Lower Jordan Valley and Dead Sea region. The karst properties give reason to assume parts of the flow system having high transmissivities and groundwater flow velocities, respectively. For estimating recharge rates and rain water infiltration time periods,  $^{36}\text{Cl}$  and  $^3\text{H}$  were used, with the anthropogenic bomb peaks as input functions. The chloride content in groundwater of the limestone aquifers enriches after contact with the saline Quaternary sediments and groundwater in the Lower Jordan Valley. The  $^{36}\text{Cl}$  Cl ratios in groundwater were found to be up to  $1\text{E}-12$  in the recharge area and decrease to  $1\text{E}-14$  in the discharge area. Groundwaters in the recharge area show partly  $^{36}\text{Cl}$  Cl ratios comparable to those in recent precipitation. The wide range of  $^{36}\text{Cl}$  Cl in the recharge area indicates different stages of chlorine isotope and elemental mixing within the recharge area or aquifer system. This may be due to varying Cl input (dependent on altitude and coastal proximity), varying  $^{36}\text{Cl}$  input (regional variation in fallout) or both. Together with  $^3\text{H}$  analyses it is possible to evaluate the recent rain water component in the springs emerging from



the uppermost part of the Cretaceous aquifers. Our results show that a combination of the  $^{36}\text{Cl}$  Cl and  $^3\text{H}$  measurements in groundwater and a correlation to the atmospheric input curves of  $^{36}\text{Cl}$  Cl and  $^3\text{H}$  allow estimating the admixture of post-bomb recharge in groundwater.



**Surface-subsurface hydrological exchange induced by a hill reservoir in a  
Mediterranean environment- Quantification and analysis  
Abstract n°2670**

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**KEYWORDS:** hill reservoir, water exchange, aquifer, Modeling, Tunisia

Hill reservoirs are hydraulic infrastructures widely used in North Africa, generally in arid and semi arid zones of the planet. These infrastructures are used for both water conservation in the catchment scale and to reduce siltation of downstream dams. The implementation and the management of water resources mobilized in this infrastructure must be based on knowledge of their hydrological functioning. However, the hydrological functioning of this system is not very known, especially the water flux exchange processes and intensity between the reservoir and the subsurface is still an open question. This study try to improve the understanding of surface-subsurface exchange induced by a hill reservoir, by quantifying their temporal variability and their dynamics, i.e. the factors and mechanisms controlling these exchanges. The study is based on the experimental catchment of Kamech (Cap Bon, Tunisia), of the Environment Research Observatory OMERÉ. In the first part of this study, we develop a water balance approach to estimate reservoir-subsurface exchange flux. The results of this approach shows that reservoir-subsurface exchange flux is dominated by infiltration that represent about 79% of the water outflow, and largely exceeds the water loss by evaporation that represents only 21 % of the total water outflow. However, the cross-analysis of the hydrological dynamics of the hill reservoir and the aquifer in the vicinity of the reservoir revealed that infiltration can occur in both directions- reservoir-subsurface exchange dominated by infiltration with the aquifer located in the foot of the dam, however the water exchange with the lateral aquifer of the hill reservoir can occur in both directions but remain very fleeting. The preliminary results of the modeling approach developed in this work have highlighted the complexity of reservoir-subsurface exchange flux. In fact, the relationship between water level in the hill reservoir and the infiltration flux is not unique and can present different behavior between the rise and decrease phase of the water level in the hill reservoir.



**Hydrogeological assessment in upper Vientiane Plain, Lao PDR- implications for sustainable groundwater development in data-scarce regions**  
**Abstract n°2671**

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**KEYWORDS:** water balance, recharge, groundwater management, Lao PDR

The abundance of surface water resources in Lao PDR has historically led to limited interest in groundwater, except for rural water supplies. However there is a recent interest in developing groundwater supplies for irrigation and increasing food production. A critical lack of knowledge on the resource availability and extent hinders effective development and management. A case study in the 600 km<sup>2</sup> alluvial aquifer of the upper Vientiane Plain provides a first step towards addressing this issue. Being almost the first study of this kind in Lao PDR, data availability was a major constraint. Simple methods have been used to characterize aquifer properties, flow systems and recharge rates. Water levels were monitored in more than 50 wells over 2 years to determine regional flow and seasonal changes. Permeability was estimated using pumping and slug tests at 12 locations. Water balance and water table fluctuation (WTF) methods allowed calculating specific yield and recharge rates. For comparative purposes recharge was also calculated using Chloride Mass Balance (CMB) method. The aquifer permeability averaged 1.6  $10^{-5}$  m.s<sup>-1</sup> for alluvium and 8.5  $10^{-6}$  m.s<sup>-1</sup> for deeper sandstone. Specific yield was estimated at 0.14. Recharge values from both methods are in the order of 400 mm.yr (17% of rainfall). Water level observations also show a probable influence from flow variations of the hydropower-controlled Nam Ngum River. With average groundwater use of only 24 mm.yr<sup>-1</sup> equivalent to 6 % of annual recharge, there is potential scope for further groundwater irrigation development. If managed sustainably, it could support enhancing food production and improve livelihoods. Finally, these results are being used by local authorities to build a model and management plan for sustainable development of the Vientiane Plain.



**NUMERICAL INVESTIGATION OF ENHANCED GEOTHERMAL SYSTEM  
PERFORMANCE IN A SEDIMENTARY BASIN  
Abstract n°2672**

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**KEYWORDS:** Enhanced geothermal systems (EGS), Numerical simulations, Natural thermal state, Discrete fracture network (DFN)

An enhanced geothermal system (EGS) consists of injecting water into naturally fractured or hydraulically stimulated deep sedimentary or basement rocks, and withdrawal of this water in other wells for heat extraction. Formations with sufficiently high temperatures at accessible depths can be viable sources of electrical energy production. Under these conditions, obtaining reliable measurements of deep subsurface temperatures and defining an optimized geothermal extraction strategy remain important challenges for EGS development. The evolution of temperature with depth in sedimentary basins is usually predicted by extrapolating bottom-hole temperature (BHT) data from shallower oil and gas wells to greater depths required for geothermal development. However, in areas with limited oil and gas activity, such as in the St. Lawrence Lowlands basin, Quebec, Canada, the low number of measured temperatures severely affects the accuracy of predicting the natural thermal state of the basin. To fill this lack of data, in the first step, a 3D conceptual model has been developed based on a detailed geological model of the basin, and the distribution of hydrothermal properties and radiogenic heat production at various depths has been obtained by laboratory experiments and well logs. Numerical simulations of the basin thermal regime under natural conditions were then conducted with the HydroGeoSphere model assuming non-isothermal single-phase flow. The calibrated model was used to define the depths (areas) for which ground temperatures are expected to be higher than 120°C. In the second step, each favorable area is characterized in detail by conducting non-isothermal single-phase flow simulations in realistic fracture networks with variable



orientation, size, and transmissivity. All simulations and model benchmarking comparison are made using Heatflow smoker and HydroGeoSphere numerical models. The results of these simulations are used to study the dynamic thermal behaviour and to define geothermal development strategies for each area, including well position, number, spacing and depth.



**Assessing the economic benefits of preserving strategic groundwater resources for present and future generations using the ecosystem services approach**  
**Abstract n°2673**

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**KEYWORDS:** economic benefits, ecosystem services, groundwater preservation

Groundwater resources provide societies with numerous benefits whose sustainability is likely to be affected by global changes. However, preserving good-quality groundwater resources faces several barriers locally, as it will set constraints in land and water management for stakeholders, while they might not be aware of the benefits of protecting these resources. One powerful lever for implementing efficient groundwater preservation measures consists in enhancing the support of local stakeholders, by improving their understanding of the benefits that preservation can bring to their territories. We develop an economic rationale based on the ecosystem services assessment framework to highlight the economic benefits of preserving territories hosting strategic groundwater resources for future water supply. Compared to conventional economic valuation methods applied to groundwater management, this approach does not focus on the sole benefit associated with the good status of groundwater. It expands the analysis by considering as benefits the broad spectrum of services provided by ecosystems that are compatible with the maintenance of a good-quality groundwater resource. Located in Southern France, the study site is a 70 km<sup>2</sup> natural area mainly covered by forest, which hosts large volumes of good-quality water that are not used today but that could be used in the future to supply the growing population of coastal urban areas. Nine ecosystem services are characterized and quantified- agricultural and wood production, climate regulation, water purification, flood protection, hunting, fishing, hiking and speleology. The overall economic benefits of preserving the strategic groundwater zone are estimated to range between 2,9 and 5,4 billion euros per year (390 - 730 € ha year), with two third of them being associated to recreational activities, and only 7% directly related to groundwater.



**Groundwater crisis in Central Syria prior to the conflict- the dangers of a consensual diagnosis**  
**Abstract n°2674**

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KEYWORDS: groundwater crisis, Syria

The Salamieh area was considered before the Syrian conflict as one of the areas that are the most affected by groundwater overdraft and general water scarcity in Syria. After being excluded for decades from the agricultural plans, it witnessed in the early 2000s the enforcement of constraining legal measures aiming at reducing water use and conserving the resource. However, the groundwater crisis diagnosis constituted a dead-end for water management by the way the environmental problem was defined and the hydrogeological studies used. It obscured local and regional water problems and their interactions with critical national agricultural and energetic issues, making impossible the identification as well as the resolution of major socio-economic problems that rooted the Syrian uprising, and leading to ineffective, if not counterproductive, local water management and regulation interventions. By preventing any controversy, it erased discussions about water use and management situations, closing the range of possibilities for the definition of alternatives. Furthermore, it obscured the power relationships shaping the uneven access to water, and, by its mostly technician and scientist aspects, excluded the local populations concerned by interventions, constituting a mirror of the weak political representation of rural populations prior to the 2011 Syrian crisis.



**The transboundary water resources of Lesotho, Swaziland and South Africa-  
complementarity, consistency, or neither ?  
Abstract n°2675**

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KEYWORDS: Southern Africa, conjunctive use, drought preparation, cooperation

The surface water resources of three countries in the South African region are entirely intertwined and significantly inter dependent. The groundwater resources are less so, primarily because the aquifer systems are localised, yet they contribute to local demands in a very important way. The 2016 drought in the region has placed an unprecedented pressure on the countries. Each have responded in somewhat different ways. While the drought has just broken with welcome rains, the legacy of this drought remains. Measures to become drought resistant that were developed in the recent years were not implemented then and are perhaps still dormant. Aquifer resources to alleviate the drought came to the rescue, but as usual – too little, too late. There is some potential for developing and expanding conjunctive use of river waters (when in flood) and aquifers, local though they may be. The paper will set out the approach to the planning that is adopted in the three countries and it is not consistent. The question has to be posed, how to make the policies and actions consistent. The paper will be based on the past 24 months field work in the three countries as part of a EU technical assistance to improve and implement integrated water resources management.



## Abstract n°2677

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### KEYWORDS:

In the Sahel, 98% of the pollution generated by excreta and domestic waste water goes back into the environment without any treatment. Given that over 50% of the population is urban, quality loss of aquatic media that collect all of these releases is important. In large cities, water needs are such that the more often the mobilization of groundwater is not sufficient. The solution involves the use of surface water which requires treatment. The cost of treatment of the water being passed on to the consumer, so, the most poor are the most affected by diseases and waterborne outbreaks, which represent a massive public health problem. This severely hampers the economic development of these countries. Although sanitation in these countries consists almost exclusively of on-site sanitation, less than 35% of households in urban areas have improved sanitation system and septic tanks, that is to say a system that take over excreta and domestic wastewater. Because of the cost of sanitation devices (about 1000 €), microbial pollution spreads in the sources and the shallows of cities or in traditional wells used by the poorest people who practice self-supply domestic water. While the benefits of improved sanitation in terms of health protection and in economic terms are not questionable, let note however that this is not a priority for water policymakers and donors in Sahel. Is it a complicated chain to understand and develop, or a socio-political issue?



**Aggregation of hydrogeological information at national and (sub)-regional scales for coherent knowledge transfer and support for decision making**  
**Abstract n°2678**

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**KEYWORDS:** hydrogeology, integrated mapping, harmonization

The process of semantic and geometric harmonization and aggregation of geological information is crucial for providing coherent information valid at and transferable between multiple overview scales. Recently, the lithological description of the International Hydrogeological Map of Europe in a scale of 1:1,500,000 (IHME 1500) of initially 1065 map units was generalized in five hierarchical aggregation levels based on a new taxonomic scheme and subsequent rock class grouping, resulting in ten rock classes and a ternary classification attributed to consolidated, partly consolidated and unconsolidated geologic materials as the highest generalization level. Additionally, IHME1500 represents basic information on general potential aquifer characteristics (productivity) for the lithologically defined map units based on expert knowledge. This presentation describes the application of this methodology to harmonize information on material compositions and potential aquifer productivities at the national scale (adopting the hydrogeological map of Germany HUEK200), as well as (sub)-regional and pilot zone scale (~400 kmC) in technical cooperation projects in Niger and Chad. The analyses involves various degrees of data availability and quality, showcasing difficulties and challenges in up- and downscaling processes. Furthermore, this contribution will highlight the need to move on to integrated hydrogeological mapping at overview scales, facilitating decision making processes on short- and mid-term time scales. This may be achieved combining the aggregated map units with information from various fields in science and engineering, as well as developing comprehensive, yet comprehensible legends that assure a transfer of precise hydrogeological data into planning societal benefit areas.



## **A multi-method approach to groundwater risk assessment Abstract n°2679**

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**KEYWORDS:** groundwater vulnerability, contamination index, risk assessment

This article attempts to assess groundwater vulnerability in the area of complex landfill sites located in southern Poland, including the metallurgical waste landfill, an illegal landfill, two municipal landfills and an area of a coking plant and a waste incinerator. Old closed landfill sites usually do not have seals above the ground or leachate drainage systems, which means that migration of contaminants into the aquifer and its spreading over long distances takes place there. The vulnerability of groundwater was determined by using chlorides as an indicator of the transformation of the groundwater chemical composition. The pollution index was calculated. The hydrochemical baseline was determined from available groundwater analyses from the 1960s. The data from the years 1990-2010 enabled to specify the changes in the chemical composition of groundwater over a 50 year period. Particular attention has been paid to the influence of local sources of pollution. Analysis of geological profiles allowed the vulnerability of groundwater to contamination to be determined – there were specified seepage times from the surface to the water table. The use of all methods allowed to reveal the significant impact of landfills in Strzemieszyce on groundwater chemical composition and allowed to indicate the area with a very high groundwater risk of contamination. The biggest transformation of the chemical composition have occurred in the vicinity of the waste incinerator, where the contamination index value is 15 times greater than acceptable.



# **Integrating Managed Aquifer Recharge into regional water management in Jordan**

## **Abstract n°2680**

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**KEYWORDS:** Managed Aquifer Recharge, Economic Assessment, Regional Water Management

The water resource availability in Jordan is on a very low level, and the population is facing absolute water scarcity according to the UN. To cope with this challenge, Managed Aquifer Recharge (MAR) was declared as a key technology in the Jordan Water Strategy. In this respect, an implementation concept for an MAR scheme was developed for a test site in the Jordan Valley, a neuralgic point in the Jordanian Water Management. The concept focuses on temporal storage of freshwater in an alluvial aquifer. The freshwater derives from King Abdallah Canal (KAC), the central water conveyor in Jordan, and will be recharged in winter time and recovered during the dry season. The hydrogeological suitability for MAR was evaluated by geo-electrical investigations and exploratory drillings. An alluvial fan was mapped close to the village of Deir Alla, consisting of sand and gravel, which is incised into fine laminated Lisan marls depicting a discrete underground store. The alluvial sediments show an effective porosity of 15 % allowing the storage of 5 million cubic meter freshwater. Results of field and laboratory experiments were used to set up a numerical groundwater model (FEFLOW) to define the optimal recharge methods adapted to the local boundary conditions. The economic and environmental assessment is done using the “benefit transfer” and “damage-avoided” methods. The damages provoked to the environment and benefits due to MAR application are expressed in monetary values. The results will be discussed by the Jordanian decision makers at the Ministry of Water and Irrigation (MWI) to get a step closer to implementation

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**What opportunities offer digital tools to train and graduate new hydrogeologist engineers?  
Abstract n°2682**

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KEYWORDS: hydrogeology+digital+pedagogy

Despite the growing weight in the public discourse of issues raised by the threats on groundwater resources quality, we cannot but acknowledge the decrease of the number of existing courses in hydrogeology at university in Europe. Seek for costs balance of training has become a request for a minimum enrollment. A number of reasons now makes it truly difficult to gather in one place the prerequisite number of students. This issue could be solved by distance education development. In France, the Cnam – Conservatoire National des Arts et Métiers – is a higher education institution dedicated to active adult life-long learning, notably through graduation. Teachings are largely webcasted to reach the francophonie worldwide and the mooc phenomenon - massive online open courses – draws a large public seemingly eager to learn. Even though mooc do not yet deliver diploma, nor aim to train engineers, we ought to consider in what respect digital tools may bring new opportunities to train and graduate hydrogeologist engineers. Such tools provide new pedagogical design perspectives that shall allow us to focus on our core activity regarding transmission of know-how and good practices that require in situ training. Existing digital learning environments allow integration of remote students, thus facilitating autonomous knowledge acquisition, participation to group dynamic and collaborative working experience. Digital media are a mean to spread results of projects that may provide elements for argument and decision making to civil society and enrich online databases. This paper exposes the design of a distance education experiment at the Cnam for a teaching unit of 6 ECTS in hydrogeology applied to the pollution risk management. Our aim with this experimental design is to contribute to the ongoing reflection in higher education on the use of digital tools. Is there an aspiration for a shift towards different ways of teaching and learning? If so, may it open the way to a form of co-construction of knowledge?



**USING RADIOACTIVE AND STABLE ISOTOPE (TRITIUM, OXYGEN-18, AND DEUTERIUM) IN DETERMINING GROUNDWATER AGE AND RECHARGE AREA OF SPRING COMPLEX AREA IN WEST JAVA, INDONESIA**  
**Abstract n°2683**

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KEYWORDS: isotope, volcanostratigraphy, spring complex

A spring complex area in Bandung and Garut Regency, West Java, roles as a major water source for inhabitant. Based on field observation, one spring point can provide clean water for three villages by using pipe to distribute the water. The groundwater age and recharge area analyses were performed in the spring complex, as important to manage the groundwater as vulnerable resource. The study was carried out by conducting geological mapping, groundwater sampling of 45 spring points, and isotope analyses. The radioactive isotope (tritium) analysis was performed to determine the age of groundwater of the research area, and stable isotope (deuterium dan oxygen-18) analysis for determining the processes occuring in groundwater and estimation of recharge area. The geology of research area, volcanostratigraphically, from youngest to the oldest unit, i.e. Khuluk Pra-Pulus comprises of Gumuk Mt. Pulus, Mt. Pasir Jugul, dan Mt. Putri+ Khuluk Pra-Mandalawangi involves Gumuk Mt. Mandalawangi, Mt. Buleud, dan Mt. Pangrajin. Generally, the lithologies of those units are pyroclastic tuff, pyroclastic breccia, igneous rock (andesite lava). The 45 spring points are classified as depression springs due to the absence of geological structure and contact of lithology. Based on deuterium and oxygen-18 analyses, recharge area is located in Mt. Guntur-Mt. Kamojang complex at an elevation of 1500-2240 masl, about eight kilometres south of the spring complex area. The elevation is confirmed by the slope direction heading to the rese arch area. The analyses also indicate that evaporation process takes place in the study area, as the evaporation held due to shallow aquifer or the water was being evaporated when discharged. Refer to tritium analysis, the groundwater is classified as modern groundwater (<5 to 10 years) which confirmed by calcium bicarbonate water. By using Darcy equation for water velocity calculation using hydraulic conductivity and head gradient, it supports that the hydraulic conductivity of the aquifer about  $1.04 \times 10^{-3}$  m sec which could be gravel exists as weathered rock or unconsolidated material.





**Monitoring Water quality in Induced RiverBank Filtration- The case study of the  
Sant'Alessio plant (Italy)  
Abstract n°2684**

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**KEYWORDS:** Managed Aquifer Recharge (MAR), Induced Riverbank Filtration (IRBF), Isotopes, Pharmaceuticals, Water quality

Monitoring water quality (i.e. chemical, i.e. emerging contaminants, and biological analytes) prior to plant set-up and during ongoing operations are needed steps in order to assure safety of the Managed Aquifer Recharge schemes and to evaluate potential risks for the environment and humans. The Serchio River Induced RiverBank Filtration (IRBF) MAR scheme in Sant'Alessio - Lucca (Italy) provides drinking water for about 300,000 people in coastal Tuscany. This scheme is constituted by ten vertical wells pumping from a high yield sand and gravel aquifer (10-2 m<sup>2</sup> s transmissivity), and it includes a weir down-stream the well field to raise river head and to increase water storage in the aquifer along the river reach. Surface geology is characterised by unconsolidated silty to sandy sediments, while in the Serchio riverbed coarse clean gravels outcrop. Currently this MAR plant is not yet routinely monitored in real - or quasi-real time for preventing risks of pollution of the abstracted groundwater. Within the EU FP7 MARSOL project a continuously monitoring network for T, EC and head along with nitrates, few organics and surface water quality fingerprinting has been set-up. This is backed up by discrete sampling for chemical analysis, including microbiology and pharmaceuticals. First results show that the most conservative elements such as Cl<sup>-</sup>, Br<sup>-</sup>, and SO<sub>4</sub><sup>2-</sup> clearly indicate mixing processes between the River Serchio water and groundwater in the pilot area. Sampled waters exhibit a bicarbonate-alkaline-earth hydrochemical facies whereas isotopic analyses of <sup>18</sup>O and <sup>2</sup>D highlight that the Serchio River constitute most part of the groundwater recharge in the plain. Pharmaceutical screening shows that stand-alone compounds concentrations are at present not of concern, aside from those determined in a ditch collecting untreated wastewater from the adjoining peri-urban area (i.e. Clarithromycine 6.9 lg l, Atenolol 1.5 lg l, Diclofenac 0.31 lg l, Ibuprofene 0.78 lg l, beta-Sitosterol 9.6 lg l, Naproxene 0.6 lg l ).



**Trade-off and robustness analysis to explore alternative groundwater policies under climate change with hydro-economic modeling**  
**Abstract n°2685**

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KEYWORDS: hydro-economic modeling+ groundwater regulation + instruments + irrigated farming+ Beauce

Due to raising environmental constraints and increasing demands, the water management issue is becoming a critical issue in many parts of the world. Hydro-economic modeling approaches are helpful to explore various water management alternatives in the climate change context and account for both impacts on resources and increasing water demands. We develop a holistic calibrated hydro-economic model that connects a detailed calibrated economic model with a semi-distributed hydrogeological model of Beauce (9750 km<sup>2</sup>), Europe's larger cereal producer. The withdrawal of water is regulated via a quota system- each year, according to the state of the aquifer the quota is revised to limit water uptake. The model is used to perform Monte-Carlo simulations of (i) the impact of climatic change on the baseline situation to assess the environmental compliance level of the reference management instrument and (ii) the combined effect of climate change and policy change among which regulatory and economic instruments. A trade-off and a robustness approach are implemented to analyze the environmental and economic performance of alternative instruments. The robustness approach internalize the uncertainty on parameters such as the level of the climatic change effect on water resources recharge and increased evapotranspiration as well as time and space variability. The results suggest that the substitution option is relevant to reduce the impact on farming but is not sufficient to improve the environmental performance.



**An overview of Research and Exploring of some caves with hydrogeological function  
in Croatian karst in the last 25 years  
Abstract n°2686**

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KEYWORDS: Cave, Speleology, Croatia

In the last 25 years, cave research were continuous. Sum of circumstances, new technology, higher level of knowledge and construction investment and work caused many new significant exploring and research of previously unknown caves in Croatia. Research of deep karstic springs. Spring of Una river dive to depth of -205 meters, spring of Gacka is 105 meters deep and 1150 meters long, in spring of Kupa, cavediver reach to a depth of 165 meters, in spring Sinjac up to 155 meters depth, in spring Rumin depth 150 meters, spring Cetina dive up to 115 meters and over 1100 meters in length, diving in Crveno jezero 161 meter depth, etc. Research and explore submarine springs along coast vrulja. In Ze ica over 900 meters cave channels were found there. In Modri over 2300 meters completely flooded channels were surveyed. In Dubci deep 161 meter were reached etc. Exploring very deep pits. Cave system Lukina jama 1431 meters deep with cave diving in output siphon, Slova ka cave is deep 1320 meters and Velebita is 1026 meters deep. Mention the discovery of the largest inside cave vertical in the World - 518 meters in Velebita and entrance vertical in Patkov gušt depth of 553 meters – the second in the World. Research and explore of long and complex caves – KitaGa ešina Draženova puhaljka is 31583 long and 737 meters deep, System ula Medvedica long 16397, and Panjkova 13052 meters etc. In all of these caves is significant quantity of groundwater. Research caverns discovered construction work - over 1100 caverns were found and explored in detail during the construction of highways. The longest tunnels (MalaKapela, SvetiRok, U ka, Svetillija, etc.) there were explored hundreds of caverns some of which are longer of 2000 and deeper than 300 meters. Measurements of geological, physical and chemical properties within the caves. Measurement concentration of radon, absolute movements of neotectonic faults, seismic activity etc. Today in Croatia are known about 12000 caves.



**Mill dam owners, farmers, fishermen and the ecological continuum- how to decide between them? The answer of infiltration, river-aquifer flow and denitrification in a natural wetland.  
Abstract n°2687**

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**KEYWORDS:** Dam, Dismantling, Restoration, Agriculture, Evapotranspiration

The EU framework directive on water advocates the dismantling of artificial limits on secondary waterways to restore ecological continuity on these watersheds where land use and quality of groundwater is marked by agriculture. One wonders about the disturbance that could cause dam leveling to the functioning of wetlands in the accompanying aquifer. These natural environments, valuable aids for the maintenance of the ecological status of the basin, are expected very sensitive to a metric variation in the level of the river. To test this hypothesis, instrumentation has been introduced within the Hauterive mill site, upstream of the Sarthe, a stream of low energy in rural area. On this site laid long ago by a dam supplying a mill, where the Sarthe is lined with a diversion channel, piezometers, limnimeters and a meteorological device were implanted. Continuous monitoring of water levels and weather parameters has enabled a water balance and a hydrodynamic model of the site. Measures infiltration and hydromorphic soil textural analysis were conducted. Contamination is characterized by chemical analysis of the water of the river and piezometers. The purifying power of natural wetland accompanying the stream and feed by the regional water table is characterized and discussed in light of nitrate and glyphosate and drug residues. The results show that the main process responsible for temporal variations in short time (less than monthly) of the groundwater level within the wetland is the couple infiltration - evapotranspiration. The water flow between the river and the aquifer and reciprocally is very slow and such is the seasonal evolution of the piezometric level in accordance with the river. A conclusion will be drawn as to the relevance of dam dismantling on such waterways that may be favourable to some fauna species but result in wetland loss and degradation of the overall quality of the river and groundwater.



## Groundwater for Sustainable Development in the MENA Region Abstract n°2689

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KEYWORDS: groundwater, sustainable development, MENA region, Arab region

A year ago, in September 2015 the international community agreed on an ambitious 2030 Agenda for Sustainable Development that includes a set of 17 Sustainable Development Goals (SDGs) and 169 targets. The United Nations Inter-Agency and Expert Group on Sustainable Development Goal Indicators (IAEG-SDGs) proposed in December 2015 a set of 231 global indicators that were adopted by the United Nations Statistical Commission (UNSC) in March 2016 as global SDG indicator framework and as practical starting point for monitoring progress towards the achievement of the SDGs by 2030. It was also noted that the indicators are subject to further technical refinement . Based on the current understanding water and groundwater, well managed and in sufficient quantities and qualities will be essential for achieving many of the SDGs. This in addition to the specific SDG 6 Ensure availability and sustainable management of water and sanitation for all . In the Middle East and North Africa (MENA) with a generally higher water scarcity than in many other parts of the world and with larger quantities of renewable freshwater already utilized, sustainable water management has been challenging for many years. Groundwater in this region has been especially burdened with inappropriate governance, over exploitation and pollution - to name only a few challenges. How will the MENA region cope with the new goals of the 2030 Agenda for Sustainable Development in the current times of transition with fragile states, crisis, war, civil unrest and occupation? Based on recent studies the presentation analyzes the current situation and derives proposals to focus on specific aspects in which groundwater can better contribute to the overarching goals for sustainable development. It will also provide guidance for improved governance of groundwater resources in the region and offer a way forward to a more just socio-economic development for the people in the MENA region.



**An overview of Research and Exploring of some caves with hydrogeological function  
in Croatian karst in the last 25 years  
Abstract n°2691**

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KEYWORDS: Cave, Speleology, Croatia

In the last 25 years, cave research were continuous. Sum of circumstances, new technology, higher level of knowledge and construction investment and work caused many new significant exploring and research of previously unknown caves in Croatia. 1. Research of deep karstic springs. Spring of Una river dive to depth of -205 meters, spring of Gacka is 105 meters deep and 1150 meters long, in spring of Kupa, cavediver reach to a depth of 165 meters, in spring Sinjac up to 155 meters depth, in spring Rumin depth 150 meters, spring Cetina dive up to 115 meters and over 1100 meters in length, diving in Crveno jezero 161 meter depth, etc. 2. Research and explore submarine springs along coast vrulja. In Zecica over 900 meters cave channels were found there. In Modric over 2300 meters completely flooded channels were surveyed. In Dubci deep 161 meter were reached etc. 3. Exploring very deep pits. Cave system Lukina jama 1431 meters deep with cave diving in output siphon, Slovacka cave is deep 1320 meters and Velebita is 1026 meters deep. Mention the discovery of the largest inside cave vertical in the World - 518 meters in Velebita and entrance vertical in Patkov gust depth of 553 meters – the second in the World. 4. Research and explore of long and complex caves – Kita Gacesina Drazenova puhaljka is 31583 long and 737 meters deep, System DJula Medvedica long 16397, and Panjkova 13052 meters etc. In all of these caves is significant quantity of groundwater. 5. Research caverns discovered construction work - over 1100 caverns were found and explored in detail during the construction of highways. The longest tunnels (Mala Kapela, Sveti Rok, Ucka, Sveti Ilija, etc.) there were explored hundreds of caverns some of which are longer of 2000 and deeper than 300 meters. 6. Measurements of geological, physical and chemical properties within the caves. Measurement concentration of radon, absolute movements of neotectonic faults, seismic activity etc. Today in Croatia are known about 12000 caves.



**Opening the sharing and reuse of groundwater datasets to new communities and citizens**  
**Abstract n°2692**

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KEYWORDS: opendata, reuse of datasets, data sharing

Accessing datasets in water, in particular groundwater on line and up-to-date data on groundwater measurements, seems easy for the experts in the appropriate field of science. In France, the ADES Information System ([http- www.ades.eaufrance.fr](http://www.ades.eaufrance.fr)) allows to download specific datasets for piezometric data levels or groundwater quality analysis. But, opening up to others actors (industrial, universities, civil society) are not provided by this type of internet platform. The Ministry of the Environment, BRGM and The French National Agency for Water and Aquatic Environments (ONEMA) have been experimenting in the Hub'Eau project - [http- www.hubeau.fr](http://www.hubeau.fr) - (winner of one of National Investment programme) new interfaces providing access to environmental data, and in particular data of the National piezometric network (Water Framework Directive), managed by the BRGM. Rather than trying to answer all the requirements of current and potential users, Hub'eau provides a mediation platform between groundwater specialists and other communities. This mediation is focused on different objectives- - A technical platform that will digest current data flows (ADES web services, specialized OGC standards,...) to (re)publish more friendly datasets through API and CSV files. This platform delivers a single interactive access point (URL) to all type of water datasets with simple opendata copyrights. - An "animation" platform that helps crossing-fertilize viewpoints and promote interdisciplinarity and succeeds to initiate new reuse of the knowledge of groundwater. For example, the organization of "Hackathon" sessions (June 2016) offers the opportunity to federate hydrogeologists, end-users, - datajournalists, NGOs,...- , and IT developers around the use of the Hub'Eau platform, share skills and invent new applications of hydrogeological data sets. The challenge of Hub'eau project is to improve value-added groundwater services outside the community of hydrogeologists- guarantee a short learning curve to use this information, without distorting them, was the technical goal. Reduce the risk of incorrect use of our datasets, with no guarantee of success, and create bridges between producers and end-users is the long-term goal.



**Groundwater recharge quantification from historical rainfall records and salinity profiling in the RAMSAR listed Verlorenvlei catchment  
Abstract n°2693**

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KEYWORDS: Recharge, Stable Isotopes, Salinisation

The Verlorenvlei RAMSAR listed wetlands, situated along the west coast of South Africa, are a fresh water estuarine system thought to be fed from the Verlorenvlei River. The river has its source in the semi-arid hinterland and groundwater salinisation is a major cause of concern for the long-term health of the wetlands. The main inputs are its tributaries+ Krom Antonies, Hol, Bergvallei and Kruismans rivers. Given the low rainfall in the area (<300 mm yr) and lack of surface water, there is a possibility that the wetlands are fed by deeper groundwater. In this study, stable isotopes and hydrochemistry are used to evaluate the recharge to these groundwater systems, which can be used to assess the interaction of groundwater with the saline surface water. These results can be compared to longer term rainfall records to predict future fluctuations in groundwater chemistry. Analysis of historical rainfall records suggests that the Krom Antonies River, situated in the Moutonshoek catchment, is the primary recharge location for the Verlorenvlei. Groundwater hydrochemistry in this catchment indicates that it is the least saline groundwater feeding into the Verlorenvlei (EC 127 IS m), similar to shallow groundwater in the tributary itself. Whilst deep groundwater in the Hol and the Kruismans sub-catchments are still relatively fresh (EC 248 IS m and 94 IS m), the equivalent shallow water in the individual tributaries is significantly more saline. This is consistent with stable isotopes which show a strong evaporation trend in surface water. The saline Kruismans River is an exception, as evaporation trends are seen in both deep ground and surface water. The chloride mass technique (CMB) and stable isotopes will be used to estimate recharge, with tritium and radiocarbon defining time constraints. Rainfall collection points have been established along three of the major tributaries, the confluence and the Verlorenvlei river itself. A number of sampling trips will be completed through the course of the year, coupled with the installation of pressure transducers in open boreholes.



**A passive heat tracer experiment to determine the seasonal variation in residence times in a managed aquifer recharge system with DTS**  
**Abstract n°2695**

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KEYWORDS: Groundwater, DTS

Targeted provisional session N°8.01 The seasonal variation in residence times is determined in a managed aquifer recharge system using a passive heat tracer test. The managed aquifer recharge system consists of a sequence of alternating elongated recharge basins and rows of recovery wells. The temperature of both the water in the recharge basin and the surface influence the temperature in the aquifer. The flow field changes when the temperature changes, as the hydraulic conductivity is a function of the temperature. Fiber optic cables were inserted up to a depth of 20 meters with direct push equipment to measure vertical temperature profiles with DTS. In this fashion, the fiber optic cables are in direct contact with the aquifer and the disturbance of the aquifer is minimal. The measured spatial and temporal temperature variations in the subsurface were modeled with SEAWAT, a coupled flow and heat transport model. MODPATH was used to compute flow paths and residence times. During the winter, a larger fraction of the water moves through the warmer lower part of the aquifer, thereby increasing the residence time. The opposite happens during the summer, when most of the water moves through the warmer upper part of the aquifer, resulting in shorter residence times.



# Groundwater Spreadsheets- a powerful learning tool in Hydrogeology

## Abstract n°2696

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KEYWORDS: groundwater spreadsheets, groundwater training, groundwater education

Spreadsheets is a simple tool for solving efficiently groundwater flow and pollution analytical and numerical problems. It's a cheap, easy to use, and a powerful tool for Hydrogeology teaching research and practice. It also helps to understand concepts and solve practical day-to-day groundwater problems. No complex programming is required and it is suitable for use by students, practitioners and researchers. In this paper various recent advances using spreadsheets are presented. Convolution is suitable for spreadsheets to solve a wide range of superposition problems with input varying arbitrary in time or space. This procedure can be applied for pumping tests analysis with discharge rate varying in time, for example for step or intermittent tests, which can include well storage in large diameter wells. Superposition can also be applied for well field analysis with input varying in space (steady state) and varying in time and space (transient state). Other superposition problems are presented as earth resistivity soundings interpretation, unit hydrograph and base flow generation. Convolution coupled with forward and inverse particle tracking are implemented in spreadsheets for advective contaminant transport problems, risk analysis, delineation of capture zones and forensic hydrogeology+ furthermore, with random walk particle tracking, dispersion can also be included. Spreadsheets are also suitable for 1-D, 2-D and 3-D finite difference models to simulate well fields, sea water intrusion, the effect of climate change in groundwater dependable ecosystems, and Flow System Analysis+ also coupled with surface hydrology models, can be used for more applications, for example, to simulated SUDS (Sustainable Urban Drainage Systems). There are hundreds of more groundwater applications using spreadsheets- land subsidence, unsaturated flow and hydrogeochemical analysis are some that are including in this paper.



**SWEing the groundwater data workflow- from data collection to reuse, opportunities  
of interoperable sensorWeb approaches  
Abstract n°2697**

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KEYWORDS: SensorWeb, interoperability, OGC, Inspire, near-real time data flows

Thanks to recent evolutions in environmental sensors, new data transmission associated with better autonomy, it is now feasible to consider raw data quality with more confidence. Even if human QA QC activity is still required (at least to check the overall workflow status), raw data can be considered as fitted for direct reuse. Groundwater level data and their near real time availability (raw data) answer to important societal needs - - Natural resource management in a climate change context with even more frequent drought episodes and their impact on quality and quantity of the resource, - But also civil security in specific geological contexts where surface ground water connexion associated with water table rise have a direct impact on flood events. Parallel to these, the ICT context is also evolving with more mature international open standards for sensorWeb interoperability (namely the OGC SWE - Sensor Web Enablement Framework) along with their endorsement by Legal obligations (INSPIRE directive) and communities. BRGM is conducting a dedicated joint SensorWeb activity between its IT and Water Environment Ecotechnologies division for several years. This transversal activity enables both - - The appropriation of the IT context and opportunities by domain experts, - And the possibility to be active on the international IT context (OGC, INSPIRE) so that international interoperability standards definition and application is close to domain needs. This presentation will focus on the IT changes the French national piezometric network is currently going through. From the sensor on the field, to the central information system, data validation, exploitation and reuse the system is progressively proposing a change of paradigm in hydrogeologists activities. As a conclusion these changes will be linked to new opportunities, partnerships with other institutions (ex-dynamic Groundwater level forecast – MétéEau des nappes) and but also to new challenges (vendor specific formats, big data, data accessibility) they create.



**What can we learn from the hydrogeological functioning of peri-urban lakes in the Ile-de-France region on their ecological status?**  
**Abstract n°2698**

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KEYWORDS: vadose zone, lake, groundwater

Aquatic ecosystem sustainability requires the appreciation of the ecosystem services they provide in order to develop integrated decision-making strategies. In this context, the PULSE project (Peri-Urban Lakes, Society and Environment, ANR CEPS) was dedicated (i) to assess the ecological status of suburban lakes from the Ile-de-France region, (ii) to develop management-focused indicators and (iii) to propose management guidelines. In order to assess their environmental status, a representative set of 48 lakes was selected. Field campaigns were conducted every summer from 2011 to 2013. The dataset includes physico-chemical variables (e.g. temperature, pH, O<sub>2</sub>...), biological variables (e.g. phytoplankton abundance including toxic cyanobacteria), and contaminants (e.g. trace metals). Predictive models based on catchment-scale characteristics were built to evaluate the impact of anthropogenic pressures on some ecosystem properties. Nearly half of these lakes are only fed by groundwater, a proportion representative of the region hydrology. A better understanding of the hydrogeological functioning of these lakes could prove very useful in order to improve the accuracy of predictive models based on catchment-scale characteristics. In this paper, we will first define a typology of the Ile-de-France lakes based on (i) the geological characteristics of their catchment (ii) their relationships with the groundwater, neighboring rivers, wetlands and sanitation network, (iii) their degree of artificialization, and (iv) the anthropogenic pressures. These indicators will be derived from GIS databases, geological and soil maps as well as management reports. The results of statistical analysis and predictive models used to evaluate the response of these aquatic ecosystems to anthropogenic pressures will be presented. Finally we will discuss to what extent hydrogeological characteristics contribute to increase the variance explained by these models.



## Using GIS for development of an Atlas of the main sources of Sebou basin - Morocco Abstract n°2699

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**KEYWORDS:** Geographic Information System, isotopic composition, Morocco.

The sources play an important socio-economic role in a semi-arid country like Morocco. The management of their water, however, requires an efficient tool that will capitalize data and restore it by going to the essentials, taking an important role in the water management decision process,. The development of such a tool should go through harvesting the available information, the acquisition of additional physicochemical and isotopic data and their integration into a Geographical Information System, which allows for operation a summary sheet for each source. These sheets are collected in an Atlas. This tool is applied to the Sebou basin which occupies 40000 km<sup>2</sup> and is home to more than two thousand springs, the most important (398) are regularly gauged and monitored. Forty of them are selected for the development of an Atlas of springs, considering their debit (from 10 to 2500 liters per second), their contribution to the socio-economic activity, origin (outfall water table or deep or mixed) and temperature (10-54 ° C). This Atlas includes not only the administrative and geographical location, topography and geology of the environment of each spring, but even a hydrogeological section which describes its context, piezometry near the source, temperature, conductivity, Chemical facies and eventual isotopic composition (oxygen-18 and deuterium), the graphic evolution of its flow, the uses of its waters and any legal texts regulating these uses. A photo album with any old and new pictures is added to highlight the impact of human intervention. The publication of the Atlas coupled with its Geographic Information System allows easy access to data, prepares the decision making in the field of water resources management and planning, and contributes to resolve eventual disputes between different users.



## **Nitrate trends in groundwater of the Campania region (southern Italy) Abstract n°2700**

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**KEYWORDS:** groundwater body, nitrate trends, Campania region

The WFD (Annex V 2.4.4) and GWD (Article 5.1) state that significant and sustained upward trends shall be identified in concentrations of pollutants, groups of pollutants or indicators of pollution found in groundwater bodies or groups of groundwater bodies at risk. Following this aim, the nitrate trends were calculated for some groundwater bodies of the Campania region (southern Italy) by adopting 3 approaches- comparison of four years monitoring periods+ statistical linear trend analysis+ extended statistics using the GWStat software, developed by the German Company Quo Data . The chemical data derive from the monitoring activity of the Regional Environmental Protection Agency (ARPAC) 2002-2014, integrated by data of the University of Naples. The trend analysis showed that while in the groundwater bodies of carbonate aquifers the nitrate content is substantially constant, multiyear fluctuations affect some areas of the plains. The results achieved with the different methods are similar, but the software has proved very useful for the following reasons- - GWStat makes the calculation of the trend very simple, compared to graphic analysis and the method has statistical significance+ - the graphic method has a lower reliability, especially in presence of the anomalous values (due to possible localized pollutions) that influence the graph+ -the method successfully identified trend reversal of nitrate concentrations. Lastly, for one groundwater body a geostatistic spatial analysis has been performed using GIS, in order to estimate the spatial variability of the nitrate trends. The location of upward and downward trends seem to be related to differences in landuse, but longer time series are needed for confirmation.



**Anthropogenic pressures on groundwater resources. Case of the Northern plains of  
Batna region (North-East Algeria).  
Abstract n°2701**

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**KEYWORDS:** water resources, climate change, overexploitation, drought.

In recent decades, groundwater is exploited at unsustainable rates. Indeed, in terms of balance sheet, the level of renewable groundwater resources of Algeria, valued at 2.5 billion m<sup>3</sup> year, is overexploited, because of the increasing needs in all sectors. The studied area, located in the North of Batna region, is composed by plains which have an agricultural vocation, and this activity is practically the only source of employment in the region. This activity is supplied by groundwater stored in alluvial aquifers and in Jurassic and Cretaceous carbonate formations. These are most often small farms of about ten hectares, exploited for seasonal crops but also multiannual as alfalfa and sorghum (Cattle food) that require continuous irrigation. This activity exacerbates the use of boreholes to catch groundwater in the absence of mobilization of surface water, by lack of a state strategy in this direction, ie, the achievement policy of small dams in sufficient numbers. It should be noted that Algeria is trying to catch up the delay in terms of achievements of water infrastructures - large dams (more than 10 million m<sup>3</sup> of capacity), hydraulic transfers, desalination of sea water and the reuse of sewage water. The realization of small hydraulic dams more suited to the reality on the ground (sparse population, agriculture in mountainous areas and peri-mountainous) remains below expectations. The overexploitation of groundwater for agricultural uses has resulted in a significant drop in water levels, the diminution of the quality of these waters and the recrudescence of situations of conflicts between users. The departments responsible of the groundwater resources management are overwhelmed by the number of drilling permit demands. Sometimes prohibited, sometimes allowed, their management obeys mainly to social pressures rather than clear management principles, which should take account of the renewal status of the water resources. Year after year, the state of groundwater is modified under the combined effect of uncontrolled exploitation and climate change of which the most significant effect on the region is drought.



**Perspectives for the development of associated raw brines in oil and gas fields of  
Kazakhstan  
Abstract n°2708**

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**KEYWORDS:** reservoir groundwater, raw brines, gas and oil fields

Theoretical and methodological basis for the researches of raw brines were established in the Soviet time. In Kazakhstan, theoretical works on raw brines studying were conducted, mainly, by the Institute of hydrogeology and hydrophysic of the NAS RK in 70-80-ies years of the previous century. In 2006-2011, scientific researches on the issues of raw brines were executed under the supervision of M.K. Absametov. The evaluation of formation factors and accumulation of microcomponent content was conducted, using data on isotopic content of reservoir groundwater, methods of paleohydrochemical analysis, statistical analysis and hydrogeochemical simulation as applied with the detected provinces and areas, including, Caspian, Mangyshlak-Ustyursk, Shu-Sarysuisk and South-Turgaisk Provinces. The conducted researches show that in the Republic's subsoil, there are sufficient resources of raw brines, which have practical interest as industrial water, on the basis of which, there is an opportunity to arrange new innovative productions. Production and processing of raw brines with a rapid payback of capital investments and a high cost-effectiveness of production, may become an additional source of the investments in gas and oil field development. Processing of additionally produced raw brines, especially in the fields with a petroleum subeconomic production, gives an opportunity to decrease a cost of petroleum production by the means of an additional supply saleable materials, and, as a result, to save existing infrastructure of oil fields and work places. The most cost-effective are the possibilities to extract iodine, bromine, lithium and other components and compounds from associated raw brines of water in gas and oil fields. Herewith, the availability of an infrastructure, a labour force and a possibility to solve ecological problems are meant. Further studies must be determined on the evaluation of specific sites and areas for the implementation of experimental and industrial technology of extraction of mineral components and compounds from raw brines in hydrocarbonaceous raw material fields.



**Estimating pressure and impact of nitrates on groundwater at national level –new  
methodological development  
Abstract n°2709**

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KEYWORDS: nitrate, pressure, impact

**Objectives** Within the water framework directive the assessment of the impact on groundwater of the pressure from nitrate from agriculture origin is requested. Detailed studies have given good results at local level (e.g. Krause et al., 2008). At basin and national levels other methods should be developed in order to provide a uniform view of the pressure impact issue. **Design and methodology** Within the framework of the Onema BRGM convention, a study was initiated in 2013 with the objective of proposing a national map of the P I issue based on the combination of various thematic layers using a geographical information system. **Original data and results** The study is carried out at a “working units”, units based on the French hydrogeological referential (BDLISA level3). Then typologies of water transfer were defined. From the combination of porosity and permeability issued from BDLISA 12 functioning classes were obtained. Then water infiltration is estimated using efficient precipitation and an infiltration runoff factor calculated from IDPR classes. For sedimentary basin, unsaturated zone depth and data of nitrate transfer velocity were coupled. For other lithologies and in parallel, apparent age data obtained using isotope and chemical tools were compiled. The various information layers were then combined in order to obtain a spatial distribution of the nitrate recharge ages. Combined with a simplified pressure layer it will then be possible to propose the pressure impact map. To validate the approach the final map will be compared with the nitrate concentration measured at monitoring points. **Conclusions** The proposed approach will give an homogeneous national view of the pressure impact approach for nitrate and will permit highlighting the sectors where today’s pressure may lead to a degradation of groundwater quality and that will need local studies in order for the Water Manager to propose adequate program of measures.



**Mechanism of saline groundwater migration under the influence of deep groundwater exploitation in the North China Plain**  
**Abstract n°2710**

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**KEYWORDS:** North China Plain+ Groundwater exploitation+ Saline water movement+ freshwater-saltwater interface

Understanding the mechanism of salt water transport in response to the exploitation of deep freshwater has long been one of the major regional environmental hydrogeological problems and scientific challenges in the North China Plain. It is also the key to a correct understanding of the sources of deep groundwater pumpage. This study will look at the Hengshui - Cangzhou region (China) as a region with typical vertical salt water distribution, and high levels of groundwater exploitation, integrating a variety of techniques in geology, hydrogeology, geophysics, hydrodynamics, and hydrochemistry - stable isotopes. Information about the problem will be determined using multiple lines of evidence, including field surveys of drilling and water sampling, as well as laboratory experiments and physical and numerical simulations. The study will characterize and depict the migration characteristics of salt water bodies and their relationship with the geological structure and deep ground water resources. The work will reveal the freshwater-saltwater interface shape+ determine the mode and mechanism of hydrodynamic transport and salt transport+ estimate the vertical migration time of salt water in a thick aquitard+ and develop accurate hydrogeological conceptual models. This work employed groundwater variable density flow- solute transport numerical models to simulate the water and salt transport processes in vertical one-dimensional (typical bore) and two-dimensional (typical cross-section) space. Both inversion of the downward movement of saltwater caused by groundwater exploitation through history, and examining future saltwater migration trends under groundwater exploitation scenarios will be conducted, to quantitatively evaluate the impact of salt water migration to the deep groundwater body in the North China Plain. The research results will provide a scientific basis for the sustainable utilization of deep groundwater resources in this area.



## **New concepts in groundwater vulnerability assessment mapping Abstract n°2711**

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**KEYWORDS:** vulnerability, underground work, IDPR

In order to prevent accidental pollution, Rte (National Electricity transportation network) asked BRGM to renew its risk analysis to prioritize the work of technical compliance of all plants (stations and high and extra-high voltage networks underground cables used, in the form of oil-filled cables) in an environmental perspective. Intrinsic vulnerability was analyzed and placed at the engineering works themselves (stations or underground lines). In these use cases, the principal constraint when an accidental discharge occurs (oil) is to prevent groundwater and surface water contamination. Data and processing of the water vulnerability analysis were architected in order to conduct the evaluation and produce an information sheet regardless of the position of each plant. This automation will facilitate the integration of new infrastructures or plan travels. A groundwater vulnerability map with the step of 25m has been drawn. 2711 stations and 118 underground connection lines were produced, implementing various software solutions, including the map construction, to use technologies which could facilitate maintenance and sharing of new project taking into account water resources. IDPR index has been used extensively in France to quickly identify infiltrating zones. In this GIS data base, some new layers and concepts have been used- - The Hydrogeological Reference System BDLISA, that helps user to locate and characterize aquifer, aquitard and aquiclude formations, with three different scales of visualization (from local to national) with the entire vertical succession of hydrogeological entities including hydrodynamic properties, - IDPR index with zonation at local scale (25m), - Each water path is calculated using the drainage derived from DTM, to knitted mesh along the line of greatest slope. Path ends when the permanent water network is reached, - The weighting of vulnerability values along the way is done by estimating with a formulation that describes lower volumes of pollutants transported in the pathway (between station and rivers lakes). This new approach is reflected in the provision of technical and cartographic records, GIS software associated webservices that facilitate the update of layers of information integrated.



## **Spatial Interpolation for the Characterization of the Aquifer System Abstract n°2718**

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**KEYWORDS:** Morocco, Semi arid, Groundwater, Spatial interpolation, kriging, GIS

Water, a vital resource, is required as a key factor for development of populations, specially in the arid to semi arid areas, such as Morocco, which is facing water stress. With this state, the spatio temporal variability of rainfall, the climate changes, the growing demand for this resource, and the low recharge of aquifer, are increasing. Therefore, the efficient sustainable and integrated groundwater management is essential for protection of this resource. Generally, the measuring and monitoring network density is limited (the hydraulic basin agencies that are in charge), due to the cost constraint. This limits the characterization of the spatial variation of parameters which are generally continuous in space. Spatial Interpolation with geostatistical methods are required to be the best way to produce the lack of data reliably. Indeed, it generates a spatial forecast for unsampled points by estimating the smallest error. In this work we propose to study the groundwater of Khemisst-Tifelt region (The Hydraulic Basin Agency of Sebou ABHS that manages this area). In this order, the spatial interpolation using kriging method through the Geographic Information System GIS, represents an original contribution. This allows to produce the needed map for studying the aquifer system's behaviour. The spatial interpolation is the best reliable solution for the data gap. This method will help the achievement of specific hydrogeological and environmental studies and obviously offer to the users an additional information about the characterization of the studied aquifer system



**Multi-tracer groundwater dating (CFCs SF6, Tritium and 14C activities) for the characterization of a thermal flow system – case of the Avène-thermal spring  
Abstract n°2719**

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KEYWORDS: age dating, thermal water, Avène

Thermo-mineral water is characterized by its constant physicochemical properties with time, which is most often a consequence of deep GW flow paths and long residence time. These characteristics result from complex and relatively unknown geological settings. Understanding the origin and transfer of the thermal water is however a key factor to implement a sustainable management of the resource. In this context, the objective of this geochemical study was to build-up a conceptual model of GW recharge and transfer for the Avène thermal system based on the assessment of residence time at various outlets of the aquifer. The Avène thermal spring (25°C) is located along the North part of the Montagne Noire, about 50km Northwestern from Montpellier, France. The main questions were focused on a hypothetical role of deep CO<sub>2</sub> fluxes on the GW chemistry, and on the GW transfer from the recharge area to the thermal outlets as compared to other non-thermal karst springs emerging from the same geological unit. The approach is based on the use of historic and new tritium, <sup>13</sup>C and <sup>14</sup>C activities data, and also dissolved gases (CFCs SF<sub>6</sub>) to constrain a lumped model. Results show that the thermal GW is flowing in depth through the Cambrian dolomites without deep CO<sub>2</sub> contribution, and that an exponential model can explain the calculated residence times for the thermal GW. GW sampled in thermal wells can actually be interpreted with a unique GW flow path showing various degrees of evolution or interaction with non-thermal karst, but with a constant physicochemical composition. This conceptual model can now be used as a reference state of the system for future investigations.



## **The New Sustainable Groundwater Management Act in California Abstract n°2720**

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KEYWORDS: sustainable, groundwater, management

California's Sustainable Groundwater Management Act (SGMA) became effective on January 2015, a landmark new law finally regulating groundwater in a state that produces 50 percent of the fruits, nuts and vegetables in the USA and is the 7th largest global economy. Historic drought, wells drying up and many more being drilled, along with increasing land subsidence helped pass the new law. SGMA requires that 127 of California's 515 groundwater basins, considered medium- and high-priority, do the following- (1) form Groundwater Sustainability Agencies (GSAs) to completely cover all priority basins by June 2017, (2) develop Groundwater Sustainability Plans (GSPs) by January 2020 for critically overdrafted basins and January 2022 for remaining priority basins, and (3) become sustainably managed within 20 years of GSP adoption. Sustainable groundwater management is defined as the use and management of groundwater in 50-year planning without causing undesirable results. Six sustainability indicators are defined as undesirable results- (1) chronic lowering of groundwater levels, (2) reduction of groundwater storage, (3) seawater intrusion, (4) water quality degradation, (5) land subsidence that substantially interferes with surface land uses, (6) depletions of interconnected surface water, adverse impacts on beneficial uses of surface water. Local agencies that supply or manage water, or have land use authority are eligible to form GSAs, which must develop and manage to measurable objectives and minimum thresholds for the six indicators in a groundwater basin. SGMA also defines "sustainable yield" as the maximum quantity of water, calculated over a base period representative of long-term conditions in the basin and including any temporary surplus, that can be withdrawn annually from a groundwater supply without causing an undesirable result. Currently, GSA formation is taking place in many basins in the state, the most difficult part of SGMA. Regulations are being developed for GSP requirements, which will set the stage for what level of groundwater industry effort is required in the near and distant future to try and reach sustainability in the next quarter century in California.



## **Irrigation and war, the drivers of change in the Orontes River basin Abstract n°2721**

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KEYWORDS: irrigation+ conflict+ Middle East

The Orontes River (Nahr Al Asi) basin, shared between Lebanon, Syria and Turkey, is a representative example of the global changes in water use that impacted surface and groundwater systems in the eastern parts of the Mediterranean basin during the last century. Since the 1950s and especially in the 1990s, the area witnessed an intensive surface and groundwater development, mostly for irrigation purposes. It led to a sharp decrease of the Orontes river discharge in its middle course+ the drying up of numerous springs and local overexploitation of groundwater in several areas. After 2011, the basin became one of the most conflict-affected regions in Syria- it witnessed a drastic spatial redistribution of the water consumption and thus a radical reconfiguration of surface and groundwater flows. As a consequence of the decrease of water consumption in its middle reach, the Orontes River discharge of the basin increased by two-fold at the Syrian-Turkish border in 2014. This presentation aims to analyze the drivers of long term and radical changes in the Orontes River basin. The interdisciplinary approach consisted of assessing the human-hydrosystem coevolution to determine these drivers through a historical water balance calculation for the Lebanese and Syrian parts of the basin. The lack of accurate and comprehensive long term datasets, the absence of current data – because of the destruction of hydrometric monitoring systems but also because of they are very sensitive – are tackled by confronting different estimation methods of historical and present surface and groundwater flows- literature reviews, historical records, statistical analysis, expert interviews, maps and satellite images analysis to assess land use changes. This study is based on the results of the Orontes River Basin Research Program conducted at the Graduate Institute of International



and Development Studies (Geneva) between 2012 and 2016, with the support of the Swiss Development and Cooperation Agency. The Orontes Program aimed to provide baseline elements to support emergency interventions and post-conflict planning in Syria and to contribute and coordinate a sustainable management, at long term, of the shared water resources of the Orontes River basin



**Groundwater knowledge challenges facing the universal access to clean water to meet the Sustainable Development Goals**  
**Abstract n°2736**

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KEYWORDS: groundwater, universal access, Burkina Faso

Burkina Faso is well known for the multitude of his water infrastructures (dams, sources and drilling) but water resources seem to no longer meet the ever increasing needs regarding the universal access to clean water for the Sustainable Development Goals. Knowledge of water resources of the country, needs, uses which are made, qualitative and quantitative impacts of these uses, is essential for an effective contribution of the water sector to the continued development of the country. Today, observation is that the knowledge of water resources remains insufficient, and sometimes even absent for some specific themes, including groundwater. Indeed, if surface water resources are better known, it is not the same for groundwater. As a result, there is a poor definition and evaluation of reserves and resources that can be collected. Information on the hydrogeological characteristics is not updated since 2001. In sedimentary basin, renewable resources come from continuous aquifers which geometry is not sufficiently known to allow a proper assessment of the reserves. In the crystalline basement, flows are generally quite low, negative drilling are numerous and drilling large flow rates, superior to 10 m<sup>3</sup> h, is difficult. Large needs are therefore difficult to satisfy from groundwater. Knowledge of the water in the broad sense includes two main aspects- - an information system on water, which includes instruments to acquire, analyze and disseminate information on the water resources, the needs, uses, impacts of the uses, risks+ - The realization and the capitalization of development research including knowledge on water resources particularly in a context of climate change. There is therefore at the level of the water resources an important issue which will consist to fill the knowledge gap by studies and appropriate research, prior to a rational and sustainable exploitation of water resources.



**MULTI-SCALE CHARACTERIZATION OF SALTWATER INTRUSION IN  
HETEROGENEOUS VOLCANIC AQUIFERS WITH AIRBORNE ELECTROMAGNETICS  
Abstract n°2865**

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**KEYWORDS:** Coastal groundwater, Hydrogeophysics, Airborne Electromagnetics, Heterogeneous context

In heterogeneous coastal environments, extension and geometry of saltwater intrusion are controlled by numerous parameters at different scales. Their analysis requires both local accurate data and extensive coverage. Given the significant electrical conductivity of the saltwater, Airborne ElectroMagnetic (AEM) method is particularly adapted for imaging the contrast between freshwater covering saltwater. A multi-scale hydrogeophysical approach has been achieved at La Reunion Island in order to study controlling factors of saltwater intrusion in heterogeneous context. Its aim is to provide a high resolution mapping of saltwater intrusion at regional scale based on AEM results. Composed by two basaltic shield volcanoes, Reunion Island is characterized by a complex geological setting. The French Geological Survey, BRGM, conducted an AEM survey over the entire island (2500 km<sup>2</sup>) and an offshore ring. First, the regional extensions of saltwater intrusion have been defined through a statistical analysis of AEM soundings. Secondly, at local scale, AEM soundings was confronted with water electrical conductivity logs and interpreted considering the geological contexts and the regional recharge. The AEM capacity to determinate water salinization has been estimated to validate geometries and lateral extensions in various configurations. These results have been used to produce a saltwater intrusion 3D map over the entire island. This approach allows comparing parameters that govern saltwater intrusion at different scales (geological settings, recharge rates, drainage networks and coastal geomorphologies...). Thus, the depth and the geometry of saltwater intrusion with a fine mixing zone and low slope have been related with different geology settings and



recharge rates. On the opposite, different behaviors have been detected in the same geological settings. For example, this approach characterize in alluvial deposits from the same volcano, stratified saltwater intrusion, saltwater intrusion within a thick mixing zone or no intrusion. This approach can be used to set up hydrogeological modelling parameters and boundaries or to elaborate sustainable coastal aquifer managements.



**Contribution of Magnetic Resonance Soundings for characterizing water storage in limestone**  
**Abstract n°2869**

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KEYWORDS: MRS, unsaturated zone, limestone

The Cigéo industrial center designed for the disposal of the most highly-radioactive French wastes is studied at a depth of 600 m in an argillite formation of the Callovo-Oxfordian located near the Bure village in the Paris sedimentary Basin. A comprehensive understanding of the surficial groundwater circulations in the Portland "Barrois" limestones is required for the setting of surface installations for the Cigéo project. Characterizing water storage and flows in both the saturated and unsaturated zones of these fractured and karstified limestones is a challenging task that requires a multidisciplinary approach. In this work we show the specific contribution of MRS soundings for the characterization of water storage in the Barrois limestones. We realized a careful selection of the soundings sites based on the geological setting (lithostratigraphy and outcropping) also as ambient electromagnetic (EM) noise conditions. MRS data acquisition was performed during four campaigns and very different EM noise conditions depending on the site and campaign were encountered. Cautious post-treatment of the data was necessary to ensure the comparability of the soundings. As a final result, MRS soundings allowed a better understanding of the water storage properties of the Barrois limestone. As a perspective of this study, hydrochemical monitoring, in-situ wells characterization and tracing experiments should provide further support of the interpretation of MRS soundings and the conceptual hydrodynamic model of the site.



# Identification of the dominant recharge discharge effects of the Zagreb alluvial aquifer

## Abstract n°2881

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**KEYWORDS:** river-aquifer interaction, recharge discharge effects

River-aquifer interaction between the Sava River and the Zagreb aquifer was analysed using comparison of duration curves of the Sava river stage and aquifer ground water levels. Analyses showed the percentage of time river stage exceeded groundwater levels' pointing at dominant aquifer recharge effects as well as percentage of time river stage was below the ground water levels pointing at dominant aquifer discharge effects. 10-year time series of the river stage measured on 9 gauging stations and ground water levels measured in 45 piezometers in a near vicinity of the river were analysed in a 22 cross-sections along the Sava river course, which were defined based on a flow net analysis. Analysis was primarily aimed at determining dominant aquifer recharge discharge effects along the course of the river Sava, using duration curves created from 10-year river stage and aquifer ground water levels time series data sets. Recharge discharge effects were also analysed using duration curves created from a yearly time series data sets in order to identify changes in aquifer recharge discharge during specific hydrological conditions, namely drought and wet hydrological years. Besides, the analysis was also pointed to identification of the river stages at which changes between recharge and discharge mainly occur. Results based on a 10-year time series analysis showed variations in aquifer recharge discharge effects along the course of the river Sava without pointing out to overall domination of either aquifer recharge or discharge. On the other hand, yearly analysis pointed out to several years with pronounced aquifer discharge effects, i.e. 2003, 2011 and 2012 as well as aquifer recharge effects, i.e. 2004, 2005 and 2008. Analysis contributes to conclusions that further management of the river Sava, the dominant boundary condition of the Zagreb aquifer system, should comprise its regulation using weirs or dams in order to prevent potential water supply shortages during drought hydrological years



**Critical Role of High Permeability Zones on Field-Scale Pathogen Transport and Retention, Infection Risk, and Setback Distance**  
**Abstract n°2910**

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**KEYWORDS:**

A stochastic stream tube model was extended to simulate field-scale pathogen transport and fate in the subsurface. Local-scale transport within each stream tube was described deterministically using analytic solutions for pathogen transport and fate in a single or dual permeability porous medium. Important pathogen transport and fate processes that were accounted for in an individual stream tube included- advection, dispersion, reversible and irreversible retention, and decay in the liquid and solid phases. The velocity in a stream tube was related to a median grain size using the Kozeny-Carman equation, and filtration theory was used to predict the dependence of physicochemical factors on retention. The field-scale velocity distribution was described using a lognormal probability density function (PDF). Alternatively, a bimodal lognormal PDF was used in conjunction with the dual permeability model to predict the influence of preferential flow and exchange between slow and fast velocity domains. The mean and variance of the field-scale concentrations were calculated from local-scale stream tube information. The setback distance to achieve a selected risk of infection was determined from the modeled concentrations and a simplified risk assessment approach. Simulation results demonstrate that field-scale pathogen transport and safe setback distance were very sensitivity to velocity distribution characteristics. Early breakthrough, higher peak concentrations, and larger setback distances were associated with high velocity domains that had little retention, whereas the opposite trends were associated with low velocity regions. The relative importance of high velocity regions increased under physicochemical conditions that enhanced retention, although the setback distance was also smaller. In contrast, increasing the rate of exchange between low and high velocity regions diminished the relative importance of high velocity regions on pathogen transport and setback distances.



**Mystery of the permanent water cavities in the “Sebkha Imlili” located in a particular ecosystem- hydrological and hydrogeological characterization (Dakhla, South of Morocco)**

**Abstract n°2929**

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KEYWORDS: Sebkha, hydrology, hydrogeology

The aim of the study is to understand the hydrological and hydrogeological mechanisms that govern the “Sebkha Imlili” functioning. This Sebkha is very special and unique depression, located in South of Morocco about a hundred kilometers south of the Dakhla bay. It is distinguished by the presence of a large number of permanent water cavities with high salinity, and hosts a diverse flora and fauna including a remarkable species of fish, Tilapia Guinea. The climate is characterized by a marked aridity and scarcity of rainfall. The rainfall is extremely irregular, typical of the Sahara and extremely arid regions. The watershed is not well developed+ wadis flow only during intense rainfall events generating floods in upstream basins and sometimes roam the depression of the Sebkha by depositing fine material. Measurements of temperature and salinity were carried out on a relatively large number of cavities of water- The water temperature ranges from 20 to 33°C, the salinity varies largely between 30 and 100 g l. Two wells located around the Sebkha show water levels between 2 and 3.5 m, the groundwater temperature ranges around 23°C and the electrical conductivity of water varies from 5380 to 6840 IS cm. The area of the “Sebkha Imlili” contains important groundwater resources of varying quality flowing into an aquifer system of shallow and deep aquifers. We distinguish a multi-domain with carbonated formations and brackish water, linked to the Mio-Pleistocen-Quaternary and partly an area with artesian water, associated with cretaceous formations. Further studies are recommended as geophysical investigations to better understand the structure of the depression and exchange opportunities between hydrogeological cavities.



**The relationship between isotopic composition of precipitation and the origin of air masses generating rainfall in the Ahaggar (Sahara central, Algeria)  
Abstract n°2930**

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**KEYWORDS:**

The massif of Ahaggar is situated just in the middle of Sahara Desert. The basement aquifers of this region, contain relatively low water resources, that are recharged by the wadi floods, generated by rare rains that occur on the high areas of the mountain. What is the origin of this precipitation and what the weather conditions that govern them. A precise definition of climatic conditions and precipitation regimes in Sahara desert is not straightforward, and different interpretations may be formulated from scientists of different disciplines. The link between isotope signature of meteoric water and climate at lower or higher latitudes is, in general, well understood. This is much or less the case for the tropics. This study is focused on spatial and temporal variability of the stable isotope content in precipitation from a mountainous region located on the tropic. The aim of the study is to recognise the isotopic signal in meteoric waters and to determine the origin of air masses, generating rainfall, in an area known for its extreme aridity and its important thermal disparity. The concentrations of deuterium and oxygen-18 in meteoric waters exhibit large variations, both in time (seasonal variation) and in elevation (altitude effect). Present-day distribution patterns of these isotopes in precipitation reveal a close linkage with some meteorological parameters such as temperature, relative humidity and amount of precipitation. The massif of Ahaggar, generally is considered to be under the climatological influence of the Guinean Monsoon. However, because of the altitude effect (2918 meters at the Tahat Mountain), but in contrast to its location, the Ahaggar presents relatively fair climatic conditions. The Assekrem meteorological station (23.3° N, 5.6° E) is located in the central part of the massif, at an altitude of 2726 meters. 225 samples of rainwater have been gathered during the period 1992-2008 for isotopic analyses. Tamanrasset town, where 23 rainwater samples have been collected during the same period, is developed at 55 Km south of Assekrem, and at 1376 meters of altitude. Spatial and temporal variability of the composition of stable isotopes of precipitation is discussed, together with available information on regional



climatology and atmospheric circulation patterns. The mean weighted contents of both oxygen-18 and deuterium in precipitation from the central part of Ahaggar massif, are  $\delta^{18}\text{O} = -2.8\text{‰}$  and  $\delta^2\text{H} = -14.6\text{‰}$ . The heterogeneity in meteoric events and the great scattering of the isotopic contents can be ascribed to the origins and to the histories of air masses. The main contribution comes from the inflow of the Guinean monsoon in the summer months+ during winter the northerly wind, Harmattan, arriving in the area, gives origin to some rain events. The deuterium excess of these winter precipitation are up to  $+26\text{‰}$ , indicating that the original vapour is supplied by the recycling of the continental vapour



**FIELD INVESTIGATION OF SURFACE WATER - GROUNDWATER INTERACTION IN A  
CANTERBURY LOWLAND CATCHMENT  
Abstract n°3081**

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**KEYWORDS:** Groundwater, management, interaction, conceptual model

The balance between development and resource conservation is a major challenge facing many New Zealand communities. The hydrologic cycle of most watersheds in the Canterbury region has undergone a fundamental change due increasing water consumption rates for agriculture and dairy farming and a change in climate towards drier conditions. Since groundwater and surface water are not isolated components of the hydrologic system, development or contamination of one commonly affects the other. Understanding the spatial and temporal dynamics of groundwater surface water interaction processes remains essential for predicting the sustainability of water resource allocation and management. Linkages between recharge, discharge, and water quality are revealed using tracer techniques to identify areas with greater vulnerability to increased stresses in Harts Creek – Birdlings Brook catchment in the Lower Canterbury Plains. Interaction between the creek and the local aquifer are identified using detailed stream surveys, temperature surveys and stream flow gauging. Longer term monitoring data including hydrometric measurements, isotopic and geochemical analyses are used to delineate the pattern of groundwater movement between aquifer systems and to develop a flux-based conceptual model for groundwater surface water interactions.



**FINGERPRINT OF CLIMATE ON THE EVOLUTION OF THE RIBBON MITIDJA WEST  
AND ARE POLLUTION DEGREE (ALGERIA)  
Abstract n°3257**

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**KEYWORDS:** Groundwater, climate change, pollution, conductivity and nitrate, water quality, irrigation

Climate change in this century was that there is great heterogeneity in rainfall, flooded areas and other or rainfall is increasingly rare. Studies have shown that in our study area, and that for some years (may meadows twenty years), the key is Mitija a decrease in rainfall which causes an automatic decrease the amount of water allocated to irrigation. In addition to the quantity, quality is lacking in several areas of storage whatsoever artificial areas such as dams or natural as tablecloths. The aim of our work is to detect or breaks in the rainfall series of our area and comparing the fluctuation of the water table in West Mitija and study it by kronostat water quality and analysis of a number of indicator elements of the pollution of water wells nearby farmland. show high concentrations of these elements (physiquo chemical such as pH, electrical conductivity, nitrate, Ca, Cl, etc. ...). We also try to see what are the different classes of groundwater pollution Mitidja by statistical analysis by PCR and by hierarchical clustering (AHC) and which will provide the dendrogram to determine the different homogeneous groups.



**Emergency water supply for the population from groundwaters in the Upper Silesia  
(Poland)  
Abstract n°3318**

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**KEYWORDS:** groundwater, water intakes, emergency situation, aquifer, Silesia

Emergency situation is a potential situation, when a total lack of ability of using surface waters and groundwaters connected to the water supply systems appears, e.g. as a result of the earthquake or warfare. In such situation, groundwater intakes which are not connected to any water supply systems, will be the only safe sources of water supply of the population. Upper Silesian population reaches 2,2 mln and needs 10 000 m<sup>3</sup> of water per day for survival supply in a case of an emergency. It is supplied mainly from surface water intakes, mostly by one contributor, who has emergency wells, but their productivity wouldn't be sufficient for the entire agglomeration in emergency situation.. As a result of the study conducted by PGI, potential areas with possibility to locate emergency wells were outlined in the Upper Silesia, located in the Triassic and Quaternary aquifers, due to significant water resources and location which ensure the convenient transfer of water to all cities. These areas have limited extent as aquifers in this region are strongly affected by mine drainage and industrial activities. Although these areas were indicated as the perspective for the location of emergency wells, they could also be considered as potential sources of the public water supply, mainly due to the closure of a number of coal and lead and zinc mines in this region. Mine waters pumped from coal mines may also be considered as an alternative source of water supply in emergency in the Upper Silesia.



**USE OF ISOTOPES IN ASSESSING WATER RESOURCES KASAI RIVERS, KWANGO  
AND KWILU IN DEMOCRATIC REPUBLIC OF CONGO  
Abstract n°3375**

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KEYWORDS:

TITRE - UTILISATION DES ISOTOPES DANS L'EVALUATION DES RESSOURCES EN EAU DES RIVIERES KASAÏ, KWANGO ET KWILU EN REPUBLIQUE DEMOCRATIQUE DU CONGO

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POINT FOCAL DU CENTRE REGIONAL A L'ENERGIE NUCLEAIRE DE KINSHASA A BANDUNDU

RESUME La République Démocratique du Congo regorge d'importantes potentialités en ressources en eau, dont la gestion, la protection et la mise en valeur sont tributaires de nouveaux défis qu'imposent le développement durable et le changement climatique. Cette recherche fournit aux décideurs, aux chercheurs et aux bailleurs de fonds des informations scientifiques sur les caractéristiques des eaux des rivières citées car à ce jour, il y a

manque d'une base des données et en plus manque des ressources humaines pour faire face aux difficultés de gestion des ressources en eau de la RDC. Ainsi, la caractérisation des eaux des rivières Kasai, Kwango et Kwilu se fait grâce à l'outil isotopique et aux techniques hydrogéologiques classiques.

Résultats scientifiques - Les paramètres physico-chimiques (PH, conductivité électrique, température) sont mesurés - Les ions majeurs (anions et cations) ont été dosés -

Le niveau d'eau prélevé	DATE	Campagne	Heure	PH	Conductivité	T°
(°c) O2 NO3 mg l PO4 mg l NO2 mg l SO4 mg l CO2 mg l Alk mg l SECHI cm	RIVIERE KASAÏ (DIMA)	16 03 2016	+ 12	10h00	10,025	28,3
4,53 ou 60,5%	4,5	0,36	0,021	1,6	16,5x2	7,5
40	RIVIERE KWANGO	16 03 2016	+ 12	12h00	9,533	46
28,9	4,82 ou 63,5%	8,1	0,64	8,1	7,1	
15,5x2	12	36	RIVIERE KWILU	16 03 2016	+12	12h25
9,245	9,2	28,30				
5,61 ou 70,2%	0,6	0,37	0,032	1,8	12x2	10,5
71	Cette recherche donne					

quelques résultats sur les caractéristiques des eaux de trois rivières Kasai, Kwango et Kwilu, la dite recherche doit continuer pour l'ensemble de la République avec l'appui des partenaires et des chercheurs. Nos remerciements à l'équipe du centre régional à l'énergie nucléaire de Kinshasa pour nous avoir doté en matériels et réactifs + nous remercions également les autorités du Journal Officiel de République Démocratique du Congo pour leur autorisation à la présente recherche.



## **Policies and tools to promote economic use of groundwater in South Australia**

### **Abstract n°3387**

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**KEYWORDS:** economic development, groundwater management, water trading, community participation

The increasing demand for high quality food by the growing middle classes of Asia represents a great economic opportunity for South Australia. Groundwater resources already supports the production of food, dairy products and premium wines, and there are several policies and management tools in place that will assist the potential increases in groundwater extraction for irrigation within sustainable limits. All the major good quality groundwater resources are managed through statutory Water Allocation Plans (WAPs) which set sustainable limits for extraction, rules for the allocation and trading of water entitlements and resource monitoring requirements. The WAP must seek a balance between economic, social and environmental water demands. Water is allocated for the environment first, then economic and social users. Over the past 20 years or so, the management approaches in these Plans have evolved from being rigid and doctrinaire, to now being more flexible and consultative. Essentially the Plans should be able to accommodate new information and understandings of the groundwater resource that may emerge during their 10 year life span, as the following examples demonstrate. In South Australia, the determination of sustainable extraction limits has traditionally been based on estimates of recharge, particularly for unconfined aquifers. Experience has shown that these estimates have large uncertainties and are highly variable both in time and space, which often leads to overly conservative extraction limits. New approaches are being introduced which allow for the use of storage in robust aquifers, and resource condition limits (RCLs) to manage extraction levels. These RCLs could be water or salinity levels which if exceeded, could cause degradation of the resource or ecosystems. Identifying these limits requires both technical expertise and community consultation. In fully allocated areas, the trading of water entitlements is a very useful management tool which can maximise the use of groundwater within sustainable limits. Trades can be permanent (sale) or temporary (lease), and should be controlled by rules to minimise impacts on the resource, ecosystems or other users. Again, these rules have recently evolved to be flexible enough to allow exceptions if the proponents can demonstrate through additional investigations that no adverse impacts will occur. Aquifers are generally very robust and processes generally occur over large time frames. Adaptive and flexible management supported by extensive monitoring, can significantly contribute to further economic development through sustainable groundwater extraction.





## Groundwater and society:

### 60 years of IAH

#### 43<sup>rd</sup> IAH International Congress

On behalf of the French and German hydrogeologist communities, the French and the German National Chapters of the IAH are proud to host the 43<sup>rd</sup> IAH International Congress, and at the same time celebrate the existence of 60 years of IAH, in Montpellier, France, from 25<sup>th</sup> to 29<sup>th</sup> September 2016.

Already at the occasion of its 40<sup>th</sup> anniversary, John Day, the former vice-president of IAH, stated: *“From small beginnings, and by its members’ persistent exertions, the Association has achieved a truly international stature and a professional reputation second to none, motivated only by its members’ desires to get to know each other and to share professional expertise despite the various political and economic barriers of the times.”*

This statement is still true and our 60<sup>th</sup> anniversary again offers ample opportunities to reflect, take stock and to assess the current state of hydrogeology within societies worldwide. Increasing challenges and contributions of hydrogeologists to society will be a central topic at the conference in Montpellier. We welcome active participations of hydrogeologists and experts of related fields from all over the world.



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